Science & Technology Foresight Center of NISTEP

Science & Technology Trends

Quarterly Review

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Life Sciences

- *Recent Trend of Cancer Research*
  — Molecular Target Therapy and Translational Research —
- *Trends in Organic Synthesis Chemistry Research*
- *Trends in Plant Molecular Biology*

Information and Communication Technologies

- *Trends in Research and Development of the Quantum Computer*
- *Digital Content Distribution and Copyright Management Technology in the Broadband Age*

Environmental Sciences

- *Trends in the Development of Measures Against Global Warming Centered on CO_2 Underground Storage*

Nanotechnology and Materials

- *Trends in Nanobiology*
- *Trends and Problems of High-Level Radioactive Waste Disposal Projects*
  — Technical and Social Aspects—
- *Trends in Distributed Power Sources*

Infrastructure

- *Trends of Disaster Simulation Technologies*

Science and Technology Policy

- *Latest Trends in US Science and Technology Policy*
  — Flash Report on 2002 AAAS Annual Colloquium—
- *Outline of Drawing up the FY2002 budget for Science and Technology*








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 3000 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 such as periodical Delphi surveys.

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.

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Executive Summary

Life Sciences

1 Recent Trend of Cancer Research
— Molecular Target Therapy and Translational Research —

p.11

Cancer accounts for approximately 30 percent of the causes of death in Japan, and conquering cancer is an important subject in the attempt to maintain and increase Japanese people's health.

Recently, the mechanisms of the proliferation of cancer cells, and invasion and metastasis have been clarified on the molecular level, and researches on new therapies to make such specific molecules a target (molecular target therapy) have progressed. As new types of anticancer drugs, molecular target drugs are expected to reduce side effects, conquer refractory cancer and advanced cancer, and bring about the realization of tailor-made medicine (optimal therapy for individual patients).

In order to promote research and development of molecular target therapy, basic researches to clarify the mechanism of cancer proliferation, etc., and to search for cancer genes must be further promoted. It is also necessary to arrange the basis for researches such as a database to support such basic researches.

Clinical studies are essential in pharmaceutical development, but occasionally research and development of state-of-the-art therapy such as molecular target drugs cannot be promoted sufficiently in the form of clinical studies (trials) conducted by companies to obtain approval for drugs, etc. Therefore, as a form of clinical study different from that of trial, it is necessary to promote translational researches (in the development of state-of-the-art therapy, researches to apply the results of exploratory basic researches for clinical studies to clinical studies). In order to promote translational researches in Japan, we need to tackle; the arrangement of legislation (such as extending the scope of clinical trials that will be conducted) in the ongoing amendment to the Pharmaceutical Affairs Law, the arrangement of a system that may verify the safety, ethics, and scientific property at an institution for translational research, and training of human resources for clinical research coordinators (CRC) to conduct duties dealing with subjects including informed consent.

Through measures like this, it is desired that new therapies such as molecular target drugs be established to attain early realization of therapies with less side effects and improvement of the curing rate of cancer.

(Original Japanese version: published in April 2002)

2 Trends in Organic Synthesis Chemistry Research

p.18

In the post-genome research, compounds affecting proteins or other molecules that function in vivo play extremely important roles. For example, a compound acting specifically on a certain protein becomes a valuable reagent in biological science research. Moreover, most pharmaceuticals, which can be considered as compounds possessing many added values, are synthesized through organic synthesis chemistry. Therefore, improving the capacity of organic synthesis

chemistry in our country should contribute to the achievement of more outcomes from the post-genome research, as well as to the continuous release of novel chemical products from Japan to the world.

The current standard of organic synthesis chemistry has already reached a level enabling syntheses of compounds with complex structures. Needless to say, the development of a new, energy-saving reaction system inhibiting the generation of by-products is desirable from the viewpoint of Green Chemistry.

Consequently, the next goal in organic synthesis chemistry is to develop reaction systems for completing multi-step reactions in one step and to replace the existing reaction systems with low-cost systems. In the future, people may live in a closed system such as outer space, so the establishment of solvent-free synthetic methods generating no by-product is required as a long-range objective.

Since the level of organic chemistry research in our country is one of the highest in the world, we must take the initiative in the research for achieving these goals.

(Original Japanese version: published in May 2002)

3 Trends in Plant Molecular Biology p.26

The principal goal of plant molecular biology is to reveal the mechanisms for controlling the forms and metabolism of plants with focus on gene functions. This is recognized as a crucial field of study in the Comprehensive Strategy to Promote Science and Technology, which was adopted at the Council for Science and Technology Policy of the Cabinet Office in September 2001.

The research basis necessary for plant gene function analysis is becoming solid today, as whole genome sequences of such model plants as rice and Arabidopsis are revealed. In such a circumstance, gene function analysis of plants including commercial crops will become far more efficient and international competition in function analysis of useful genes may become severer.

Therefore, in promoting plant molecular biology, we must exploit every tool in Japan related to agricultural and plant research, and develop function analysis of useful genes. Furthermore, we must take the following needs into consideration in boosting this field of study.

i) In order to develop plants that will help solve global issues like food and environmental problems, we must advance detailed function analysis of various genes involved in such basic functions as metabolism and signal transmission. We need to broaden our understanding of higher plants at the molecular level making good use of model plants.

ii) Plant genome research in the post-genome era has peculiar methodologies of gene function analysis compared with human genome research; for example, genetic modification is easier in plants than in animals. Meanwhile, it is hoped that such function analysis of useful genes of plants is efficiently carried out in cooperation with the departments of physiology and ecology of institutes like agricultural experiment stations.

iii) In promoting research in large-scale projects, we must highly recognize that information and bioresources, which are obtained by comprehensive research on whole genomes, need to be promptly offered to researchers of universities and other institutions.

(Original Japanese version: published in June 2002)

Information and Communication Technologies

4 Trends in Research and Development of the Quantum Computer

p.37

The difficulty for current computers to execute factorization is a foundation of security for the public key cryptosystem (RSA cryptosystem). The quantum computer is in the spotlight since it can calculate certain problems such as factorization at a speed overwhelmingly faster than current computers. Since energy for operating a single quantum is very small and its required time is short, it can theoretically be a low-heat-generation, super-high-speed computer, the same as nanodevices.

Now, various researches are being executed in many countries, but they are still on the level where a model of the hardware for confirming the theory has just been produced. For software (algorithms), the number of algorithms that can effectively use the advantages of the quantum computer, which is a capability of parallel computing by using quanta, is very limited. It is necessary to expand its application area through future researches as well as solving the problem of error correction.

To put the quantum computer to practical use, there are possibilities to apply it as an auxiliary unit of computers specialized in the parallel computing function or as a transmitter/receiver and a repeater unit for the quantum cryptosystem and quantum communications. It may take a lot of time and it is necessary to solve many problems before it can be put to practical use.

On the other hand, a research field of the quantum computer is in the area of crossing various other research fields, and it is expected that new ideas and technical breakthroughs will be produced through exchanging these different fields with each other.

(Original Japanese version: published in April 2002)

5 Digital Content Distribution and Copyright Management Technology in the Broadband Age

p.48

Development of digital technology and the sophistication and rapid spread of personal computers have resulted in digitization of a variety of content, which is distributed over networks like the Internet. In addition, the emergence of broadband access lines to the Internet, typically ADSL, is enabling transmission of digital content via networks in significantly larger volumes and higher quality than through the conventional technologies. Meanwhile, as an enormous number of illegal copies have become available through networks, technologies to protect the copyrights of digital content are growing in importance.

To meet these demands, comprehensive copyright management technologies that can control a variety of processes — from distribution via a network up to playback and copying on a user terminal — and prevent the transmission and use of illegal copies are being developed and put into practical use. Called the digital right management (DRM) system, this scheme mainly consists of technology designed to protect content through encryption, and technology for utilizing digital watermarks to identify content and sort out illegal copies. However, DRM involves many problems concerning compatibility and standardization. Legislation to protect copyrights of digital content distributed over networks is also needed.

While many countries in the world are working on their civil laws to conform to the WIPO (World Intellectual Property Organization Copyright) Treaty and the WIPO Performances and Phonograms Treaty adopted by the WIPO, they are not yet acting in unison.

As new technologies emerge one after another, the form of content distribution and use will be subjected to constant change. Copyright management technology that can provide a balance between user-friendliness and protection ability is being awaited for to come into common use. Also, a new approach to copyright may be needed to cope with changes in areas other than distribution and use.

(Original Japanese version: published in June 2002)

Environmental Science

6 Trends in the Development of Measures Against Global Warming Centered on CO_2 Underground Storage

p.58

Japan has ratified the Kyoto Protocol and has assumed the responsibility of reducing greenhouse gases. However, there is a limit to further reducing greenhouse gases only through energy-saving measures, since Japan has already achieved the world highest efficiency in energy use. On the other hand, the exploitation of natural energy and nuclear energy seems unfeasible for the time being. Therefore, looking ahead into the next decade or two, it is quite important to conduct R&D of CO_2 underground storage, where CO_2 recovered from emissions of thermal power plants and other industrial installations is stored in underground aquifers.

Japan has been pushing ahead with a number of researches in this particular area and has developed outstanding element technologies, though economically feasible systems proportionate to the possible impacts on the environment have yet to be developed. In the meantime, several new technologies have been developed thus far - e.g., the CBM (Coal Bed Methane) technology for recovering methane gas contained in coal beds, where CO_2 is injected into coal beds to replace the methane gas. This technology is an application of various established technologies in the field of oil and natural gas production; it is technologically feasible and highly promising in terms of its introduction as well as potential for reducing CO_2 domestically. Moreover, in view of the massive coal reserves throughout the world, the CBM technology can be applied to developing countries as well.

Considering these circumstances, R&D of emitted-CO_2 reduction technologies should be pursued with particular emphasis on the following aspects:

i) The course of development should be determined explicitly (including evaluations on the practicability of projects as a system) at the planning stage of R&D projects, and energy policies should be taken into consideration.

ii) With regard to technologies (the CBM technology, etc.) that can be applied to overseas projects, R&D should be promoted in a comprehensive manner, encouraging technological exchanges between countries with versatility of those technologies in mind (initiatives in international standardization, applications to overseas projects, etc.).

(Original Japanese version: published in June 2002)

Nanotechnology and Materials

7 Trends in Nanobiology

p.68

Nanobiology is a field of study extending across nanotechnology and life science, and comprises of three spheres as follows: 1. Employ and apply nanotechnology such as microprocessing to the field of life science; 2. directly use biological materials in producing nanodevices; and 3. utilize biological functions and principles in developing nanotechnology. It is greatly hoped that application of the above-mentioned sphere 1 will promote life science in the post-genome era, and, moreover, spheres 2 and 3 will bring nanotechnology to a higher level.

(Original Japanese version: published in April 2002)

8 Trends and Problems of High-Level Radioactive Waste Disposal Projects

— Technical and Social Aspects —

p.76

High-level radioactive waste disposal is one of the problems that we inevitably encounter as long as we use nuclear power generation systems. Today, the U.S. has entered the final phase where it must decide on whether or not the Yucca Mountain site should be selected as a geological repository, and the world's nuclear power interests have paid much attention to the site selection process.

This article analyzes the domestic and foreign trends of high-level radioactive waste disposal projects. In addition, it analytically discusses the present situations and future perspectives of the technical and social aspects regarding this problem, especially focusing not only on the possibility of conducting researches on high-level radioactive wastes as a part of the frontier researches necessary to expand and strengthen the scientific and technological bases, but also on the efforts made to solve the site problems.

More concretely, researches on high-level radioactive wastes include the frontier research areas that make great contributions toward expanding and strengthening the scientific and technological bases, including researches on the deep geological environment, nuclear transformation and control, and the coupled process system. It is effective to actively commit to these research areas in order to maintain the vitality and technological potentiality in the field of researches on high-level radioactive wastes.

To solve the most important problem of sites, it is imperative to ensure disclosure of information to the public, transparency, and public involvement in the policy-making processes. It is also necessary to conduct scientific researches and rouse public discussions on the "NIMBY" (Not in My Backyard) problem —coordination between individual and public interests— that relates to a fundamental part of the democratic society system.

Various arguments will continue to be made on HLW disposal problems. Ultimately, however, the political leaders are required to establish their leadership and communicate adequately with citizens, based on the results of scientific researches, domestic and foreign situations, etc.

(Original Japanese version: published in May 2002)

9 Trends in Distributed Power Sources

p.88

The energy supply system of Japan has entered a crucial turning point in response to the recent progress in liberalization of the electricity market and the need to reduce greenhouse gases. Under these circumstances, distributed power sources are receiving attention as a measure to cut down energy costs. However, reducing energy costs and creating "environmentally efficient systems" are indispensable for promoting these power sources, which are expected to become widespread in the future.

With an eye toward achieving long-tem security of energy supply, "eco-friendly distributed power sources" such as co-generation and wind/solar power generation are growing steadily, supported by subsidies, low-interest loans and other public assistance.

On the other hand, "distributed power sources that put a burden on the environment" are also becoming widespread in response to the need of users to further reduce energy costs. The liberalization of the electricity market, moreover, will extend the range of choices for these users - e.g., the installation of distributed power sources, competitive bidding for electricity and respective contracts for electricity.

The following three stages are indispensable for promoting eco-friendly distributed power sources:

i) Provide environment-conscious users with subsidies and other supports, thereby encouraging them to introduce distributed power sources that prioritize their principles above cost efficiency.
ii) Encourage organizations serving the public interest (government institutions, local public bodies, etc.) to adopt eco-friendly facilities or to choose eco-friendly power sources through competitive bidding, thereby creating the basis for the environment industry.
iii) Promote distributed power sources in the general market.

In order to achieve long-tem security of energy supply, the government and the private sector must cooperate with each other in promoting distributed power sources. Japan has just entered the Stage 2 mentioned above. Organizations serving the public interest should therefore take the initiative in selecting and introducing power sources, considering not only reductions in energy costs but also environmental aspects such as reductions in CO_2 emissions, in order to create technological and industrial foundations.

(Original Japanese version: published in May 2002)

Infrastructure

10 Trends of Disaster Simulation Technologies

p.96

Recently, the policy covering disaster prevention has been shifted from the provision of countermeasures for checking disasters to focus on "Damage Reduction," which emphasizes minimizing damages caused by disasters. Disaster simulation technologies are technologies that will largely contribute to materializing this "Damage Reduction."

As the results of improvements in measuring technologies and enrichment of

observation structures as well as rapid progress in computer technologies, accuracy of the simulation of phenomena, such as the inner drainage inundation analysis in an urban area and the strong ground motion analysis of an earthquake in the Tokai region and so on, has been improved remarkably.

In order to make measures for Damage Reduction more effective, it is important that the respective people gain greater knowledge and understanding about disaster information, as well as to improve the accuracy of analyzing technologies. Following this, it is necessary to positively promote publication and enlightenment of the results of analysis at other times, in addition to what is being done now.

In the future, local autonomies standing at the forefront of disaster prevention administration need to strongly promote various crisis management policies including construction of a system capable of providing real-time disaster prevention information and to also estimate damages on facilities under their control by integrating rainfall prediction & GIS and simulation technologies. Some budgetary and technical supports are also required. Furthermore, it is important that simulation technologies are used effectively for supporting civil life according to the needs of residents, such as the inundation prediction map incorporating the detailed digital national land information, etc., provision and publication of the liquefied soil distribution map, the hazard map, and so forth.

(Original Japanese version: published in April 2002)

Science and Technology Policy

11

Latest Trends in US Science and Technology Policy

Flash Report on 2002 AAAS Annual Colloquium
Impact of Terrorist Attacks on US Science and Technology Policy and Priority Targets for FY 2003

p.105

The terrorist attacks have had a major impact on US science and technology policy, and departments and agencies connected with science and technology are tackling counter-terrorism R&D programs as a priority issue, but the various types of programs are complex, and urgent coordination is sought. Also, counter-terrorism R&D is being vigorously pursued in universities under the leadership of the National Academies, but there is a risk that said R&D will at the same time become a source of supplying terrorist methods, and R&D management that incorporates psychological and sociological viewpoints is sought.

Apart from counter-terrorism measures, nanotechnology and life science are priority areas of FY 2003. As a result of the campaign to double the NIH budget (ending in FY2003), the issue is arising that the federal government's R&D budget allocation is biased towards the life science field, and while conventional area concepts continue to change, the federal government is groping it way for technologies that will break new ground for the next generation and are suitable as investment targets.

However, as the deficit economy continues to grow, greater efficiency of government R&D investment is sought, and the direction of R&D management, on which the Bush Administration places great importance, will be watched with much interest.

(Original Japanese version: published in April 2002)

12 Outline of Drawing up the FY2002 budget for Science and Technology

p.110

Year 2002 is the second year for the Second Science and Technology Basic Plan. The FY2002 budget is the first budget under the new science and technology administrative structure.

The Council for Science and Technology Policy (CSTP) established various expert panels to examine sectorial promotion strategies and resource allocation guidelines, and determined its budget request guideline based on these expert panels' findings. When submitting budget requests based on the special requests for structural reform, CSTP evaluated the policies of the related ministries and agencies and set priorities on these policies. CSTP carefully examined its budget requests and compiled important points for drafting the budget.

The government determined the FY2002 budget and increased the budget for science and technology by 2% from FY2001. Although the amounts are small, nano-technology/materials and environment fields enjoy significant budget growth in their main initiatives in comparison with FY2001.

(Original Japanese version: published in April 2002)

1

Recent Trend of Cancer Research
— Molecular Target Therapy and Translational Research —

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1.1 Introduction

Cancer accounts for approximately 30 percent of the causes of death in Japan, and conquering cancer is an important problem in the attempt to maintain and increase Japanese people's health.

Recently, the mechanisms of the proliferation of cancer cells, invasion and metastasis have been clarified on the molecular level, and researches on new therapies to make such specific molecules a target (molecular target therapy) have progressed. Therapy with molecular target drugs is expected to lead to the reduction of side effects and the treatment of refractory cancer and advanced cancer, against which existing therapies are revealing their limitations. The development of molecular target drugs is being accelerated throughout the world, and it must be promoted in our country as well.

However, in Japan, it was pointed out that the part combining the results of exploratory basic researches and clinical practice was insufficient at the "Intellectual conference on future ideal ways of cancer research," etc., and the necessity of translational research (exploratory therapy or exploratory clinical research) to bridge the gap between basic researches and clinical practice has been regarded as important.

In this report, we will state the trend of research and development of molecular target drugs that are highly expected as new therapies, and consider measures to promote research and development in this area.

Figure 1: Target for the Millennium Project in cancer research

- Discovery of more than 50 genes including disease-related genes and drug reactivity-related genes.
- 50% reduction of anticancer drug-induced side effects, such as vomiting and headache, by optimal medications (tailor-made medicine), etc., for individual patients.
- Improvement of therapeutic results by optimal medications for individual patients.
- Start of the development of epoch-making new drugs, for example, a drug to improve the 5-year survival rate by 20%.

Source: "The Millennium Project" decided by the Prime Minister on Dec. 19, 1999

1.2 System to promote cancer researches

1.2.1 Measures taken in Japan

In our country, the promotion of cancer researches has been attempted in multiple ministry and agency, centering on the "Comprehensive 10-year Strategy for Cancer Control (1984-1993 (cumulative total of actual research expenses was ¥102.4 billion))" and the "Second Term Comprehensive 10-year Strategy for Cancer Control (1994-2003 (cumulative total of actual research expenses was (1994-2001) ¥147.1 billion))". In the Millennium Project, cancer researches were taken up as one of the themes, and the target shown in Figure 1 was set as the goal up to fiscal 2004.

Based on these policies, cancer researches in Japan have been promoted and subsidized from the Grant-in-Aid for Scientific Research by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), and from the Grant-in-Aid for Health Science Basic Research and Cancer Research Subsidy by the Ministry of Health, Labour and Welfare (MHLW).

In addition, future ideal ways of cancer research, etc., that follow the "Second Term Comprehensive

10-year Strategy for Cancer Control" are now being considered at the "Intellectual conference on future ideal ways of cancer research," collaboratively held by MEXT and MHLW.

1.2.2 Measures taken in the United States

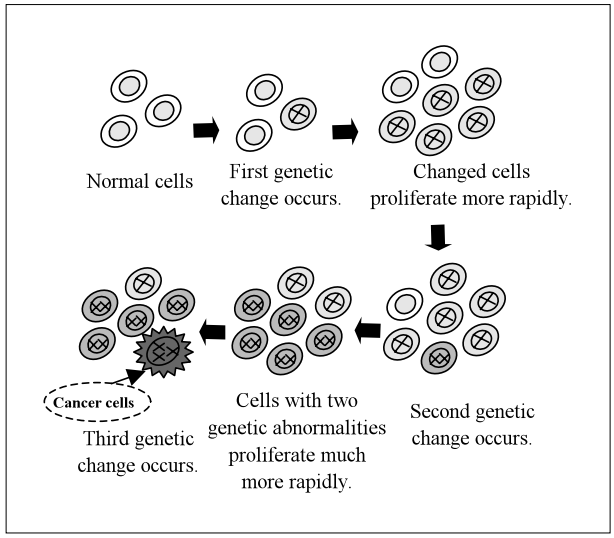
In the United States, since the National Cancer Act was established under the Nixon administration in 1971, the promotion of cancer researches has been taken up on a national basis centering on the National Cancer Institute (NCI). NCI is the largest institute that belongs to the National Institutes of Health (NIH). he budget of NCI tends to increase year by year, and for fiscal 2002, approximately $4,180 million (approx. ¥501 billion) has been appropriated.

1.3 Characteristics and therapies of cancer

1.3.1 Characteristics of cancer

Cancer is a disease attributable to genetic abnormality caused by any trigger such as chemical substances called carcinogenic substances, and radioactivity. Most cancer cells are formed by repeating multiple genetic changes and cell growth, as shown in Figure 2. A part of cancers such as some forms of breast cancer and colon cancer are gene related.

Figure 2: Conceptual flow chart of the multiple-stage process of carcinogenesis



Source: "Cancer -- Challenge of health science" (1998), the Second Term Comprehensive 10-year Strategy for Cancer Control, Cancer Research Subsidy

Cancer cells mainly have the following characteristics, and recently many molecules related to these characteristics have been clarified (Table 1).

i) Abnormal cell growth due to abnormality in the cell cycle, signal transmission system, cell

Table 1: Major biological characteristics of cancer cells and the related molecules

Characteristics	Related molecules
Abnormal cell proliferation	Proliferation-related molecule, signal transmission molecule, etc.
Invasion / Metastasis	Adhesion molecule, protease, bone metastasis-related molecule, etc.
Vascularization	Signal transmission molecule, protease, adhesion molecule
Drug resistance	Membrane transport protein, etc.

Source: Authors' own compilation

Table 2: Major cancer therapies and their outlines

Cancer therapy	Outline
Chemotherapy	Methods using anticancer drugs effective against cancer cells. Multiple anticancer drugs are often used concomitantly.
Surgical therapy	Methods to remove cancer cells by operation. Recently, enhancement of a patient's QOL is being attempted by low invasive endoscopic operation.
Radiotherapy	Methods to destroy cancer cells by radiation. Aiming to concentrate radiation on the area of focus as much as possible to reduce cytotoxicity in the surrounding normal cells; recently, methods using a gamma knife or ion beam have been developing rapidly.
Immunotherapy	Methods to utilize the immune system, which detects molecules or pathogens recognized as non-self, to attack them. A method using monoclonal antibody as a drug and a method using peptide vaccine are being developed.
Gene therapy	Methods to enhance a patient's immunity to cancer by introducing tumor suppressor genes to inhibit the development of cancer, or by introducing immune-related genes.

Source: Authors' own compilation

Table 3: Comparison between molecular target drugs and general anticancer drugs

Subject item	General anticancer drugs	Molecular target drugs
Hypothesis of efficacy	Empirical	Based on theory.
Main action	To destroy actively proliferating cells.	To inhibit, prevent and add the effects of molecules characteristic to cancer cells
Dosage setting	Higher dosage is desirable, although side effects are taken into account.	Optimal dose that may act on the target molecules.
Type of subject cancer	All cancers such as solid cancer.	Cancer with the target molecules.
Main efficacy	Regression of cancer.	To inhibit the progression of cancer.

Source: Authors' compilation based on the material prepared by Saburo Sone, professor at the School of Medicine, University of Tokushima

differentiation, or cell death (apoptosis).

ii) Formation of secondary tumors due to abnormality of cell adhesion, and, thereby, causing invasion or metastasis in the surrounding organs.

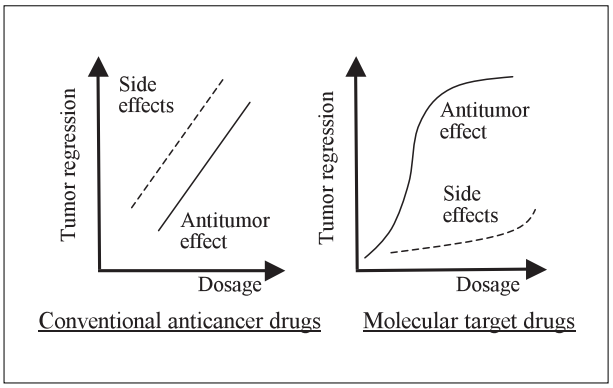
iii) Vascularization that forms new blood vessels to secure oxygen and nutrition.

iv) Drug resistance that makes drugs ineffective.

1.3.2 Cancer therapies

Major therapies for cancer are shown in Table 2. In an actual therapy, multiple therapies are combined occasionally.

Figure 3: Tumor regression of molecular target drugs and general anticancer drugs, and the relationship with occurrences of side effects



Source: Material prepared by Saburo Sone, M.D., Ph.D., professor at the University of Tokushima School of Medicine

1.3.3 Molecular target drugs

Anticancer drugs generally being used now inhibit and stop abnormal cell proliferation, as one of the characteristics of cancer cells, in order to destroy cancer cells.

When cells proliferate, there are 4 steps in the cell cycle including; i) gap phase of cell cycle and cell differentiation phase (G1 phase), ii) DNA synthesis phase (S phase), iii) cell division preparatory phase (G2 phase), and iv) cell division phase (M phase).

For cells frequently repeating the cell cycle, most anticancer drugs have an action to inhibit their DNA synthesis and cell division. For example, an anticancer drug called "Taxol" has an action to stop the progress of the M phase. However, cells frequently repeating the cell cycle are not limited to only cancer cells, but include normal cells such as hematopoietic cells and hair root cells. Therefore, most anticancer drugs also destroy normal cells, causing side effects.

On the other hand, the molecular target therapy is a therapy targeting molecules (Table 1) characteristic to cancer cells, and reductions in side effects may be expected from it. In addition, it is expected that molecular target drugs have possibilities to conquer intractable cancer such as advanced cancer and refractory cancer (e.g. lung cancer) for which there is the limit of the traditional treatment.

Also, molecular target drugs are being used based on individual patients' genetic abnormality and excessive protein expression, an aspect of tailor-made medicine (optimal therapy for individual patients), and are highly expected to represent what cancer therapy should be like after this.

In Table 3 and Figure 3, a comparison of the characteristics between general anticancer drugs and molecular target drugs are shown.

From the above, molecular target drugs are highly expected as new types of anticancer drugs, and various research and development are being accelerated throughout the world.

For example, STI571 (brand name: Glivec), developed as a drug for chronic myelogenous leukemia (CML) by Novartis Pharma , Switzerland,

was approved by the Food and Drug Administration (FDA) only 3 years after the start of clinical studies (May 2001). The drug is a molecular target drug that only acts on genetic products (protein with actions such as the abnormal proliferation of leukemia cells and the inhibition of apoptosis of blood cells) produced by the abnormality of the BCR-ABL gene as a cause of CML.

An anti-HER2 humanized monoclonal antibody, trastuzumab (brand name: Herceptin), developed as a breast cancer drug by Genentech, U.S.A., is a molecular target drug for metastatic breast cancer with excessive expression of a protein HER2. The excessive expression of HER2 is observed in approximately 20~25% of breast cancers. Herceptin selectively binds to the HER2, and has a cytotoxic effect on the cancer cells or an inhibitory effect on proliferation.

1.3.4 Problem in the development of molecular target drugs

As shown in Table 3, although efficacies of general anticancer drugs are evaluated from the regression of cancer, molecular target drugs are mainly aimed to inhibit the progression of cancer, and regression cannot be necessarily expected.

However, evaluations of anticancer drugs in clinical studies are mainly based on the regression of cancer. Therefore, the following criteria often shown as therapeutic effects of molecular target drugs have not been recognized as clinical evaluations in treatment; stable disease (state without exacerbation of cancer), time to progression (time to malignancy of cancer once again), and tumor dormancy (state of cancer growth settling down). In the future, it will be necessary to investigate the parameters for effective clinical evaluations.

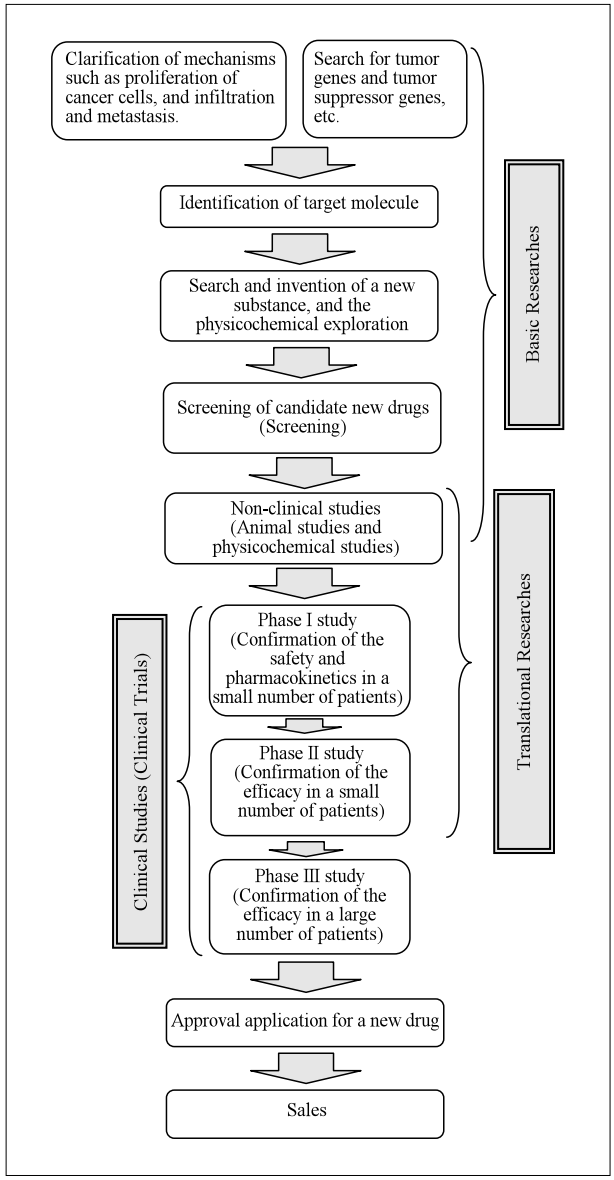
The development of a molecular target drug is based on exploratory basic researches, and high risk is associated with the stage to apply the drug as a therapy in clinical studies. Therefore, in order to promote the research and development of state-of-the-art therapies such as molecular target drugs, clinical trials conducted by the companies stated later are not sufficient, and clinical studies in a different form from the clinical trials are desired. Therefore, the necessity of translational researches is rapidly increasing.

1.4 System to promote the development of molecular target drugs — Promotion of translational researches —

1.4.1 What is Translational Research?

There is as yet no particular definition of translational researches that has obtained world consensus. In this report, we define this as researches to apply the results of exploratory basic researches for clinical studies to clinical studies in the development of state-of-the-art therapies such as molecular target drugs and

Figure 4. Process of research and development of molecular target drugs



Source: Authors' own compilation

regenerative therapy, and we distinguish them from clinical trials to obtain approval for drug, etc.

In Figure 4, the process of research and development of molecular target drugs is shown. Pharmaceutical development goes through basic researches, non-clinical studies, and clinical studies. Translational researches are likely to be in the range of the non-clinical studies to the phase II studies that can confirm the efficacy in humans.

In the current legal system, translational researches are outside of the regulations of the Pharmaceutical Affairs Law, as stated later. However, translational researches are aimed at establishing new therapies, and it is necessary to sufficiently secure ethical and scientific validity in clinical researches, and, therefore, it is also necessary to conduct researches according to the regulations of the Pharmaceutical Affairs Law and arrange for a system to conduct studies in translational researches.

1.4.2 Arrangement of legislation related to translational researches

In pharmaceutical research and development, a number of regulations have been made under ordinances based on the Pharmaceutical Affairs Law. Particularly, clinical studies (trials), which are conducted by medical institutions entrusted by a pharmaceutical company in order to obtain approval for drugs, etc., are being conducted according to Good Clinical Practice (GCP), strictly securing ethical and scientific validity.

On the other hand, GCP is not applied to clinical researches conducted mainly by researchers at universities and medical institutions, and the research data obtained there cannot be used for the approval application of drugs.

Thus, in clinical studies conducted mainly by universities and medical institutions, the research results are not smoothly integrated with pharmaceutical development and not required to comply with the provisions of GCP. As a problem, therefore, it was indicated that clinical studies were in a status that they could be conducted without sufficient consideration of the ethics and safety for patients and scientific validity.

In the background of such present status, the Ministry of Health, Labour and Welfare is proceeding with the amendment of the Pharmaceutical Affairs Law to extend its scope to utilize the results related to clinical researches. The proposed amendment was decided by Cabinet meeting, and submitted to the 154 times ordinary session of the Diet.

In the proposed amendment, the scope of clinical trials is to be extended to clinical researches conducted mainly by physicians and medical institutions intending to apply for clinical studies in the future (trial-type clinical researches). This will make it possible to use the results obtained from translational researches as part of the application data, and to provide new medical technologies to patients at an early stage while securing the ethical and safety aspects.

Thus, the results of translational researches will be easily combined to clinical trials, and the development of molecular target drugs is expected to accelerate.

1.4.3 Arrangement of the system to conduct translational researches

At medical institutions such as university hospitals, etc., efforts to arrange a system to conduct translational researches are getting under way.

As the first foothold of translational researches in Japan, Kyoto University Hospital established its Translational Research Center in April 2001. The Translational Research Center has implemented a public participation-type "Invited Research Project" with the functions such as preparing protocols, etc. and assessing the safety of the adopted project; actually conducting the clinical application, monitoring the safety and ethical aspects, and analyzing the biostatics.

Kobe City Government, which is proceeding with The Kobe Medical Industry Development Project, plans to establish a Translational Research Informatics Center in fiscal 2002, aiming to arrange a database of clinical researches, etc., in Japanese, in cooperation with the Ministry of Education, Culture, Sports, Science and Technology.

At the Council for Science and Technology Policy, Cabinet Office, in the promotion strategy of prioritized areas of life science (September 21, 2001) based on the Science and Technology Basic Plan 2001-2005 (decided by Cabinet meeting on

March 30, 2001), translational researches was taken up as one of the fields for which measures taken on a national basis should be strengthened, and measures to promote this were started.

1.4.4 Measures taken for translational researches in the United States

In the United States that has been extending the scope of the state-of-the-art therapy, measures taken for translational researches are being accelerated.

The National Cancer Institute (NCI) supports clinical researches being conducted by approximately 10,000 researchers at approximately 1,700 hospitals and cancer centers in the United States.

NCI is already proceeding with several programs for translational researches. For example, NCI started Specialized Programs of Research Excellence (SPOREs) to promote translational researches in cancer researches in 1992, and supports interdisciplinary research teams of translational researches for specific human cancers through public recruitment, etc. The budget of SPOREs for fiscal 2002 is approximately $107 million (approx. ¥12.8 billion), and is expected to further increase in the future.

1.5 Conclusion

To conquer cancer is an important problem in the attempt to maintain and increase Japanese people's health. Particularly, it is desired that therapies with less side effects, and therapies for refractory cancer and advanced cancer be established.

The research and development of molecular target drugs taken up in this article are important to our country as ways to explore new cancer therapies. In the development of molecular target drugs, translational researches are necessary to promote clinical studies, simultaneously with the promotion of basic researches.

To promote the development of molecular target therapy, the following measures are necessary.

(1) Promotion of exploratory basic researches targeted for clinical application

- Clarification of the mechanisms of the proliferation of various cancers, and invasion and metastasis, and identification of target molecules by searching for tumor genes and tumor suppressor genes.
- Search for drug reactivity-related genes, and search for and invention of new substances.

(2) Arrangement of a system to support researches

- Arrangement of an information management system such as a database specialized for cancer.
- Arrangement of a management system for research materials such as genes and cells (bio-resources).

(3) Arrangement of a system to conduct translational researches

- Following the current ongoing amendment to the Pharmaceutical Affairs Law, the legislation arrangement for the scope of clinical trials that is expected to extend in the future.
- Arrangement of a system to verify scientific validity, safety and ethics at institutions for translational researches such as university hospitals, and a system to deal with unexpected emergencies, as exploratory therapy is associated with high risk.
- Arrangement of participating teams (researchers of basic molecular biology, basic efficacy pharmacology, and clinical medicine, etc.) to effectively promote translational researches.
- To secure clinical research coordinators (CRC) to conduct duties dealing with subjects including informed consent, and human resources to conduct data management and analyses.
- To promote Japanese people's understanding about clinical studies, so as to recruit subjects more easily.

Through these measures, it is desired that new therapies such as those utilizing molecular target drugs be established to attain early realization of therapies with less side effects and improvement of the curing rate of cancer.

Acknowledgements

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2

Trends in Organic Synthesis Chemistry Research

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2.1 Introduction

The DNA sequence of genome, the blueprint of life, has been deciphered in human and other various organisms, and structural and functional analyses of proteins are currently in progress as post-genome research. Compounds that affect proteins or other functional molecules *in vivo* play critical roles in the post-genome research. For example, a compound acting specifically on a certain protein becomes a valuable reagent in biological science research. Moreover, most pharmaceuticals, which can be considered as compounds possessing many added values, can be synthesized through organic synthesis chemistry. Therefore, improving the capacity of organic synthesis chemistry in our country should contribute to the achievement of more outcomes from the post-genome research, as well as to the continuous release of novel chemical products from Japan to the world.

It has been considered that the current standard of organic synthesis chemistry has reached a level enabling total syntheses (synthesis using easily available starting materials) of compounds with quite complex structures, but tasks still remain, such as cost reduction or inhibition of by-products. For some compounds with complex structures such as Taxol, an anti-cancer drug, total synthesis techniques have been established, but their cost-performances are too low compared to other synthesis techniques. Furthermore, when chemically synthesizing certain kinds of useful substances, 3,000 times higher amounts of by-products are emitted besides the target substance, applying a heavy load on the environment. As a consequence, the development of new energy-saving reaction systems inhibiting the production of by-products are expected for synthesizing compounds that are essential for disease treatment or productive activities. In general, the introduction of a catalyst into a reaction system is expected not only to reduce the energy required but also to permit only the desired reaction to proceed among several potential reactions. Therefore, the development of a new reaction system is often accompanied by the development of a new catalyst.

In this report, we will introduce the recent research achievements in the area of organic synthesis chemistry and discuss the future long-term trends.

2.2 Main achievements in organic synthesis chemistry

2.2.1 Progress in organic chemistry and the Nobel Prize

Table 1 shows a list of Nobel Prize winners who have received the awarded for work in the area of organic chemistry since 1950.[1] Their efforts over these 50 years have made feasible the accurate syntheses of organic compounds. This is not limited to simple compounds, which can be prepared on industrial scales with low costs; it also applies to compounds with extremely complex structures, which can be synthesized on small, laboratory scales (in mg scales) at the expense of cost and time.

The organic chemistry research in our country has constantly retained its high level, which has been proven by the recent award of Nobel Prizes in Chemistry to Japanese researchers for two consecutive years.

The following sections will introduce the Wittig

Table 1: Winners of the Nobel Prize in Chemistry for the Area of Organic Chemistry since 1950.

Year awarded	Winner(s)	Works awarded
1950	Diels, Otto, Paul Hermann (Germany) Alder, Kurt (Germany)	Diene synthesis
1955	Du Vigneaud, Vincent (U.S.)	Synthesis of peptide hormone
1963	Ziegler, Karl (Germany) Natta, Giulio (Italy)	Chemistry of high polymers
1965	Woodward, Robert Burns (U.S.)	Modern organic chemistry theories
1969	Barton, Sir Derek H. R. (U.K.) Hassel, Odd (Norway)	Concept of conformation and its application in chemistry
1973	Fischer, Ernst Otto (West Germany) Wilkinson, Sir Geoffrey (U.K.)	Organometallic catalysts
1975	Cornforth, Sir John Warcup (U.K.) Prelog, Vladimir (Switzerland)	Stereochemistry of enzyme-catalyzed reactions
1979	Brown, Herbert C. (U.S.) Wittig, Georg (West Germany)	Use of boron- and phosphorus-containing compounds in organic synthesis
1981	Fukui, Kenichi (Japan) Hoffmann, Roald (U.S.)	Frontier orbital theory
1984	Merrifield, Robert Bruce (U.S.)	Chemical synthesis on a solid matrix
1987	Cram, Donald J. (U.S.) Lehn, Jean-Marie (France) Pedersen, Charles J. (U.S.)	Host-guest chemistry
1990	Corey, Elias James (U.S.)	Development of the theory and methodology of organic synthesis
1992	Marcus, Rudolph A. (U.S.)	Theory of electron transfer reactions in chemical syntheses
1994	Olah, George A. (U.S.)	Carbocation chemistry
2000	Heeger, Alan J. (U.S.) MacDiarmid, Alan G. (U.S.) Shirakawa, Hideki (Japan)	Discovery and development of conductive polymers
2001	Knowles, William S. (U.S.) Noyori, Ryoji (Japan) Sharpless, K. Barry (U.S.)	Development of chirally catalyzed hydrogenation reactions Development of chirally catalyzed oxidation reactions

Source: Authors' own compilation

reaction as a typical reaction of organic synthesis chemistry, and Taxol, an anti-cancer drug, as an example of organic compounds with extremely complex structures whose total syntheses have been reported recently. The subsequent sections will cover the versatile research on novel chiral catalysts, represented by asymmetric hydrogenation, the work of a 2001 Nobelist Dr. Ryoji Noyori, and asymmetric carbon-carbon bond generation.

2.2.2 A typical reaction of organic synthesis chemistry

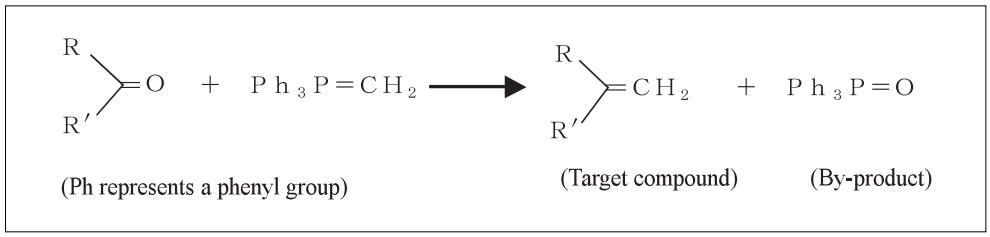
In the area of organic synthesis chemistry, Dr. Wittig was awarded the Nobel Prize in 1979, for developing an efficient reaction called "Wittig reaction" in 1953 (Figure 1). Wittig reaction employs phosphorus ylide ($Ph_3P=CH_2$) for specifically generating double bonds in carbonyl groups via the generation of carbon—carbon bonds. The reaction is frequently employed for manufacturing various pharmaceuticals and perfumes.

In the second half of the 20th century, the area of organic synthesis chemistry progressed with emphasis on chemical yield improvement. Here, the generation of by-products was not considered a big problem, even if they were generated at amounts equal to the target products, as in the Wittig reaction.

2.2.3 Example of compounds with complex structures ~synthesis of Taxol~

Taxol is a compound having a complex structure as shown in Figure 2. It is found in the barks of yew trees (*Taxus brevifolia*) in trace amounts and acts as an anti-cancer drug effective for breast or uterine cancer. In the Charts of the present

Figure 1: Wittig reaction



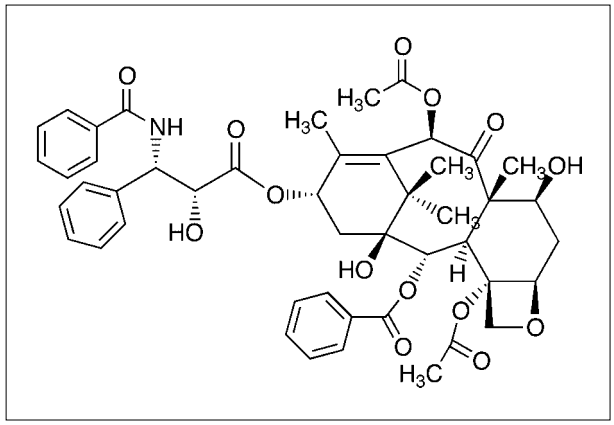
Source: material prepared by Professor Masakatsu Shibasaki of the Graduate Course of Pharmacy, Graduate School of Tokyo University

report, chemical bonds are represented by either bold solid lines or dotted lines. The bold solid lines are bonds that are positioned toward this side of the sheet, while the dotted lines are those positioned away to the other side of the sheet. As can be seen from Figure 2, Taxol has a sterically complex structure. Since the amount of Taxol required for treating one patient corresponds to 3 yew trees, the isolation of Taxol from plants is not suitable as a manufacturing process for a pharmaceutical product.

The total synthesis of Taxol was first reported in 1994 in the *Journal of the American Chemical Society*. This report attracted great attention as a study demonstrating the possibility of synthesizing complex-structured chemicals. However, the technique presented in the study barely enabled the synthesis of about 10 mg of Taxol in a high-tech laboratory for organic synthesis chemistry. The total synthesis required too much cost, which was fatal as a process for manufacturing pharmaceuticals. Later, a technique for producing Taxol through organic synthesis in fewer steps was developed using an intermediate material (baccatin). Baccatin can be isolated in a relatively large amount from leaves of a shrub named European yew (*Taxus baccata*), and this technique is currently used for Taxol production.

Furthermore, the partial modification of the total synthesis of Taxol has enabled the synthesis of an anti-cancer drug that is superior to Taxol. The clinical trials for this "novel Taxol" are currently in progress. So far, this novel compound cannot be synthesized from baccatin. This is a good example demonstrating that even for a naturally existing compound, the establishment of an organic synthesis technique is extremely important for the subsequent research in areas such as pharmaceutical chemistry.

Figure 2: Structural formula of Taxol

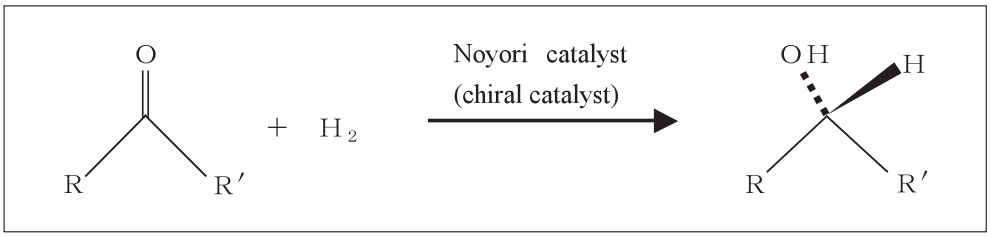


2.2.4 Asymmetric catalytic reaction ~asymmetric hydrogenation~

Most molecules are "asymmetric," having two forms that are mirror images of each other, just like a person's right hand and left hand. For some asymmetric molecules, only one of the mirror-image forms is biologically useful while the other is harmful. A considerable number of pharmaceutical products are known to have such "asymmetric" structures, and the difference between the two forms may lead to a matter of life and death in some cases. Therefore, it is crucial to make the two forms separately.

In 2001, Dr. Ryoji Noyori was awarded the Nobel Prize in Chemistry for his work "BINAP — Development of Chirally Catalyzed Hydrogenation based on Transition Metal Complex". Dr. Noyori developed a versatile catalytic molecule that enables the synthesis (asymmetric synthesis) of only one of the two enantiomers in asymmetric hydrogenation (Figure 3). The results from his research are applied to the industrial production of antibiotics and antibacterial agents.[1]

Figure 3: Example of chirally catalyzed hydrogenation



Source: material prepared by Professor Masakatsu Shibasaki of the Graduate Course of Pharmacy, Graduate School of Tokyo University

2.2.5 Asymmetric Carbon —Carbon bond generation

Because the bonds between carbon atoms form the skeletal structure of every organic compound, carbon—carbon bond generation is the central subject of organic synthesis. Particularly great attention is paid to asymmetric carbon—carbon bond generation, i.e., the asymmetric synthesis (separate production of "right hands" and "left hands") of carbon—carbon bond generation. An example of such asymmetric carbon—carbon bond generation is a reaction known world-wide as "Mukouyama reaction," which was developed by Dr. Mitsuteru Mukouyama, a professor emeritus of Tokyo University. Mukouyama reaction is described in Figure 4 through an example generating the target product ⑥ from acetone ① and aldehyde ④.

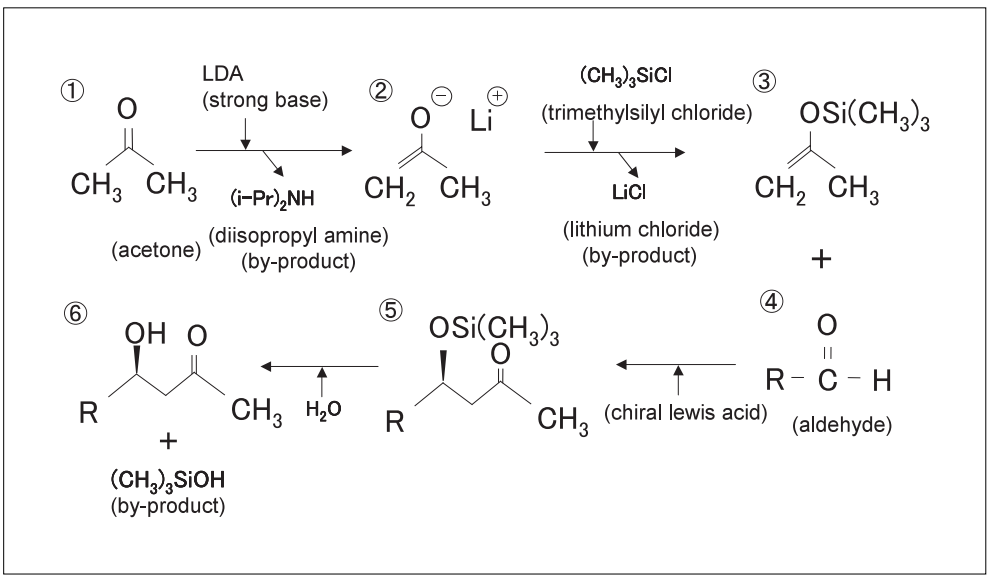
Mukouyama reaction is an outstanding research result with high originality. As a next step, one of the most important research subjects in the world today is the development of a new versatile reaction system or catalyst for efficiently performing asymmetric carbon—carbon bond generation in one step (Figure 5).

2.3 Long-term trends in organic synthesis chemistry research

The current standard of organic synthesis chemistry has already reached a level enabling syntheses of compounds with complex structures. Needless to say, the most important subject is to develop techniques for reducing costs and inhibiting by-product generation.

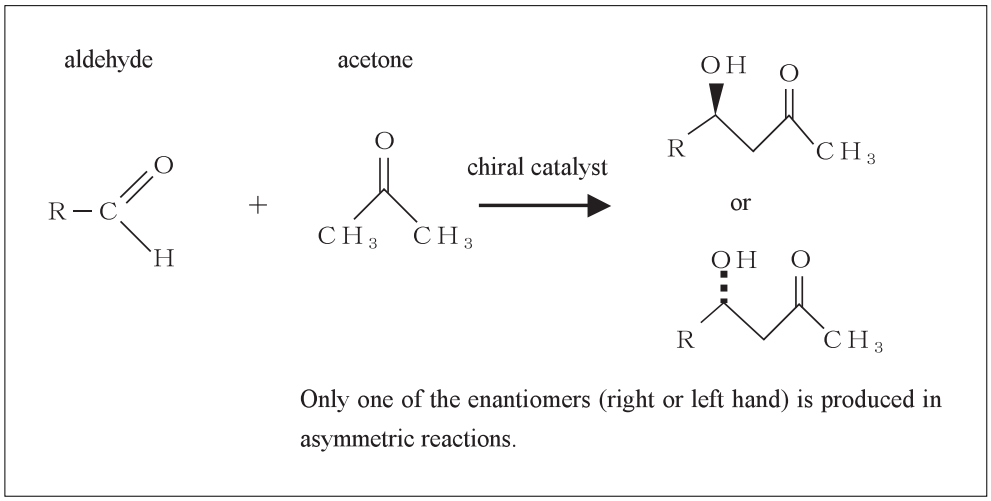
From the point of environmental conservation, it will be important to develop industrial techniques based on the standpoint of "Green Chemistry" (a movement involving a wide range of areas including basic/applied chemistry and chemical technology/industry, which aims at the establishment of a sustainable chemical

Figure 4: Example of Mukouyama reaction (asymmetric albol reaction)



Source: material prepared by Professor Masakatsu Shibasaki of the Graduate Course of Pharmacy, Graduate School of Tokyo University

Figure 5: Example of efficient generation of asymmetric carbon-carbon bond (asymmetric aldol reaction)



Source: material prepared by Professor Masakatsu Shibasaki of the Graduate Course of Pharmacy, Graduate School of Tokyo University

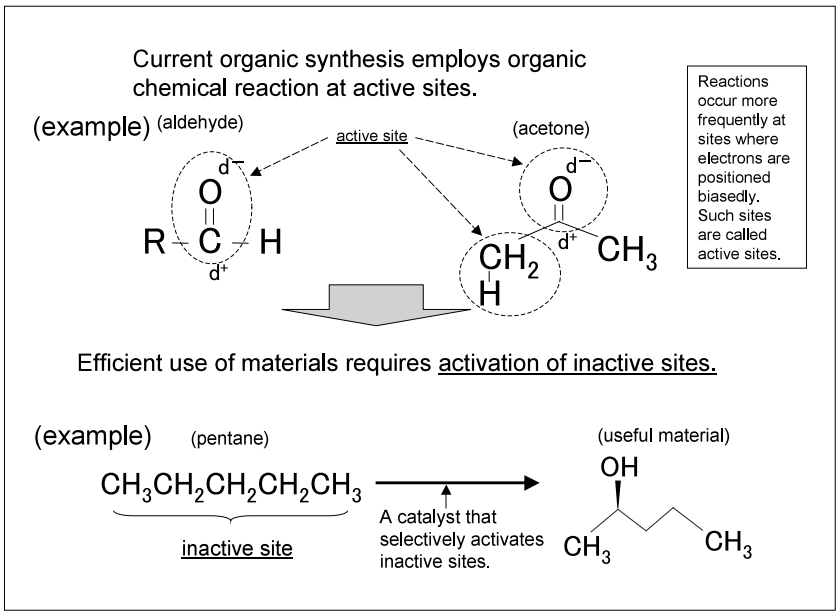
technology system suitable for future society).[2] Furthermore, people may live in a closed system such as outer space in the future, and such possibility must also be taken into consideration. Here, we will introduce some examples of reactions that are expected to be developed in the future in the area of organic synthesis chemistry.

2.3.1 Development of reaction systems that selectively activates specific inactive sites

Current organic synthesis chemistry utilizes organic chemical reactions taking place at active sites (functional groups) such as aldehydes, ketones and hydroxyl groups. If catalysts that promote selective activation of specific inactive sites in various compounds were to be developed, it would be possible to produce useful substances using resources or compounds that are rarely used today. One example is a reaction which introduces functional groups such as hydroxyl groups (—OH) into selective sites in a saturated hydrocarbon compound such as pentane (Figure 6).

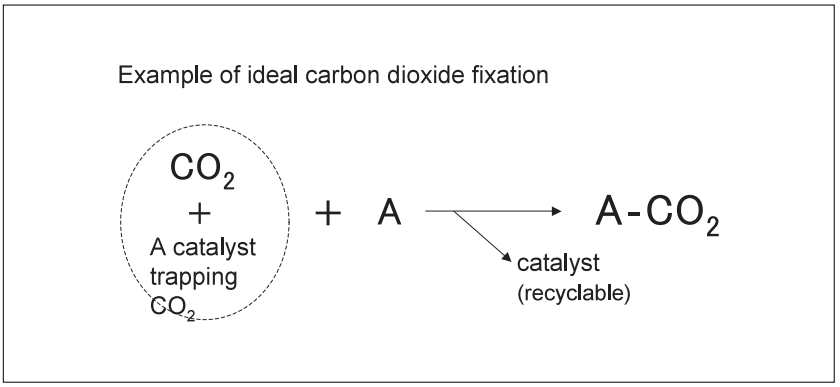
Studies on the site-specific activation of inactive sites are gradually making progress, realizing such reaction in a limited number of systems. However, it seems that much more time will be required before reactions such as those represented in

Figure 6: Selective activation of specific inactive sites



Source: material prepared by Professor Masakatsu Shibasaki of the Graduate Course of Pharmacy, Graduate School of Tokyo University

Figure 7: Example of carbon dioxide fixation by organic synthesis chemistry



Source: material prepared by Professor Masakatsu Shibasaki of the Graduate Course of Pharmacy, Graduate School of Tokyo University

Figure 6 can be put into practice.

2.3.2 Development of a carbon dioxide fixation system

Figure 7 illustrates a reaction that allows a trace amount of carbon dioxide at a level equivalent to that in the air (approximately 0.03%) to form a complex compound with the catalyst, and, subsequently, to be fixed in substance A. If such reaction were to be developed, carbon dioxide present in the air can be used as a substitute for carbonous materials such as petrol that may be exhausted in the future. The development of such reaction is also important from the point of reducing the carbon dioxide level in the environment. However, such reaction cannot be realized, since there is no catalyst that can distinguish and bind carbon dioxide at a level of approximately 0.03%.

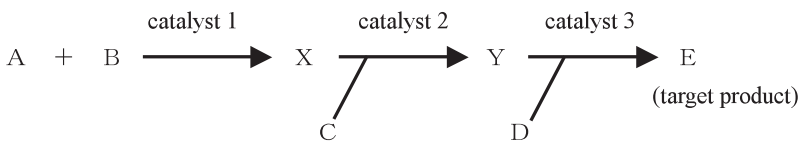
The fixation of carbon dioxide in the air is mainly studied by researchers in the area of biomimetics who are attempting to mimic photosynthesis. This reaction is assumed to take many years before its realization, but once a catalyst that can capture carbon dioxide in the air is discovered, the research may progress radically.

2.3.3 Example of ideal organic synthesis chemical reaction

Generally, organic synthetic reaction requires hundreds or thousands of times as much organic solvents as the reaction product. To solve this problem, researchers are working on the development of organic synthetic reaction in water that requires no organic solvent. This research area is expected to grow more and more in the future. The ultimate goal is to carry out organic synthetic reactions in the absence of any solvent, and, therefore, researchers must contemplate on the development of such reaction systems.

One of the ideal forms of organic synthesis chemical reaction involves chemical syntheses of useful substances without emitting any by-

Figure 8: Example of the ideal form of organic synthesis chemistry reaction



Each reaction proceeds without using any solvent and without generating any by-product.
All of the catalysts are available and recyclable.
(A, B, C and D each represents a reaction material. X and Y each represent an intermediate product.)

Source: material prepared by Professor Masakatsu Shibasaki of the Graduate Course of Pharmacy, Graduate School of Tokyo University

product. In order to realize this, various catalysts must be available for promoting reactions without using any solvent (solvent-free) or generating any by-product (Figure 8).

For example, a solvent-free catalytic reaction is employed in a one-step reaction system for forming cyclohexane via the addition of hydrogen to hexane. However, it is difficult to apply the ideal synthesis method shown in Figure 8 to the synthesis of complex compounds that are formed via several steps. It will take many years before such methods become available.

2.4 Conclusion

2.4.1 Public interest in organic synthesis chemistry research

One of the important academic journals in the area of basic chemistry is the *Journal of the American Chemical Society* (*JACS*). This journal published the first report on the total synthesis of Taxol.

Based on the JICST files (covering documents published since 1975), a database of documents in the area of science and technology, we have counted the number of papers written by the three 2001 Nobelists in Chemistry, Dr. Noyori, Dr. Sharpless and Dr. Knowles, published in *JACS*, *Science*, and *Nature* before May 13, 2002. *JACS* published 66 and 47 papers written by Dr. Noyori and Dr. Sharpless, respectively. On the other hand, Science published only five and two papers by Dr. Noyori and Dr. Sharpless, respectively, and Nature had no publications of the two Nobelists. Meanwhile, Dr. Knowles had four publications in *JACS* but none in *Science* or *Nature*. During this period, Dr. Knowles had only eight papers published in all the journals covered by the JICST files.

Furthermore, we calculated the proportions of papers in the areas of basic chemistry and organic chemistry (included in basic chemistry) published during the same period in Science and Nature. As a result, among a total of 17,159 papers published in Science, 910 (5.3%) were from the area of basic chemistry and merely 151 (0.9%) from organic chemistry. Meanwhile, among 20,197 papers published in Nature, 691 (3.4%) were from basic chemistry and merely 79 (0.4%) from organic chemistry.

Since the Japanese media tend to cover mainly the works published in Nature and Science, the research results published in these two journals are easily propagated to the public. However, as mentioned above, organic synthesis chemistry is an area that does not appear very frequently in Nature or Science, so there is little chance for the research in this area to be covered by the media and attract public attention.

2.4.2 Expectations toward organic synthesis chemistry research

As mentioned earlier in the beginning of "Introduction," organic synthesis chemistry is an important research area in life science. Compounds that affect proteins or other molecules that function *in vivo* play extremely important roles in the post-genome research. For example, a compound acting specifically on a certain protein becomes a valuable reagent in biological science research. Moreover, most pharmaceuticals, which can be considered as compounds possessing many added values, can be synthesized through organic synthesis chemistry. Therefore, improving the capacity of organic synthesis chemistry in our country should contribute to the achievement of more outcomes from the post-genome research, as well as to the continuous release of novel chemical products from Japan to the world.

The current standard of organic synthesis chemistry has already reached a level enabling syntheses of compounds with complex structures. Needless to say, the development of a new, energy-saving reaction system inhibiting the generation of by-products is desirable from the viewpoint of Green Chemistry.

Consequently, one of the next goals in organic synthesis chemistry is to develop reaction systems for completing multi-step reactions in one step and to replace the existing reaction systems with low-cost systems. Since people may live in a closed system such as outer space in the future, we must also consider about such possibility on a long-term basis. Therefore, the establishment of solvent-free synthetic methods generating no by-product will become the long-range objective in this area.

Since the level of organic chemistry research in our country is one of the highest in the world, we must take the initiative in the research for achieving these goals.

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[2] Makoto Misono, Shunichi Murahashi edited, Green Chemistry, 2001 Kodansha Scientific (in Japanese).

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3

Trends in Plant Molecular Biology

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3.1 Introduction

The principal goal of plant molecular biology is to reveal the mechanisms for controlling forms and metabolism, and the evolutional process of plants with focus on the gene function. This field of study is highly expected to boost development of plants necessary for solving food, environmental and energy problems in the future. In addition, plant molecular biology is recognized as a crucial field of study in the Comprehensive Strategy to Promote Science and Technology, which was adopted at the Council for Science and Technology Policy of the Cabinet Office in September 2001.

Studies on the gene function of so-called model plants such as *Arabidopsis thaliana* and rice have progressed all over the world since the mid-1980s for several reasons. First, the fruits of genetic and physiological studies on these plants have been accumulated for a long time. Besides, their genome sizes are small, mating and gene transfer are uncomplicated, and biological resources for gene function analysis can be easily obtained.

A joint project of Japan, the U.S. and Europe completed genome sequence in *Arabidopsis* in December 2000 for the first time in higher plants. Meanwhile, Syngenta of Switzerland and the Beijing Genomics Institute of China separately completed genome sequence in rice in April 2002. Moreover, an international consortium, which Japan takes a leading part, is expected to complete more accurate genome sequence in rice by the end of 2002. The research basis for plant gene function analysis is solidifying, as whole genome

Table 1: Number of sequenced plant nucleotides registered in the DDBJ/EMBL/GenBank DNA databases (as of April 2002).

Ranking	Scientific name (Common name)	Number of registered nucleotides (b) *1	Genome size (Mb) *2
1	Oryza sativa (Rice)	397,636,312	430
2	Arabidopsis thaliana (Arabidopsis)	313,816,117	125
3	Brassica oleracea (Cabbage, broccoli)	195,244,865	1,200
4	Glycine max (Soybean)	116,211,613	1,290~1,810
5	Zea mays (Maize)	102,365,381	2,300
6	Lycopersicon esculentum (Tomato)	84,099,550	950
7	Medicago truncatula (Barrel medic)	73,695,194	450
8	Hordeum vulgare (Barley)	70,306,697	4,800
9	Chlamydomonas reinhardtii (Chlamydomonas)	64,781,512	100
10	Sorghum bicolor (Sorghum)	42,412,607	750
11	Triticum aestivum (Wheat)	37,072,790	16,000
12	Solanum tuberosum (Potato)	36,961,099	—
13	Physcomitrella patens (Moss)	25,834,542	400
14	Pinus taeda (Pine)	18,645,322	—
15	Lotus japonicus (Lotus)	17,707,239	440~490

1 Registered nucleotides include not only genomes but also cDNAs.[1]
*2 One Mb is equal to 1 x 10^6 b.

Source: Authors' compilation on the basis of DDBJ's statistical data

sequences of rice and *Arabidopsis* are revealed.

In the meantime, international competition in gene function analysis is becoming keener as firm research bases like whole genome sequence information and biological resources are established. Therefore, also in Japan, we immediately need to obtain study results that will contribute to solving food, environmental and energy problems.

In this report, we will survey trends in plant molecular biology in Japan and other countries, and discuss about the policy for promoting this field of study in our country.

3.2 History of plant molecular biology

3.2.1 Plant species with advanced gene analyses

Table 1 shows the amount of each plant's sequenced nucleotides registered in the DDBJ/EMBL/GenBank DNA databases. This list indicates what kinds of plants have been mainly studied in plant molecular biology.

When the amount of sequenced nucleotides registered in this database is compared among plant species, rice has the largest number of sequenced nucleotides. Rice has been studied as a model plant of Poaceae, which includes various agricultural plants such as rice, maize and wheat. Meanwhile, *Arabidopsis thaliana* takes second place. *Arabidopsis* is a model plant of higher plants and its worldwide gene function analysis has been promoted since the mid-1980s. The amount of sequenced nucleotides of these two model plants surpasses that of other plants. Researchers all over the world are pursuing the study of these two species as major materials for unveiling the gene function.

In third place comes cabbage and broccoli, which belongs to Brassicaceae, the same family as *Arabidopsis*. Researchers have promoted the study of the gene function of cabbage and broccoli, making good use of its gene homology with *Arabidopsis*.

Soybean takes fourth place. Soybeans are cultivated around the world as a source of protein and oil, and nitrogen fixation by their symbiotic bacteria is notable. *Meanwhile*, *Medicago truncatula* and *Lotus japonicus*, model plants of Fabaceae, take the seventh and 15th places, respectively.

3.2.2 Arabidopsis thaliana

Table 2 shows the chronology of research on *Arabidopsis*.

Arabidopsis is a wildflower distributed around the Northern Hemisphere. Basic research on *Arabidopsis* as a material for genetics began in Germany around 1965. Later, *Arabidopsis* came to be widely used as a major material for plant molecular biology due to its advantages. For example, though its genome size is as small as 125Mb, it has basic gene functions that a higher plant has, such as growth, flowering, environmental response, and pest resistance. In addition, it has a rapid life cycle of about two months. Furthermore, its gene manipulation is relatively easy.

Researchers in Japan, the US and Europe established an international research organization to study *Arabidopsis* in 1990. This grew into a whole genome sequencing project in 1995. Then, genome sequence of *Arabidopsis* was completed

Table 2: Chronology of Arabidopsis research

1965	Basic research such as isolation of mutants is conducted in Germany.
1985	Extensive application of molecular genetics starts in the U.S., Europe, Japan, Australia and other countries.
1990	A committee for promoting international joint research of Arabidopsis is established. Gene introduction becomes generalized, and production of tag lines*2 and gene cloning begin.
1995	A whole genome sequencing project is launched with international cooperation.
2000	Genome sequence is completed. The 2010 Project is initiated. Analysis of the function and interactive network of the gene starts. Research on mechanisms of diversification and evolution by comparison with genomes of various plants begins.

Source: the figure made by Prof. Kiyotaka Okada of the Graduate School of Science, Kyoto University

in December 2000. The Kazusa DNA Research Institute, which is subsidized by Chiba Prefecture, was the Japanese organization that joined this international project. This institute decoded 30% of the entire genome, the largest amount among the six groups joined in the project, and its achievement is recognized throughout the world.

3.2.3 Rice

Rice, as well as being an agricultural plant, serves as a model plant in clarifying the common gene function of Poaceae like maize and wheat. Japan launched a rice-genome-project in 1991, the first in the world on this subject, and established the basis for rice genome studies by mass analysis of cDNAs*1 and construction of high-density gene linkage maps*3 and chromosome maps.

In 1998, the International Rice Genome Sequencing Project (IRGSP) was established as the second rice-genome-project with Japan as its leading country, and started whole genome sequencing of rice. As of May 2002, 317Mb or 74% of the entire rice genome (430Mb) has been sequenced, and the National Institute of Agrobiological Sciences and the Society for Techno-innovation of Agriculture, Forestry and Fisheries have jointly sequenced about 60% of the nucleotides. This project will complete high-accuracy sequencing of the major parts of rice genome by the end of 2002.

In the meantime, Syngenta of Switzerland (a multinational enterprise ranking first in the field of agricultural chemical and third in the high-value commercial seeds market of the world) and the Beijing Genomics Institute of China separately completed draft genome sequence in rice in April 2002 (*Science*, April 5, 2002).

Some Japanese and foreign researchers using rice had said, "IRGSP must immediately release nucleotide sequence information covering the entire genome even if its accuracy is low, so that anyone can use it." To meet such a request, IRGSP, in 2001, changed its policy of unveiling data after nucleotides were completely sequenced at an accuracy of 99.99%: It decided to release data earlier even if some regions are not sequenced.

Meanwhile, international consensus exists on the need for whole genome sequencing in rice at an accuracy of 99.99%, or with less than one nucleotide sequencing error in 10,000 base pairs (bp). For example, Syngenta, which already completed draft genome sequence in rice, agreed to offer its data for free to IRGSP in order to help with the completion of the high-accuracy sequencing. In the meantime, according to a press release on May 6, 2002 by the Rockefeller Foundation, which has subsidized plant biological researches to solve food and environmental problems, Dr. Gordon Conway, president of the foundation, praised Japan for its initiative in rice genome sequencing. He stated, "Japan's leadership and commitment to accurately sequencing the rice genome will enable research leading to better food security throughout the developing world." Moreover, he urged that this project "be carried to completion."

3.2.4 Fabaceae

In world food production, monocots such as rice, wheat and maize are cultivated as starch sources, and fabaceous plants such as soybeans are grown as protein sources. Fabaceae is an important object of study in plant molecular biology, because it has marked features such as protein accumulation in the seed and nitrogen fixation by bacterium living symbiotically in their roots.

Gene function analysis is progressing around the world with intensive studies on two model plants, Medicago truncatula, a relative of alfalfa, and Lotus japonicus, an indigenous species in Japan.

The US and France heavily subsidize research on *Medicago*, and gene mapping, preparation of tag lines*2 and symbiotic-bacteria-genome sequencing are more advanced on this plant than in Lotus. European and U.S. research groups are taking the initiative in *Medicago* studies.

In Japan, analysis of expressed sequence tags (EST)*4 of *Lotus* is progressing with contributions by the Kazusa DNA Research Institute, because *Lotus* is Japan's indigenous species and its genetically diverse strains are stocked. In the meantime, this institute, in December 2000, completed genome sequence in *Mesorhizobium* loti, a symbiotic bacteria with a genome size of 7.6 Mb, which lives symbiotically in *Lotus* and contributes to nitrogen fixation.

3.3 Recent progress in plant molecular biology

3.3.1 Estimate of the gene function

In *Arabidopsis* and rice, with their whole genomes sequenced, the total number of genes in their genomes and gene functions can be estimated from the genome sequence information on the basis of homology with genes with unveiled functions (Figure 1).

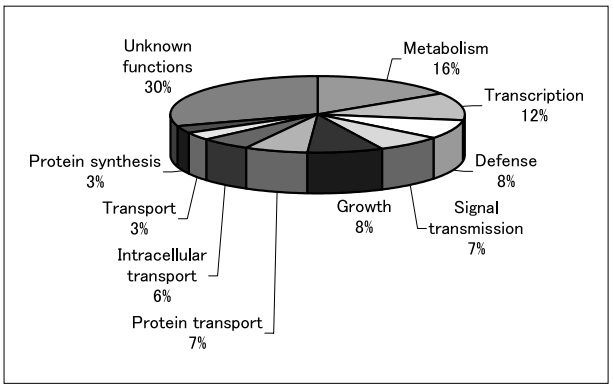
From homology with nucleotide sequences of particular genes that are already analyzed, the *Arabidopsis* genome presumably contains approximately 25,500 genes. It has been revealed that a considerable part of the genes are related to metabolism and gene expression control. Yet, the functions of about 30% of all the genes could not be assessed at the time of genome-sequence completion.

3.3.2 Genes related to morphogenesis

The whole genome sequence of *Arabidopsis* has been revealed and gene function analysis has proceeded. Among various functions of plant genes, several features of genes involved in morphogenesis, or genes determining forms, have been clarified:

1) Functional change of a few genes brings about remarkable change in forms.
2) Functional change of genes expressing in the apical meristem of the stem brings about remarkable change in the plant form.
3) Genes related to intercellular transmission of the positional information play an important role in cell proliferation and differentiation.

Figure 1: Functions of about 25,500 genes that Arabidopsis genome presumably contains



Source: the figure made by Prof. Kiyotaka Okada of the Graduate School of Science, Kyoto University

4) More than one gene has the same function in many cases.

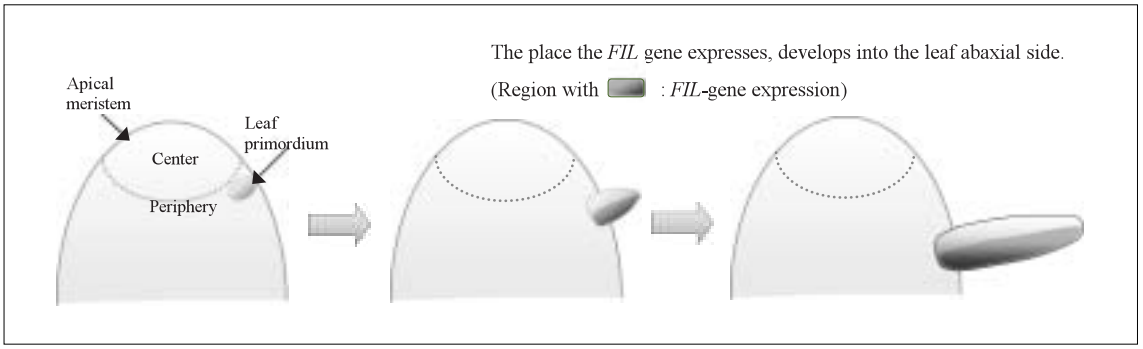
Genes involved in plant morphogenesis are important objects of basic research because they often affect such traits as yield and quality of commercial plants like crops.

3.3.3 Genes to determine abaxial and adaxial sides of the leaf

Cell division is active in the apical meristem of the plant stem, and the primordium, or the tissue that develops into plant organs such as the leaf and flower, is generated there. Positions of leaf primordium cells relative to the meristem probably determine the abaxial and adaxial sides of the primordium. Different genes are presumably expressing in the abaxial and adaxial sides because their structures in a mature leaf are distinct.

The research team of Kiyotaka Okada, professor of the Graduate School of Science, Kyoto University, isolated the *FILAMENTOUS FLOWER*

Figure 2: Expression process of the *FIL* gene



Source: the figure made by Prof. Kiyotaka Okada of the Graduate School of Science, Kyoto University

(*FIL*) gene, making good use of a mutant that cannot successfully develop leaf abaxial and adaxial sides of *Arabidopsis* (Figure 2). The team discovered that the place the *FIL* gene expresses, develops into the leaf abaxial side. Moreover, detailed structural analysis of the *FIL* gene revealed that the region of 50 bp from 1745 bp to 1795 bp upstream of the start codon of the *FIL* gene has a promoter of the *FIL* gene, so that the *FIL* gene expresses in the leaf abaxial side.

Today, the gene involved in the control of *FIL*-gene expression is about to be isolated. This gene presumably encodes the protein binding to the above-mentioned region of 50 bp. That is, researchers are trying to identify the signal serving as the positional information, supposing *FIL*-gene expression is controlled as follows. First, this signal is transmitted from the center of the meristem to the leaf primordium. Then, the strength of the signal varies in the abaxial and adaxial sides of the primordium due to the difference in their distance from the meristem, thereby affecting *FIL*-gene expression.

It has been understood that various signal transmissions are related not only to the leaf abaxial-adaxial determination but also to other important stages of plant morphogenesis such as flower bud differentiation and fertilization. Almost all plants including crops probably have a common mechanism of signal transmission, so clarification of this mechanism with such model plants as *Arabidopsis* is crucial in plant molecular biology.

3.3.4 Genes related to the height of rice

The International Rice Research Institute (IRRI) of the Philippines selected the high-yielding variety IR8 through breeding in the 1960s. IR8, being short and hardly lodging, greatly contributed to the increase in food production in Asian countries, which is known as the Green Revolution.

The research group of Makoto Matsuoka, professor of the BioScience Center, Nagoya University, isolated the sd1 gene, which was deeply related to the Green Revolution as a gene involved in rice-height determination (Nature, April 18, 2002).

The sd*1* gene,which encodes the $GA20_{OX}$-2 enzyme related to biosynthesis of gibberellin, a plant hormone, is deleted in IR8. Plant height decreases in this variety because of the reduction of gibberellin (Figure 3).

Figure 3: Mutation in the sd*1* gene, which is involved in gibberellin synthesis, makes the plant height short: left, wild-type rice; right, sd1-mutant rice.

Source: the home page of the BioScience Center, Nagoya University

Mutation of the isolated sd*1* gene can realize an ideal height of rice, so molecular breeding using this gene may become possible in other rice varieties as well.

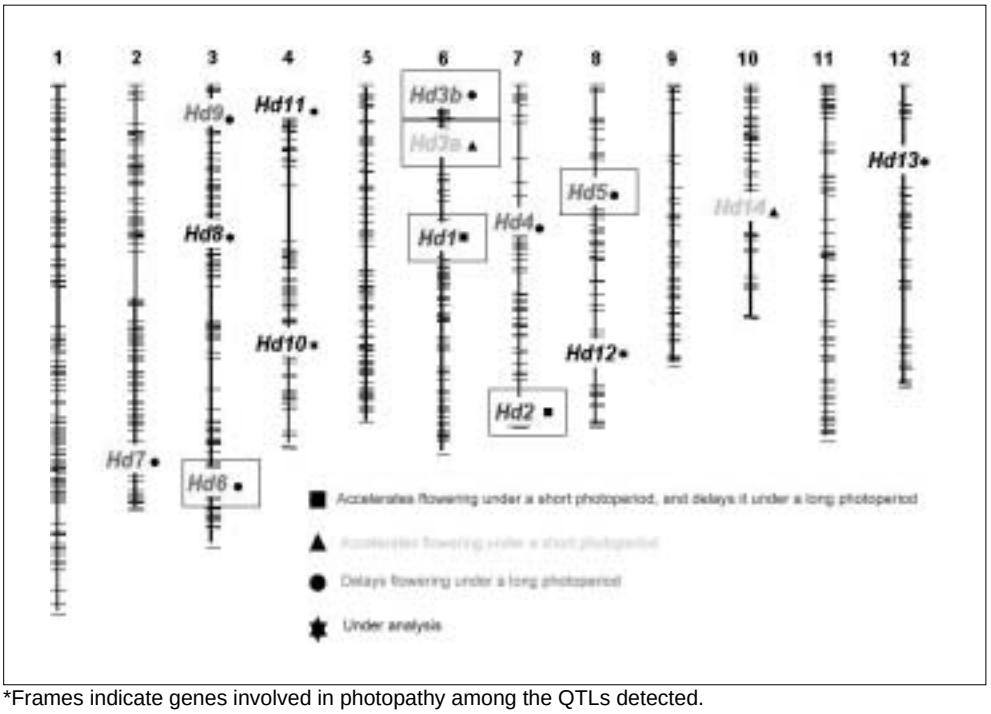
3.3.5 Genes controlling the flowering time

Most quantitative traits such as flowering time have been hardly researched: Various genes control them, so that analysis of such traits has been complex. However, molecular genetic analysis of the characters determined by quantitative trait loci (QTL) is becoming feasible with DNA markers*5 and nucleotide-sequence information obtained through rice genome studies.

The research team led by Masahiro Yano of the Department of Molecular Genetics, National Institute of Agrobiological Sciences, generated a population for gene analysis derived from a cross between rice varieties Nipponbare and Kasalath by such hybridization methods as replacement of certain chromosomes. Based on gene analyses with DNA markers, this group found 15 QTL regions in chromosomes related to the rice flowering time (Figure 4).

Moreover, this team isolated genes (*Hd1*, *Hd3a* and *Hd6*) related to the flowering time from three QTL regions by map-based cloning*6 and analyzed their gene structures. It revealed that the *Hd1* and *Hd3a* genes are homologues with the flowering-related genes of *Arabidopsis*, while the *Hd6* gene

Figure 4: Locations in chromosomes and functions of QTLs involved in the determination of the flowering time of rice.



*Frames indicate genes involved in photopathy among the QTLs detected.

Source: a figure made at the National Institute of Agrobiological Sciences

is homologues with the biological-clock-associated genes of *Drosophila* and *Arabidopsis*. These results indicated that rice, a short-day plant (a plant that flowers under a short photoperiod), and *Arabidopsis*, a long-day plant, have flowering-related genes with similar structures, although they have a converse response to the day length (*Plant Cell*, December 2000; *Proceedings of the National Academy of Sciences*, July 3, 2001).

The method of analyzing rice QTLs with DNA markers, which Yano's research group established, can be applied to analysis of traits other than the flowering time. Thus, this technique will help researchers to understand the control mechanism of genes related to useful traits, whose analysis have been difficult.

3.3.6 Genes related to resistance to environmental stress

Development of technology to improve plant tolerance to environmental stresses such as high and low temperatures, drought and salt has been hoped for to solve food and environmental problems. However, only recently have such research and development activities proceeded because the resistance mechanism is complicated. Lately, researchers have isolated genes that are induced by drought and salt stresses and encode proteins involved in acquisition of stress resistance, as well as many transcription factors*7 controlling the expression of these genes.

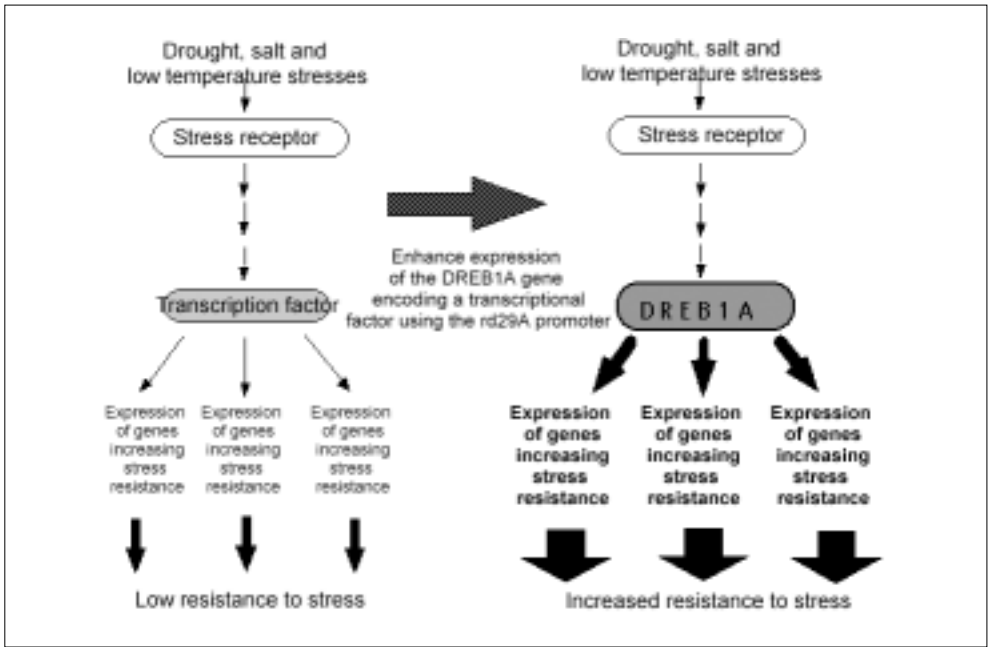
The research group of Kazuko Shinozaki, a chief researcher at the Japanese International Research Center for Agricultural Sciences, isolated the *DREB1A* gene that encodes the transcription factor controlling gene expression in response to drought, salt and low temperature by analyzing various genes related to the resistance mechanism of *Arabidopsis*. In addition, when the rd29::DREB1A construct, consisting of the *DREB1A* transgene and the rd29A promoter enhancing transgene expression under stress, was introduced into *Arabidopsis*, this transgenic plant showed high tolerance to drought, salt and frost (Figure 5).

The environmental-response mechanism controlled by the transcription factor encoded by the *DREB1A* gene is probably common to plants. Thus, it is greatly hoped that combination of the *DREB1A* gene and the rd29A promoter will be applied to the development of environmental-stress-resistant varieties of trees and crops like rice, wheat and maize.

3.4 2010 Project in progress

In 2000, when the *Arabidopsis* genome sequence was completed, Japanese, US and

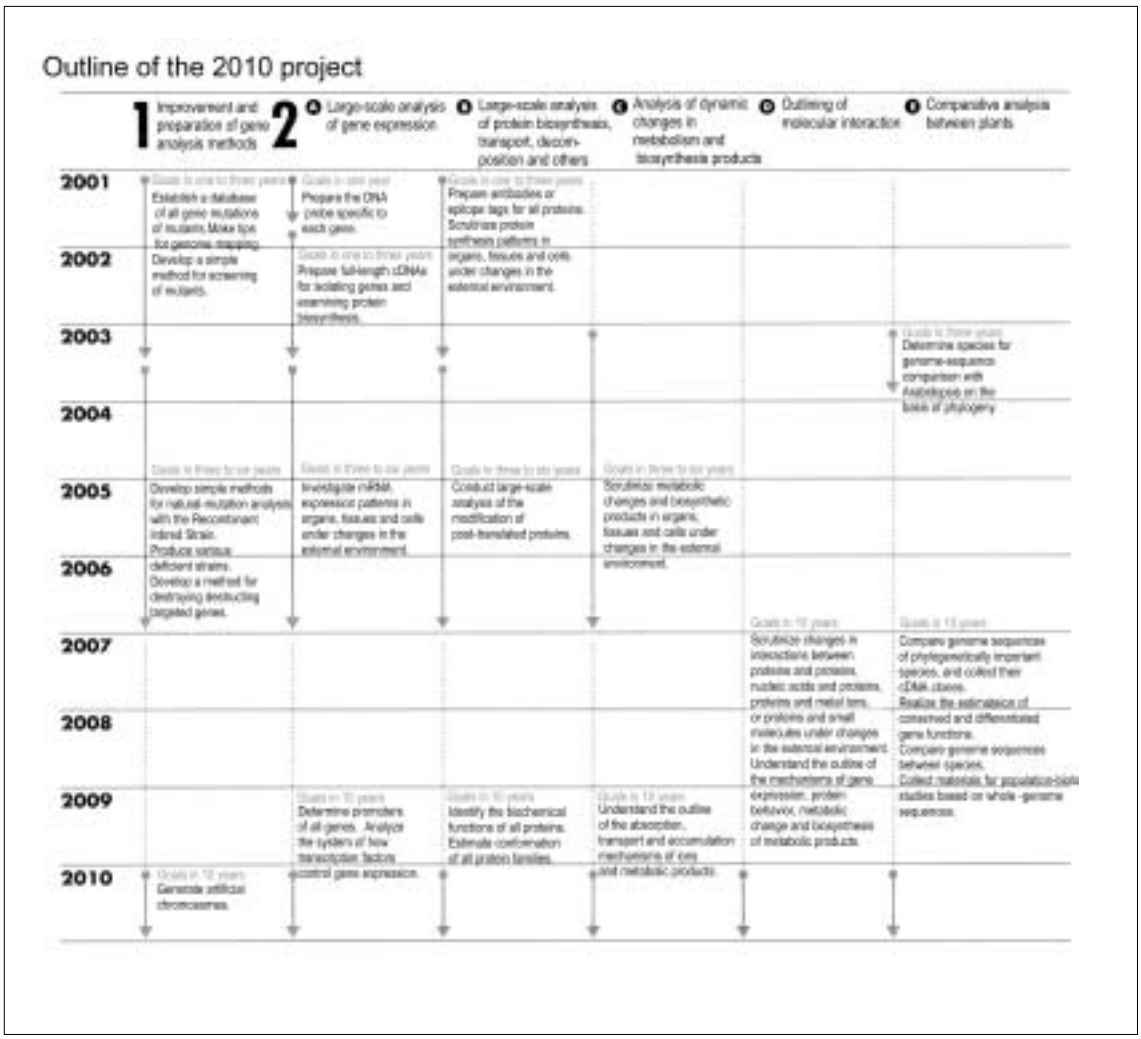
Figure 5: Mechanism of increasing resistance to environmental stress



*Though three stress-resistance-increasing genes expressed by DREB1A-gene expression are drawn in this chart for illustrative purpose, various genes are actually expressed thereby increasing stress tolerance.

Source: a figure made at the Japan International Research Center for Agricultural Sciences

Figure 6: Outline of the 2010 project



Source: the figure made by Prof. Kiyotaka Okada of the Graduate School of Science, Kyoto University

European researchers of plant molecular biology jointly drew up and announced the 2010 Project with the support of the National Science Foundation of the US (Figure 6).

In this program, researchers from Japan, the U.S., Europe and other countries are conducting detailed function analysis of each gene. This project plans to comprehensively analyze the genes, proteins and metabolism of mainly *Arabidopsis* within the decade by 2010. Such studies using model plants will broaden our understanding of higher plants at the molecular level.

3.5 Hurdles in promoting plant molecular biology

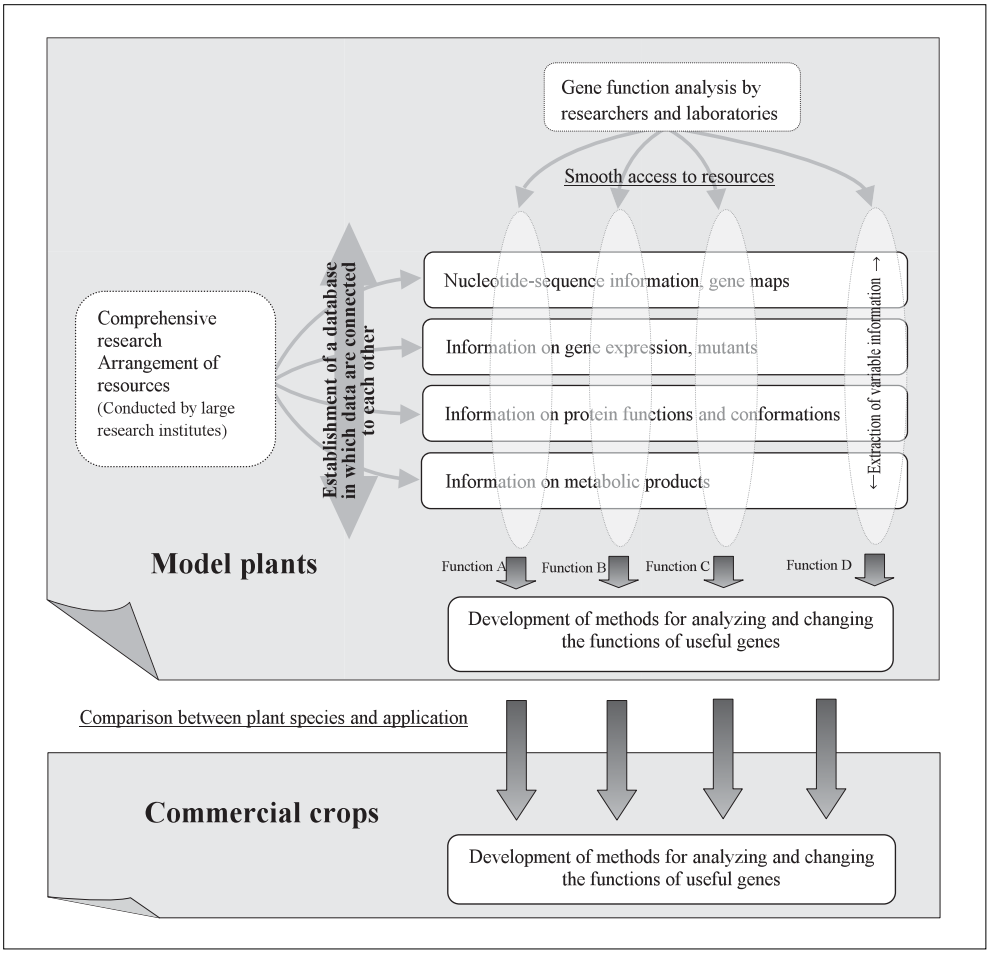
3.5.1 *Plant molecular biology and large-scale sequencing projects*

As seen in *Arabidopsis* studies, led by projects, plant molecular biology advances. First, large-scale and comprehensive sequencing projects are launched on plants whose experimental methods are established. Then, detailed analysis of each gene is conducted.

In such large-scale and comprehensive sequencing projects, along with whole genome sequencing, bioresources necessary for gene function analysis are prepared thoroughly by, for example, generating various mutants with T-DNAs*8 and transposons.*9 In these projects, only a few research institutes or groups of considerable size usually conduct steps from genome sequencing to arrangement of bioresources. Results of gene function analyses of model plants of especially Poaceae and Fabaceae can be promptly used in applied research like the development of crop varieties. Thus, these few institutes have to be careful in disclosing research information and offering bioresources to others.

On the other hand, university researchers and laboratories have clarified the detailed functions of each gene using genome sequence information and various gene resources. As described in

Figure 7: Framework for the promotion of plant molecular biology



Source: Authors' own compilation

Chapter 3.3, plant gene analysis usually proceeds from screening of mutants with mutations in targeted genes. Therefore, data and bioresources should be managed so that researchers in Japan can have smooth access to whatever is necessary for their studies (Figure 7).

Meanwhile, data formats in comprehensive analysis are becoming diversified. They include not only nucleotide sequence information but also other formats like gene expression profiles*11 obtained by microarray.*10 Laboratories and researchers of universities need to extract variable information related to the function of the targeted gene from such assorted data and gene resources. Thus, a database that can be used conveniently and in which relevant data are connected to each other needs to be established, led by specialists on bioinformatics with consideration of the opinions of others such as university laboratories about data disclosure.

3.5.2 Difference between plant and human genome research in the post-genome era

Gene function analysis in plant molecular biology has been accomplished as characterized in Chapter 3.3, in which progress in plant morphogenesis was described. First, bioresources such as mutants are stocked thoroughly. Then, mutants that seem to have mutation in the targeted gene are screened on the basis of their phenotypes, targeted genes are identified from mutant genomes, and experiments such as function recovery by gene transfer are conducted to assess the gene function (Figure 8). Such procedure has been common in plant molecular biology until now.

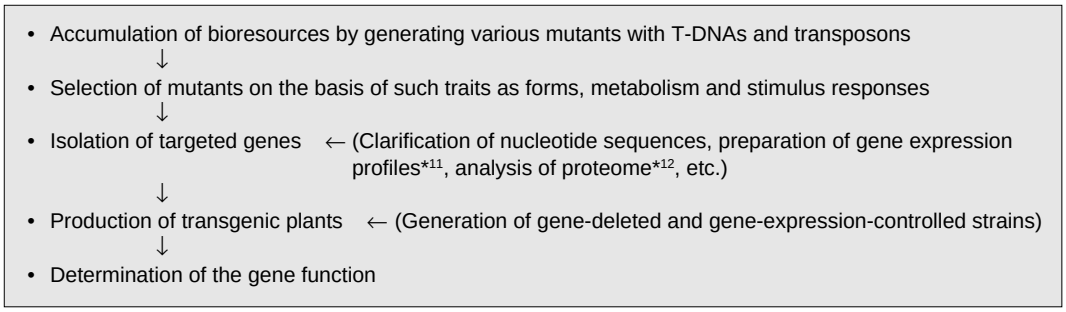
Steps from gene manipulation such as gene destruction to generation of mutants are much easier in plants than in animals because each plant cell is totipotent. Moreover, since a number of offspring can be obtained by crossing, it is effective even now to use such methods as map-based cloning in which candidate genes are found from a large-scale population by using DNA markers and natural recombination of chromosomes.

Meanwhile, in human post-genome researches, experiments in which human genes are directly manipulated are impossible. Moreover, even if, for example, a knockout mouse is necessary for gene function analysis, its production in a laboratory is impossible at the current general technological level. Unlike plants, comprehensive generation of animal mutants is quite difficult. Consequently, demands for research in which the function of protein is assessed from its conformation analysis and, thus, the biological mechanism is understood will increase more in animals than in plants.

Although whole genomes have been sequenced in several plants, only a few gene functions have been clearly revealed. Therefore, gene function analysis by using diverse mutants will be promoted further in plant research in the post-genome era. Plant and human genome researches in the post-genome era have different methodologies, so it is important to pursue research using the advantages of experimental methods peculiar to plants.

In the meantime, knowledge about plant morphology and physiology and the talent of such institutes as agricultural experiment stations, which have bred crops, will play a crucial role in steps like "Selection of mutants on the basis of such traits as forms, metabolism and stimulus responses," "Production of transgenic plants" and

Figure 8: Main steps of plant molecular biological research



Source: Authors' own compilation

"Determination of the gene function" as shown in Figure 8.

3.5.3 Goals to be reached and the present research level in plant molecular biology

There is much hope that plant molecular biology will help solve the problems associated with an increasing population, food shortages caused by the decline and desertification of farmland, and environmental issues such as global warming and environmental pollution by various chemicals. As shown in Table 3, plants are being developed through the application of achievements in plant molecular biology.

According to a survey by the International Service for the Acquisition of Agri-biotech Applications (ISAAA), an international nonprofit organization, the total cultivated area of genetically modified plants in the world exceeded 50 million hectares in 2001 for the first time. It reached 52.6 million hectares, or 3.8% of the world's cultivated acreage of 1.38 billion hectares, surging 19% from the previous year. However, only a few plants have become widespread so far, as seen in the fact that herbicide-resistant soybean, maize and cotton account for 77% of the GM-plant-cultivated area and Bt plants, or pest-resistant plants into which genes encoding insecticide proteins are introduced, account for 15%. In these herbicide-resistant and Bt plants, not genes in plant genomes but genes isolated from microbes were transferred to add new functions.

As in the research on drought-resistance acquisition described in Chapter 3.3, technology for revealing plant gene functions and introducing a desired function into a plant has developed just recently along with the progress in *Arabidopsis* genome studies. We have just reached the stage in which we can evaluate the effectiveness of the technology by conducting field tests and adding various improvements. Similarly, we need to thoroughly analyze the numerous genes involved in a plant's basic functions such as metabolism and signal transmission, and introduce desired traits into targeted plants by applying these functions. Such technique will realize the development of plants, such as high-yielding plants, salt-resistant plants, drought-resistant plants, heavy-metal-absorbing plants, and NO_X/SO_X absorbing or decomposing plants, which will help to solve global issues like food and environmental problems.

Therefore, in order to achieve such higher goals as solution of global issues like food and environmental problems through plant molecular biology, we need to promote function analysis of genes related to desired plant traits making good use of model plants like rice and *Arabidopsis*. In this way, we will broaden our understanding of higher plants at the molecular level.

3.6 Conclusion

In December 2000, an international consortium of Japan, the U.S. and the U.K. reported to Nature that it completed *Arabidopsis* genome sequence for the first time in higher plants. In April 2002, Syngenta and the Beijing Genomics Institute reported to Science that they separately

Table 3: Types of genetically modified plants with respect to their purposes

Plant types	Added properties
Plants benefiting producers	Herbicide-resistant plants, pest-resistant plants, virus-resistant plants, high-yielding plants, salt-resistant plants, drought-resistant plants, etc.
Plants benefiting consumers	High-quality plants (e.g., high-oleic-acid plants), good-tasting plants, inexpensive plants, etc.
Plants for health care and medical treatment in developing countries	High-vitamin-A plants, plants for preventing infections, plants producing diagnostic medicine, etc.
Plants for recovering the environment	Heavy-metal-absorbing plants, NO_X / SO_X absorbing or decomposing plants, etc.
Others	Plants generating clean energy

Source: the figure made by Prof. Hiroshi Kamada of the Institute of Biological Sciences, University of Tsukuba

completed rice genome sequence. As the research basis for gene function analysis becomes firm, it is expected that gene function analysis of plants including commercial crops will become far more efficient and international competition in function analysis of useful genes will become severer.

Meanwhile, it is required of plant molecular biology to develop plants supporting the life of humanity while enhancing the safety and credibility of genetically modified plants, so that this field of study may help to solve global issues such as food and environmental problems.

Therefore, we must take advantage of the peculiarity of plant experiments, that is, the simplicity in generating bioresources necessary for gene function analysis by gene transfer, and exploit every tool in Japan related to agricultural and plant research. We must make fruits of plant molecular biological studies, the common property of humanity, as soon as possible.

Acknowledgements

Together with our findings, we have compiled this report based on the lecture "Plant Molecular Biology—Now and Future" given Professor Kiyotaka Okada of the Graduate School of Science, Kyoto University, on April 23, 2002.

We earnestly thank Professor Okada for providing us with valuable advice and the related data for the writing of this report.

Glossary

* 1 cDNA
A complementary DNA copy of mRNA, which carries the amino acid sequence of the protein.

* 2 Tag line
Mutants produced by introducing DNA fragments with known sequences into the genome at random are called tag lines. Genes causing mutation can be isolated from mutants with targeted phenotypes by analyses of the adjacent sequences using the introduced transgenes with known sequences.

* 3 High-density gene linkage map
A map showing gene locations in the genome with high density by calculating the distances between genes from natural recombination values.

* 4 Expressed sequence tag (EST)
A partial sequence of a cDNA.

* 5 DNA marker
A distinctive nucleotide sequence whose location in the genome is identified.

* 6 Map-based cloning
A method for identifying gene location in the genome by using DNA markers located near the targeted genes.

* 7 Transcription factor
A factor controlling gene expression.

* 8 T-DNA
Agrobacterium, a bacterium infecting plants, has a Ti plasmid that is a circular DNA carrying a region called T-DNA. When an Agrobacterium infects a plant, its T-DNA is transferred to the plant's chromosome. Thus, T-DNA is used for gene introduction into plants.

* 9 Transposon
A transposable genetic element that can move from a certain location to another location in the genomic DNA.

*10 Microarray
An array in which various cDNAs are applied with high density to a slide glass. It enables detection of numerous genes at a time.

*11 Gene expression profile
Data showing the temporal and spatial expression pattern of each gene.

*12 Proteome
A set of protein relations in cells and tissues.

(Original Japanese version: published in June 2002)

4

Trends in Research and Development of the Quantum Computer

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4.1 Introduction

It was announced in "Nature," a British science magazine, on December 20, 2001 that a research group of MIT (Massachusetts Institute of Technology) and IBM had succeeded in a fundamental experiment to make a simple factorization using a quantum computer. The actual calculation used in this experiment was very simple; 15 = 3 x 5. Why does this topic have such an important meaning as to be taken up in Nature? Because this calculation was made by a computer incorporating a completely different theory from ordinary computers currently being used.

Semiconductor devices based on the Si processing technology and ordinary computers using these semiconductor devices have evolved quickly according to Moore's Law. However, it is said that the limit will soon be reached due to problems of minuteness and generation of heat. It is said that even if the technology can break through the issue of minuteness by around 2010, it will in the end face the problem of heat generation by around 2020. Nanodevices and molecular devices are in the spotlight as means to break through this problem.

Ordinary computers currently available have several other limits. Factorization of large numbers is one of them. With current computers, the calculation may take a vast amount of time, making it practically impossible to do. For instance, the fastest computer currently available may take several hundred million years to make a factorization of a number with 200 digits. In the last 10 years, the calculation speed of a computer has improved by about 200 times. Even if the development progresses at the same pace and the speed improves again by 200 times in 10 years from now, it may take several million years to do the same calculation, making it still impossible to do practically. However, the quantum computer operating at a clock speed of around 100 MHz may be able to calculate a factorization of a number with 200 digits within several minutes.

The level of difficulty of the factorization is a foundation of security for the public key cryptosystem (RSA cryptosystem), which is now widely used on the Internet. If the quantum computer is put to practical use, the security of the public key cryptosystem will be lost. In 1994, Mr. P. Shor announced a factorization algorithm using the quantum computer and logically indicated that factorization could be made quickly. With this as a momentum, quantum computer research activities have become active.

Thus, the quantum computer can make certain calculations outstandingly faster than computers currently available (they are referred to as the classic computer in contrast with the quantum computer). Since the required energy to operate a quantum is very small and its time is so short, the quantum computer can theoretically be a low-heat-generation, super-high-speed computer, the same as nanodevices. However, in order to put it to practical use, it may take a lot of time and there are many problems that must be solved.

In this report, I examine the future evolution to put the quantum computer to practical use, while explaining about the theory of the quantum computer as well as the trends of research and development activities.

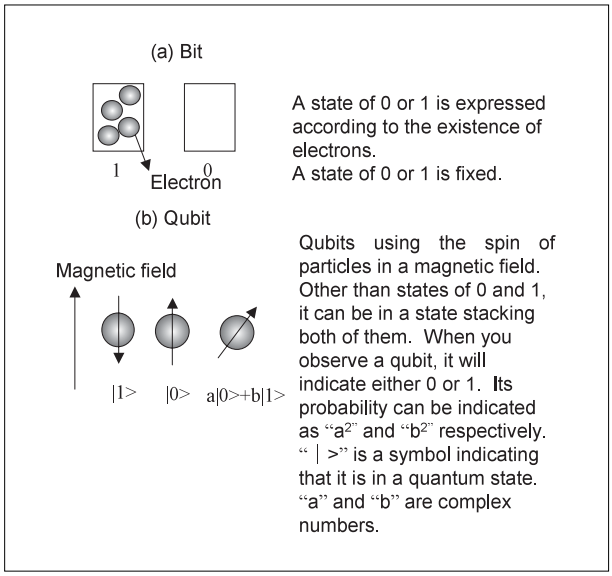
4.2 What is a quantum computer?

4.2.1 Differences between the quantum computer and the classic computer

A classic computer is composed of bits (memories) storing data and logic gates (combinations of transistors) operating the bits. The bits are basically capacitors and the state of 0 or 1 will be decided according to conditions of whether the bit has a charge or an electron. A single bit indicates either 1 or 0, so then n pieces of bits express a binary value with n digits.

On the other hand, the quantum computer is also composed of bits (called quantum bits or qubits) and mechanisms operating and observing the qubits. Two quantum-mechanical states are used for expressing 1 or 0. (A quantum computer using three or more states is also possible.) In the qubit, various kinds of systems can be used, which include spin directions of electrons or nucleuses, energy levels of electrons of quantum dots, polarization of photons, directions of quantized magnetic fluxes, and the ground/excitation states of the electron orbits of atoms. Operating methods of them also depend on the qubit. Although the explanation about qubit as shown in Figure 1. (b) is often used for convenience, knowledge of expression with wave functions based on quantum mechanics is required to correctly understand the qubit (Figure 1).

Figure 1: Differences between bits and qubits



Source: Author's compilation on the basis of "The quantum computing" of C. P. Williams et al., and so on

The following four basic characteristics of quantum mechanics are important for the quantum computer.

(a) Stack

This is to send photons or electrons one by one so that they will go through 2 slits at the same probability, and observe where the particles passed through will arrive. Although they must be observed at points corresponding to the respective slits, according to the classic theory, we can observe similar patterns of interference fringes of waves. This indicates not that the respective particles have gone through either one of the slits, but that states where particles have gone through both of the slits are stacked each other provide the same phenomena as the interference of waves.

(b) Convergence of wave packets

In the above-mentioned experiment, quantum mechanics foretells only that particles will be observed at a certain probability corresponding to the intensity of an interference fringe at a certain position. It is impossible to predict where the respective particles will be observed. However, you will know the positions of where the respective particles are detected if you actually observed them. This means that wave functions spread in a form of an interference fringe before observation have been converged at a certain point by the observation.

(c) Uncertainty

In classic mechanics, positions and momentums of particles can be observed at the respective arbitrary accuracies. However, in quantum mechanics, positions and momentums of particles cannot be decided indivisually; for instance, when you attempt to decide a position, a momentum will be uncertain, and when you attempt to decide a momentum, a position will be uncertain.

(d) Entanglement

This is a phenomenon where a special interrelation takes place among multi qubits. In terms of the direction of spin (magnetization) of two electrons, this is a state where probabilities to

turn toward either one of the directions are equal but when one of them turns toward one direction, the other one always turns toward the reverse direction. When this state is expressed as a wave function, wave functions of two separate qubits are not independent but they can be expressed by a stacked wave function. Particles that have been in the entangle state once, will not loose their characteristics. However, there is a possibility that this interrelation will be lost due to disturbance. This is referred to as decoherence.

For the quantum computer, characteristic (a) as mentioned above is particularly important. With the stack characteristic, a qubit can be in both(or intermediate) state of 0 and 1 in the same time. A difference from the analog computer is the fact that an answer obtained when you observe this qubit is either 0 or 1.

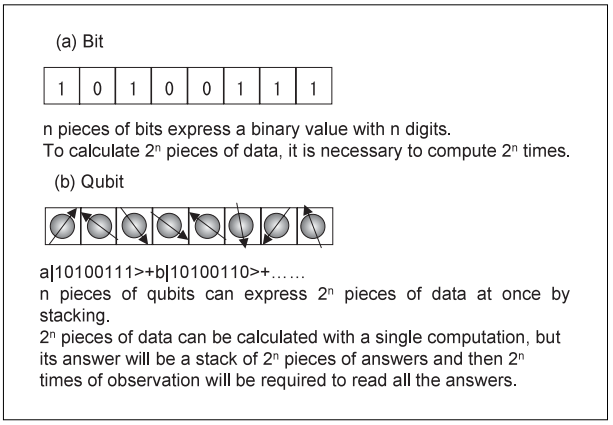
When this stack characteristic is expanded to n pieces of qubits, it is possible to express 2^n pieces of binary values with n digits simultaneously. Calculating with this qubit group, you can obtain 2^n pieces of answers in a single calculation. This is referred to as quantum parallel computation. This is one of the advantageous points of the quantum computer in comparison with a classic computer (Figure 2).

However, an answer will also be a stack of 2^n pieces of answers. Due to the convergence of wave packets as mentioned in the above (b), this stack will be converged at a certain value by observing the answer. Since it is arbitrarily decided at this moment which answer in the stack will be obtained, it is necessary to examine an algorithm so that wave packets will be converged at the required answer with a high probability. Furthermore, at the same time when stacked answers will be converged on a value, stacked input values will also be converged on a value corresponding to the answer. This is one of the characteristics of the quantum computer that this interrelation between input and output values is always maintained with the entanglement (a stack of wave functions) as mentioned in the above (d). If explained in a very simplified way; the quantum computer will stack up numerous wave functions composed of multi qubits, and pick up a wave function that will be an answer by operating the stack.

Other than the quantum computer, the above (c) is a basic theory of the quantum cryptosystem and the above (d) is used in quantum communications referred to as quantum teleport.

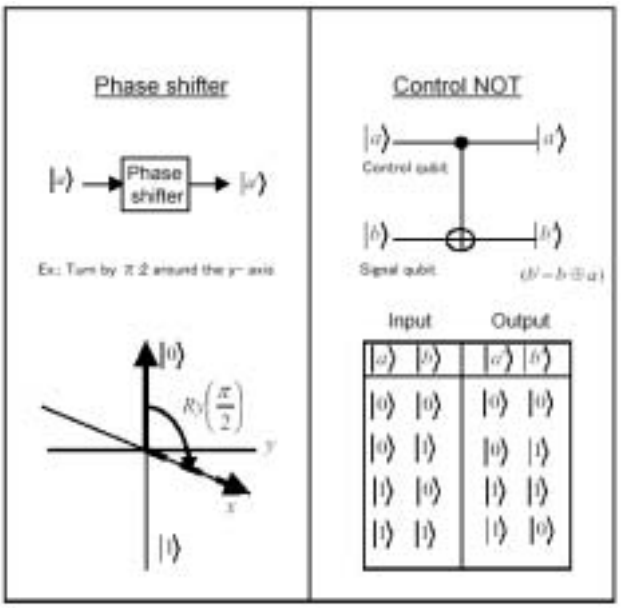
In order to actually operate qubits on the quantum computer, quantum gates must be configured. There are two types of quantum gates; namely, the phase shifter (it is also called the phase gate) and the control NOT gate, which corresponds to AND and NOT (or OR and NOT), the basic logic gate of current computers (Figure 3). If these two gates can be materialized, the

Figure 2: Stack of qubits



Source: Author's compilation on the basis of "The quantum computing" of C. P. Williams et al., and so on

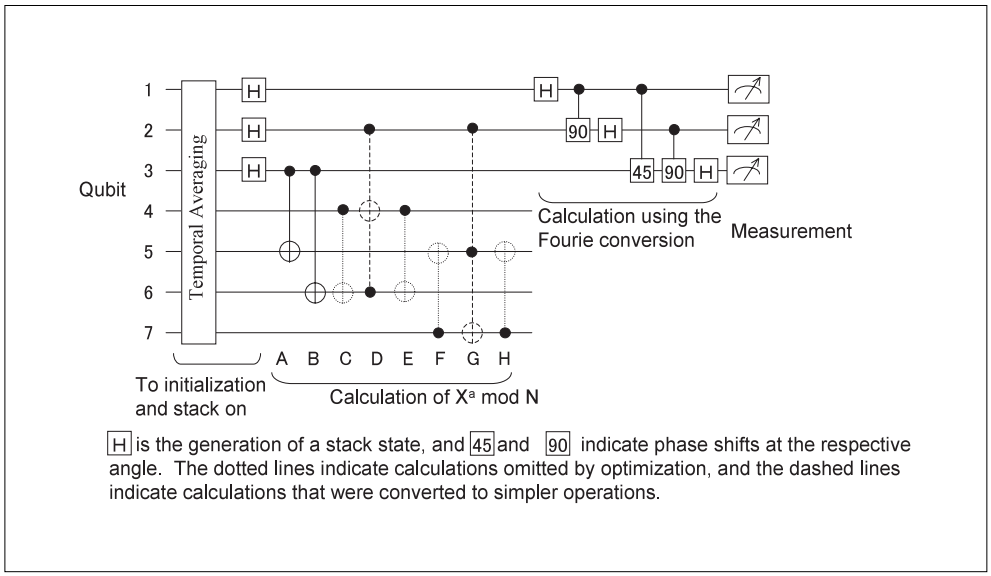
Figure 3: Quantum gates



The phase shifter is used for expressing a stack of quantum states. The control NOT appears the same as a logic circuit of 0/1, but there is a difference that the control NOT can accept a stack state.

Source: Infromation-teconology Promotion Agency's investigation report, "Investigation on the research and development of the quantum computer."

Figure 4: An example of an algorithm for the quantum computer (Shor's factorization algorithm made by Chuang et al.)



Source: Author's compilation on the basis of the reference [5]

quantum computer will be able to calculate any algorithm that can be calculated (Figure 3).

An example of algorithms for the quantum computer is shown in Figure 4.

4.2.2 History of the quantum computer

The possibility of the quantum computer had been pointed out a relatively long time ago. However, practical research activities started in the 1970s. The research started from a study on what would happen if the size of the current LSI were reduced up to where the quantum effect would be dominant. In the 1970s to 1980s, it had been indicated that all the logic gates available in a current computer could be materialized with the quantum computer logically. However, the activities declined in the later half of the 1980s, due to the difficulties in materializing hardware and no advantageous points in comparison with current computers, etc.

The quantum computer gained the spotlight again in 1994, when Mr. P. Shor of AT&T (present Lucent) Bell Laboratories logically verified that the quantum computer could calculate a factorization of a high number within a reasonable time, which a current computer could not do practically. The difficulty of the factorization is a foundation of security for the public key cryptosystem (RSA cryptosystem), which is now widely used on the Internet. If the quantum computer is materialized, the public key cryptosystem will be broken easily. Through this research, the quantum computer became widely recognized as a useful item, and, as such, many researches related to it have been conducted positively all over the world. At the same time, various kinds of research activities related to communications technologies based on quantum mechanics progressed as well, such as the quantum cryptosystem and quantum communications, and, as a result, new technology fields namely the quantum information theory and quantum information technology (QIT) have shown up.

4.3 Examples of the quantum computer

4.3.1 Hardware

Five conditions required for configuring the quantum computer are cited as follows.

(1) Qubits can be practically materialized as a physical system and integrated. (5,000 pieces of qubits are required for factorizing a number with 1,000 bits.)
(2) The respective qubits can be measured.
(3) The respective qubits can be operated. (Computation of basic qubits must be possible.)
(4) The time for interaction among qubits (the decoherence time) must be sufficiently longer than the calculation time (time for operating a qubit once x the number of operations). (It is said that the decoherence

time must be at least 1,000 to 10,000 times longer than the calculation time. For factorization of a number with 1,000 bits, 5 x 10^{11} times of operations are required.)

(5) Qubits can be initialized.

Table 1 shows the candidates of quantum computers now being researched that satisfy the above-mentioned conditions. All of them are now on the basic research level. Among them, the method combining organic molecules and NMR, which is now being developed by a group led by IBM, is the most progressed. However, it is very difficult for this method to support multi qubits and it is said that there is a wall at around 10 qubits. Other methods also have merits and demerits, and various ideas are now being proposed for further breakthroughs. There is also a proposal to use a molecular device itself for the quantum computer.

4.3.2 Algorithm

As mentioned above, if two basic quantum gates can be materialized, the quantum computer can calculate any kind of algorithm by combining these two gates. However, if the same algorithms as the ones used in current computers are utilized, it is not necessary to be the quantum computer. Under existing circumstances, there are roughly three algorithms (and some other problems similar to them) where the quantum computer can make overwhelmingly more efficient calculations than a classic computer as follows.

(1) Factorization (Shor's algorithm)

(2) Database retrieving (Glover's algorithm)

(3) Traveling salesman problem (given a finite number of "cities" along with the road of travel between some pair of them, find the shortest way to visit all the cities once and return to your starting point)

Table 1: Candidates of quantum computers being researched and their features

Method	Qubit	Advantages	Disadvantages	Current situation
Ion trap	Vibration mode of the gravity center of an ion fixed by an electromagnetic field under vacuum	The decoherence time is long.	It is difficult to support multi qubits. It will operate only under a vacuum condition.	The entanglement with 4 qubits has been confirmed.
NMR (Nuclear Magnetic Resonance)	Nucleus spin of organic molecules in a solution (a single molecule is a quantum computer)	It can operate at normal temperature. It can measure many molecules (quantum computers) at once. It can be materialized with the NMR equipment.	It is difficult to support multi qubits. (Designing of molecules is required.) If the number of qubits increases, it will be difficult to analyze the measured results.	Shor's algorithm has been materialized with 7 qubits.
	Nucleus spin of a crystal or an atomic line	It is relatively easy to support multi qubits. The decoherence time is long (?)	It is difficult to analyze the measured results. It will operate only at an extremely low temperature. It is difficult to provide elements.	The element is under development.
Quantum dot	Spin of an electron kept in a quantum dot	It is relatively easy to support multi qubits. The decoherence time is long (?)	It will operate only at an extremely low temperature. It is difficult to provide elements.	The element is under development.
Superconducting element	Magnetic flux or cooper pairs generated on a superconductor	It is relatively easy to support multi qubits. The decoherence time is long.	It will operate only at an extremely low temperature.	The entanglement with 2 qubits has been confirmed.
Photon	Polarization state of photons, etc.	The decoherence time is long. It can operate at a normal temperature.	The interaction between quanta is not sufficiently strong. It is difficult to support multi qubits.	An experiment with 3 qubits.

Source: Author's compilation on the basis of the Information-technology Promotion Agency's investigation report, "Investigation on the research and development of the quantum computer," etc.

These problems are basically issues for choosing one among numerous candidates. In these problems, a feature of the quantum computer, i.e., capability to make a large amount of calculations with a few steps by using quantum parallel computation, can be effectively used. However, since the calculation results will also be observed in a stack state, it is necessary to at least converge them on a few numbers of wave functions, which can be analyzed to choose a wave function to be an answer. This is one of the most difficult points of algorithms for the quantum computer. (Refer to the supplemental explanation.)

It is theoretically impossible to reduce to zero the probability of the quantum computer observing an incorrect answer. Since the stack among qubits is also arbitrarily destroyed (decoherence), there is a possibility of calculation errors. Thus, it is necessary to reduce the error rates by performing more than one calculation or to provide some type of error correction means. Then, it is required to maintain the efficiency of the algorithms within a reasonable range even if these extra works are included.

Conversely speaking, at present, the quantum computer can be applied to only these three areas (and some other similar problems), and it is expected that algorithms supporting a wider range of problems will be developed. It is also important to develop efficient error correction algorithms.

4.4 Current situations of research and development activities for the quantum computer in the respective countries

The quantum computer is often developed not only as a future computer technology but also as a part of quantum data communications technologies including the quantum cryptosystem and quantum communications, or nano-technologies. In this section, I take up several projects relatively concentrating on the quantum computer.

4.4.1 U. S.

In the U. S., there are many big names involved in this field, including IBM famous for the NMR quantum computer, Bell Laboratory (AT&T to Lucent) of algorithms for quantum computing, NIST of the qubits using Ion trap and Los Alamos Laboratory of the qubits using the quantum dot. As governmental projects, the quantum computer has been taken up for the first time in the annual budgetary request of the U. S. Information Processing and Communications Policy (Blue Book) FY1997 (issued in November 1996) and in the implementation plan (issued in January 1997) as a part of the High End Computing and Computation (HECC) program. In these documents, the quantum computer is treated as a future technology of which research activities must be supported by the government, along with the bio computer and the optical computer. This point has not changed in the budgetary request for FY2002 as well. Meanwhile, it was proposed that the research and development of quantum information communications technology be promoted as a fundamental information and communications technology in the IT^2 Plan announced in 1999.

Core institutes in the field of HECC are NSF, DARPA, NIST, NSA, DOE, NOAA, NASA and so on. Among these institutes, NSA, maintaining a watch on decipherment of cryptosystems with the quantum computer and the quantum crypto-system, leads projects related to the quantum computer. The first phase of the project was jointly executed among more than 9 universities and companies, and governmental institutes such as DARPA and NIST from 1994 to 1999. The second phase is now being executed successively. The budget amounts of the individual projects are unknown, but the total amount of the budget for HECC of NSA is around $20 to $25 million/ annually.

Since FY2001, DARPA has started a series of research and development activities for the next generation technologies including the quantum computer, with the title of "Beyond Silicon," under the "Microelectronic Device Technology" project. The "Beyond Silicon" activity was upgraded to project status in FY2002. Among the themes of the "Beyond Silicon" project, "The Quantum Information Science and Technology" is directly related to the quantum computer and quantum

<Supplement>

Method of factorization using the quantum computer

In the case of factorization, the simplest algorithm is as follows. A number "N" to be factorized will be divided by "a" that is any integer of 2 or more and $N^{1/2}$ +1 or less. The quantum computer will execute this calculation as follows.

1) To store "N" in the 1st quantum memory and a stack of integers of 2 or more and $N^{1/2}$ +1 or less in the 2nd quantum memory, respectively.
2) To divide the 1st memory by the 2nd memory, and store the residual of this division in the 3rd quantum memory.
3) The number indicated in the 2nd memory when the observed result in the 3rd memory is zero (the 2nd memory will be converged by the observation of the 3rd memory), will be one of the desired factors.

In this method, the dividing operation can be made with a single step due to the stack of qubit and quantum parallel computation, but the probability for reading numbers other than zero in the 3rd memory will be overwhelmingly high. Consequently, the number of observations repeated in the 3rd memory until observing zero will be almost the same as the number of steps for repeating the dividing operations in the classic computer. (If the "N" is a number of the order of 10,000 and a product of 2 pieces of prime numbers, there is only one case of which the residual is zero among stacks of $N^{1/2}$ (around 100). In this case, the probability for observing zero during the repeats up to 100 times is only 63%. On the other hand, it is certainly possible to obtain an answer by repeating the dividing operation up to 100 times in the classic computer.)
Thus, the following characteristic of integers is used in the Shor's algorithm.

1) x^a mod y ("x^a mod y" is a function for finding a residual after dividing "x^a" by "y") is a periodic function of "a" relative to integers x and y, which are prime numbers each other (they don't have any common measure other than 1).
2) If a period "r" satisfying x^{nr} mod y = 1 ("r" will be an integer, "n" will be 0, 1, 2, 3 …) under the condition the above 1) exists and "r" is an even number, its equation will be as follows.

$$(x^r - 1) \bmod y = \{(x^{r/2} - 1)(x^{r/2} + 1)\} \bmod y = 0$$

Then, either one of $x^{r/2} - 1$ or $x^{r/2} + 1$ at least, and y will have common measures other than 1.

The actual calculation will be as follows.

1) To choose an integer "x" (N > x) that is a prime number relative to an integer "N" to be factorized at random.
2) To choose an appropriate integer "q" satisfying $N^2 < q < 2N^2$
3) To calculate $y = x^a \bmod N$ (a = 0, 1, 2, … q-1) for all "a" by using quantum parallel calculation. If you obtain a value "k" as observing "y" on this stage, "a" will be a stack of an integer h + nr ("h" is an integer, "r" is a period, and n = 0, 1, 2, …) satisfying $x^{h+nr} \bmod N = k$, but "r" cannot be found since all "h", "r" and "n" are unknown.
4) To make Fourie conversion for "a". The details of the process will be omitted. The value to be obtained will be a stack of mq/r (m = 0, 1, 2, … r-1).
5) To find a single value of "c" satisfying $c = m_0\, q/r$ (m_0 = 0, 1,2, … r-1) as a result of observation of the above 4).
6) If "m_0" and "r" are prime numbers each other, "r" can be calculated by reducing "c/q" (both of them are known). It is possible to increase the probability for that "m0" and "r" are prime numbers each other by repeating the calculation.
7) If "r" is a even number, you can find the greatest common measure between $x^{r/2} - 1$, $x^{r/2} + 1$ and y.

Source: Author's compilation on the basis of the reference [1, 2] and [5]

Table 2: The number of research projects related to the quantum computer approved by NSF

Year	The number of approved projects	Total amount ($)	Amount / project	Term
1995	23	4,930,629	214,375	1 - 4 years
1996	20	5,851,012	292,551	2 - 4 years
1997	23	5,923,848	257,559	0.8 - 4 years
1998	25	6,504,615	260,185	2 - 4 years
1999	22	4,808,112	218,551	2.8 - 4 years
2000 (Note)	6	1,361,800	226,967	3 years
Total	119	29,380,016	246,891	0.8 - 4 years
Programs under execution	61	15,435,106	253,035	

Note: Data for 2000 is as of April 2000.

Source: The investigation report of the Ministry of Posts and Telecommunications (the present Ministry of Public Management, Home Affairs, Posts and Telecommunications), "For creating revolutionary quantum information processing and communications technologies in the 21st century."

communications technology. Its actual budget for FY2001 was about $14.3 million, and its requested budget for FY2002 is $23.8 million. It is planning to request a budget of $27.1 million for this project in FY2003. Other than this, technologies related to the quantum computer such as the quantum dot or the quantum algorithm, etc., have been taken up in the themes of "Materials Science," which is a research project related to nanotechnology, or the "High Performance and Global Scale System" related to computer science. Furthermore, laboratories under NIST are promoting research on the quantum computer and quantum communications. In particular, their research on the ion trap method is famous. Table 2 shows the number of projects related to the quantum computer, which NSF fosters.

4.4.2 Europe

EC has provided and executed its research plan (Framework) for the entire region every 4 years since 1984. The 5th Framework is now being executed. For information processing and communications technology including the quantum computer, research and development activities have been conducted as a part of the ESPRIT project in the 1st to the 4th Frameworks.

The 5th Framework (from 1998 to 2002) is classified into 4 vertical fields and 3 horizontal theme, and information processing and communications technology including the quantum computer is executed as a part of the IST (Information Society Technology research).

Programs in the IST are classified into 9 kinds: 5 kinds by technology field including 4 kinds of existing technologies and 1 kind of new technology; and 4 kinds by its activity formation mainly aiming to support research activities. Researches on quantum information processing and communications are executed in the Quantum Information Processing & Communications (QIPC) project in the Future and Emerging Technologies (FET) in the field of new technologies.

In the QIPC, there are 12 research projects (started in 1999 to the beginning of 2000, with terms of 3 to 4 years) invited in 1999, and additionaly, 4 projects (their terms are 1 to 3 years) are currently conducted through FET-OPEN, a system inviting research projects at any time. According to the "For creating revolutionary quantum information processing and communications technologies in the 21st century" (the investigation report of the Ministry of Posts and Telecommunications), the total amount of the research fund for QIPC is expected to be about 22.4 million Euro. Out of this, about 17.2 million Euro (about 77% of the total) will be borne by EC.

A feature of the research projects of EC is that many institutes from many countries participate. The IST has the "Network of Excellence" Program aiming to intensify cooperation among the participating research institutes and to pass back the research results to the industries more

positively, and QIPC also has a network project that is referred to as The Physics of Quantum Information European Research Network (QUIPROCONE). Its term is for 3 years from July 2000.

In the 6th Framework starting from 2002 up to 2006, the IST and the QIPC will continue, and the 2nd invitation of research projects was conducted in March 2002.

Other than the programs of EC, research networks among universities in the countries in Europe, which are led by Oxford University in the U. K., have spread spontaneously since around 1995.

4.4.3 Japan

In Japan, theoretical researches done by certain research groups were main streams of research activities on the quantum computer up to around 1990. Since around fiscal 1994, researches related to the quantum computer had been conducted as parts of selective themes of the CREST (Core Research for Evolutional Science and Technology) and the ERATO (Exploratory Research for Advanced Technology) of the JST (Japan Science and Technology Corporation). In 1999, the

Table 3: Major research projects related to the quantum computer and quantum communications in Japan

Research and development scheme	Theme	Research institute (Term)	Remarks
Japan Science and Technology Corporation International joint research	Quantum transition project	The University of Tokyo Notre Dame University, University of California (For 5 years from 1994)	
Japan Science and Technology Corporation Core Research for Evolutional Science and Technology	Correlative electronics	NTT, The University of Tokyo, The Graduate University for Advanced Studies, Electrotechnical Laboratory (For 5 years from 1998)	
Japan Science and Technology Corporation International joint research	Quantum entanglement	Stanford University, CNRS (National Center for Scientific Research of France) (For 5 years from 1999)	Japan will bear ¥1 billon for 5 years
Japan Science and Technology Corporation Core Research for Evolutional Science and Technology	Dynamics control of quantum correlative functions	The Institute of Physical and Chemical Research (Started from 1999)	
Japan Science and Technology Corporation Core Research for Evolutional Science and Technology	Nucleus spin network Quantum computer	Osaka University (Started in 2000)	
Japan Science and Technology Corporation Exploratory Research for Advanced Technology	Imai quantum computing mechanism	The University of Tokyo (Started in fiscal 2001)	
Ministry of Public Management, Home Affairs, Posts and Telecommunications Invited research projects	Research and development of quantum information processing and communications technologies	Invited research projects started in fiscal 2001	Budget ¥250 million

Source: Author's compilation on the basis of the investigation report of the Ministry of Posts and Telecommunications (the present Ministry of Public Management, Home Affairs, Posts and Telecommunications), "For creating revolutionary quantum information processing and communications technologies in the 21st century."

Quantum Information Technology Symposium was organized as a research society for a limited period under The Institute of Electronics, Information and Communication Engineers, so that a system for exchanging information and cooperating with research activities among researchers in various fields of science and engineering could be launched. In February 2000, the Information-technology Promotion Agency published "Investigation on the research and development of the quantum computer," and the Ministry of Posts and Telecommunications (the present Ministry of Public Management, Home Affairs, Posts and Telecommunications, MPHPT) published an investigation report titled "For creating revolutionary quantum information processing and communications technologies in the 21st century" in June 2000, respectively. Table 3 shows the on-going projects in Japan. For notes, The MPHPT's research projects are covering the entire quantum information processing and communications technology including the quantum cryptosystem and quantum communications.

4.5 Conclusion —For materializing the quantum computer

The direct, successive technologies of the current(classic) computer are the nano and molecule devices. With nano and molecule devices, it is expected that a computer having higher integration and extremely low power consumption will be materialized. Then, what is the position of the quantum computer?

The first thing we can think of is application as a subset of computers specialized in problems that can be solved efficiently with the quantum computer. However, for this, it is necessary to integrate a certain amount of qubits and materialize advantages in calculation speed that must be sufficiently faster than the classic computer, and it may take a lot of time. There is another problem in that fields where the quantum computer can be applied are too limited.

Thus, the transmitter/receiver and repeater equipment for quantum communications and the quantum cryptosystem are considered as the first application for the quantum computer. Becouse in which application, the quantum computer can be put to practical use even if the number of qubits is relatively few. The quantum cryptosystem is currently ready to be put to practical use except for its cost and limited communication distance. In particular, the photonic quantum computer is compatible with the quantum cryptosystem, in terms of hardware and technologies including the generating and detecting mechanism of single photon, etc.

On the other hand, there is a possibility for the quantum computer to be put to practical use quickly if completely new algorithms can be developed. As an idea, the quantum computer may be used for material development by simulating quantum states. While the classic computer requires peta flops class computing for simulating 1,000 pieces of atoms (see Science & Technology Trends, December 2001), it is considered that the quantum computer originally using the quantum state may calculate more efficiently. No practical result has been announced yet, but several research groups seem to be conducting relevant researches.

Thus, I think it is important to promote the quantum computer from an area where it can be put to practical use, such as seeking new fields where it can be applied and in technical breakthroughs.

On the other hand, the research field of the quantum computer and quantum information processing technology extend over a wide range covering from theoretical computer science, information theory, mathematics, physics, chemistry, and optics, and engineering such as materials and manufacturing technologies. It is possible to say that the research field is a boundary area having the potentiality to produce new ideas from various other research fields. Since it is a new research area, many attractive and untouched areas probably remain. In this sense, it may be required to introduce methods promoting many projects, taking in new concepts.

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5

Digital Content Distribution and Copyright Manegement Technology in the Broadband Age

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5.1 Introduction

Development of digital technology and the sophistication and rapid spread of personal computers have resulted in digitization of a variety of content such as software, documents, photographs, paintings, music and video, which is now widely distributed over networks like the Internet. In addition, the emergence of broadband access lines to the Internet, typically ADSL, is enabling transmission of digital content via networks in significantly larger volumes and higher quality than through the conventional technologies. In particular, distribution of entertainment content such as music, movies and TV dramas, which plays an essential role in promoting the use of broadband networks, is expected to form a major market in the business to consumer (B2C) segment. Other areas having large potential include new services combining digital broadcasting with network communications, and the new hardware devices to support such services.

On the other hand, as digital content is known to be easily copied and distributed online while minimizing degradation from the original during copying, illegal replication and piracy have been causing critical problems. Now that a large number of illegal copies are available on the Internet, the situation is becoming more serious.

In order to expand the legitimate digital content market online, copyright protection technologies to prevent the creation and distribution of such illegal copies are indispensable. At the same time, laws and social systems that are suited for copyrights in the broadband age will soon be demanded.

This report focuses on copyright protection technologies for entertainment content (books, music, movies, etc.) in the B2C segment with additional consideration on developments concerning the copyright law. Note that copyright in general consists of copyright in a narrow sense and neighboring rights: the former is given to the creator of music, a novel and so on while the latter is given to adapters of works over their musical arrangement, scriptwriting, editing, etc., as well as to performers such as musicians and actors and to producers of sound recordings, movies and so on. Whereas more detailed definitions exist, this report only covers copyright in a broad manner, which includes both copyright and neighboring rights.

5.2 The current status of digital content distribution

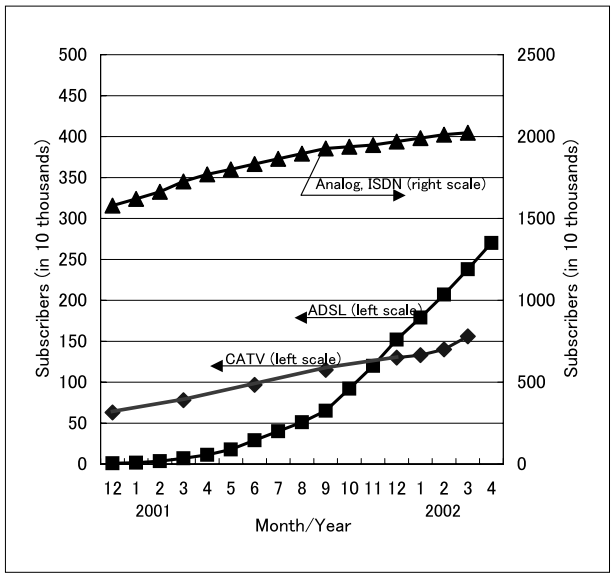
5.2.1 Spreading broadband and its capability

Among the available broadband connection services, through which users are allowed faster communications than ISDN (64 Kbps/128 Kbps), CATV Internet and ADSL (around several Mbps) have been sharply increasing the number of their subscribers since the middle of 2001 (Figure 1).

On the other hand, the number of subscribers of optical fiber connections, a service that utilizes fiber-optic networks to provide more than a 10 Mbps transmission speed, remains relatively small at 26,000 (preliminary chart from the Ministry of Public Management, Home Affairs, Posts and Telecommunications) as of the end of March 2002, probably because of the limited areas of coverage. However, the chart is expected to grow rapidly as the coverage areas expand in the future.

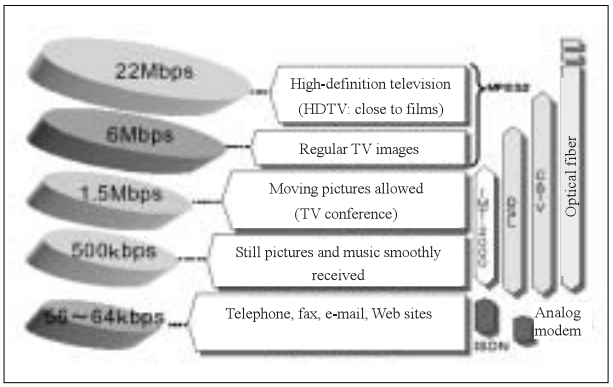
The currently popular ADSL and CATV Internet

Figure 1: Number of Internet connection service subscribers



Source: Ministry of Public Management, Home Affairs, Posts and Telecommunications, "Prompt report on the number of Internet connection service subscribers as of the end of May 2002."

Figure 2: Transmission speeds and distributable content



Source: Study Group of the Ministry of Public Management, Home Affairs, Posts and Telecommunications, "Toward copyright protection of digital content and smoother network distribution."

connections offer transmission speeds ranging from hundreds of Kbps to several Mbps, and are enabled to distribute near-TV quality moving images when combined with image compression technology. If optical fiber communications, which are even faster, become widely available, distributing moving pictures comparable to those on high definition TV (HDTV) will become possible (Figure 2).

In response to such developments, Internet service providers (ISP) and content holders (creators and owners of content such as movie companies, TV networks and record firms) have already begun services to distribute digitized music, images, books, and so forth (Table 1). Some are finding niches by offering exclusive content such as several-minute short dramas, Korean movies, and interactive material specifically created for broadband.

Material like movies, music and software have long been considered suitable for online transactions, because a transaction can be completed without physical transportation of the goods if payment and data exchanges are made over networks. Even a traditional hurdle that data exchanges via slow connections like analog modems and ISDN take too long is being overcome by the spread of ADSL.

Of the entire B2C e-commerce market in Japan, which was worth ¥1,484 billion in 2001, the digital content market accounted for approximately 6%, or ¥93 billion. However, as much as ¥86 billion of this (about 90% of the digital content market) was from mobile telephone (sales of ring melodies, idle screen images, etc.), indicating that the market targeting broadband has just begun to bud (by "FY2001 survey of e-commerce market scale and conditions," Ministry of Economy, Trade and Industry).

Table 1: Content distribution services

Category	Service Name (provider)	Distributed Content
ISP	Yahoo! BB (Yahoo! BB)	Moving images, games, books, etc.
	Nifty (Nifty)	Short films, games, music, etc.
	Dream Screen (DTI)	Movies, film previews
Content holder	TV-Tokyo Broadband, etc. (TV stations)	Previews, behind-the-scenes video, short dramas, TV programs
	Label Gate (Sony)	Music
	@music (AVEX)	Music
	Chuokoron-Shinsha	Electronic books

Source: Author's compilation from newspaper articles and other data.

5.2.2 Actual conditions of illegally used digital content

Digital content is:

— Easy to copy (mass and quick replication is easier than analog content).
— Easy to distribute online by using compression technologies.
— Not degraded by copying.

For such characteristics, illegal copying and piracy have been major problems for digital content. The situation is worsening now that an enormous number of illegal copies are available over the Internet. Once an illegal copy is posted online, it can instantly spread throughout the world. In the case of musical works, illegal copying is extremely rampant, since most of the CDs are not copy-protected, data extraction and compression from CDs are easy on PCs, and compression technologies like MP3 have become commonly known. Even large-volume content such as software and motion pictures has begun to suffer from the same trouble as broadband users grow. Furthermore, the emergence of peer-to-peer (P2P) file exchange technology accelerated illegitimate copy distribution.

With P2P technology, which is attracting attention as a next-generation Internet tool, users can share or download files (data) stored on other computers over the network. It has advantages such as allowing data to be shared through the Internet without a particular server constantly connected online and permitting users to search for and retrieve information without a search functioning server. By using Napster, Gnutella, WinMX or other free programs, users can easily post and trade over the Internet music data created by copying CDs they personally own.

In the U.S., the Recording Industry Association of America (RIAA) and others filed lawsuits against Napster and other P2P service providers, demanding them to pay copyright fees and to eliminate unauthorized copies from their servers. Also in Japan, MMO Japan Ltd., a company that had started a Napster-like service, was ordered by the court to stop service in a case brought by record companies and others. Whereas it is not clearly known how many illegal copies are distributed online, RIAA stated in court that 300,000 accesses were being made to Napster's Web site per day. Another survey by the Association of Copyright for Computer Software (ACCS) and the Recording Industry Association of Japan (RIAJ) estimates that the total number of downloaded music files through P2P services up to January 2002 reached 75 million in Japan.

It should be recognized, however, that there is nothing illegal about the P2P service itself, and, furthermore, it is given a lot of attention as a useful technology. Should the illegal copy issue lead legislators to regulate it, development of the Internet would be adversely affected. On the other hand, posting illegal copies of copyrighted material is regulated by World Intellectual Property Organization (WIPO) treaties as mentioned later and thus illegal in countries like Japan that have enacted laws in accordance with the treaties.

5.3 Copyright management technology

5.3.1 Digital rights management (DRM) system

In the similar way the criminal law cannot stop a burglar from breaking into an unlocked house, the copyright law cannot protect copyrights without copyright protection technology, which acts as a lock for copyrights. The mainstream of traditional copyright protection technologies has been the copy protection applicable to home recording devices (Table 2). In addition to this, however, digital content distribution in the broadband age requires data at any stage of its process — from transmission over the network to end user's playback and copying to storage media — to be prevented from exposure, because once the data is exposed and recorded, it can be easily replicated and distributed online. In addition, measures against cracked protection and distribution of illegal copies are needed. To this end, a comprehensive protection system that covers a variety of entities — from distributors, user terminals and output devices to storage media — needs to be established. The scheme is called the Digital Rights Management (DRM) system (Figure

3). All protection technologies, including conventional ones, that are used for DRM and related systems are collectively referred to as copyright management technology in this report.

Table 3 shows major DRM technologies. Some of these technologies require special hardware such as a memory card, while others ask users to obtain a separate license for each memory card they use because of the lack of compatibility between networks and user terminals. With respect to output to digital displays, standardization of the authentication and encryption methods between connectors is in progress to define the specifications of output connectors (USB and IEEE1394) used apart from DRM.

5.3.2 Measures against cracked DRM

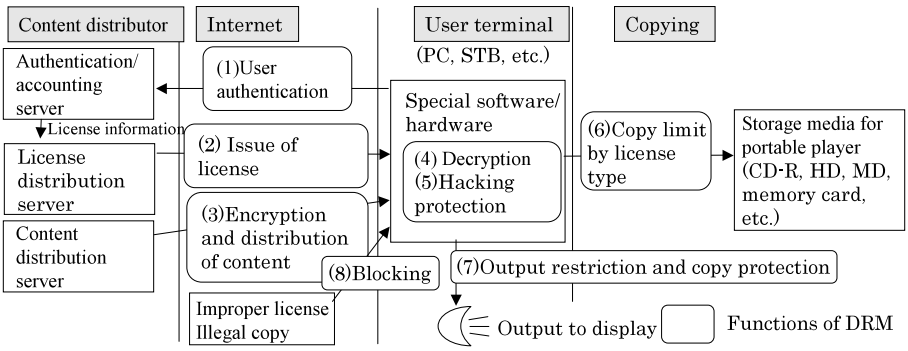
However tough a DRM system is, there is always

Table 2 : Major conventional copy protection technologies

Name	Applied Media	Outline	Standardization Body
Macrovision	VHS videotape, DVD	Copies are identified through signals added to analog video data, and their images are scrambled when played.	Macrovision (U.S.)
SCMS (Serial Copy Management System)	MD, DAT, CD-RAM, DVD, etc.	Permits only first-generation digital-to-digital copies of music.	Sony, etc.
CSS (Content Scrambling System)	DVD-Video	Encrypts content to disable direct copying of digital data.	DVD Copy Control Association
CPPM (Content Protection for Prerecorded Media)	DVD-Audio	An enhanced mechanism of CSS.	Same as above
CDS	CCCD (Copy Control CD)	Partly changes the file data to prevent ripping (taking out music data) on PCs. The media is playable on regular CD players.	Midbar-Tech (U.S.)

Source: Author's compilation from "Home Network" (Atsushi Matsushita et al., Shokabo) and others

Figure 3: Digital right management system



(1) During user authentication, software/hardware is checked for conformity to the DRM.
(2) License includes the encryption key and conditions to use the content (playable period/times, copy limit, etc.). To prevent the illegitimate use of the license, an encryption key is used, for example, in combination with a unique ID of the special software/hardware.
(3) When encrypting the content, content ID, terms of use and electronic authentication data (for preventing forgery of IDs and terms of use) are sometimes encrypted together with the content itself. This is called encapsulation. Aside from distribution via networks, distribution in the form of CD-ROMs or other media should also be taken into account.
(4) Access from the outside to the decrypted content is blocked.
(5) To prevent the content and encryption key from leaking out by the cracking of software/hardware, encryption of software or other measures are taken.
(6) Whether the copy destination is conformable to the DRM is verified and the total number of copies is controlled. Also, further distribution of copies is prevented through measures such as encryption by using the unique ID of the copy destination.
(7) For digital output, the destination is authenticated and the data is encrypted between connectors. For analog output, copy protection technology like Macrovision is sometimes used.
(8) Illegal copies, which are detected by digital watermarks, etc., are barred from use. Information about illegitimate licenses and cracked encryption keys is distributed, so as to invalidate them or to deliver new encryption keys.

Source: Author's compilation from the homepage of Recording Industry Association of Japan, etc.

Table 3: Major DRM technologies

Company Name (technology name)	Outline
Microsoft (WMRM, Windows Media Rights Manager)	Part of Windows Media Technology (WMT). To play content, a license that contains a decryption key and terms of use is needed separate from the content. The license cannot be copied to another terminal to play the content.
InterTrust (MetaTrust Utility)	A U.S.-based venture business. Adopted by Real Networks. Information on access control and accounts is encrypted/distributed with content. For each use, access terms are checked and charging data is sent for processing at the central office.
IBM (EMMS: Electronic Media Management System)	Consists of five software applications including a content mastering program, a hosting tool to store/distribute content in EMMS format ??and a sales system to supporting online stores.??
Sony (Open MG/Magic gate)	A copyright protection technology developed by Sony. It works with MDs and memory sticks. Compatible with IBM's EMMS technology.
Fujitsu, Hitachi et al. (UDAC: Universal Distribution with Access Control)	Supports the superdistribution scheme (separate distribution of content and license). Applied to solutions designed for PCs. Uses the Secure Multimedia Card (MMC) as the storage medium.
Intel, IBM, Matsushita, Toshiba (CPRM: Content Protection for Recordable Media)	A copyright protection technology that can be built into hardware devices such as hard disks and memory cards. Used for the SD memory card system called "SDAIR."

Source: Author's compilation from a report by the Study Group on the Formation of the Network Distribution Market of Digital Content of the Ministry of Public Management, Home Affairs, Posts and Telecommunications, and Web sites of relevant organizations.

a risk of it being cracked. In addition, a 100% secured DRM technology would cost too much and provide less usability for both users and content distributors.To be more realistic, measures to minimize damage in case of cracking should be incorporated into DRM, with its primary goal set as prohibiting non-expert users from effortlessly making illegal copies (so-called casual copies). If a DRM technology is broken and the protected content illegally leaks out onto networks, the following measures should be taken.

(1) Detect the illegal content on the network.
(2) Filter and block the illegal content on the server side.
(3) Filter and block the illegal content on the user side.
(4) Track down the location of the leak.
(5) Suspend and update the key/license.

Step (1), which is usually carried out by a program that automatically makes the rounds of the network, is not effective if the original file names and extensions are changed. In step (2), the files detected during step (1) are screened and blocked on the servers of the ISP, which also fails to detect files with their names changed. For step (3), a certain control code or ID should be embedded in the content in advance so that it can be identified. Step (4) requires the ID of the legitimate user or playback system to be embedded in the key or the content itself.

The most preferable method is to embed a preset ID or control code in the content, and detect and block it based on that signal. If the user information is included in the ID, the location of a leak can be easily discovered. To inhibit the removal of the embedded ID in the content, digital watermark technology, which is mentioned later, is used.

In step (5), a list to invalidate the leaked content and the relevant keys is issued, the keys are renewed, and the access right of the user (system) who is responsible for the leak is suspended. The updated invalidation list also needs to be transmitted to user terminals. This process should preferably be conducted automatically. As of this point, no DRM system is known to be capable of carrying out the complete set of these measures.

While DRM technologies that use specifically designed hardware such as mobile telephones or set-top boxes (STBs) are, in general, harder to break, they require extra costs and penetration of such devices. Difficulty with improvements and upgrades of devices in the case of cracking is another disadvantage of hardware-oriented technologies. On the other hand, although DRM solutions that are based on software like computer

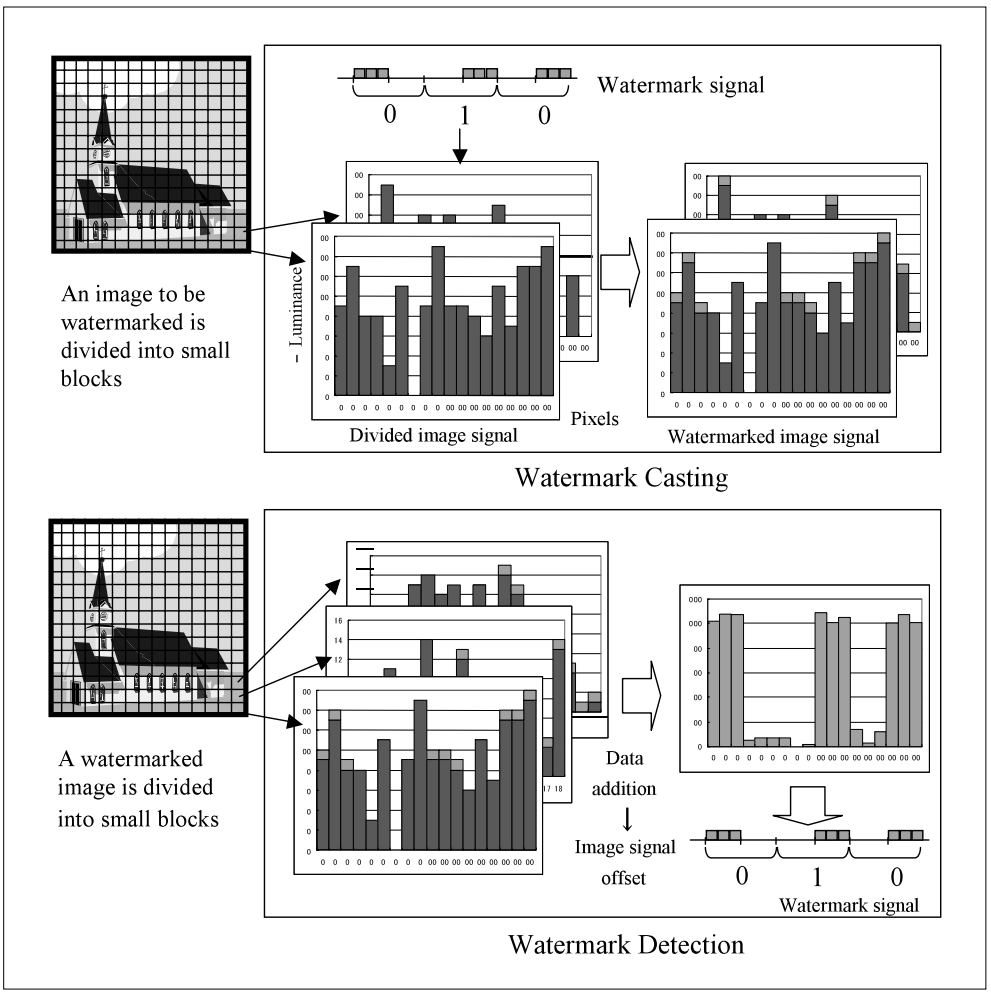
applications are relatively vulnerable, a countermeasure in the case of cracking can be as simple as distributing an upgraded version of the software over the Internet.

5.3.3 Digital watermarking technology

Digital watermarking technologies are used to place a non-removable signal on content. As mentioned before, signals such as copy control code, code to detect illegal copies, unique content IDs and user/author IDs can be embedded as effective measures against illegitimate copy distribution. There are two types of watermarks: invisible watermarks are imperceptible to human senses, and visible watermarks are used to indicate "sample" signs or to stamp the name of the author. Generally, invisible watermarks are employed for copyright protection.

Figure 4 shows how digital watermarks work. For invisible watermarking, the content signal is divided into small blocks of time or area, each of which a watermark signal is inserted into. A watermark signal is defined as, instead of the absolute value, relative information calculated by, for example, comparing two consecutive blocks to see which has a higher value. To decode the watermark, signals are synchronized with the division cycle, so that the original content signals add up to random signals to offset each other while watermark signals intensify each other so as to be detectable (there are many other schemes). Robust watermarks that can withstand image processing such as compression, scaling and cutting while imperceptible during legitimate use are needed. To meet these two conflicting requirements, watermark developers are building a variety of mechanisms to insert or adjust the signal — for example, a scheme in which a strong signal is embedded to highly detailed areas and a weak signal to flat areas. Despite their efforts, none of the current digital watermarking systems resist well to distortions like random bending

Figure 4: How digital watermarks work



Source: Author's compilation from materials made by Hitachi, Ltd

attack, in which random parts of an image are distorted. The volume of an inserted signal is typically several hundred bytes.

While there are many problems to be resolved, including cost issues and standardization (a requirement for application to packaged products like DVDs), watermarking is an effective technology to prevent distribution of unauthorized copies and, thus, its early commercialization is awaited. Also needed are systems to confirm the distributors of illegal copies in a manner they cannot repudiate such violation, for instance, by combining the digital watermark with a digital signature or allowing authentication by a third-party organization.

5.3.4 Standardization of DRM

For the benefit of users as well as content providers, a universal standard or compatibility should be provided for DRM. In practice, there are a variety of DRMs designed for different types of content or platforms. As shown in Table 2, several DRM technologies are competing to become the de facto standard for PC-oriented platforms. As a preparation to the rise of home networks (networks built within homes by using home servers, which are divided into audiovisual-oriented and white-goods-oriented), some vendors of PC-based DRM systems are promoting their technology for adoption to other distribution channels while others are enhancing their systems' compatibility with different types of content and distribution channels.

In the area of audio content, the Secure Digital Music Initiative (SDMI) led by RIAA had been consolidating the specifications for music distribution over the Internet and for recording/playback devices. In 1999, SDMI released Phase 1 specifications, which demand restriction on the number of copies and the adoption of digital watermarks. Many of today's DRMs are compliant with Phase 1. Next, SDMI began discussing Phase 2 to specify how to detect illegally copied music from digital watermarks and to prohibit its playback, only to fail in reaching an agreement and dissolving in 2001. However, the specifications set by SDMI are expected to remain effective in the industry as a standard required by copyright holders. In Japan, the Japanese Society for Rights of Authors, Composers and Publishers (JASRAC) has been selecting recommended digital watermark technologies for music under projects called Step2000 in 2000 and Step2001 in 2001.

In the motion picture field, the Copy Protection Technical Working Group (CPTWG), an organization where international standardization of copy control technology is discussed among content providers, IT companies and home electrical products manufacturers, and the DVD Copy Control Association (DVD CCA), a standardization body for DVD copy control technology, are working on standards for copy protection and encryption, while the Video Watermark Group, a joint organization of CPTWG and DVD CCA, is specifying the requirements for digital watermarks.

5.3.5 Content ID

An obstacle to content distribution over networks, aside from the ones arising from copyright management technology, is the complication of the copyright authorization procedure. This is especially true for content such as a TV program, where many copyrights (and neighboring rights) are involved and there is no standard procedure for handling copyright agreements. In such a case, a process of obtaining additional permissions from all copyright owners for distribution over networks could be an extremely difficult task. To make matters worse in Japan, copyright holders often grant authorizations without written contracts, or if any, conditions on the scope of permitted rights are most likely left unclear, further inhibiting content commerce. Another challenge is that copyright holders sometimes want some of their works to be used under certain conditions (with the indication of the author's name, with no modification without permission from the author, etc.) rather than protecting them with DRM. However, defining terms of use for individual copyright properties would be troublesome for copyright owners and time- and cost-consuming for content users, who would have to contact the owner to confirm the terms before distribution.

As a solution to this, the mechanism of "Content ID" is under development as a means to identify digital content with a unique code that is assigned

to each content item in accordance with a database containing the copyright holders' information and licensing conditions. Content IDs are embedded into digital content by using digital watermarking and other technologies. Groups working toward this goal include the Content ID Forum (cIDf), established by Prof. Yasuda at the University of Tokyo and involving Matsushita, Hitachi, NTT and other companies, ISO/MPEG21 (Moving Picture Experts Group 21) and ISO/TC 46 (Technical Committee 46, which is developing an identification system for movies). The Content ID scheme studied in cIDf, for example, offers DRM functions such as copy protection and encryption of content data, other than the capacity of identification.

On a national level, the Ministry of Economy, Trade and Industry and the Ministry of Education, Culture, Sports, Science and Technology (the Agency for Cultural Affairs) take the initiative in similar activities. They are building a database system called the Japan Copyright Information Service (J-CIS) as a model for centralized management of copyright information, although there are many problems to be solved such as who will be in charge of database management and who will bear the expenses.

5.3.6 *New forms of content and copyright distribution*

In conventional content distribution, content would be sold through distributors (publishers, music labels and broadcasting companies) under contracts with the author, who would later receive the profits. The spread of the Internet and broadband connectivity services have raised the possibility of a new type of content distribution in which the author can directly sell his or her works to the general public. Many software programs, mostly those developed by individuals, are now distributed as shareware, for which a user pays directly to the author, and freeware, software that is available without charge but sometimes with restrictions on use and redistribution. Even musical works and novels are sometimes seen sold on their authors' web sites.

Such distribution by authors, however, puts both the author and the user through much trouble with payment transactions, license (a key for the user to decode encryption) management and other procedures. To save them from having to carry out these complicated tasks, web sites such as Vector (Vector Inc., the operator of a shareware download site) have emerged to provide online marketplaces where license management and license-fee collection for digital content created by individuals are carried out by the site operators.

Another new approach to content distribution is superdistribution, a concept in which digital content is made available freely so that content providers can automatically charge a small fee for each use of their content, proposed by Dr. Mori, emeritus professor at the University of Tsukuba. Widespread availability of constant connection services has made the costs for transmitting accounting information, which is an essential element of superdistribution, negligible and has led to the development of a compatible DRM system. This new form of content distribution, however, has yet to be disseminated widely. Taking a view opposite to superdistribution, a service in which a user who purchases a license is allowed access to the content stored on the server from anywhere on the network has launched on a limited basis.

Just like content, copyrights may be distributed through direct transactions between the author and the user or through an intermediary. Copyrights for illustrated images, photographs and music to be used on personal web sites could be sold in the form of licenses for the right of public transmission. Such distribution may also provide content distributors with the possibility of uncovering prominent amateur works.

What are required in order for these new distribution systems to spread are an inexpensive settlement system to handle small payments, reliable copyright management technology available at low prices, a standardized copyright contract that is simple as well as easy to understand, and a copyright information management mechanism like Content ID.

5.4 Developments in relevant legislations

To reflect copyright holders' urgent demand for a new form of copyright protection to cope with

digitization and networking, in December 1996, the World Intellectual Property Organization (WIPO) adopted two treaties: the WIPO Copyright Treaty (provisions about software copyright, prohibition of the circumvention of copy protection systems, the right to transmit copyrighted works like phonograms through networks, etc.) and the WIPO Performances and Phonograms Treaty (provisions about the rights given to performers to transmit their works through networks, etc.). With respect to content distributed over networks, these treaties have granted copyright holders the right to make public transmission of copyright works (right of public transmission) and the right of holding such works in a transmittable state, as its previous step, on a server or other storage media (right of making transmittable).

In Japan, where the right of public transmission has already been incorporated into the Copyright Law in 1986 to cope with online karaoke systems, the government amended the Copyright Law as shown in Table 4 in line with these treaties. As a result, the right of making transmittable was given to broadcasting and cable broadcasting companies, making the Japanese Copyright Law more sophisticated than its counterparts in many other nations in terms of content distribution.

On the other hand, in the U.S., the Digital Millennium Copyright Act was enacted in 1998 to regulate the circumvention of copy protection systems and to define the procedure to remove illegal copies from networks (notice and takedown). However, this law does not cover the right of making transmittable. Therefore, the Napster case was prolonged, disputing whether exchanging copies of copyrighted materials stored on individual users' computers via P2P falls within the scope of the social agreement about the use of personal copies, or "Fair Use," and whether Napster aids and abets infringement of copyrights through its services. Japan also has provided a procedure similar to notice and takedown in the "Law Concerning the Limitation of Damages to a Specific Telecommunications Service Provider and Disclosure of Sender Information" issued on November 11, 2001.

Meanwhile, China, where the Business Software Alliance (BSA) and others point out that piracy is commonplace, revised its copyright law in October 2001, as it became a full member of WTO. The amendment prescribes for copyrights in a networked environment, which are equivalent to rights of public transmission and making transmittable in Japan, legal procedures to help victims who are seeking court orders to stop violations and to seize evidence, and for compensation from overseas entities (Copyright

Table 4: Amendments to the copyright law of Japan concerning digital content

Revision in 1997	— Wired/wireless interactive transmission was defined as "automatic public transmission" and the overall transmission including this was defined as "public transmission." Right to make public transmission of copyright works was given to copyright holders. Right of public transmission includes the right of making transmittable as its previous step, under which works are held in a transmittable state. — Right of making transmittable was newly given to performers and phonogram producers.
Revision in 1999	— Manufacture and distribution of devices intended to circumvent copy protection and other technologies to protect copyrights were restricted. — Illegitimate modification or removal of copyright control information was restricted. — Rights of distribution and presentation, which had been only associated with films, were expanded to other copyright material.
Revision in 2000	— Cases in which works can be used for the vision or hearing impaired without permission of the authors were specified. — Provisions on judicial procedures against copyright infringements were enhanced and the ceiling of a fine was raised from ¥3 million to ¥100 million to further deter violations.
Revision in 2002	— Right of making transmittable was given to broadcasting and cable broadcasting companies.

Source: Author's compilation from data on the Web sites of the Copyright Research and Information Center, the Cultural Affairs Agency and others.

Research and Information Center, People's Daily/Nikkei Biz-Tech).

Since the Internet can deliver information across national boundaries, illegal copying may not be controlled solely by civil laws. In fact, some P2P companies are leaving Western nations to escape from their strict regulations and intend to continue their business in third world countries. Copyright policies differing from state to state and lobby groups with strong political influence like RIAA also contribute to the current lack of international cooperation in legislation for copyright protection. In fact, the signatories of the WIPO Copyright Treaty and the WIPO Performances and Phonograms Treaty barely reached 34 and 30, respectively, as of March 2002 (data from Copyright Research and Information Center). Meanwhile, Japan, which had not joined the WIPO Performances and Phonograms Treaty, made a decision on accession to the treaty in June 2002.

5.5 Conclusion

Some copyright protection technologies such as DRM have already been put to practical use, allowing music and other content distribution services to launch. As mentioned in chapter 5.3, however, the lack of compatibility between DRM systems or between hardware devices can make such schemes unfriendly to users. Considering the difficulty with standardization under the fierce competition among DRM vendors, other means to enhance compatibility are called for.

Conventional content distribution systems relied on technologies in which data is transmitted in a form inseparable from "physical" entities such as books, CDs and DVDs, or in which data is broadcasted under centralized control. The widespread use of tape recorders and VCRs enabled content to be treated independent of physical products, and freed it from constraints such as timetables and show schedules. The emergence of broadband networks, digital broadcasting and other new distribution channels, and the penetration of PCs and other networked appliances to record/play digital content are bringing about an environment in which content can be distributed as information. When the third-generation mobile telephone and high-speed wireless LANs become more prevalent and the capability of mobile digital devices further enhances, people will be able to use any desired content anywhere, any time. In reality, however, many of the current DRM systems intend to protect copyrights by linking the content with physical entities (specifically-designed devices and storage media) to meet the demands of content holders. This is where they are failing to cater to users, as indicated before. There are other technical attempts that have yet to come into wide use. One of them is DRM based on superdistribution, a concept in which content is distributed freely and content providers can automatically collect payments for the use of their services.

Widespread use of PCs and personal recording devices has enabled individuals to create digital content with ease. Furthermore, taking advantage of increased connectivity to the Internet, anybody can post his or her works to the general public throughout the world. From this perspective, copyright management is no longer an issue only concerning specific copyright holders such as professional writers, composers, and movie and record companies. A copyright protection technology that can provide a balance between user-friendliness and protection ability, while securing availability to anyone, is being awaited for to come into common use.

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6

Trends in the Development of Measures Against Global Warming Centered on CO_2 Underground Storage

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6.1 Introduction

Greenhouse gases, which cause global warming, are comprised of six gases including carbon dioxide (CO_2) and methane (CH_4). Of these gases, CO_2 constitutes some 94% of the total greenhouse-gas emissions. Reductions in CO_2 emissions are therefore becoming a major challenge. The IPCC (The Intergovernmental Panel on Climate Change) 3rd Assessment Report points out that a number of adverse effects may arise from global warming — e.g., abnormal weather conditions, a decline in agricultural productivity, a deterioration in the global ecosystem, and a rise in sea levels that would decrease the area of our living environment. In addition to the technological aspects, there have been some political movements over the past several years. For instance, the Seventh Conference of the Parties to the United Nations Framework Convention on Climate Change (COP7 held in 2001) saw an agreement on the management of the Kyoto Protocol (1997). In response to this, each of the countries concerned is gearing up for the ratification of the protocol. Japan aims to reduce the total greenhouse-gas emissions by 6% from the 1990 level during the period between 2008 and 2012. However, the track record for 1999 stood at 1.314 billion tons (CO_2 equivalent), already up 6.9% from the 1990 level — a situation that necessitates some 13% reduction in real terms. All segments of industry as well as the public should thus make further efforts to cut down on greenhouse-gas emissions.

In accordance with this worldwide progress in measures against global warming, Japan set out the Law Concerning the Promotion of Measures to Cope with Global Warming (2002), bringing up the promotion of forest absorption of CO_2, energy-saving measures and innovative technologies, and the utilization of the Kyoto mechanism*1. The Council for Science and Technology Policy (CSTP), in its "Promotion Strategy for the Environment Sciences (2001)", specified R&D of zero-garbage/resource-recycling technologies and global warming as priority issues, announcing a national initiative designed to develop technologies for reducing and sequestering greenhouse gases. Among the variety of measures and technologies to cope with global warming, the significance of which is being recognized worldwide, this report highlights those for CO_2 separation, capture, storage, and sequestration technologies while addressing potential technological problems in order to recommend possible solutions for them.

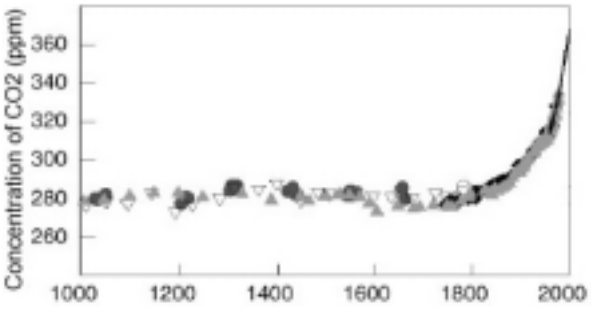
6.2 The present state of global warming issues

6.2.1 The present state of global warming

The atmosphere stabilizes temperatures that may otherwise fluctuate dramatically due to natural phenomena such as sunlight, radiational cooling, etc. Among others, CO_2 plays an essential role in maintaining the mean air temperature of our planet nearly 115 F. However, the concentration of CO_2 in the atmosphere, which stood at 280ppm (0.0280%) before the Industrial Revolution, has increased to 368ppm (0.0368%). It is on the rise hand-in-hand with increasing global temperatures (see Figure 1 and 2).

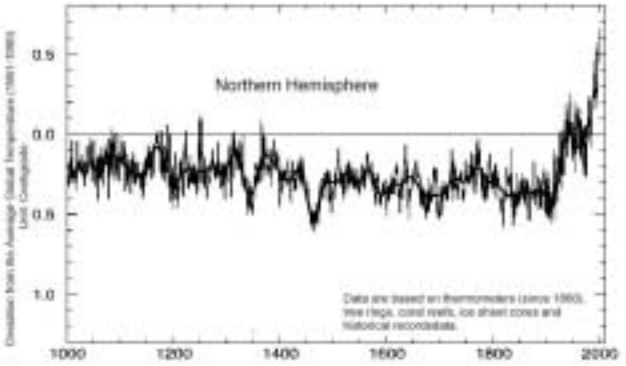
According to a forecast made by IPCC, future CO_2 emissions may vary substantially, depending on several scenarios of economic growth. For

Figure 1: Variation of the CO_2 concentration in the atmosphere



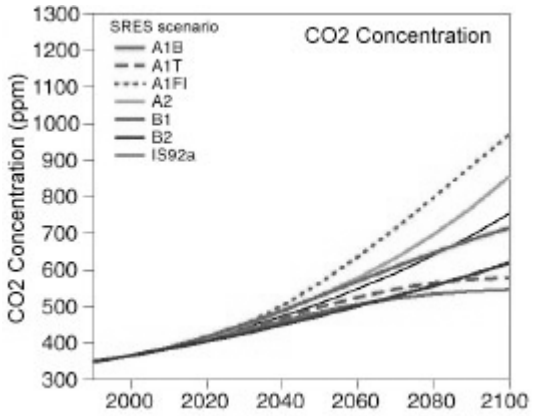
Source: The Third Assessment Report of the IPCC (2001, WGI-SPM Fig. 2)

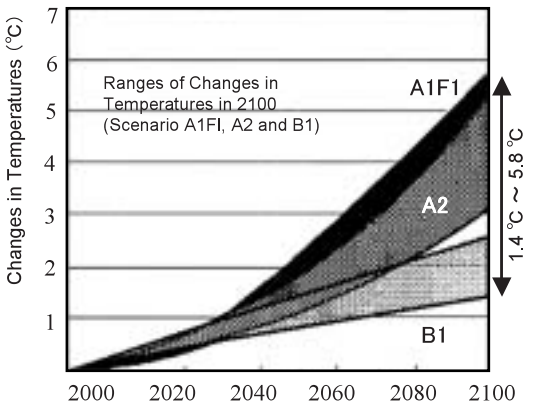
Figure 2: Deviation of annual mean temperatures from the average global temperature (1961-1990)



Source: The Third Assessment Report of the IPCC (2001, WGI-SPM Fig. 1)

Figure 3: Forecasts of atmospheric CO_2 concentrations and increases in global mean temperatures





instance, a scenario that emphasizes fossil energy sources*2 forecasts that the world's mean temperature in 2100 will increase by 1.4~5.8 degrees centigrade from the 1990 levels (see Figure 3).

The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilize the concentration of greenhouse gases within the range where the climate system is not threatened by dangerous human intervention. This very range, however, has yet to be determined scientifically. The issue of global warming involves considerable risks; left unattended without any measures being adopted, the costs of alleviating its potential effects could be tremendous, reaching the point of no return if worst comes to worst. Therefore, despite a number of uncertainties, the issue must be addressed properly and promptly.

6.2.2 An overview of technologies for curbing global warming

Table 1 shows an outline of technologies for curbing global warming, R&D of which is being conducted at home and abroad.

As mentioned at the outset, measures for reducing CO_2 emissions (the promotion of energy-saving technologies, etc.) specified in the Law Concerning the Promotion of Measures to Cope with Global Warming are promising technologies for reducing greenhouse gases (see Figure 4).

However, making dramatic improvements in the field of energy saving is by no means easy for Japan, which has been leading the world in energy use efficiency. Shifting fuel sources to generate power from conventional fossil fuels to natural gas does not reduce our dependence on fossil fuel; it is hardly a fundamental solution to global warming. Moreover, given several constraints (the current technological level, the considerable amount of investment involved, geographical requirements, etc.), environmentally friendly energy is not likely to be the main source of energy in a decade or so unless innovative technologies come into being. Likewise, it is least likely that nuclear power plants, the mainstay of

measures against CO_2 emissions, will be newly set up anywhere in the world over the next 10 years or so.

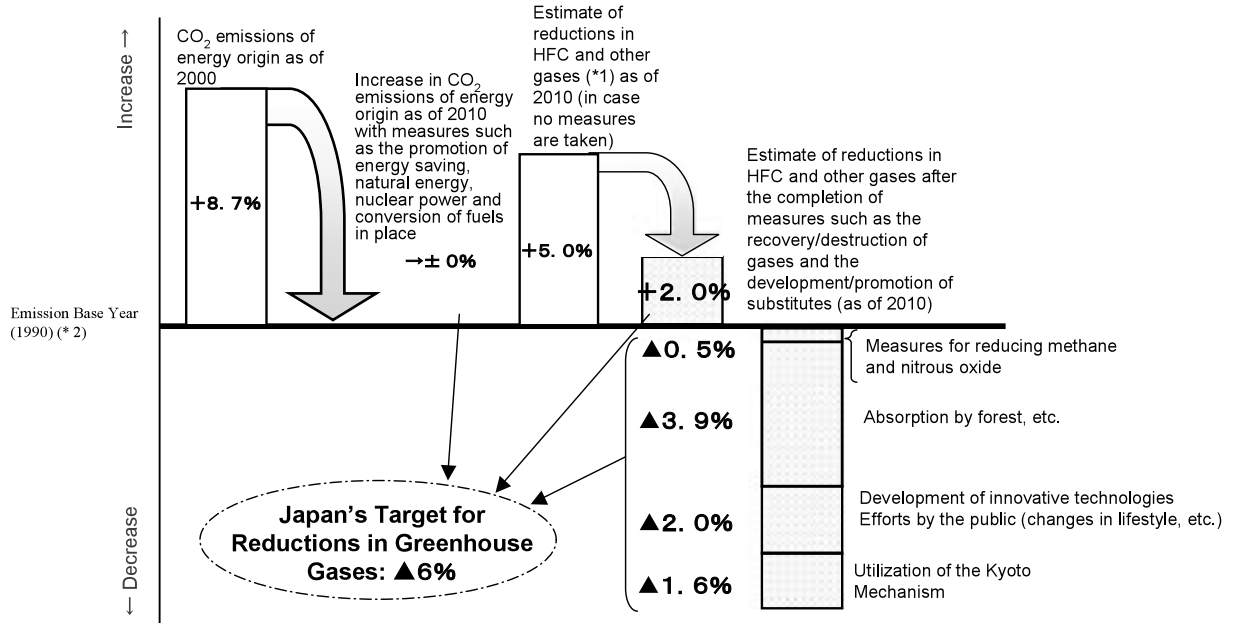
In the meantime, technologies for reducing emitted CO_2 (hereinafter referred to as "emitted-CO_2 reduction technologies"), particularly those for removing CO_2 contained in combustion gas, are being developed worldwide. These technologies cover a fairly broad spectrum, as shown in Figure 4, with their technological levels ranging from experimental stages to close-to-commercial stages. Measures against global warming are not mandatory at the moment. Industry and other sectors concerned are thus offered little incentive to promote practical measures. For this reason, relevant technologies that have been developed and commercialized so far are limited to secondary measures for curbing global warming — e.g., a plant producing urea from CO_2 recovered from effluent gas, using an absorption process (160 tons per day), and the Enhanced Oil Recovery (EOR), a process that

Table1: Overview of technologies to cope with global warming

Classification		Technologies		Description	
CO_2 Emission Control (Proactive Measures)		Energy Conservation		Improve efficiency in energy use.	
		Conversion to Other Fossil Fuels		Shift to natural gas.	
		Conversion to Non-fossil Fuels		Renewable energy such as solar power, wind power, waterpower, geothermal heat, biomass and ocean energy.	
				Nuclear power.	
				New energy-use technologies such as electric cars, fuel cells and hydrogen engines/turbines.	
Reductions of Emitted CO_2 (Passive Measures)	Reductions of CO_2 in Effluent Gas	Capture	Absorption Method	Amine Absorption Calcium Carbonate Absorption	— Absorb CO_2 in alkaline solutions.
			Adsorption Method	Physical Adsorption	— Adsorb CO_2 with solid adsorbents
			Gas Separation Method	Polymer Membrane Separation	— Utilize the differences in the permeability of gases to membranes.
				Cryogenic Separation	— Utilize the differences in the concentration of gas components.
		Storage	Underground Storage	Storage in Aquifers	— Inject CO_2 into aquifers lying some 1,000m underground.
				Storage in Oil and Gas Fields	— Inject CO_2 into oil/gas strata to recover oil and gas, and to dispose of CO_2.
				Storage in Coal Beds	— Dispose of CO_2 in unexploitable coal beds.
			Ocean Storage	Deep-sea Storage	— Store CO_2 in abyssal floors (3,000m or deeper). Utilize the density of CO_2, which is higher than that of deep-sea water.
		Sequestration	Chemical Sequestration	Electric / Optical Reactions	— Reduce CO_2 electrochemically (irradiation,electrode reaction, etc.).
				Catalytic Hydrogenation Reaction	— Synthesize organic compounds (methane, etc.) from CO_2 and hydrogen in the presence of catalysts.
	Reductions of CO_2 in the Atmosphere		Biological Sequestration	Afforestation / Reforestation	— Promote afforestation (mangroves, etc.) to fix CO_2 into plants through photosynthesis.
				Fungi	— Fix CO_2 into algae as $CaCO_3$.

Source: Author's own compilation

Figure 4: Scenario for Reducing Greenhouse Gases (The Law Concerning the Promotion of Measures to Cope with Global Warming)



Source: Author's own compilation

improves recovery rates of crude oil by injecting CO_2 into oil strata.

6.3 The present state of CO_2 capture, storage and sequestration technologies

As mentioned at the outset, the Council for Science and Technology Policy specified R&D of zero-garbage/resource-recycling technologies and global warming as priority issues, announcing a national initiative designed to develop technologies for reducing and sequestering greenhouse gases. Since the beginning of fiscal 2002, in particular, a global warming initiative encompassing all the ministries concerned has been in place in order to promote efficient and effective researches in these areas.

In the US, meanwhile, the Department of Energy (DOE) presented in 1999 emitted- CO_2 reduction technologies (referred to as "carbon sequestration technology" in the US) as one of five technological categories indispensable for energy plants in the 21st century[1]. DOE subsequently announced a plan in 2000 for promoting these technologies[2], and has launched a number of research projects so far. Moreover, President Bush stressed in his speech in June 2001[*3] that reducing emitted CO_2 holds the key to curbing greenhouse gases. CO_2 capture, storage, and sequestration technologies are thus receiving widespread attention as promising measures against global warming mentioned in Chapter 6.2. In view of these circumstances, this chapter addresses these particular technologies, highlighting their development trends and future prospects.

6.3.1 Domestic trends in emitted-CO_2 reduction technologies

Japan has been pursuing R&D to address global warming, with the government taking the initiative. Table 2 shows a variety of research projects that have been carried out under the auspices of the Ministry of Economy, Trade and Industry (METI).

Although these national projects have come up with some remarkable element technologies, their performance as a total system for commercializing specific technologies is said to be insufficient.

Table 3 shows the ongoing research projects of METI.

As is evident from Table 2 and 3, R&D is being conducted for almost all of the measures shown in Table 1. Japan maintains high levels of R&D in this particular area, yielding practical results as far as element technologies are concerned. On the other hand, some of the EU nations (U.K., Norway, etc.) are introducing systems designed to give incentives to emitted-CO_2 reduction technologies — e.g., taxes against global warming and emission trading. The EU and Japan have both ratified the Kyoto Protocol, and hence the need to develop these technologies is expected to grow further.

Table 2: Completed researches on emittted-CO_2 reduction technologies

Project Name	Description	Achievements and Appraisal	Period
Technologies for Utilizing Catalytic Hydrogenation Reaction, and for Sequestering CO_2	• Capture high concentration CO_2 (discharged from fixed sources) massively and continuously with the use of separation membranes. Add hydrogen to the captured CO_2 to synthesize useful chemical substances such as methanol.	• Developed element technologies in the fields of catalytic hydrogenation reaction, separation membranes and electrolytic layers. • Remains uncompleted in terms of system technologies.	1990-1999
Technologies for Utilizing Bacteria and Algae, and for Sequestering CO_2	• Culture bacteria and algae industrially. Sequester CO_2 by means of their photosynthesis activity in order to recycle resources.	• Accumulated the highest level of knowledge in the course of exploring and culturing useful bacteria and algae. • Poor prospects for commercialization.	1990-1999
Technologies for Capturing and Recycling CO_2 Under High Temperature Conditions	• Develop technologies for capturing and recycling CO_2 under high temperature conditions, using materials such as ceramic separation membranes. Research adaptability of developed systems to the market.	• Developed technology for producing separation membranes that function under high temperature conditions (the state-of-the-art technological field). • Poor prospects for commercialization; project targets are unlikely to be achieved in the foreseeable future.	1992-1999
Technologies for Estimating Impacts of Sequestering CO_2 in the Ocean	• Develop technologies for estimating impacts of CO_2 disposed of in the ocean on the marine environment - e.g., possible behavior of CO_2 stored in the ocean.	• Evaluated findings in the marine ecosystem as basic materials for the marine environment. • Poor prospects for commercialization due to the considerably long periods required for evaluating impacts on the marine environment.	1997-2001

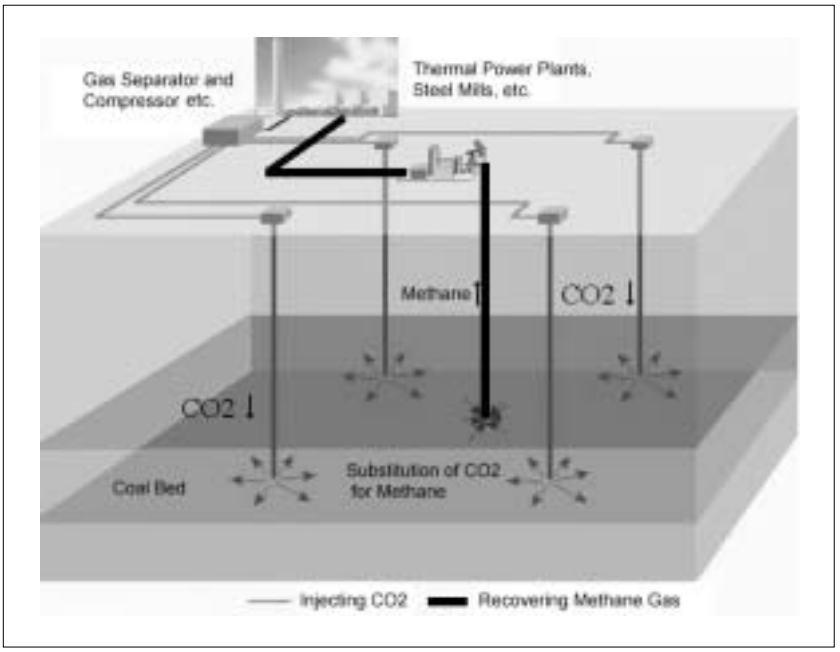
Source: Author's compilation based on the 2001 Sectoral Assessment Report of the Industrial Structure Council, METI.

Table 3: Ongoing development of emitted-CO_2 reduction technologies in Japan

Project Name	Description	Period
Technologies for CO_2 Underground Storage (Aquifer Storage Technology)	• Develop technologies for storing CO_2 recovered from major source origins (thermal power plants, etc.) in underground aquifers, tools for selecting optimal places for storage, and models for appraising the behavior of CO_2 injected into aquifers.	2000-2004
Technologies for Capturing and Utilizing CO_2 with the Use of Coal and Natural Gas	• Reform the quality of coal and natural gas with the heat recovered from sunlight, and add hydrogen produced by renewable energy (the electrolysis of water) to reformed CO and hydrogen gases, thereby establishing the process technology for synthesizing methanol without producing byproducts, namely CO_2.	2000-2004
Technologies for Biologically Sequestering and Utilizing CO_2	• Develop plants resistant to drought and intense sunlight based on genetic manipulation technology.	1993-2002
Technologies for Sequestering CO_2 through the Utilization of Used Paper	• Convert used paper (biomass) into sugar by means of microorganisms, and sequester CO_2 in the course of converting the sugar into organic acids.	2000-2004
Technologies for Estimating the Impacts of Storing CO_2 in the Ocean	• The second phase of the "Research on Circulation Mechanisms of Carbon in the Ocean." • Develop technologies for evaluating impacts of CO_2 disposed of in the ocean on the marine environment, and contribute to creating international and social agreements on technologies for sequestering CO_2 in the ocean.	2002-2006

Source: Author's compilation based on the original business record of NEDO.

Figure 5: Concept of CBM



Source: Author's own compilation

6.3.2 *Trends in overseas technological development*

The EU and other countries are pursuing international joint researches within the framework of the IEA Greenhouse Gas Research and Development (IEA GHG R&D). Aside from the EOR technology, which is not feasible in Japan due to geographical constraints, their researches are almost identical to those being conducted in Japan. However, the EOR technology, which is being developed in the EU and other countries, is primarily designed to increase oil production; reduction in CO_2 emissions remains a spillover effect.

The US, as is the case with Japan, is pursuing almost all of the technologies shown in Table 1. DOE has been increasing the budget for developing emitted-CO_2 reduction technologies[3]: 18.4 million dollars in 2000; 32.4 million dollars in 2001; and 54.0 million dollars in 2003 (budgetary request). This dramatic increase in the budget clearly indicates that the U.S. is placing great expectations on these technologies, which may reduce emitted CO_2 despite the continuous use of fossil fuel. Among all the research subjects, the CBM (Coal Bed Methane) technology is given the highest priority in terms of budget allotments. This particular technology takes advantage of the properties of coal, which absorbs CO_2 several times as much as methane. Specifically, CO_2 is injected into coal beds lying deep underground, and methane adsorbed in the coal beds is replaced by CO_2 — a process that serves the double purpose of CO_2 sequestration and the recovery of methane gas (see Figure 5). The U.S. and the EU nations are pushing ahead with this CBM technology along with the EOR technology (see Table 4).

Unlike conventional measures against CO_2 emissions, state-of-the-art technologies such as CBM and EOR make the most of CO_2 in securing new energy sources, while functioning as measures for curbing global warming.

6.4 Prospects of emitted-CO_2 reduction technologies

Figure 6 shows the feasibility of introducing emitted-CO_2 reduction technologies along with their potential capacity. Of these technologies, the aquifer storage technology (see Figure 7) seems promising due to the following reasons:

1. This technology has solid track records abroad in EOR and other processes, and is an application of established technologies in the field of oil and natural gas production.
2. There is little likelihood that CO_2 injected into aquifers will be released into the

atmosphere, and its safety risks are almost negligible.

3. Unlike the ocean storage technology, in which impacts on the ecosystem need to be monitored carefully, the aquifer storage technology is not likely to have secondary impacts on the ecosystem.
4. It is estimated that aquifers off the coast of Japan can store some 90 billion tons of CO_2, the equivalent of 70~80 years of CO_2 emissions in Japan.

Thus, the aquifer storage technology needs to be pursued and developed.

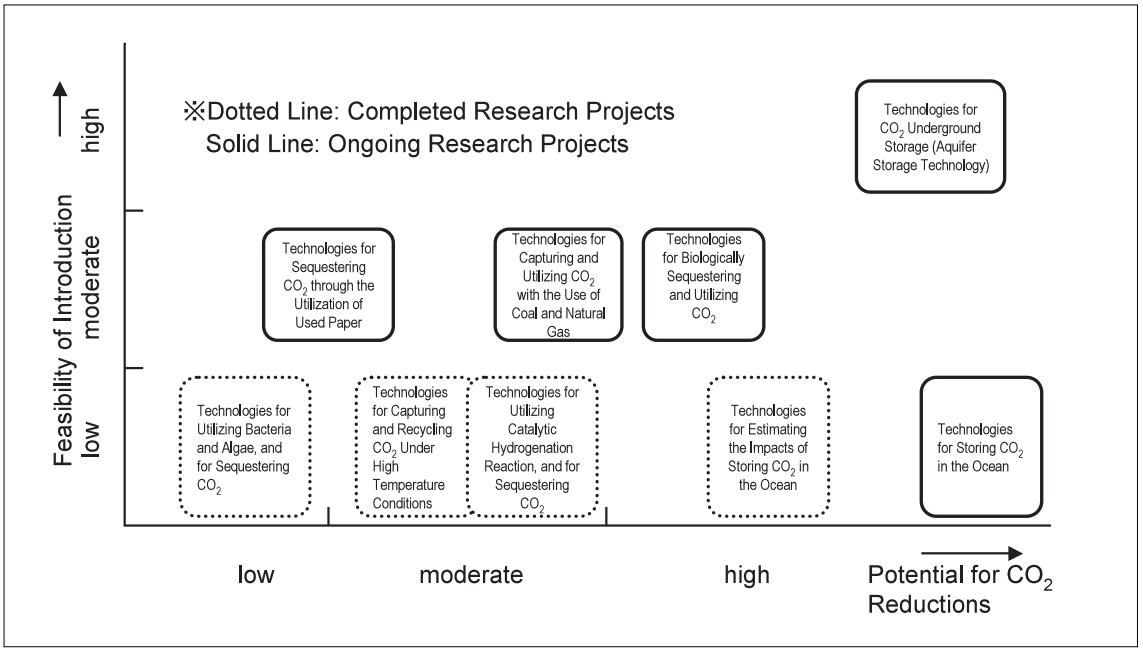
On the other hand, the CBM technology, on which Western countries are placing great

Table 4: Overseas projects for developing technologies for CO_2 underground storage

Country	Project Name	Operating Body	Description	Period
Norway	SACS (Saline Aquifer CO_2 Storage)	Stat Oil (State-owned Oil Company)	CO_2 contained in natural gas (concentration: 9%) produced by oil / gas fields in the sleipner west field, which is located 240km off the coast of Norway (the center of the Northern Sea), is captured through the amine absorption method. The captured CO_2 is then stored in sandstone aquifers about 1,000m below the surface of the sea. One million tons of CO_2 is injected into underwater aquifers annually — a volume equivalent to 3% of the total annual CO_2 emissions. The incentive for the project is derived from carbon tax imposed on offshore oil fields. The amount of tax at the planning stage of the project stood at 350 krone per one ton of CO_2 emissions (1 krone = 12 yen).	1996-
U.S.	Carbon Sequestration R&D Program	DOE (Department of Energy)	An R&D program for technologies for capturing, storing and sequestering CO_2: DOE will conduct a CBM pilot test in the San Juan Basin with an eye toward reducing carbon sequestration costs from the current 100-300 dollars / ton to 10 dollars/ton. The total budget for carbon sequestration projects to be carried out by 2015 is estimated at 922 million dollars.	1999-
Australia	GEODISC (Geological Disposal of Carbon Dioxide)	APCRC (Australian Petroleum Cooperation Research Center)	A research project for evaluating technological, economical and risk aspects of technologies for CO_2 underground storage in Australia: APCRC is looking at six options (aquifers, depleted oilfields, CBM, etc.) in order to dispose of CO_2 produced by northwest gas fields, investing 10 million dollars in four years. CBM is a promising option. In addition to the Australian government, seven companies including BP, Amoco, Chevron and Shell have a stake in the project.	1999-2003
Canada	Weyburn CO_2 Monitoring Project	PTRC (Petroleum Technology Research Center)	A CO_2 Monitoring Project being conducted at the Weyburn oilfield in Saskatchewan: the total cost of the project is estimated at 15.3 million Canadian dollars. With Environmental Canada and the Alberta Research Committee (ARC) as the center, the governments of Canada, the U.S., Australia and the Netherlands as well as fifteen other organizations take part in the project. CO_2 to be injected into oilfields for EOR (enhanced oil recovery) purposes is transported from a coal gasification plant in North Dakota through pipelines. The purpose is to gather information regarding the behavior of stored CO_2, mechanisms of storage, and its long-term safety.	July 2000-2004
The Netherlands	The RECOPOL Project	VROM (The Netherlands Ministry of Housing, Special Planning and the Environment)	The purpose is to create a CO_2 network among European countries, and to evaluate the feasibility of storing CO_2 in coal beds in Europe. The project is being carried out at the Silesian coalfield, which was identified as an optimal site for CBM in the IEA report (2000). The total cost of the project is estimated at 3.5 million euro, with the EU shouldering 50% (1 euro = 115 yen). Universities in the Netherlands, Poland, Germany, France and Australia as well as nine other organizations take part in the project.	November 2001-2004

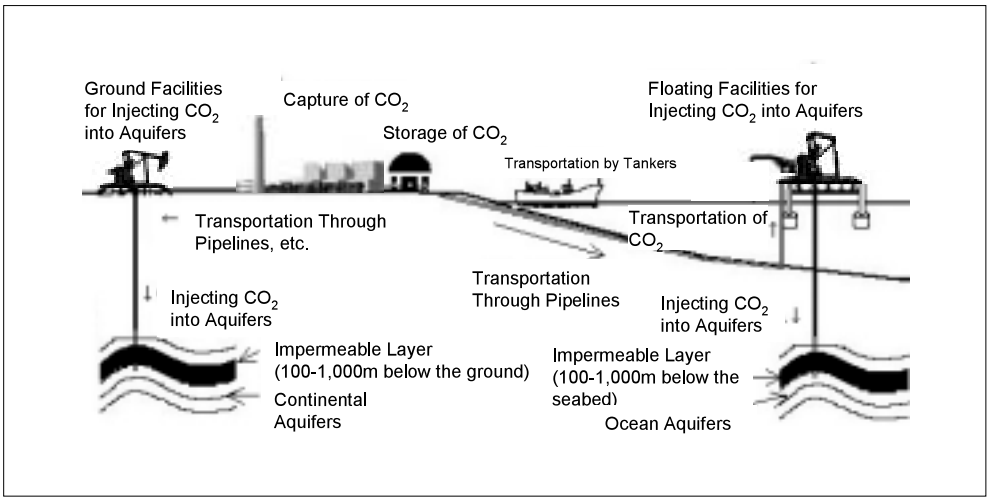
Source: Author's compilation based on relevant materials [2, 4, 5, 6, 7].

Figure 6: Evaluation of emitted-CO_2 reduction technologies



Source: Author's compilation based on the 2001 Sectoral Assessment Report of the Industrial Structure Council, METI.

Figure 7: Concept of aquifer storage technology



Source: Author's own compilation

expectations, is not being studied in Japan, though it is categorized within the underground storage technology, along with the aquifer storage technology. Coal beds in Japan generally contain large amounts of methane gas, and hence there is great possibility that methane gas trapped in depleted mines or in deep coal beds, exploitation of which is not yet feasible, can be recovered through this technology[9]. Moreover, some reports state that coal beds in Japan can sequester 10 billion tons of CO_2[9], since the technology accommodates even low-grade coal (The Agency of Natural Resource and Energy plans to launch new researches regarding coal-bed storage in 2002 [10]). This technology is expected to develop in China, which is blessed with coal resources; the country is most likely to emit increasing amounts of CO_2 in response to expanding domestic demand for energy. Supported by systems such as Clean Development Mechanism (CDM) and Joint Implementation (JI), the effectiveness of these emitted- CO_2 reduction technologies will probably be further improved.

6.5 Conclusion

Various measures against CO_2 emissions typified by energy-saving technologies are effective in curbing global warming since they are designed to control the emissions themselves. However, being

technologically feasible is one thing, while implementation of these measures by all segments of industry as well as the public. Therefore, regardless of what measures or systems will be adopted in the future, the government must educate everyone concerned about the significance of their participation in economic and practical efforts toward the resolution of global warming, and request them to take specific measures against global warming. In addition to these activities, the introduction of a system that provides economic incentives for measures against global warming (e.g., a global warming tax) could increase the awareness among industry and the public about this problem — a situation that will inevitably promote various measures against global warming. Meanwhile, the concentration of CO_2 in the atmosphere cannot be reduced only through the combination of these measures, even if they function as originally intended. As mentioned in Section 6.2.2, renewable energy and nuclear energy are not likely to be reliable energy sources for the foreseeable future. Therefore, looking ahead into the next decade or two, there is a need to develop emitted-CO_2 reduction technologies.

Japan has been addressing a number of technologies in this particular area, and there have been some achievements, namely the development of element technologies. However, there is a general recognition that total systems have yet to be developed. While the whole world is basically still dependent on fossil fuel, developing countries typified by China and India are expected to emit increasing amounts of CO_2 in response to their growing demand for energy. For this reason, CO_2 underground storage, which could control increases in CO_2 despite the continuous use of fossil fuel, is expected to be of help not only to developed countries but also to developing countries. With a growing movement toward the ratification of the Kyoto Protocol as a backdrop, the advantage of these technologies will probably increase further due to external factors associated with obligatory reductions in greenhouse gases (a global warming tax, etc.).

Considering these circumstances, R&D of emitted- CO_2 reduction technologies should be pursued with particular emphasis on the following aspects:

1. Looking ahead into the next decade or two, the importance of emitted-CO_2 reduction technologies will increase as effective measures against global warming. Therefore, considering their feasibility for introduction as well as potential for reducing CO_2, R&D of CO_2 underground storage should be prioritized.
2. In pushing forward with R&D, the course of development should be determined explicitly (including evaluations on the practicability of projects as a system) at the planning stage of R&D projects, and energy policies should be taken into consideration.
3. With regard to technologies (the CBM technology, etc.) that can be applied to overseas projects, R&D should be promoted in a comprehensive manner, encouraging technological exchanges between countries with versatility of those technologies in mind (initiatives in international standardization, applications to overseas projects, etc.).

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for the Development of Technologies for Sequestering and Utilizing CO_2 (Technologies for CO_2 Sequestration in Coal Beds) (The Agency of Natural Resources and Energy)

Glossary

*1 Kyoto Mechanism

The Kyoto Mechanism is a system through which its member countries are allowed to count emissions reduced by other countries as their own reductions, or their reduction targets can be achieved by purchasing emission credits from other countries. The mechanism is comprised of the following three systems.

- Joint Implementation (JT): Developed countries jointly implement projects for reducing greenhouse gases in order to transfer or acquire CO_2 credits.
- Clean Development Mechanism (CDM): Developed countries and developing countries jointly implement projects for reducing greenhouse gases in order to transfer or acquire CO_2 credits.
- Emission Trading (ET): Developed counties trade with one another in the balance between targets and the actual amount of emissions as emission credits.

Through this mechanism, each country concerned will be able to implement specific measures against global warming in countries where the cost of implementation is relatively lower, or to purchase emission credits at lower prices, thereby economically achieving its reduction target.

*2. A1FI Scenario

The Third Assessment Report of the IPCC presented a scenario dubbed "A1FI scenario," which emphasizes fossil energy sources. There are scenarios forecasting a future society where the world economy continues to grow, the world population starts to decline after peaking in the middle of the 21st century, and new technologies for improving efficiencies are adopted rapidly. These can be divided into the following three scenarios according to the energy sources they emphasize:

- A1FI : a scenario that emphasizes fossil energy sources.
- A1B : a scenario that emphasizes a well-proportioned balance among all the energy sources.
- A1T : a scenario that emphasizes non-fossil energy sources.

References

- A2 : a scenario based on regional economic development. Forecasted economic growth per capita and technological innovations are slower than those of other scenarios.
- B1 : a scenario that emphasizes global measures for achieving sustainability of the world economy, society and environment.
- B2 : a scenario that emphasizes regional measures for achieving sustainability of the world economy, society and environment. The world population increases more slowly than the forecast made by A2; economic growth remains at moderate levels; and extensive technological innovations take place, though its pace is slower than those forecasted by A1 and B1.

Incidentally, each scenario specified in SRES (Special Report on Emission Scenarios), namely A1FI, A1B, A1T, A2, B1 and B2, should be regarded as having common grounds. None of these scenarios assumes that reduction targets based on the Framework Convention on Climate Change and the Kyoto Protocol will be completed.

*3. Speech of President Bush in June 2001

"America's the leader in technology and innovation. We all believe technology offers great promise to significantly reduce emissions- especially carbon capture, storage and sequestration technologies." REMARKS BY THE PRESIDENT ON GLOBAL CLIMATE CHANGE, THE WHITE HOUSE, June 11, 2001.

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7

Trends in Nanobiology

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7.1 Introduction

National governments have adopted policies for promoting nanotechnology since then President Bill Clinton announced the National Nanotechnology Initiative in January 2000. A goal of nanotechnology is to create what surpasses the semiconductor device, whose miniaturization will probably reach its limit in the near future. While there are some candidates of such products like molecular-electronic elements, people are trying to develop products to which brand-new principles are applied, such as quantum computers and DNA computers. Meanwhile, microprocessing and single-molecule measurement, which are fruits of nanotechnology, have come to be employed in the field of life science such as in the development of new medicines, gene function analysis and research on biological information transmission.

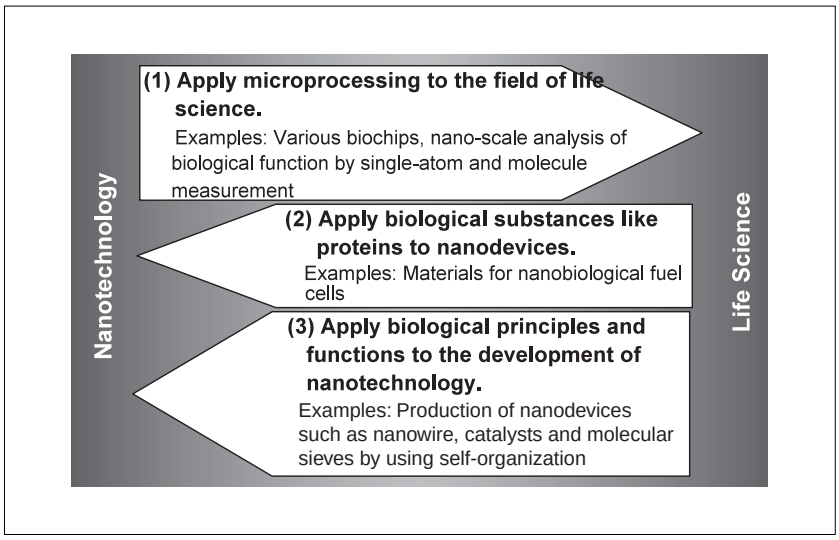
In this report, we introduce to you trends in nanobiology, which is widely seen as a boundary sphere between life science and nanotechnology.

7.2 What is nanobiology?

The Promotion Strategy of Prioritized Areas of the Council for Science and Technology Policy of the Cabinet Office recognizes nanobiology, in which medical micro systems and materials and biological mechanisms are applied and managed, as one of the five crucial domains in the field of nanotechnology and materials science. This strategy defines the primary goal in nanobiology as discovery of the basic principles for establishing a high-efficiency and ultra-integrated system with biomolecular structures and functions applied.

In the U.S., six educational and research institutions jointly established the Nanobiotechnology Center (NBTC). It employs the word "nanobiotechnology" with its definition as follows: "Nanobiotechnology applies the tools and processes of nano/microfabrication to build devices for studying biosystems. Researchers also

Figure 1: Three spheres extending across nanotechnology and life science



Source: Authors' own compilation

learn from biology how to create better micro-nanoscale devices."[1]

In the meantime, there is a term indicating a more limited sphere than nanobiotechnology does. The Asia-Pacific Economic Cooperation Center for Technology Foresight, which is estimating the future development of nanotechnology, reports on "nanobiosystems." According to its paper, nanobiosystem is "the use of biology to aid in the development of nanotechnology." In addition, this report says nanobiosystem has two levels.[2] First is to utilize biological materials as devices or functional materials. For example, enzymes with high specificity and catalytic powers may help to produce nano-fuel cells and bioelectronic elements. The second level of nanobiosystem is to scrutinize biological principles in order to grasp and use them. For instance, highly functional nanosensors have been produced by analyzing the function of ion channels, which detect chemicals, and imitating its structure and properties.

Nanobiology and nanobiotechnology are new ideas, so their definitions are still nebulous. Yet, we can deem that these fields include three spheres as follows, and as shown in Figure 1. They; (1) employ and apply nanotechnology such as microprocessing to the field of life science, (2) directly use biological materials in producing nanodevices, and (3) utilize biological functions and principles in developing nanotechnology.

7.3 Application of the fruits of life science to nanotechnology

In this chapter, we introduce to you instances of research and application regarding spheres (2) and (3) of Figure 1, which can be called nanobiosystem research. Table 1 shows research categories and examples on which the APEC Nanotechnology Position Paper reports.

We should also mention that Table 1 includes the development of new devices by imitating biological functions without using biological materials, as well as the direct use of biological materials like cells and enzymes.[2] Let us look at some examples in detail.

(1) Example of the use of biological materials: nanobiological fuel cell

Researchers are trying to make a miniature fuel cell using catalysts, or biological enzymes, instead of a platinum catalyst. Various enzymes exist in a living organism to help smooth redox reaction. Distinct biological catalysts are employed for hydrogen oxidation and oxygen reduction in developing a fuel cell comprising of hydrogen and oxygen. However, many technological hurdles lie in generating as much energy as possible, and it is necessary to establish a precise nano-scale structure in which active sites of enzymes, substrates and complementary elements are in

Table 1: Nanobiosystem research discussed in the APEC Nanotechnology Position Paper

Research spheres	Examples
Application of biological principles to existing fields of study	Enzyme transistors, whole-cell biocomputing, DNA computers
Biological and chemical sensors	Physical sensors using receptors, biomimetic sensors
Bioelectronics	Electronics elements and circuit parts using enzymes, antibodies, antigens and DNAs; nanobiological fuel cells
Opto-nanobiosystems	Biocomputer device elements, optobioelectronic device elements
Biological nanomachine	Parts of nanoelectromechanical systems (NEMS) and microelectromechanical systems (MEMS); chemical chip parts; drug-delivery systems (DDS)
Building of nanostructures of biomolecules by using self-organization	Molecular sieves, catalysts
Artificial organs and muscle with biological functions applied	Actuators, tissues for regenerative medicine

Source: Authors' compilation on the basis of a reference [2]

ideal locations. Finding and making such an optimum structure are the immediate objectives in this field.

(2) Example of the use of self-organization: production of silver nanowire

Among various biological functions, it is hoped self-organization will be applied to the development of nanowire. In the method of making a nanostructure by building up each atom and molecule through the use of an atomic force microscope (AFM), though certain structures can be easily built, there are technological obstacles in making large structures and carrying out mass production. In contrast, mass production may be easily realized if self-organization is applied.[3]

Substances in a living organism that effectively employ self-organization are often used when devices are produced by self-organization. In this section, we introduce to you an example in which hydroquinone, a substance involved in biological energy conversion, is applied.

B. H. Hong *et al*. of Pohang University of Science and Technology, South Korea, made silver nanowire with a diameter of about 0.4 nanometer and a length of several micrometers using a template containing hydroquinones.[4] Metal nanowire attracts attention as a nanoelectronic material for its applicability in producing ultra-micro electronic circuits. Hong *et al*. made a template with an inner diameter of several nanometers by the self-organization of calix[4]hydroquinone, a compound including hydroquinones. This substrate consists of four hydroquinone subunits and has a calix-like shape. Hong *et al*. generated nanowire by letting this template absorb a silver nitrate solution and reducing silver ions by irradiating ultraviolet rays. In the cross section of this template, tubes form square-lattice-like arrays, and silver nanowire grows inside of these tubes. According to this paper, similar nanowire can be made with gold, palladium, platinum and mercury ions.

(3) Example of the imitation of biological functions: chemical sensors using artificial ion channels

An ion channel is a molecule converting stimuli into electric or chemical signals in the cell. It has a nano-scale tubular structure, penetrates the biomembrane, and comprises a pore in its center through which ions pass. This pore has an ion selectivity filter, so only specified ions can pass through it. This filter has a "door" with a sensor, and this door opens or closes in response to external stimuli. Researchers are striving to develop such products as a sophisticated ion sensor, and an amplifier of electric and chemical signals making good use of the function of ion channels. However, the functional principles of ion channels have not been fully revealed as yet.[5]

In the meantime, researchers are attempting to synthesize artificial ion channels with simple structures that can be easily made in order to understand the function of ion channels. There is a lot of research on artificial channels in which peptides are used as in biological ion channels. Meanwhile, Sokabe *et al*. of the Graduate School of Medicine, Nagoya University, synthesized artificial channels consisting of molecules with simpler structures without peptides, *i.e.*, comprising of hydrophilic and hydrophobic chain molecules, in order to understand the fundamental principles of ion channels.[5]

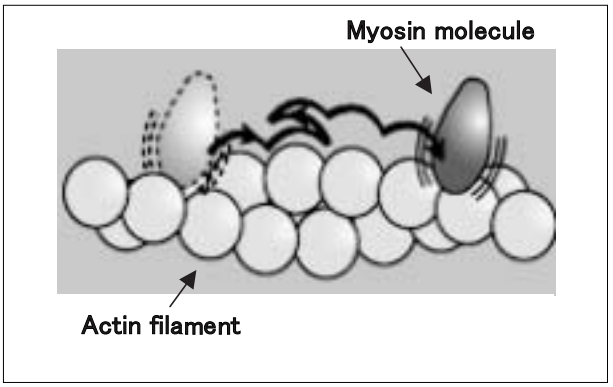
7.4 Examples of the application of nanotechnology to life science

In this chapter, we introduce to you examples of research regarding sphere (1) in Figure 1.

7.4.1 Analysis of motor molecules in the muscle by single-molecule measurement

Measurement and control of proteins, with their size of several tens of nanometers, are necessary to understand the function of biological machines like molecules involved in muscular movement. Researchers are promoting the development and application of high-accuracy measurement and molecular manipulation, making good use of the fruits of nanotechnology such as with an AFM and optical tweezers. This technique, which is called single-molecule measurement, is helping in the pursuit of research on motor molecules, kinds of molecular machines. This research has progressively revealed the unique mechanism of the molecular machine.[6]

Figure 2: Movement of a myosin molecule



Soruce: Authors' compilation on the basis of the reference [6] of Prof. Toshio Yanagida

First, let us look at the motor mechanism of myosin, a protein, as an example of a motor molecule. Myosins move along actin filaments, in which proteins called actin are bound together (Figure 2). This movement requires chemical energy generated by hydrolysis of ATP, a biological energy source. Recently, single-molecule measurement has clarified how myosins gain chemical energy from ATPs and move. Myosins move at random on actin filaments by the Brownian movement before receiving energy from ATPs. Directions of their movement are not set because they randomly move backward and forward with equal probability. Research with single-molecule measurement revealed that directional movement is efficiently produced from the combination between random and mechanical movements of system by the chemical energy of ATP. This is a discovery overturning the established theory. This research clarified a mechanism peculiar to a molecular machine and different from that of an artificial machine. It is hoped that this system will be applied to actuators of artificial muscles and robots.

7.4.2 Application of nanochip and microchip technology to life science

In this section, let us introduce to you the trends in nanochip and microchip technology, which will probably become practicable in the near future. In research after the completion of DNA nucleotide sequence analysis, it is necessary to accomplish mass processing and reduction of analysis and reaction time by highly integrating experimental systems and speeding up experimental procedures. The 30 to 40 thousand human genes are presumably producing about one hundred thousand to one million proteins.[7] We need not only to analyze this enormous amount of proteins but also to isolate and purify them. The high throughput screening explained below, to which nanochip and microchip technology is applied, may help such studies.

(1) Microchamber array

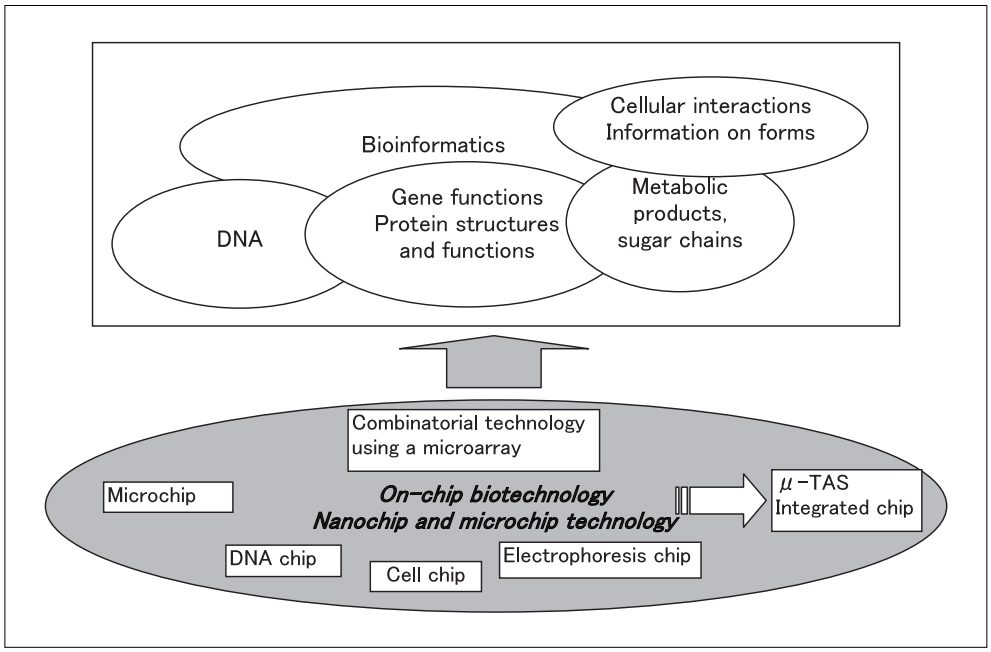
In this section, we introduce to you an example of the application of nanochip and microchip technology to the discovery of medicine working on proteins. Effectiveness of various synthesized compounds, which are medicine candidates, should be measured promptly in developing new medicine. A microchamber array with reactors miniaturized to the micro/nanometer scale is prepared using the technique of semiconductor microprocessing. Then, each compound is arranged in a distinct reactor, and the array is processed simultaneously by applying reagents and sampling materials. In this way, effective compounds are found. It is hoped that reduction of analysis time, saving of reagents and improvement of their sensitivity will be realized by highly integrating several thousand to tens of thousand reactors onto a single chip.[8]

(2) Protein chip

Draft sequence of the human genome was announced in February 2001, and the number of human gene products, or proteins, is thought to reach 30 to 40 thousand. Functions of 60% of these proteins have been revealed to some extent, while 40% are still unknown. Researchers are advancing analysis of conformation, production volume and interaction of these proteins with unrevealed functions.

A protein chip as well as a surface plasmon resonance sensor, which is a real-time analyzer of interactions between biological substances, and a mass spectroscope is used in the analysis of protein interaction. Ligands such as antibodies, enzymes and hormones are fixed on a chip, solutions including proteins are applied there, and then proteins interacting with the ligands are analyzed with a mass spectroscope. Currently, 20 to 30 materials on a single chip can be analyzed in about ten minutes. Researchers hope to develop a

Figure 3: Application of nanochip and microchip technology in life science



Source: Authors' compilation on the basis of references [8, 11]

chip with which thousands of materials can be analyzed in a short time.[9]

Chip technology is already used in gene function analysis, and application of nanochip and microchip technology will be crucial as well in analysis of proteins, metabolic products and cellular interactions. Moreover, researchers are promoting the development of on-chip technology, with which analyses that laboratories have conducted through several steps by using various analyzers can be carried out with a chip by making analyzers compact and automatized. The Micro Total Analysis System, or μ-TAS, is an example of such system (Figure 3).

Semiconductor microprocessing has been used in nanochip and microchip technology. Silicon technology, which has been developed for a long time, is applied to improve biochips and μ-TAS, and some of them have already come into practical use. Miniaturization of these chips will probably develop as in semiconductors for the time being.[10] Several enterprises have already launched R&D of biochips, expecting rapid growth of the life-science market.

7.5 Arguments over nanobiology

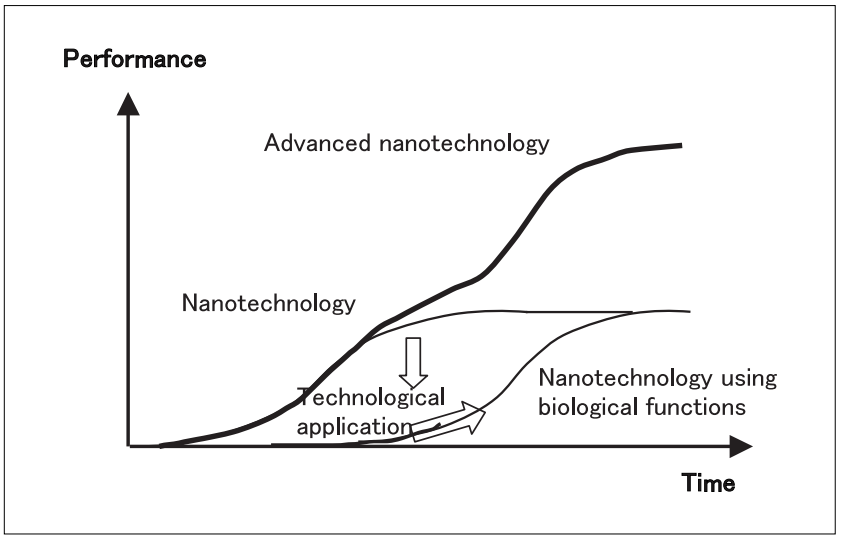
People hope that nanobiology will bring about qualitative changes in nanotechnology by incorporating biological functions and principles that artificial machines do not have. For example, people tend to think that nanotechnology requires an enormous sum of money considerably exceeding the level of private research as in R&D of semiconductor devices. However, if nanotechnology changes qualitatively along with the development of nanobiology, its research may become small in scale and inexpensive.[2, 3] Yet, prediction of the long-term technological and economic impact of nanobiology is impossible so far.

Most research on the application of life science to nanotechnology as shown in Table 1 is still at the basic level, except for studies on biological and chemical sensors. Even the concept that these products will be environment-friendly is not fully understood yet.

How to organize nanobiological research is highly interesting. People point out the necessity of the creation of new spheres extending across various fields of study and of comprehensive efforts beyond borders between different disciplines.

Functions peculiar to biomolecular machines, which are different from artificial machines, are being clarified in the boundary sphere between nanotechnology and life science. Although much research has been conducted to apply such functions to nanotechnology, most of these studies are at the basic level. In the meantime, in the

Figure 4: Concept of the development of nanotechnology with biological functions applied.



Source: Authors' own compilation

nanochip and microchip technology, which is a field of application of existing nanotechnology, researchers have already made road maps for putting this technology to practical use.[12]

After biological function research with existing nanotechnology, nanobiology will probably grow into an applied research with biological functions used. It is greatly hoped that the appropriate use of unique biological functions will bring nanotechnology to a higher level (Figure 4).

7.6 Conclusion

Will biology be the science in the 21st century? The answer is yes and no, says Cees Dekker, professor of the Molecular Biophysics Group, Department of Applied Physics of Delft University of Technology, the Netherlands. He explains the reason as follows.[13] Science has ramified as well as deepened in the 20th century. In this process, each field of study has fostered its own system that may be even called a culture. However, in the 21st century, people from various fields must jointly pursue research for clarifying the function of the biological system. Unveiling the function of the biological system is difficult through the conventional domain of biology only, and cooperation with other fields such as physics is essential. Therefore, his answer is "no" from the viewpoint that the 21st century will not be the century of biology only. However, it is "yes" from the viewpoint that a primary research objective in science will be the clarification of the biological mechanism.

Nanotechnology has realized microscopic measurement and control of biomolecules. Nanotechnology is making researchers from different fields of study scrutinize the same object. For example, in a living organism, physicists study structure and movement of biomolecules, chemists study biochemical reactions, and biologists study phenomena peculiar to the organism. It is hoped that clarification of the biological function progresses further with nanotechnology, a novel framework where various fields are merged together.

In addition, understanding of, for example, soft matters is thought to be necessary to reveal the biological function. Soft matters include liquid crystal, polymers, gel and colloid, which have been studied in the field of materials science. However, physical understanding of soft matters is still poor and a mountain of tasks is left to be tackled.[14]

Moreover, the concept of self-organization, whose application to nanotechnology is thought to be crucial, has not obtained a scientific consensus as yet. In the International Symposium on Chaos and Order in Chemistry held in 1999, researchers from various fields of study from molecular design to chemical chaos reconsidered the concept of self-organization, but a solid consensus was not established on any one definition.[15]

In this way, numerous difficulties involving different fields exist in revealing the biological function, like comprehension of soft matters and understanding and reestablishment of the concept

of self-organization. The twofold answer of Prof. Dekker may be based on such a background.

Attempts for merging various fields of study are carried out in the forefront of research such as international conferences and schooling where the latest research results are discussed. Recently, young researchers such as graduate students majoring in biology, physics and chemistry from Asian and other countries gathered, learned and discussed up-to-date life science like nanobiology at the Asian Winter School "New Trends of Biochemical Physics" hosted by the Institute for Molecular Science.

As understood from the above discussions, nanobiology is still a new sphere with many problems to be solved. However, we need to foster and develop nanobiology as a merged domain breaking down the borders between different academic disciplines in order to fulfill its great potential.

Acknowledgements

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8

Trends and Problems of High-level Radioactive Waste Disposal Projects — Technical and Social Aspects —

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8.1 Introduction

One of the issues concerning the rights and wrongs of nuclear power generation is the problem of high-level radioactive waste disposal. This problem has greatly awakened the public's interest, and it has been discussed among the people not only from the technical aspect, but also from other views including repository sites, environmental ethics such as generations' equal responsibility for environmental loads, and the non-proliferation of nuclear weapons.

High-level radioactive wastes are inevitably generated in nuclear power plants. It is considered that the appropriate disposal of these wastes is the responsibility of the generations enjoying the benefits from the nuclear power generation industry. The 7th Technology Foresight[1] published by the National Institute of Science and Technology Policy in 2001 ranked third in "importance" the subject "Commercialization of solidification disposal technologies for high-level radioactive wastes" among 1,065 topics in 16 fields

Today, the world's nuclear power interests are paying much attention to whether or not the Yucca Mountain site in the U.S. will be selected for a geological repository. This site is the only candidate for a high-level radioactive waste repository in the country. For about 15 years, the Department of Energy (DOE) and other organizations made design and safety assessments for the prospective repository to be installed in this site. Finally in February 2002, DOE Secretary Abraham recommended the Yucca Mountain site for the final repository to President Bush. President Bush approved this site, and recommended it to Congress. In Nevada, however, the local people expressed deep-rooted opposition to the repository construction project in the Yucca Mountain site. Early in April, Governor Gwyn filed his disapproval with Congress, as most people expected.

To overturn Governor Gwyn's disapproval, the House and Senate needed to pass President Bush's approval. On the 8th of May, the House approved the Federal Government's decision. The Senate will vote on this measure in July at the latest. However, the result cannot be forecasted, because the number of seats in the Senate supporting the Government's decision is almost equal to that of the opposition. If the Senate approves this measure, the DOE will file its application for a license with the Nuclear Regulatory Commission (NRC). If the Senate rejects this measure, the project will start with a clean slate.

In Japan, the "Law on Final Disposal of Specified Radioactive Waste" was enacted in May 2000, and, under this Law, the Nuclear Waste Management Organization of Japan (NUMO) was established as the main disposal project implementation organization (hereinafter referred to as the "implementation organization") in October 2000. To select its repository, the NUMO will start public invitation of candidates for preliminary survey sites in the 2002 fiscal year as scheduled.

This report describes the domestic and foreign trends of high-level radioactive waste disposal projects, and discusses the technical and social aspects of this problem from various points of view, especially focusing on the aspect of scientific and technological frontier researches as a part of the research and development for HLW disposal

technologies, and on the social aspect represented by site problems.

8.2 High-level radioactive wastes and the disposal options

This chapter summarizes basic information about high-level radioactive waste disposal.

In nuclear power plants, uranium oxide fuels are generally replaced about three years after reactors are charged with them. Table 1 indicates that the spent fuel contains: uranium 238, accounting for a greater part; uranium 235, left not fissioned; fission products derived from the fission of uranium 235; and plutonium and other actinides produced from uranium 238.

Today, Japan and France have adopted the policy of recovering uranium and plutonium by reprocessing spent fuels to improve the efficiency of uranium resource utilization. Plutonium, especially, has such a high value of utilization for energy that it is mixed with uranium to produce the mixed-oxide fuel (MOX) used for light water reactors, and is expected to be used as the fuel for fast breeders in the future. On the other hand, fission products and actinides are vitrified and sealed up in stainless steel containers. These vitrified waste forms are called high-level radioactive wastes[Note] and have the highest radioactivity level among all the wastes derived from nuclear power generation. Because they contain long-lived nuclides, they require a very long-term control and disposal system.

On the contrary, the US and Sweden have adopted the policy of directly disposing of spent fuels without reprocessing them. In this case, spent fuels themselves are treated as high-level radioactive wastes. Unless otherwise specified, vitrified waste forms from the spent-fuel reprocessing process as well as spent fuels to be directly disposed of are referred to as high-level radioactive wastes in this article.

Representing international consensus, from the viewpoints of technological reliability and waste producers' responsibility, the most appropriate disposal method for high-level radioactive wastes is geological disposal, where the wastes are buried in strata at a depth of several hundred meters below the ground. In addition to geological disposal, various methods have been proposed, including seabed disposal, ice-cap disposal within the Antarctic Circle, and space disposal using rockets. However, seabed disposal and ice-cap disposal are prohibited under international treaty, and cosmic disposal faces problems such as the technological reliability of rocket launching. Therefore, this article will discuss only geological disposal hereinafter.

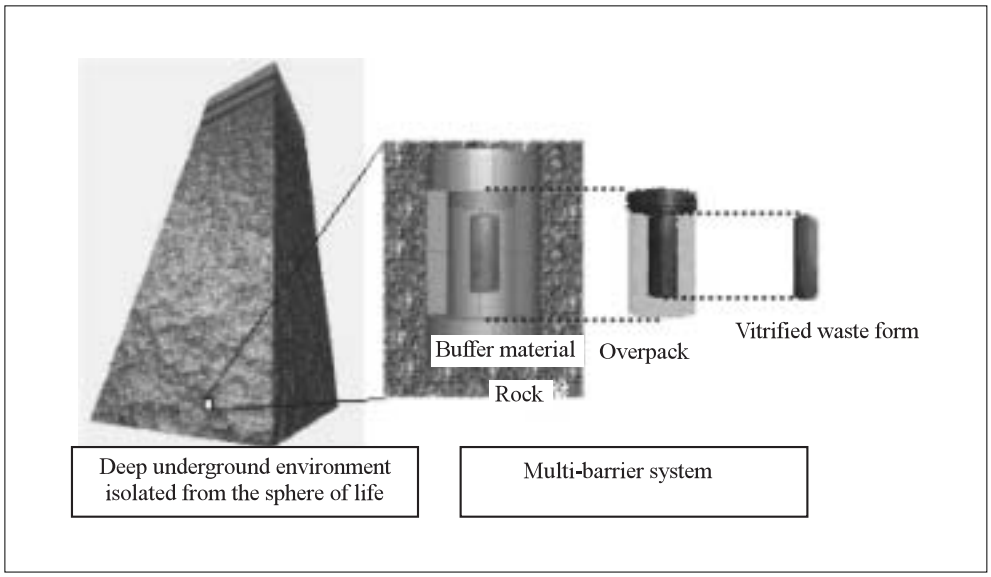
Figure 1 shows a typical model of a geological disposal system as proposed in Japan. In this figure, radioactive nuclides are isolated from the sphere of life by: a vitrified form; a stainless steel overpack; artificially installed barriers — engineered barriers — such as impermeable buffer materials (ex., bentonite); and the surrounding rocks — natural barriers — having the functions of adsorbing and diffusing

Table 1: Examples of new and spent fuel compositions and spent fuel processing methods

	Fuel Composition (% in weight)		Spent Fuel Processing Method	
	New fuel	Spent fuel	Direct disposal	Reprocessing
Uranium 238	Approx. 97	Approx. 95	Geological disposal	Recovery and reuse for nuclear fuel
Uranium 235	Approx. 3	Approx. 1		
Plutonium	0	Approx. 1		
Fission products and actinides	0	Approx. 3		Vitrification and geological disposal

Note: In the strict definition, "high-level radioactive wastes" include not only vitrified waste forms, but also the solutions to be vitrified. "Specified radioactive waste" as used in the "Law on Final Disposal of Specified Radioactive Waste" means vitrified wastes.

Figure 1: Model of a geological disposal system [2]



radioactive nuclides (namely, a defense-in-depth system). It should be noted that the design of a geological disposal system, like that shown in Figure 1, largely depends on the country's policy, especially whether or not spent fuels are reprocessed.

8.3 Domestic and foreign high-level radioactive waste disposal projects

Table 2 shows the high-level radioactive waste disposal methods used, the implementation bodies, and the scheduled start time of operations in Japan and other countries.

(1) Japan

The total number of vitrified waste forms containing spent fuels produced by the operation of nuclear reactors for power generation was 13,300 before the end of 1999, and is expected to reach about 40,000 by 2020.[4] It should be noted that about 30 vitrified waste forms are produced by one-year's operation of a nuclear power plant having an output of 1 million kW.

In 1999, the Japan Nuclear Cycle Development Institute (JNC) prepared the "H12: Project to Establish the Scientific and Technical Basis for HLW Disposal in Japan — Second Progress Report on Research and Development for the Geological Disposal of HLW in Japan"[5] (hereinafter referred to as the "H12 Report") by compiling the past results of geological disposal researches, and submitting it to the Japan Atomic Energy Commission (JAEC). The Commission reviewed the H12 Report, and concluded that the Report proved the technical reliability of geological disposal and provided the technical bases on which the Commission should select the projected disposal sites and establish safety

Table 2: High-level radioactive waste disposal projects by country [3]

Country	Disposal Option	Implementation Organization	Scheduled Start of Operation
Japan	Vitrification	Nuclear Waste Management Organization of Japan (NUMO)	Within 2033 to 2037
U.S.	Direct disposal	Department of Energy (DOE)	2010
Finland	Direct disposal	POSIVA	2020
Sweden	Direct disposal	Nuclear Fuel and Waste Management Company (SKB)	2015: Preliminary 2023: Normal
France	Vitrification	Agence nationale pour la gestion des Déchesradioactifs (ANDRA)	Not scheduled
Germany	Direct disposal & Vitrification	Federal Radiological Protection Agency (BfS)	Around 2030

standards.[6]

Based on the H12 Report, the "Law on Final Disposal of Specified Radioactive Waste" was enacted in May 2000 (and promulgated in June 2000). This Law provides for the basic framework necessary to implement high-level radioactive waste disposal projects. Under this Law, the Nuclear Waste Management Organization of Japan (NUMO) was established as the implementation organization for HLW disposal projects in October 2000.

The Japanese Government will prepare the safety review guidelines, based on the future results of researches made by JNC and other organizations. The NUMO will undertake works to select the "preliminary survey sites", "detailed investigation sites" and "construction site for the final repository" in turn. The final disposal repository is scheduled to start operation within the period of 2033 to 2037.[7]

(2) The US

Under the amendment of the Nuclear Waste Policy Act in 1987, the Yucca Mountain site adjacent to the Nuclear Weapons Test ground in Nevada was designated as the only repository candidate. The US Department of Energy (DOE) has undertaken design and performance, environmental impact and other assessments of repository facilities to be installed in this site.[8, 9]

Finally in February 2002, DOE Secretary Abraham recommended this site as the repository to President Bush, as described earlier in this article. President Bush then accepted this site, and recommended it to Congress. In Nevada, however, the local people expressed deep-rooted opposition to the repository construction project in the Yucca Mountain site. Early in April, Governor Gwyn filed his disapproval of President Bush's decision with Congress.

To overturn Governor Gwyn's disapproval, the House and the Senate had to vote on this measure within 90 days. On the 8th of May, the House passed the Government's decision by an overwhelming margin of 306 to 117 votes. The Senate will vote in July at the latest. However, the result cannot be forecasted, because the Democratic Party now dominates the Senate, and because Majority Leader Daschle and Floor Leader Read of the Democratic Party are in the forefront of opposition to this project.

If the Government's decision passes the Senate, the DOE will apply for an operation license with the NRC. After the obtainment of the license and the construction of the repository facilities, it is expected that the repository will start operation in 2010 at the earliest. The repository will receive about 77,000 tons of high-level radioactive wastes (of which the greater part is spent fuels from commercial reactors) for about 25 to 30 years after it has started operation. Performance assessment monitoring will continue to be implemented after the reception of HLW has been completed. The repository will be closed in the 2110s. If the Senate rejects the Government's decision, this project will start with a clean slate.

(3) Europe

High-level radioactive disposal projects are making rapid progress especially in Finland and Sweden.

Finland is the only country where the Congress approved a candidate repository site. In May 1999, POSIVA, a private company as the implementation organization, made an application to the Government for the "Decision in Principle" that the Olkiluoto district, about 200 km northwest of Helsinki, is to be selected as the final disposal site. In May 2001, the Finnish Congress approved the "Decision in Principle" after approval by the local assembly and the Government. At this site, POSIVA plans to start underground rock surveys in 2003, and the construction and operation of a repository in 2010 and 2020, respectively.

In Sweden, the implementation organization is SKB, a nuclear fuel and waste management company. In November 2001, the Swedish Government approved the site characterization surveys to be conducted by SKB at 3 points in the country. The local governments in Oskarshamn and Östhammar officially expressed their acceptance of the respective surveys. In April 2002, however, the local government in Tieölp rejected any type of survey to be made there. SKB plans to finally select a repository site by 2007, and start normal operation of the constructed repository by 2023. The project by SKB is

characterized by the two-phase approach in which a full-scale repository is constructed after a 5 to 10% smaller-sized plant has been completed for the purpose of technical demonstration.

In France, ANDRA, a radioactive waste management organization, filed its application with the Government in 1996 to obtain licenses to construct and operate underground research centers at 3 sites. In 2000, construction of an underground research laboratory (URL) started at Bure. However, the Government rejected the projects at the 2 other sites. Following this, ANDRA started to conduct site characterization surveys at 15 granite sites in order to construct the second underground research center. However, these surveys have been halted because of the local people's opposition.

In Germany, an underground environment characterization survey had been conducted at Gorleben in the state of Nieder Sachsen since the 1980s. In 2000, however, an agreement was concluded between the Federal Government and electric power companies for the secession from the nuclear power industry. Thus, it was decided under this agreement that the characterization survey at this site should be suspended for 3 to 10 years to "identify problems regarding the repository concept and safety technologies."

8.4 Various aspects of the high-level radioactive waste disposal problem

As described earlier in this report, there are various issues concerning the high-level radioactive waste disposal problem. This complicatedness in the social aspect of this problem is one of the remarkable characteristics that high-level radioactive waste disposal technologies or, more generally, nuclear power technologies present. This chapter discusses the high-level radioactive waste disposal problem in the 4 aspects shown in Figure 2.

(1) Vital nuclear power generation technology

High-level radioactive wastes are inevitably produced by the operation of nuclear power plants, whether spent fuels are directly disposed of or reprocessed.

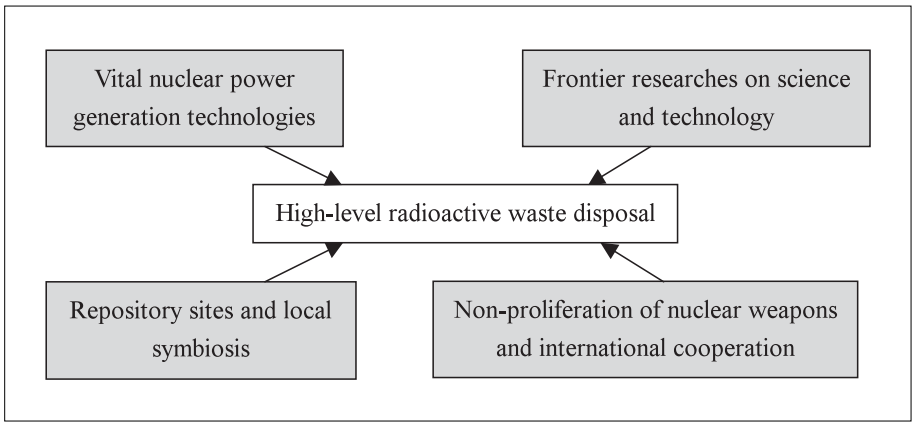
As of the end of 2000, about 430 nuclear power plants were under operation throughout the world, and nuclear power accounted for about 7% of the total primary energy production. Today, however, geological disposal of high-level radioactive wastes has yet to be implemented in any country, and the accumulated wastes are stored in ground facilities. If mankind continues to depend on nuclear power generation systems in this century, it is imperative to establish sophisticated HLW disposal technologies that have high technical reliability and that are accepted by society.

(2) Frontier researches on science and technology

Researches on high-level radioactive waste disposal present remarkable characteristics as a part of the frontier researches that expand and strengthen the scientific and technological bases, and have far-reaching effects on other fields.

These researches include, for example, those on

Figure 2: Aspects of the high-level radioactive waste disposal problem



the structure, characteristics and very long-term changes in the deep geological environment, on the structures of atomic nuclei and the control of nuclear reactions, and on the designs and very long-term performance assessment methods of complex engineered systems involving many natural phenomena and physical and chemical reactions. Furthermore, much attention is directed to research and development projects using the most advanced beam science, including those for nuclear transformation technology using an accelerator. The next chapter will describe these researches in more detail.

(3) Repository sites and local symbiosis

Today, the repository site problem constitutes a major barrier to the implementation of high-level radioactive waste disposal projects. In many countries, the site selection processes for geological disposal or research facilities have faced opposition campaigns organized by the local governments and residents in the vicinities of candidate sites, as described in the previous chapter.

One of the recent striking moves regarding the problem of nuclear facility sites was the inhabitants' referendum adopted in the municipalities concerned. In Japan, inhabitants' referendum has been performed on the construction of a nuclear power plant (at Maki-cho in the prefecture of Niigata in 1996), the introduction of a plutonium thermal utilization system (at Kariwa village in the prefecture of Niigata in 2001) and the invitation of a nuclear power plant (at Miyama-cho in the prefecture of Mie in 2001), and the majority of the inhabitants voted against the respective projects.

For not only nuclear facilities, but also waste disposal facilities, dangerous matter handling facilities, military bases, etc., the site selection processes have encountered local residents' oppositions in the vicinities of the facilities. In some aspects, it may not always be appropriate to generalize the site problem of nuclear facilities into those of other facilities. However, efforts made toward solving the site problem faced by the nuclear power industry will probably provide valuable information necessary to build up a new social system in the 21st century, where science and technology will most likely continue to play important roles. These efforts will be further discussed in the chapter following the next.

(4) Non-proliferation of nuclear weapons and international cooperation

The problem of high-level radioactive wastes is related to nuclear substances management and nuclear weapons non-proliferation, and, as such, is delicate from the viewpoint of international politics. In countries such as Japan and France that adopted the policy line of recovering plutonium from spent fuels, there may be a low risk of nuclear weapons proliferation arising from high-level radioactive wastes themselves. However, these countries are required to establish a strict management system for the recovered amount of plutonium.

In countries such as the U.S. that adopted the direct geological disposal of spent fuels as high-level radioactive wastes in which plutonium remains, it is necessary to consider the risk of nuclear weapons proliferation due to theft or some other illegality during the period from the storage of spent fuels or wastes in ground facilities through the disposal and storage of wastes in the geological environment.

Furthermore, high-level radioactive wastes will be produced by the disposal of plutonium recovered from American and Russian surplus nuclear weapons as the nuclear weapons reduction process makes progress. The plutonium recovered from surplus nuclear weapons has a higher content of fissile plutonium, and, consequently, a higher risk of nuclear weapons proliferation than that in spent fuels recovered from commercial reactors. Especially, there is international concern about the management and disposal of plutonium recovered from Russian surplus nuclear weapons. At present, the Japan Nuclear Cycle Development Institute (JNC) is working with Russia to implement a joint disposal project for plutonium from surplus nuclear weapons by using the Russian breeder BN600.[10] In addition, international joint storage and disposal initiatives for radioactive wastes are being discussed in international conferences. However, it is more important for each country to make efforts in domestically disposing of radioactive

wastes.[11]

8.5 Researches on geological disposal as a part of frontier researches on science and technology

As described in the previous chapter, many researches on geological disposal of high-level radioactive wastes are conducted as a part of the frontier researches that contribute to expanding and strengthening the scientific and technological bases. This chapter will discuss researches on the deep geological environment, nuclear transformation and control, and the coupled process system as some examples of frontier researches.

(1) Researches on the deep geological environment

Knowledge of the deep geological environment is the base on which a geological disposal system is built up from. However, the deep geological environment is unknown to mankind, as the deep sea and space are. Researches on the structure and environmental characteristics of the deep geological environment, as well as the flow of underground water, the influences of natural phenomena, etc., in this environment, are interesting as a part of the frontier researches.

The Japan Nuclear Cycle Development Institute (JNC) is implementing an underground research laboratory (URL) project (at Mizunami in the prefecture of Gifu) and the Horonobe URL project (at Horonobe in Hokkaido) targeting crystalline rocks and sedimentary rocks, respectively.[12] In these projects, various researches, for example, on the characterization of rocks and underground water, will be conducted in the exploratory drifts excavated at the depths of 500 to 1,000 m below the ground. It is expected that these underground research facilities will play the roles as places not only for the development of basic technologies for high-level radioactive waste disposal, but also for scientific exploration of the deep geological environment. The Nuclear Long-term Program[7] also states that the underground research facilities will be "constructed as open research places that can contribute to scientific researches on the deep underground environment in our country."

In the Horonobe URL project, one of the research themes is "Researches Using Underground Spaces." The JNC has a plan to invite local governments, external research organizations, companies, etc., to participate in this project, and to provide these underground research facilities for the participants to conduct tests and researches by using underground spaces.[13] Most of the underground spaces now used are located in relatively shallow regions at the depth of about 50 meters below the ground, and it is estimated that there will be various needs for using these underground spaces. However, the JNC's plan is regarded as a unique attempt full of visions.

(2) Researches on nuclear transformation and control

Today, various industries are based on the atom- or electron-level reaction control technology. However, there is insufficient basic data even on the structures and reaction characteristics of atomic nuclei. Therefore, the utilization of nuclear reactions is limited to the nuclear power generation technologies and some radiation utilization technologies. In this sense, the world of atomic nuclei is unknown to mankind. Therefore, basic researches on atomic nuclei and the development of technologies using atomic nuclei have the potentiality of providing benefits to mankind.

The OMEGA (Options for Making Extra Gains from Actinides and Fission Products) project — a research project in which long-life nuclides are separated from high-level radioactive wastes and transformed into short-life or stable nuclides by using accelerators or nuclear reactors — was implemented in the 1990s. Thanks to the separation and transformation processes, the required period for the radioactivity levels of high-level radioactive wastes to become almost equal to that of uranium ore decreased from several tens to hundreds of thousands of years down to several hundred years.

Research on the nuclear separation and transformation processes is one of the research themes for the High-Intensity Proton Accelerator Project[14] jointly implemented by the Japan Atomic Energy Research Institute (JAERI) and the

Table 3: Main research themes for the high-intensity proton accelerator project [15]

Researches on matter and material sciences	• Development of new materials • Technological innovations and the creation of new industries • Explication of superconductivity at high temperatures
Researches on life science	• DNA decoding • Explication of genetic mechanisms • Analysis of protein structures • Development of new drugs and foods
Physical researches on atomic nuclei and elementary particles	• Explication of the mysterious birth of the cosmos • Researches on elementary particles as the smallest units of the cosmos • Explication of star formation processes • Creation of unknown new elements
Research on nuclear transformation	• Researches on radioactive waste reduction technologies

High-Energy Accelerator Research Institute (HEARI). Table 3 indicates the main research themes for this project.

In this project, the world's highest-level high-intensity proton accelerator facility will be constructed in the Tokai Research Center of the JAERI. This accelerator will produce a proton nearly at the speed of light. If the proton collides against a target nucleus, spallation will occur producing secondary grains such as neutrons, mesons, muons and neutrinos. The secondary grains will be used for a wide range of researches not only on the micro world made of biological molecules, atoms, elementary particles, etc., but also on the macro world including space and energy.

The "research on nuclear transformation technology," one of research areas in this project, will use the concept that spallation neutrons are radiated on long-life radioactive nuclides to transform them into short-life or stable nuclides. For this research, a plan has been set to start the construction of an experimental facility in the 2005 fiscal year. It is expected that this research will make great contributions not only to reducing the amount of high-level radioactive wastes, but also towards establishing the bases of nuclear transformation and control technologies.

(3) Researches on the coupled process System

The coupled process system is defined as a system that comprises of plural processes having influences on each other, and in which all the processes must be analyzed at the same time. This system has substantial properties specific to a complex system. Experimental researches on the coupled process system have limitations, because they must use many parameters having a high non-linearity. Researches have been conducted by digital simulation mainly on a fluid — structure or electromagnetic field — structure coupled process system. However, there are only a few research cases on coupled process systems comprising of three or more elements, because of the theoretical difficulty as well as restrictions on computer resources.

On the other hand, various coupled phenomena may occur in a geological disposal system, and it is necessary to analyze their behaviors for a very long period. To evaluate, for example, the deterioration rate of a waste package or the migration velocity of a radioactive nuclide in an engineered barrier system, it is necessary to simultaneously consider the thermal, hydrogeological, mechanical and chemical processes that have influences on each other in the geological disposal system as they are making progress. Literature 8 also points out that it is necessary to consider various events occurring in the drift of a repository, including chemical reactions, temperature variations, the alteration and corrosion of artificial materials, the pH of cement raised up by its partial dissolution, the changes of oxidation-reduction atmosphere and the associated production of colloid, in-crack minerals and zeolite, etc.

The Japan Nuclear Cycle Development Institute (JNC) has developed a model necessary to process the behaviors of a buried and re-submerged engineered barrier system as the coupled process of thermal migration, moisture migration and mechanical behaviors. In the future, JNC plans to promote the development of a heat-water-stress-

chemical reaction coupled process model by adding material migration and geochemical models to the first.[16]

Coupled phenomena may occur in various engineered systems, as the sodium leakage accident that occurred in the prototype fast breeder "Monju" in 1995 was caused by the coupled structure — fluid vibrations of a thermometer sheath and a coolant of sodium (hydrodynamic vibrations). It is expected that researches on high-level radioactive waste disposal will make great contributions to explicating the mechanism of coupled processes and developing effective system performance assessment methods and tools.

8.6 Toward solving repository site problems

The problem of high-level radioactive waste disposal has a variety of social aspects, as repeatedly described above. Today, the most important aspect is the site problem. This chapter focuses on this problem.

Site selection for nuclear facilities has had an increasing tendency of facing difficulties since the latter half of the 1980s. Researchers not only in the field of atomic energy, but also in the other fields such as administrative science, politics, socio-psychology and social information science have conducted a number of researches. Many of the researches conducted in recent years pointed out that it was important to disclose information to the public, ensure transparency, and involve citizens in the policy-making processes (public involvement).[17]

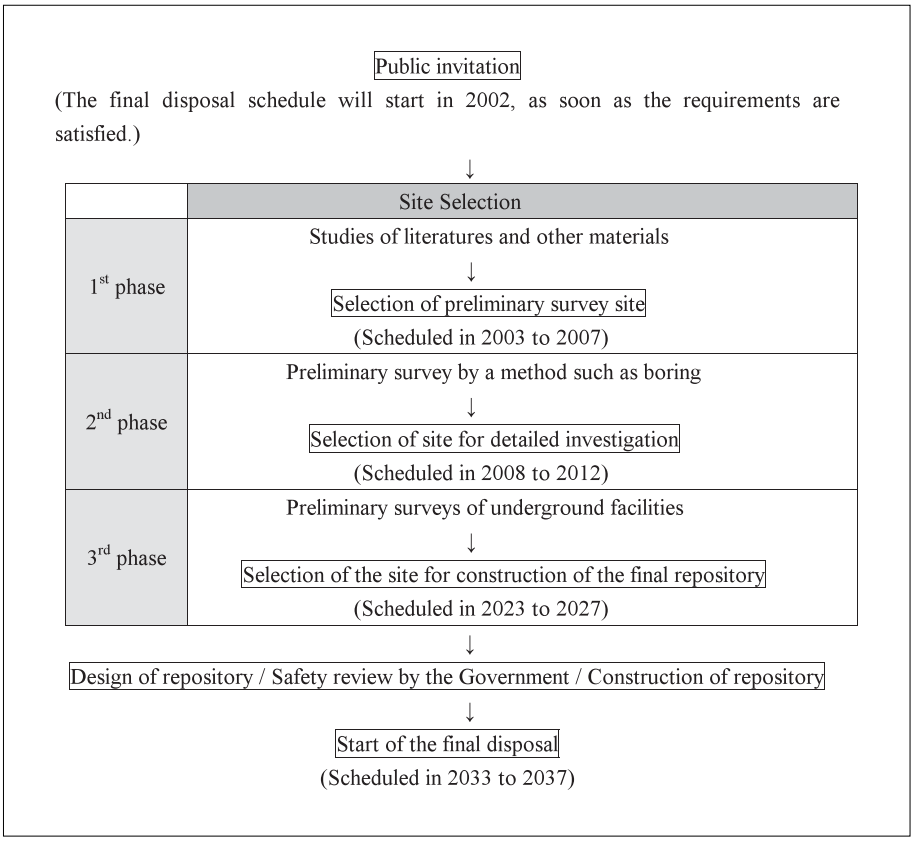
In recent years, the Japanese Government and nuclear power interests have made considerable efforts in promoting the disclosure of information and enhancing transparency. The 2000 Nuclear Long-term Program[7] also specifies: "all nuclear information should be disclosed to the public in principle, except that about nuclear material protection and others." In addition, information about discussions made on the national energy policy in organizations such as the General Science and Technology Council, the Atomic Energy Commission, the Nuclear Safety Commission and the Advisory Committee for Energy is now opened to the public, and the related materials such as proceedings are available on the Internet. Furthermore, the ministries and agencies as well as enterprises are making efforts to provide general nuclear information on their home pages and through other media.[18]

In regard to public involvement, a recent striking move is the collection of public comments. The collection of public comments on draft reports and other documents issued by the ministries and agencies as well as commissions and committees has been generalized since the Cabinet council set the "Public Commenting Procedure" in 1999. There has been an increasing number of cases where the representatives of consumer groups and NGOs as well as attorneys-at-law officially participate in the Government's commissions and committees. Inhabitants' referendum also may be considered as the ultimate form of public involvement. However, the legal status, effectiveness, appropriate subjects and method of inhabitants' referendum are still controversial among experts.

In the future, the Nuclear Waste Management Organization of Japan (NUMO) plans to select the "preliminary survey site", "site for detailed investigation" and "site for construction of the final repository" in turn (see Figure 3). The "Basic Policy for Final Disposal of Designated Radioactive Waste" decided by the Cabinet council in September 29, 2000 states that "it is imperative to obtain the related residents' understanding and cooperation in order to select the preliminary survey and other sites, and, to do so, it is necessary to thoroughly disclose relevant information to the public and ensure transparency." The Basic Policy for Final Disposal also specifies that it is necessary to diversify access to information, provide the requested information honestly, and make efforts to provide correct and understandable information.

The NUMO is also required: to prepare and inspect reports that contain the results of surveys, the justifications of selections and assessments, etc.; to organize briefings in the related prefectures including Tokyo the capital and Hokkaido; and to provide the public with opportunities to submit their comments on the reports. The NUMO plans to prepare a summary

Figure 3: Schedule of Works for Starting the Final Disposal [20]



of the submitted comments, send the copies of the summary, together with its own views, to the governors of the related prefectures and the heads of the related municipalities, and select the final preliminary survey site while considering the public's comments on the reports.[19]

As described above, it can be said that the environment for the disclosure of information and public involvement has been considerably established, though this is only one of the requirements to solve the site problem. The reasons why people are opposed to the selection of nuclear facility sites in their neighborhoods are entangled with complicated factors such as doubts about the safety of nuclear facilities, the lack of people's confidence in the related companies and nuclear power interests, and the political environment of the municipalities concerned. Furthermore, many have long pointed out the so-called NIMBY (Not in My Backyard) attitude where people resist the construction of any dangerous facility in the vicinity of their houses, though they recognize the necessity for such facility. However, it can be considered that this attitude is natural from the viewpoint of human feelings. How to coordinate individual and public interests in sites for worrisome facilities is a problem related to the foundation of a democratic society. In the future, it is important to make efforts in solving this problem.

8.7 Conclusion

This report has described the domestic and foreign trends of high-level radioactive waste disposal projects, reviewed the technical and social aspects of the problem, and discussed not only the possibility of conducting researches on high-level radioactive waste disposal as a part of the frontier researches that expand and strengthen the science and technology bases, but also efforts made in solving the site problem.

Repositories for high-level radioactive wastes are engineered systems by nature. However, people have a great interest in these repositories, and discussions have been made on these repositories from various viewpoints such as politics, laws, society, nuclear weapons non-proliferation, international relations, environmental harmony, and environmental ethics. The specifications and safety standards of these repositories cannot be decided only on the theoretical aspects. Finally,

only a solution that is elaborated through discussions and modified through the different stages of the democratic decision-making process will be recognized by the public and validated.

In Japan, the first repository for high-level radioactive wastes is scheduled to start operation within the period of 2033 to 2037. To maintain the vitality and technical potentiality in the field of research and development related to this repository up to the scheduled time, it can be considered effective that active efforts are made in conducting not only researches directly related to this high-level radioactive waste disposal project, but also advanced basic researches making use of the accumulated results of researches and the expected far-reaching effects on the other fields. Some examples are the researches on the deep underground environment, nuclear transformation and control, and the coupled process system, as covered in this article.

The political and social situations involved in energy problems as well as people's awareness of safety and the environment may change with the times. Under these circumstances, it can be expected that the functional and safety requirements for high-level radioactive waste disposal systems will greatly change. To ensure that policies flexibly adaptable to the changing social environment can be implemented, it is essential to allocate research resources to R&D efforts on a variety of disposal options.

In recent years, administrative organs and other organizations have promoted the disclosure of nuclear information. The Government's commissions and committees also have largely collected and added public comments onto their reports and other documents. The representatives of consumer groups and NGOs as well as attorneys-at-law have generally participated in the related commissions and committees. Under these circumstances, it can be said that the conditions for citizens to participate in policy-making processes (public involvement) have been established considerably.

However, site problems have not yet been solved. The NIMBY problem involved in sites for worrisome facilities such as nuclear facilities is related to the fundamental part of a democratic society system. To solve this problem, it is required to adopt an interdisciplinary approach. Today, however, the opportunities for exchange are still limited between researchers in the disciplines such as humanities and social science, and those in the disciplines such as physics and engineering. To attract researchers from various disciplines in order to solve this problem, it is important that the societies in disciplines such as humanities and social science and those in disciplines such as physics and engineering provide interdisciplinary opportunities attractive to each other, take actions such as participation in the societies as qualified moderators, and promote the regular exchange of researchers between the interrelated disciplines.

In any event, it is expected that public arguments will continue to be made on the utilization of nuclear energy. Ultimately, however, the political leaders are required to establish their leadership and communicate adequately with citizens, based on their energy strategies after considering the results of scientific researches, domestic and foreign situations, and so forth.

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9

Trends in Distributed Power Sources

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9.1 Introduction

The energy supply system of Japan has entered a crucial turning point in response to the recent progress in liberalization of the electricity market and the need to reduce greenhouse gases. The Law Concerning the Promotion of the Measures to Cope with Global Warming, which provides an overview of measures to achieve the Kyoto Protocol's target (a 6% reduction in greenhouse-gas emissions), has been revised recently to incorporate measures included in the previous version of the law — i.e., additional measures for promoting energy conservation, new energy sources and the conversion of conventional fuels to other fuels. In the meantime, the extent of the liberalization and applicable systems are currently under review; the Electric Utility Law will also be revised with an eye toward phase-in liberalization. Under these circumstances, distributed power sources are receiving attention as a measure to cut down energy costs. However, achieving reductions in energy costs and creating environmentally efficient systems are indispensable for promoting these power sources, which are expected to become widespread in the future.

This report provides an overview of the circumstances surrounding distributed power sources, turning the spotlight on how much they have been adopted, trends in technological development and specific efforts being made by the government, municipalities, enterprises and the public, while bringing up challenges that need to be addressed.

9.2 Classification of distributed power sources

In general, large-scale centralized power sources distribute electricity through grids. Distributed power sources, on the other hand, refer to small-to-medium-scale local facilities (e.g., diesel

Table 1: Classification of distributed power sources

		Resources to be Used	Output (Energy)
Renewable-energy-based Power Sources	Solar Power Generation	Sunlight	Electricity
	Wind Power Generation	Wind	Electricity
	Small-to-medium-scale Hydro Power Generation	Water	Electricity
	Geothermal Power Generation	Subterranean Heat	Electricity, Heat
Recycled-material-based Power Sources	Biomass Power Generation	Wood Waste, Sludge, etc.	Electricity, Heat
	Waste-based Power Generation	Flammable Waste	Electricity, Heat
On-site Power Sources	Diesel Engines	Heavy Oil, Kerosene etc.	Electricity, Heat
	Gas Engines	City Gas, LPG, etc.	Electricity, Heat
	Gas Turbines	City Gas, Kerosene, etc.	Electricity, Heat
	Fuel Cells	Hydrogen, Oxygen, etc.	Electricity, Heat

engines, gas engines and gas turbines) that supply electricity to local markets. However, there is no clear domestic and international definition of these power sources in terms of generating capacity, types of facilities, etc.

Distributed power sources fall into three categories in terms of the fuel sources they use: 1) renewable-energy-based power sources; 2) recycled-material-based power sources; and 3) on-site power sources (see Table 1).

Renewable-energy-based powers sources make use of natural energy typified by solar and wind power energy. Unlike oil, coal and other fossil fuels, renewable energy sources are unlimited and clean, having less of a load on the environment (CO_2 emissions, etc.). The drawback: their supply capacity tends to fluctuate, being subject to natural conditions.

Recycled-material-based power sources reuse resources and exhaust heat — energy sources that have hitherto been disposed of.

On-site power sources refer to power systems (diesel engines, gas engines, gas turbines, etc.) and fuel cells. Being located near local markets, these power sources involve less transmission loss; they make the most of the associated exhaust heat, a byproduct of power generation.

Meanwhile, patterns of energy being supplied can be categorized into co-generation, where total energy efficiency is improved by utilizing exhaust heat associated with power generation, and mono-generation where only electricity is supplied.

In this report, distributed power sources are considered eco-friendly power sources because they emit less pollutants (nitrogen oxides, sulfur oxides, particulates, etc.) and greenhouse gases (CO_2, etc.). Specifically, eco-friendly power sources include renewable-energy-based power sources (solar power generation, wind power generation, etc.), biomass power generation and co-generation using fuel cells and power systems such as gas turbines and gas engines. The promotion of these distributed power sources will thus contribute to promoting renewable energy and improving the efficiency in energy use.

9.3 Present state of and targets for distributed power sources

Table 2 shows targets for introducing eco-friendly distributed power sources by 2010: solar power generation (4.82 million kW), wind power generation (3.0 million kW), biomass power generation (0.33 million kW) and fuel cells (2.2 million kW).

Table 2: Present state of and targets for distributed power sources

	Installed Capacity in 1999 (Cumulative Total)	Prospects and Targets for 2010	
		Scenario of Maintaining Present Measures	Targets
	Installed Capacity (1,000 kW)	Installed Capacity (1,000 kW)	Installed Capacity (1,000 kW)
Solar Power Generation	20.9	254	482
Wind Power Generation	8.3	78	300
Biomass Power Generation	8.0	16	33
Waste-based Power Generation	90.0	175	417
Fuel Cells	1.2	4	220
Co-generation Systems			
Diesel Engines	203.5	319	—
Gas Turbines	246.1	436	—
Gas Engines	47.8	103	—

Source: "Future Energy Policies," (Jul. 2001) prepared by the Total Supply and Demand Subcommittee of the Advisory Committee on Natural Resources and Energy, and "The Present State of and Prospects for Co-generation," (Jan. 2001) prepared by the 1st New Energy Subcommittee.

The government has been supporting these new energy sources by means of measures such as subsidies and low-interest loans, making up for their higher costs compared with those of conventional energy sources. However, there is a large gap between the scenario of maintaining the present measures and targets — a situation that necessitates further political assistance.

There are quite a few problems to be addressed in promoting distributed power sources: the quality of electricity may deteriorate as a growing number of distributed power sources are connected to grids; the cost of maintaining connections with grids could increase; large-scale wind power plants produce noise and impair landscapes; waste disposal facilities indispensable for operating waste-based power generation could have negative impacts on the environment; and above all, there is a need to convince local residents that distributed power sources are beneficial to their communities.

The installed capacity of co-generation systems such as diesel engines (DE), gas turbines (GT) and gas engines (GE) increased four times more than that of other distributed power sources (renewable-energy-based power sources, recycled-material-based power sources, etc.) in 1999. These co-generation systems and mono-generation systems that produce only electricity are currently the mainstay of distributed power sources.

9.3.1 Present state of co-generation systems

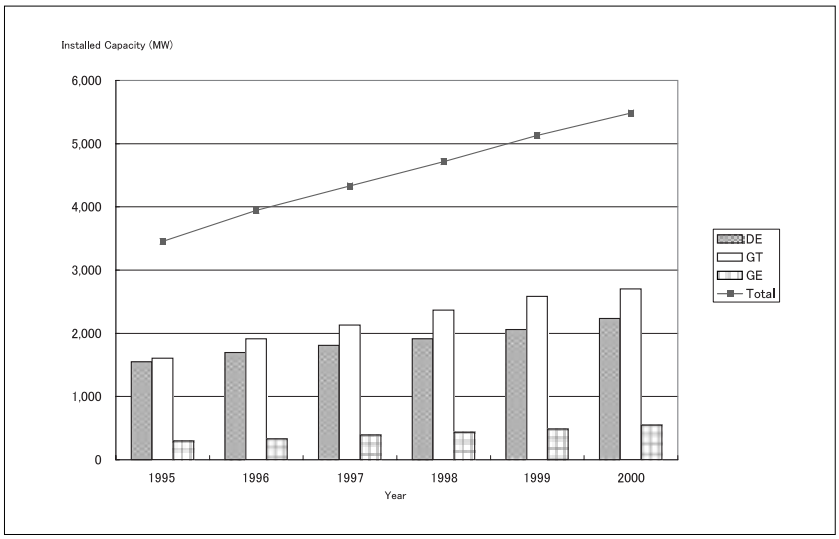
The total installed capacity of co-generation systems stands at 5,485 MW as of fiscal 2000 (GT: 2,702 MW, DE: 2,233 MW and GE: 549 MW), with 3,364 facilities or 5,603 units operating across the country. This amount constitutes some 2% of the total installed capacity of power generation facilities in Japan. Co-generation systems are growing steadily, with a total of 350-400 MW being added annually thanks to governmental subsidies and low-interest loans (see Figure 1).

Large-scale units with the installed capacity of multi-thousand kW command a large share of co-generation systems that have been introduced primarily to industrial facilities such as plants, hospitals and hotels, each of which consumes a large amount of electricity and heat. However, co-generation systems are becoming increasingly smaller thanks to the advance of waste heat recovery technology, improvements in power generation efficiency and lower generation costs; compact systems are becoming widespread among small-scale commercial establishments such as supermarkets and family restaurants that have hitherto been considered inappropriate for these systems.

9.3.2 Present state of independent power generation facilities

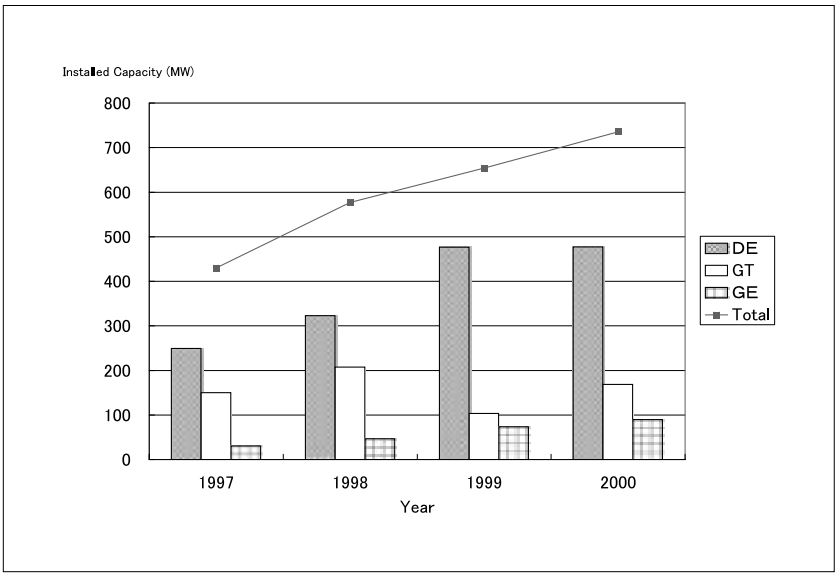
While there are no accurate statistics on the installed capacity of independent power

Figure 1: Co-generation systems: year-by-year total of installed capacity



Source: The Japan Co-generation Center

Figure 2: Independent power generation facilities: year-by-year total of installed capacity



Note: Facilities directly imported from overseas makers are not included.

Source: The Japan Engine Generator Association

generation facilities using DE, GE and GT, the Japan Engine Generator Association surveyed the actual shipments of domestic manufacturers. According to the results of this survey, a total of 2,420 MW had been installed during the period between 1997 and 2000, which corresponds to an increase of some 600 MW a year (see Figure 2). Specifically, DE increased from 249 MW to 477 MW, and GE, from 31 MW to 90 MW. DE registered remarkable growth, commanding a 65% share of the total installed capacity in 2000. Meanwhile, growth of GT varied from year to year, standing at 207 MW in 1998 and 103 MW in 1999. The capacity of GT units usually exceeds 500 kW, which in turn brings about fluctuations in their installed capacity each year.

The revision of the Electric Utility Law, which was carried out in 1995, spurred the promotion of these kinds of distributed power sources — i.e., any third party who carries out private power generation for its clients no longer needs to obtain authorization as long as the job is done within the precinct of the clients' facilities. Thus, full-service systems taking on private power generation for clients are becoming the mainstay of the distributed power source business. Specifically, these systems provide comprehensive services ranging from consulting services to the installation of units, monitoring, the supply of fuel and making arrangements for licensed engineers.

9.4 Trends in technological development of distributed power sources

On-site distributed power sources usually take the form of co-generation, a system in which power balances with heat at the respective locations. If operated with high overall efficiency, the system will outperform conventional systems that use commercial power and auxiliary facilities such as boilers.

According to a survey conducted by the Japan Engine Generator Association, 55.8% of the total installed capacity of distributed power sources comes from co-generation (GT facilities: 92.8%, GE facilities: 88.4% and DE facilities: 39.4%). DE facilities lag behind the other two because: 1) temperatures of their exhaust heat are too low to make efficient use of the heat; and 2) the costs of small-scale mono-generation systems are becoming lower, making the recovery of capital investment easier.

If mono-generation systems that give first priority to cost effectiveness, or co-generation systems that make poor use of exhaust heat become widespread among distributed power sources, they might underperform conventional systems in terms of CO_2 emissions. It is thus important to promote co-generation systems that work with higher overall efficiency. The government is now

in the process of reviewing the standards for evaluating overall efficiency in the framework of the Energy-saving Law, strengthening its subsidies and other supports. In addition to these measures, there is a need to push ahead with R&D of technologies for improving efficiency and making use of low-temperature exhaust heat. Table 3 shows some of these technologies being pursued by NEDO (the New Energy and Industrial Technology Development Organization).

With regard to co-generation systems for internal combustion engines, a project for developing technologies of ceramic gas turbines for 300 kW-cogeneration systems had been carried out during the period between 1988 and 1998 as part of the New Sunshine Program. The project came up with high-strength structural ceramics resistant to high temperatures and corrosion, obviating the need to air-cool the hot sections of the 300 kW-gas turbines, which had been too small to be air-cooled. Through this breakthrough, energy loss in cooling was reduced, NOx in exhaust gas was cut down dramatically, and both durability and serviceability improved substantially — achievements that brought about heat efficiency of 42.1%.

Another project for developing technologies for industrial co-generation systems is underway; it started in 1999 and is slated for completion in 2003. This project aims to verify the reliability of 8,000 kW-hybrid gas turbines (the hot sections of which are made of metals and ceramics) through a series of tests for applicable components and their durability, thereby promoting the

Table 3: Development of technologies for improving efficiency and utilizing low-temperature exhaust heat by NEDO

	Developed Technologies	Description
Technologies for Improving Efficiency	Industrial Co-generation	Develop heat-resistant ceramic components for high-efficiency and low pollution medium-scale (8,000 kW) hybrid gas turbines (the hot sections of which are made of metals and ceramics), and test the reliability and durability of those components, thereby promoting the commercialization of industrial co-generation technology using hybrid gas turbines.
	Flexible Gas Engine Combined Heat and Power System	Develop power generation systems (output: 500-2,000 kW) that can be operated with various ratios between heat and power, using high-efficiency lean-burn gas engines, while aiming at 42.5% for power generation efficiency, and 10-20 points higher for overall efficiency compared with those of conventional gas turbine systems (the ratio between heat and power: 0.5-1.5).
	Next-generation Micro Turbine Trigeneration	Develop high-efficiency tri-generation systems that can supply three forms of energy simultaneously (power, hot water, and cold water) by means of next-generation micro turbines using highly humid air, while aiming at 35% for power generation efficiency, and at least 75% for overall efficiency.
Technologies for Utilizing Low-temperature Exhaust Heat	Hybrid Air Conditioning System Using Low-temperature Exhaust Heat	Conduct R&D on hybrid air conditioning systems using distributed power sources and exhaust heat - i.e., systems made up of absorption refrigerating machines that can be driven by low-temperature (60 degrees centigrade) exhaust heat produced by proton-exchange membrane fuel cells, and compression refrigerating machines that use natural refrigerants such as CO_2.
	Flexible Turbine System Responding to the Wide-ranging Needs for Energy Saving	Recover and make the most of untapped exhaust heat (low-temperature steam, etc.) produced by small-to-medium scale plants. Conduct R&D on turbine systems that enable efficient energy supply in response to the various needs of users - i.e., high-efficiency steam-regenerative / water-sprayed small turbines (compressors), high-efficiency turbines recovering low-quality steam, and flexible turbine systems comprised of load following generators and storage batteries.
	New Thermal Conversion System Driven by Low-temperature Exhaust Heat with the Use of Natural Refrigerants	Conduct R&D on hydraulic compression technology based on new pressure exchange using intermittent flow and helical flow, with an eye toward developing low-cost / compact new thermal conversion systems that can be driven by low-temperature exhaust heat with the use of natural refrigerants.
	Basic Technology of the Moisture and Temperature Controlling Cycle Using High-performance Polymer Adsorbents	Develop high-performance polymer adsorbents, adsorbability of which is twice as much as that of conventional materials (under temperatures between 40 and 80 degrees centigrade). Commercialize adsorbents for desiccant air conditioning systems, etc.
	Ultra-high-performance Activated Carbon and Ultra-compact / High-performance Heat Pumps Using the Activated Carbon	Develop high-performance hydrophilic activated carbon with large adsorptive capacity in order to utilize low-temperature exhaust heat (100 degrees centigrade or lower) produced by distributed power sources, and conduct R&D on high-performance adsorptive heat pumps (AHP) using the activated carbon.

Source: NEDO's website, etc.

commercialization of industrial co-generation technology using hybrid gas turbines, while reducing CO_2 emissions by means of efficient energy use.

Moreover, next-generation micro-turbine trigeneration technology is being developed. Combining a micro-turbine generation system using highly humid air with an absorption refrigerating system using exhaust gas, this particular technology can utilize three forms of energy simultaneously; namely, power, hot water (90 degrees centigrade) and cold water (7 degrees centigrade).

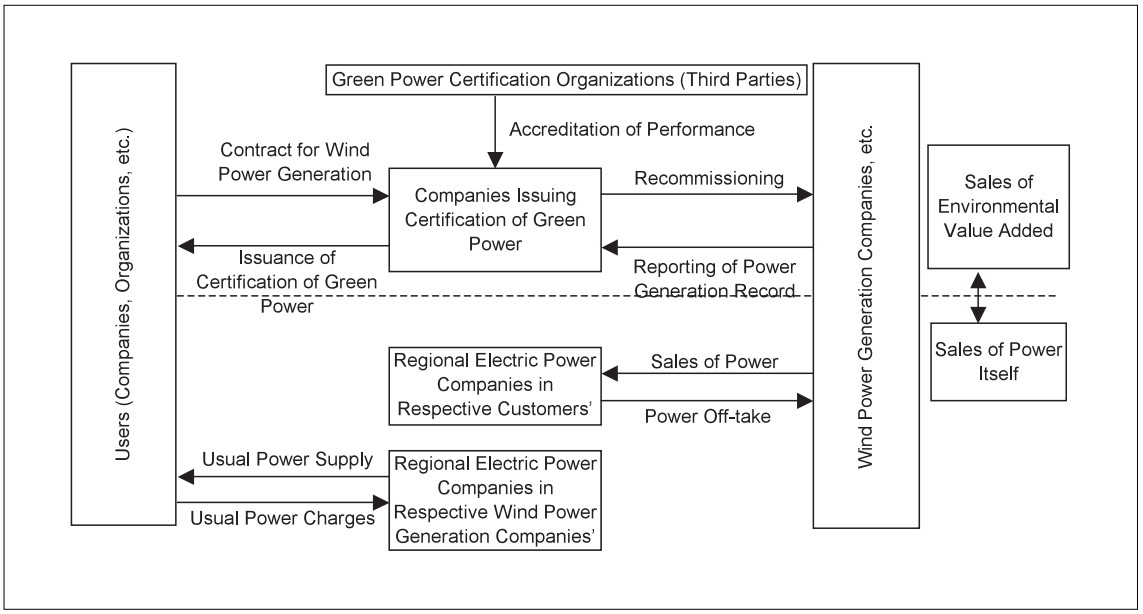
Foreign and domestic companies are also developing and commercializing a variety of technologies relevant to distributed power sources in a bid to further improve efficiency and reduce costs as well as possible impacts on the environment — e.g., micro gas turbines, flexible gas turbines, miller cycle gas engines, and lean-burn gas engines.

9.5 Approaches to the promotion of eco-friendly distributed power sources

9.5.1 Commitments of users, companies and other organizations

Although renewable energy (new energy) has yet to be improved in terms of its cost efficiency and stability in supply, it has the great advantage of being eco-friendly. For this very reason, users, companies and organizations concerned have been promoting this energy by taking part in relevant projects conducted by civil groups, customer groups and research institutes. Electric power companies, meanwhile, have been purchasing surplus electricity from the producers. The awareness among consumers and companies of environmental issues is changing, with most of them committed to voluntarily contributing to the environment. On the other hand, the development of wind power generation is progressing dramatically in specific regions, local economy of which is booming. Certain electric power companies in these regions are thus forced to shoulder the burden of purchasing surplus electricity. With this situation as a backdrop, "The Green Power System" was adopted in 2000 as a measure to promote renewable energy domestically. This system is comprised of two subsystems, each of which responds to the specific needs of users. One is "The Green Power Fund," which is designed to collect contributions from electric power companies and general consumers (by means of electricity bills), thereby providing aid to renewable energy facilities. And the other one is "The Green Power Certification System," which separates the value of power generation into the value of electricity itself and the environmental value added; electric power companies purchase the electricity itself produced

Figure 3: Mechanism of green power certification system



Source: The website of Japan Natural Energy Company Limited

by electric power suppliers, whereas companies or organizations determined to contribute to the environment purchase the portion of the environmental value added (see Figure 3). Any company or organization planning to consume energy can reduce CO_2 emissions by purchasing these certifications.

The number of items of the Green Power Fund stood at 39,294 as of June 2001 (¥500 per item, or ¥100 per item in some areas), and the fund is being appropriated to wind power and solar power generation.

With respect to the Green Power Certification System, 27 companies including Sony (a total of 4.5 million kWh) and Koshigaya City (1 million kWh) have signed contracts, with a growing number of companies and organizations following on. In fact, many environment-conscious municipalities like Koshigaya City are taking part in the system in succession.

9.5.2 Commitments of the government and municipalities

As mentioned earlier, the government is beefing up its support for developing and promoting new-energy technologies through measures such as subsidies and low-interest loans. Pushing forward with these measures, and in accordance with a series of relevant laws and plans, namely the New Energy Law (enforced in 1997), the Law Concerning the Promotion of the Measures to Cope with Global Warming (endorsed in 1998), the Effective Implementation Plan based on the Basic Environment Plan (enforced in 1995) and the Green Purchasing Law (enforced in 2001), the government is expected to take the initiative in introducing new energy (solar power generation devices, etc.) into public facilities such as government offices and schools in order to fulfill its responsibilities as an energy user.

On the other hand, municipalities are developing new regional energy visions in consideration of regional characteristics such as their respective natural environment. Based on these visions, new energy sources such as solar/wind power generation making use of natural advantages are being introduced into government offices and schools, each of which could play an important role in educating local residents. In addition to municipalities, moreover, an increasing number of citizens are installing solar power generation devices in their houses. Municipalities are thus supporting these environment-conscious people financially, offering additional subsidies, and low-interest loans.

9.6 Conclusion

The users of electricity such as companies and public institutions are increasingly making use of the services provided by ESCO (Energy Service Companies); comprehensive energy-saving efforts including the introduction of co-generation systems are progressing as intended.

The suppliers of electricity, meanwhile, will be mandated to purchase a certain amount of renewable energy in line with the RPS (Renewables Portfolio Standard: standards for introducing renewable energy based on certifications) system. With this system in place, the electric power suppliers will have to introduce renewable energy systematically, based on the prospects for supply-demand situations in energy toward 2010.

However, distributed power sources that put a burden on the environment are also becoming widespread in response to the need of users to further reduce energy costs. The liberalization of the electricity market, moreover, will extend the range of choices for these users — e.g., the installation of distributed power sources, competitive bidding for electricity, and respective contracts for electricity.

Under these circumstances, the following three stages are indispensable for promoting eco-friendly distributed power sources:

1. Provide environment-conscious users with subsidies and other supports, thereby encouraging them to introduce distributed power sources that prioritize their principles above cost efficiency.
2. Encourage organizations serving the public interest (government institutions, local public bodies, etc.) to adopt eco-friendly facilities or to choose eco-friendly power sources through competitive bidding, thereby creating the basis for the

environment industry.

3. Promote distributed power sources in the general market.

In order to achieve long-term security of energy supply, the government and the private sector must cooperate with each other in promoting distributed power sources. Japan has just entered the Stage 2 mentioned above. Organizations serving the public interest should therefore take the initiative in selecting and introducing power sources, considering not only reductions in energy costs but also environmental aspects such as reductions in CO_2 emissions, in order to create technological and industrial foundations.

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10

Trends of Disaster Simulation Technologies

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10.1 Introduction

In Japan, 50% of the population live within river flooding areas (floodplains), which accounts for 10% of the land area, and 75% of properties is concentrated within these areas. A great part of a floodplain consists of low-laying flatlands having new and unstable strata. Due to these geographical and geological conditions, occurrences of natural disasters result in fatalities.

To ensure the "security" of the citizens, countermeasures against disasters are vital issues. In the past, a main stream of disaster prevention was to provide countermeasures for checking the occurrences of disasters, which required enormous costs and long-term maintenance of the relevant facilities. Recently, the policy has been shifted to focus on "Damage Reduction," which emphasizes minimizing damages caused by disasters.

In order to materialize this "Damage Reduction," it is necessary to establish a disaster prevention plan supporting evacuation and rescue methods as well as providing the necessary facilities.

On this viewpoint, simulation technology for estimating damages and phenomena may be an effective method for providing fundamental information for such disaster prevention plan.

The development of simulation technology is largely supported by computer technology. Numerical analysis using a supercomputer capable of processing complicated phenomena in a short time exhibits strong abilities in the fields of earthquake analysis, weather forecasting, and so on.

On the other hand, according to the "public-opinion census on disaster prevention and information" conducted by the Prime Minister's Office, 52% of the citizens pointed out that they would like to gain knowledge and understanding of the inundation prediction map, the earthquake damage estimation map and the hazard map. To respond to these social needs, analysis results of the inundation prediction map and the earthquake damage estimation map were recently made public through the Internet. For earthquake damage estimation, in particular, relevant detailed data are published on the Internet to respond to the needs of the residents.

In this report, I will report on the current situation of disaster simulation technology, its recent trend from a viewpoint of the social background, and discuss about the effective methods for using this technology.

10.2 The current situation of technologies effectively using fundamental information

10.2.1 Digital national land information

Digital national land information has been provided by the Geographic Survey Institute, and various kinds of information including land shape, land use, etc., are classified in a mesh form and stored as digital data. This information will be updated every 5 years at the time of the national census, in principle. In the past, information of 100 m to 500 m meshes was used for analyses. For instance, a representative altitude was calculated by averaging several altitude data at different points. With this method, the accuracy of analyses was fairly coarse since detailed land shape could not be captured.

Then, the Geographic Survey Institute provided "Detailed Digital Information" for the Tokyo metropolitan area and the Chubu and Kinki regions, which consists of digital information of 10 m meshes on land use produced by deciphering

aerial photographs. This information is based on the "Housing land use trend survey," which is conducted about every 5 years and whose data are sold publicly on CD-ROMs.

Recently, a new technology has been developed where laser beams are emitted from an aircraft to the ground, and then the time difference of the laser beams reflected from the ground are analyzed to measure land shape, positions and heights of natural features on the earth, while simultaneously acquiring images using a digital camera. This aircraft interlocks with GPS standard stations to calculate the 3-D coordinates of the laser measuring points and the digital image main points. Using this technology, digital information of 2 m meshes can be obtained, and the accuracy of analysis of flood simulations, etc., is expected to improve by leaps and bounds.

10.2.2 Current conditions of the technology of the Geographic Information System (GIS)

The technology of the Geographic Information System (hereinafter referred to as "GIS") was developed in the 1990s, and is now displaying its functions in various fields as increasing the social needs after that.

Promotion of the GIS is included in the IT basic strategy of the Japanese government's "e-Japan strategy," as one of the important issues.

For instance, the administrative organs of the Japanese government have already provided the GIS facilities for use with infrastructures including rivers and sewerages, etc., and the local autonomous bodies also promote the provision of the GIS for facilities under their management or classification of land use, etc.

In the GIS, data can be comprehensively managed together with maps and images, and overlapped with each other. As a result, the system contributes to effective management operations including management of use conditions of facilities and land, etc., by applying diversified processes.

In the case of analyzing the extent of phenomena in the vertical direction, 3-D maps can provide very useful information. For instance, in previous inundation analysis, the speed and depth of running floodwater could be grasped, but the analysis would only indicate their influences on a two dimensional scale. By linking 3-D maps to the analysis, it is possible to grasp the distribution of the speed of running floodwater in its depth direction. With this technology, it is possible to individually estimate the influences of the impact of floodwater on different building structures such as wooden buildings and concrete buildings, etc., or influences on buildings by the way they are used. Through this, it becomes possible to analyze the influences of the respective buildings very accurately and thoroughly, such as damage estimation of underground facilities, influences on the people in hospitals and welfare facilities, etc., requiring support due to disasters.

10.3 Current situation and trends of various kinds of disaster simulation technologies

10.3.1 Outline of disaster simulation technology

Future development of various kinds of disaster simulation technologies are expected to make possible real-time prediction of natural phenomena and disasters by merging the developments of computer hardware and technologies for measurement and observation. It seems that the role of disaster simulation technology in disaster prevention and crisis management will become more and more important in the future. Subjects and contents of analyses of various kinds of disaster simulation are listed below in Table 1.

In the analyses, I set various calculation constants and coefficients in consideration of geographical and geological characteristics, and then verified the adequacy of these assumed values by applying them to phenomena that actually occurred in the past in order to ensure the accuracy of the analyses.

For the damage estimation, I made the necessary analyses as relating the results to the actual phenomena by using the digital national land information as mentioned in the section above.

Table 1: Outline of various disaster simulation analyses

Type of disaster	Phenomena	Major input data	Major output data
Flood	Flood effluences *1	Rainfall distribution in a basin, Topography of a basin, Topography data, Data of soil and vegetation	Fluxes at respective points on a river
	Outer drainage inundation*2	River courses flux, Shapes of broken banks, Topography data of an inundation area	Inundation flux, Depth of inundation, Inundation area, Speed of running water, Time to arrival
	Inner drainage inundation*3	Topography of a basin, Dimensions of draining facilities, River courses flux	Ditto
Landslide disasters	Avalanches of earth and rocks	Rainfall, Topography, Soil data, Vegetation, River courses flux, Speed of running water, Shear stress	Amount of escaped soil, Running speed and thickness of accumulation, Distance to arrival
	Landslips	Rainfall, Topography, Soil data, Vegetation, Pore water pressure	Slipping form, Amount of corrupted soil and distance to arrival
Volcanic eruptions	Steam of lava	Atmosphere data, Topography, Soil	Thickness of accumulation, Range of flow, Running speed
	Cinder and volcanic bombs	Mountain configuration	Distance to arrival, Speed, Impact
	Falling pyroclastic rocks	Mountain configuration, Atmosphere data	Distance to arrival, Thickness of accumulation
	Volcanic mud flow	Rainfall, Accumulated amount of volcanic ash, Topography	Range of flow, Thickness of accumulation, Running speed
	Pyroclastic flow	Mountain configuration, Atmosphere data, Topography	Range of arrival, Speed, Temperature, Thickness of accumulation
Earthquake	Strong ground motion	Seismic center, Intensity, Soil, Ground configuration	Acceleration distribution, Seismic intensity distribution, Liquefied soil distribution
Tsunami	Overtopping wave	Land topography, Height, Lasting time, Amount of overtopping wave	Depth of inundation, Distance to arrival, Hydrodynamics
Storm surge	Overtopping wave inundation	Topography of a basin, Flux in a river, Sea topography, Meteorological tide level data	Depth of inundation, Inundation flux, Time to arrival, Inundation range

*1 A phenomenon where rainfall flows from a basin to a river.
*2 A phenomenon where river water floods into a town due to the breakage of a bank.
*3 A phenomenon where rainfall floods into a town from sewerages in the case of a localized torrential downpour, etc.

Source: Author's own compilation

10.3. 2 Trends of disaster simulation technologies

In this section, I briefly explain about the current situation of various kinds of disaster simulation technologies and the technological development activities for solving the current issues. In Table 2, important issues on floods, landslide disasters, volcanic eruptions, earthquakes, tsunami and storm surge are summarized respectively.

10.4 Examples of recent simulation technologies

10.4.1 The inner drainage inundation simulation of the Tsurumi River

In the past, it was difficult to analyze the amount of rainwater in drainage networks in the case of inner drainage inundation in a basin having sewerages, etc. In 2000, a high-accuracy version of software for inundation analysis in urban areas (MOUSE) was developed by the Danish Hydraulic Institute. As a result, it is currently possible to create an inner drainage inundation simulation using a solid analyzing method by entering the amount of the effluences of the "quasi linear effluences calculation model,"*1 an analysis of effluences in a basin of a river, into the software program as a boundary condition. This simulation has the following features.

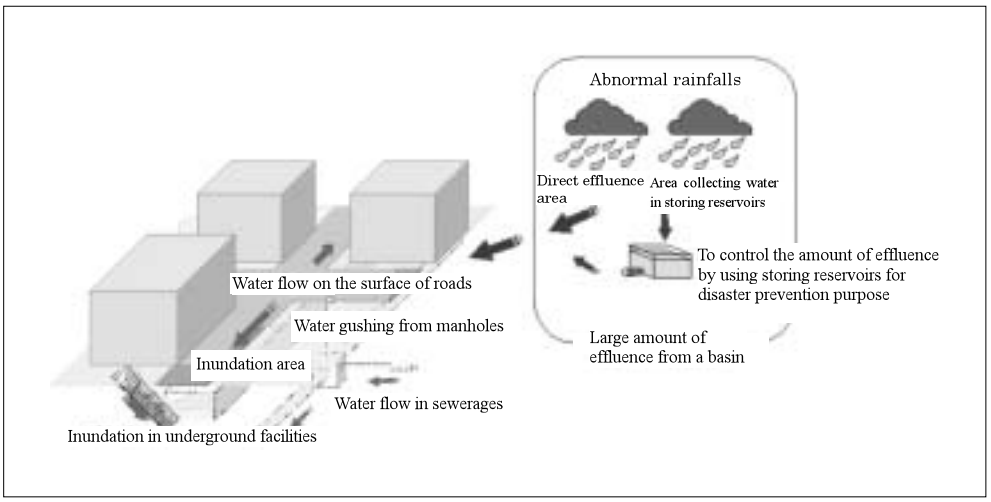
— You can grasp data on the amount of flowing water and water levels at an arbitrary point in a time series.
— You can incorporate information about drainage networks (including loop lines),

Table 2: Trends of various disaster simulation technologies

Type of disaster	Current technologies	Required development of technologies
Flood	— The effluence amount of inundation water, the running speed, the range of inundation, the depth of flood water and the inundation range can be displayed in a time series.	— To firmly materialize an inner drainage inundation simulation having effluence from sewerages, operating conditions of draining pumps and the effluence amount from a basin (Partially available).
Landslide disasters	— The shear stress of soil including large pebbles and scours on mountainsides can be estimated. — The Finite Element Method is used for landslips in the case of uneven ground conditions.	— There is an issue of accuracy in application of a coefficient of friction among soil particles in avalanche phenomena. — To develop a technology applying the Finite Element Method to corruption phenomena of rock beds, which are mainly cracks and dislocations.
Volcanic eruptions	— The respective phenomena associated with eruptions (Figure 1) can be analyzed numerically.	— To develop numerical analyzing methods for estimating transitions of eruptions and the relevant damages. — It is a significant issue to estimate the behavior of magma, which is a kind of multi-phase fluid.
Earthquake	— Strong ground motion simulation estimating shocks on the ground surface can be analyzed with fairly high accuracy. — Dynamic behaviors of buildings are practically analyzed with the Finite Element Method.	— To develop a numerical analyzing method for seismic wave motion propagation, accurately reflecting complex underground constructions. — To develop analyzing methods estimating the occurrence and size of liquefied soil. — To develop analyzing methods estimating the breaking processes of dislocations, and the forming processes of seismic dislocation on the ground surface that is caused by the dislocation.
Tsunami	— The final changing amount on the seabed can be calculated with a dislocation model assuming a rectangle slipping surface. — The tsunami propagation analysis can calculate the water level at every moment with the propagation equation.	— To develop a model of the energy loss relating to wave edge conditions for the retroaction analysis to the land and coarseness on the land. — To develop technologies for instantly making a numerical analysis with input of detailed data of topography of the seabed and observed values in the distant offing.
Storm surge	— As a result of the fact that accumulation of topography data on the seabed and tide levels observation data have expanded drastically, the wave calculation analysis is in practical use.	— To develop a numerical prediction method using a model solidly estimating tidal waves with the assumed size and course of a typhoon and inundation.

Source: Author's own compilation

Figure 1: Analyzing concept



Source: Documents of the Ministry of Land, Infrastructure and Transport

weirs and pumping facilities, etc.

— You can simultaneously analyze flows in drainages and inundation conditions of roads, etc., and, subsequently, you can grasp the conditions of water entering into underground facilities.

— You can provide various types of presentation using graphs and animation of the analysis results.

By using this simulation technology, Ministry of Land, Infrastructure and Transport conducted inner drainage inundation analysis of a lowland area of Tsurumi River (an area where forced draining with pumping facilities are required) in the case of a localized torrential downpour as follows.

The outlines of the analysis are as follows. They were able to make the following estimations, which were impossible in ordinary systems.

— As shown in Figure 3, the inundation will spread to almost all of the lowland areas, and the depth of inundation will be 2.0 m or more in some spots.

— As shown in Figure 4, the depth of inundation will reach 60 cm within about 40 minutes. Quick evacuation is required.

— In the area around Shin-Yokohama, all 18 underground facilities will be flooded.

Figure 2: Conditions in the basin and the subject rainfall

Area of the basin:	709 ha
Ratio of urban area:	About 99%
Underground mall:	1
Underground room:	18
Draining method:	By pumping facilities
Capacity of water storage for disaster prevention:	22,758 m^3
Subject rainfall	88 mm/hr

Source: Documents of the Ministry of Land, Infrastructure and Transport

Reference: Risks of underground rooms in the case of inundation

In the case of inner drainage inundation, underground facilities can be flooded within a short time. Some people were either killed or injured due to inundation in underground rooms in Fukuoka Prefecture, etc. From these facts, risks of underground facilities are pointed out.

They introduce an analysis based on a verification experiment about the risks of underground rooms in the case of inundation as follows.

Figure 3: Inundation situation

Source: Documents of the Ministry of Land, Infrastructure and Transport

Figure 4: Changes of inundation conditions around Shin-Yokohama

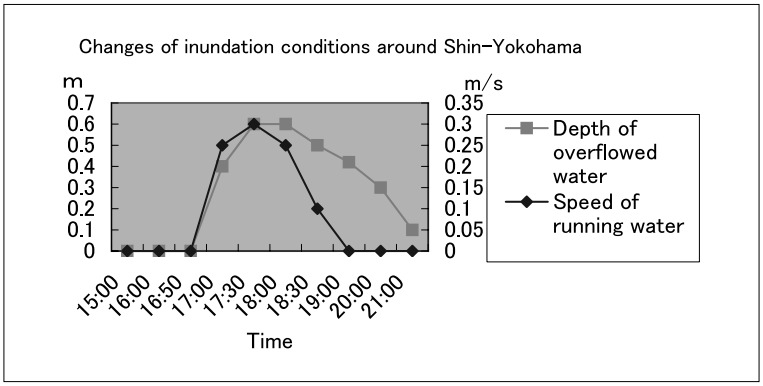
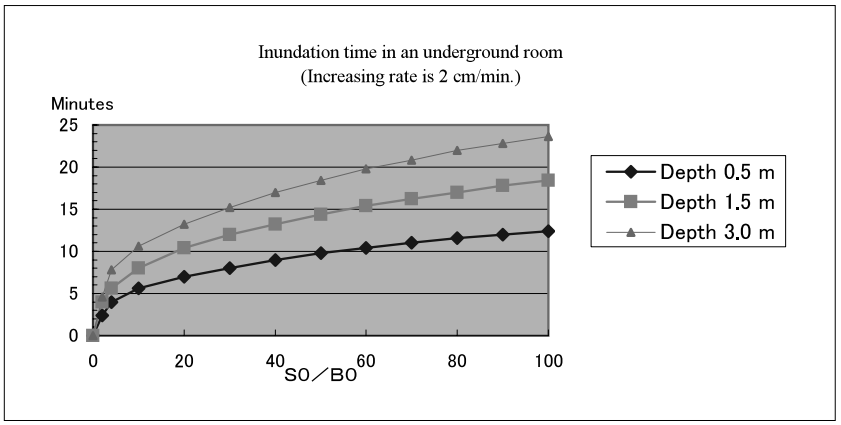


Figure 5: Relations of inundation in an underground room



Source: Documents produced by Nihon Kenchiku Bosai Kyokai

1) Water will enter into a room very quickly

If the flood increasing ratio at a town is 0.02 m/min. and there is no gap at the entrance, the relation between the depth of the flood in an underground room, and the ratio of the area of the room and the width of the entrance (S0/B0) will be as shown in Figure 5. For instance, if a room has an area of 10 m2 and its entrance width is 1 m, the water level height will reach 1.5 m within about 8 minutes.

2) A door will not open immediately after flooding

Many underground rooms have doors at their entrances. In the case of inundation, water first accumulates in the entrance room in front of the door. In this case, the door's operation will be as follows.

(1) In the case of a door that opens out

In the condition that water accumulates in an entrance room, you need to use force to push the door open. This required force is estimated to be 10 to 20 kgf for adults, and at least 4 to 6 kgf for aged people and children. If the necessary force is assumed to be 15 kgf, the corresponding water level will be around 26 cm. This means that the door of the above-mentioned underground room (1) will not open after only about 4 minutes from the start of flooding.

(2) In the case of a door that opens in

You need to use a large amount of force to turn the doorknob, due to the pressure of the water accumulating in the entrance room. This force is estimated to be 20 to 30 kgf-cm for women. Assuming that force of 50 kgf of water pressure is applied to the door, the corresponding water level will be 47 cm, i.e., you cannot open the door after around 5 minutes.

3) Electric systems will fail due to the inundation, and all types of electric equipment will stop.

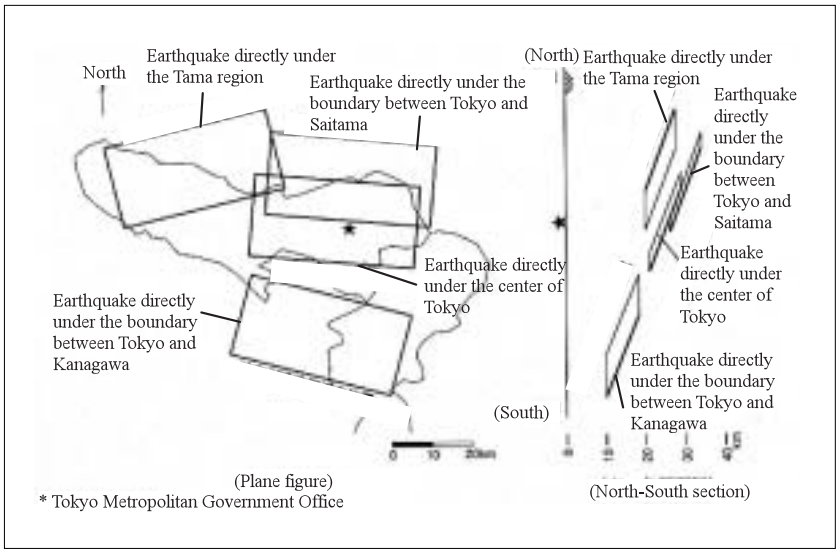
If an underground room is flooded, a series of power failure processes will take place, i.e., the deterioration of electric isolations — short circuits or leakage of electricity — cut of electric power by breakers — power failure, and all functions will be out of order. Even in the case of an emergency lighting facility, its functions may probably stop if the equipment and wiring are flooded.

4) It is very dangerous to walk up a stairway against flowing water. The force of water coming from the upper stairs will become stronger and stronger.

10.4.2 Analysis simulation for Tokyo of an earthquake directly under the south Kanto region

This analysis is based on the assumption of a plate-boundary type earthquake along the surface of the Philippine Sea plate, of which imminence has been pointed out in the Central Disaster Prevention Conference of the Cabinet Office and the largest amount of damage is expected from this disaster. In this analysis, they conducted seismic intensity analysis and liquefied soil distribution on the basis of the latest strong ground motion numerical analysis, and reflected

Figure 6: Estimations of seismic centers of an earthquake directly under the south Kanto region



Source: Documents provided by the Tokyo Metropolitan Government

detailed data on the actual damage in the 1995 Hyogoken-Nanbu (Kobe) Earthquake to this analysis. In estimating the damage, they analyzed the cause and effect relationships for the respective damaged items based on the damage data of the 1995 Hyogoken-Nanbu (Kobe) Earthquake and so on; provided a damage estimation formula; and then calculated the estimated amount of damages by applying the digital national land information to this formula. They produced and released this analysis in 2001, and used data of the digital national land information in 1998.

The assumptions of the earthquake and the damages are as follows.

The seismic center:

They estimated for 4 cases: directly under the center of Tokyo; directly under the Tama region; on the boundary between Tokyo and Kanagawa; and on the boundary between Tokyo and Saitama.

Intensity: Magnitude (M) 7.2

Depth of the seismic center:

20 to 30 km underground

Area of the seismic center(Area of the rock bed destroyed):

Length around 40 km x Width around 20 km

Time and weather conditions:

At 18:00 on on a weekday in winter, clear, wind velocity of 6 m/s

- The estimated items are as follows.

1) The shock of the earthquake, the liquefied soil, damages caused by tsunami and flood damages due to the earthquake
2) Damages to buildings, etc.
3) Fires
4) Damages to railways and roads, etc.
5) Damages to lifelines
6) Human casualties
7) Damages to social life (food, medical services, etc.)

— In calculating the estimated damage, they used the maximum acceleration for the ground surface for buildings, the ground surface velocity for lifelines, and the seismic intensity for railways/roads as the respective indexes.

Outline of the results of the damage estimation analysis

— Since the seismic center dislocation of the assumed earthquake was set to a deep point of 20 to 30 km underground, the maximum seismic intensities of the 4 cases are all around the 6th plus degree.

— Since the sinking angle of the Philippine Sea plate directly under Tokyo is nearly flat, the dislocation motion of the assumed earthquake also takes place in nearly a flat position. Consequently, the shock of the earthquake will spread horizontally, and, as a

Table 3: Results of damage estimation

Ward	Presumed population during the evening time	Area Km^2	Ration of seismic intensity relative to area (%)			Ratio of possibility of liquefied soil relative to area (%)		
			5th Plus	6th minus	6th Plus	A	B	Non
Chiyoda	837,243	11.64	34.1	65.9	0.0	27.3	20.5	43.2
Koto	476,981	39.2	0.0	37.5	62.5	65.1	33.9	0.0
Ota	706,786	59.46	0.0	70.0	30.0	78.6	0.0	21.4
Suginami	413,387	34.02	59.9	40.1	0.0	0.0	0.0	100
Entire center of Tokyo	11,222,592	616.35	26.6	59.1	14.3	46.4	6.6	45.7
Entire Tokyo Metropolitan	14,404,325	1,776.25	30.0	31.1	5.1	16.8	2.4	80.4

* In the case of Rank A of liquefied soil area, 18% of the mesh area will be liquefied, while Rank B means that 5% of the same will be liquefied

Ward	Ratio of buildings completely destroyed (%)	Ratio of failed lifelines (%)				Lost area Km^2	No. of fatalities	No. of persons seriously and slightly injured	No. people who cannot return home
		Water supply and sewerage	Gas supply	Electricity	Telephone				
Chiyoda	3.3	33	66	16	4	0.00	114	8,868	603,930
Koto	4.4	62	100	15	33	2.63	227	9,689	71,265
Ota	3.1	46	82	27	59	10.76	1,104	11,822	118,967
Suginami	0.8	11	0	29	53	8.69	478	4,962	53,331
Entire center of Tokyo	2.2	31	32	20	30	74.85	6,717	136,825	3,348,023
Entire Tokyo Metropolitan	1.6	27	25	17	27	95.75	7,159	158,032	3,714,134

Source: Author's compilation on the basis of documents of the Tokyo Metropolitan Government

result, the estimated area of damage will spread widely in the Tokyo region, even though it takes place directly under Tokyo.

— It is estimated that there will be numerous damaged buildings, and damages caused by fires will be extensive in areas where many wooden houses are densely built up such as areas along Loop-7 or the Chuo Line of JR, etc.

Table 3 shows estimated damages in some typical wards in Tokyo, in the case of an earthquake directly under the center of Tokyo.

10.5 Conclusion

In this report, I outlined the current situation and the trends of disaster simulation technologies, as well as the trends of fundamental information supporting the analysis technologies. The following is a summary of the items that must be promoted in the future.

1) Construction of a real-time disaster prevention information providing system, etc.

— In terms of crisis management, it is important to construct a system providing short-time rainfall prediction and detailed digital national land information as well as real-time disaster prevention information obtained using the GIS technology.

— In is necessary to promote the elucidation of the mechanisms of earthquakes / dislocations, and establish simulation technologies reproducing and predicting such phenomena.

2) Efforts to be made by local autonomies standing at the forefront

— As a result of the revision of the Flood Prevention Act, the flood inundation prediction map of rivers under the control of the government and prefectures must be

provided and released publicly as a matter of duty. And the coverage of the designated rivers requiring inundation prediction has been expanded to rivers under the control of prefectures. In the future, it will be necessary to provide flood inundation prediction maps and short-time prediction announcements including rainfall prediction for more than 20,000 rivers under the control of prefectures.

— Disasters will have a terrible long-term influence on the economic activities and civil life in urban areas together with the human casualties and damages to buildings. Other than reproduced simulations of natural disasters, development of evacuation, rescue and relief simulations at the time of disasters should be promoted as well.

— Based on disaster simulations, slightly less than 20% of the hazard maps for flood, slightly less than 30% of the same for landslide disasters, and slightly less than 50% of the same for volcanic eruptions are currently provided and publicly available. It is necessary to promote the provision and announcement of further information.

— In providing simulation analyses and hazard maps, it is necessary to have some expert support from people of leaning and experiences, and budgets from the government as well.

3) Expansion of applications

— There is currently no noticeable policy to use disaster prevention simulation other than uses for the hazard map and disaster prevention plans. In the future, simulation must be used effectively in various fields. For instance, risks estimated in the simulation must be actively made public, information based on disaster simulations must be added to "Important items to be explained" stipulated in the Housing Trading Act at the time of purchasing houses, as a matter of duty, and the results of inundation simulations must be reflected in the building standards of underground room constructions.

— The national topographic maps at a scale of 1/25000 are currently used in the fundamental maps for inundation prediction, etc., and inundation prediction map data are displayed in a mesh form of around only 500 m. In the future, the inundation map or the liquefied soil distribution map must be displayed on large-scale information maps such as the residence area map, etc., after utilizing as much as possible the detailed digital national land information and the GIS technology.

Reference

[1] Computational Engineering and Science Vol. 6, No. 3 2001
The Japan Society for Computational Engineering and Science

Glossary

*1 Quasi linear effluences calculation model
This is a model that can estimate the respective changes caused by use of land in a basin, including storage and permeation of rainfall, in addition to the ordinary effluence model simulating effluence conditions of rainfall from a basin to a river.

(Original Japanese version: published in April 2002)

11

Latest Trends in United States Science and Technology Policy
Flash Report on 2002 AAAS Annual Colloquium
Impact of Terrorist Attacks on US Science and Technology Policy and Priority Targets for FY 2003

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11.1 Introduction

On April 11 and 12, 2002, an AAAS (American Association for the Advancement of Science) colloquium, "Science and Technology in a Vulnerable World-Rethinking Our Roles") was held in Washington D.C. The said colloquium is held each spring, this year marking its 27th session, and as a conference on the theme of science and technology policy, it is the largest in the United States.

This year, a total of 500 or more persons participated, including Dr. John H. Marburger, appointed as Presidential Science Advisor in October, 2001; persons connected with the United States Government; researchers and managers from universities, research institutions and R&D companies; policy thinktank analysts; and also persons concerned with science and technology policy in foreign countries. Topics they discussed included 1. the desired state of science and technology policy following the terrorist attacks and 2. trends in the organization of the United States federal R&D budget for FY 2003.

This paper introduces the latest trends in United States science and technology policy, based upon details of discussions at the said colloquium and interview surveys with persons involved.

11.2 Science and technology policy after the terror attacks

11.2.1 Action by academia and bureaucracy

Since the terrorist attacks, the Bush Administration has been working on counter-terrorism measures as the top priority. Quick to respond on behalf of the scientific community was the National Academies[1].

(1) Response of National Academies

On September 20, 2001, National Academies announced to President Bush that it would pool together the resources of the scientific community to cooperate with measures to combat terrorism, as well as[2] set up an internal committee to study ways science can contribute to combating terrorism. Under the joint chairmanship of Harvard professor emeritus Dr. Lewis Branscomb and former National Cancer Institute (NCI) director Dr. Richard Klauser, the said committee is expected to submit a final report to the federal Government in summer, 2002. The committee held its inaugural meeting in September, 2001, and proposed to the federal Government that R&D of counter-terrorism measures be promoted across all agencies and departments.

(2) Establishment of Government Counter-Terror R&D Taskforces

In response to a proposal from the aforementioned Natonal Academies, Advisor Marburger set up five taskforces under the National Science and Technology Council[3] to promote R&D on counter-terrror measures.
Of the five taskforces, four are in charge of the following respective themes:

— Detection and treatment of biological and chemical substances
— Detection and treatment of nuclear substances
— Protection of vital infrastructure
— Research on terrorist psychology based on social science and human engineering

The fifth taskforce makes technical evaluations of counter-terror R&D proposals that each agency and department submits, and compiles them into a database.

Since counter-terror R&D covers many academic areas, it is hoped that construction of said database will avoid program overlaps between departments and agencies, and will contribute to increasing the efficiency of program design by each department and agency.

(3) Interim evaluation of Government Counter-Terror R&D Programs

Since the terrorist attacks, a few departments and agencies have made a tentative start on counter-terror R&D programs. In order to improve the efficiency of these efforts, Advisor Marburger commissioned the thinktank RAND, Inc., to conduct an interim evaluation of programs currently in progress. RAND, Inc., has compiled these programs into a common format spreadsheet, and is advancing preparations for the interim evaluation while clarifying program overlaps, gaps between related departments and agencies, and cooperative possiblities between departments and agencies.[4]

(4) Finding human talent

Since the terror attacks, the federal government has received numerous counter-terror R&D proposals from the general public. The National Coordination Office (NCO), which oversees the OSTP (Office of Science and Technology Policy) and the government's IT initiative, "Networking and Information Technology R&D", is gathering information on proposers of the aforementioned proposals and compiling it into a database. Under President Bush, who is enthusiastic about the new employment of private citizens necessary for counter-terror measures, each department and agency is using said database to gather the necessary human talent.

Table 1: Changes in R&D budget for counter-terror Measures

	R&D Budget for Counter-Terror Measures (in 100 million dollar units)	Percentage increase from previous year (%)
FY 2001	5.8	—
FY 2002	15	159
FY 2003	28	87

Source: AAAS Report XXVII: Research and Development FY 2003

11.2.2 R&D budget for counter-terror measures

Since the terror attacks, the budget for R&D of counter-terror measures has been increasing (Table 1).

In FY 2003, it is predicted that most of the budget for R&D of counter-terror measures will be allocated to NIH R&D on bioterrorism countermeasures.

11.3 Impact of terror attacks on universities

11.3.1 Impact on the internationality of universities

In an AAAS address, Georgia Institute of Technology President G. Wayne Clough pointed out that, "Since the terror attacks, examinations for visa issuance to foreign students have become rigorous. It is also causing obstacles to the promotion of international collaborative research." In addition, University of California at Santa Cruz President Greenwood noted, "Since the terror attacks, overseas students, Moslems in particular, have come under severe criticism, and many foreign students have returned to their home

countries."

Furthermore in the United States Congress, the enactment of a "Technology Talent Act" is being discussed, which supports students (restricted to US citizens and permanant residents) who study science and technology at university, and if said bill is approved, it is feared that the closed nature of universities to foreign countries will intensify.

11.3.2 The role expected of universities

Unlike a conventional war, a terror offensive involves many uncertain elements: who is the enemy? and from where and how will they attack? For this reason, universities are being counted on to research terrorist psychology, and collect, analyze and compile information on terrorism into databases. Expectations are also being placed in universities for R&D on anthrax and other vaccines; biometrics research, which increases the accuracy of personal verification; improving the accuracy of sensors that detect dangerous substances, and so forth.

In respect to this emeritus professor Branscomb notes in an AAAS address that, "Universities should aggressively advance R&D on counter-terror measures, and contribute to maintaining the solidity of US society. However, much of this R&D is highly interdisciplinary, and preparations for a method of evaluation are a matter of urgency."

11.3.3 Danger of becoming a source for providing terrorist techniques

In an AAAS address, Advisor Marburger pointed out, "while expectations are high in universities for counter-terror measures, there is a risk that universities will become a source for providing terrorist techniques such as biological weaponry."

In order to reduce this risk, the "USA Patriot Act" was established, which demands that universities and the National Center for Educational Statistics (NCES) provide personal data on researchers, when requested by the FBI, CIA, etc. Emeritus Professor Branscomb commented in an AAAS address that, ..while the method is effective in preventing terrorism, there is concern that the privacy of researchers is infringed upon."

11.4 Government R&D budget for FY 2003

11.4.1 Trends in budget organization

On February 4, 2002, President Bush announced the FY 2003 Budget Request (FY 2003 is October 2002 to September 2003). According to said Budget Request, the FY 2003 R&D budget will increase 8.6% over the previous year to 112 billion dollars, and showing conspicuous budget increases are the Department of Defense (DOD), up 9.9% from the previous year, and the National Institute of health (NIH), similarly up 16% (for more details on the FY 2003 Presidential Budget Request, see report in the forth issue of Science and Technology Trends — Quarterly Review: "The Trend of the R&D Policy in the U S - Transition of priority areas inof the R&D budget allocation of the federal government -").

11.4.2 Priority Areas for FY 2003

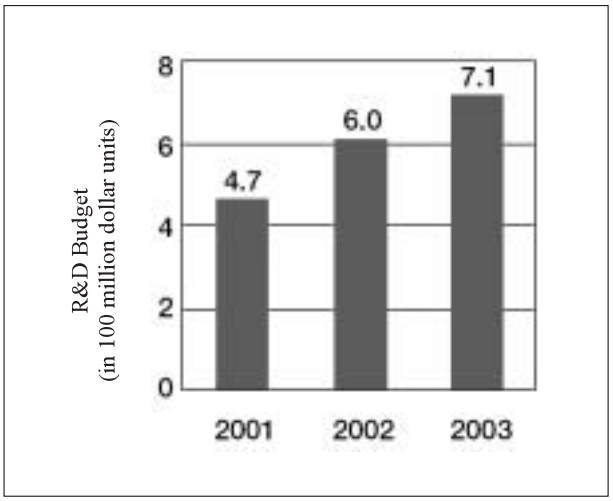
Priority areas for FY 2003 are nanotechnology and life science.

(1) Nanotechnology

The FY 2003 Budget Request demands an increase in the NNI budget compared with the previous year (Figure 1).

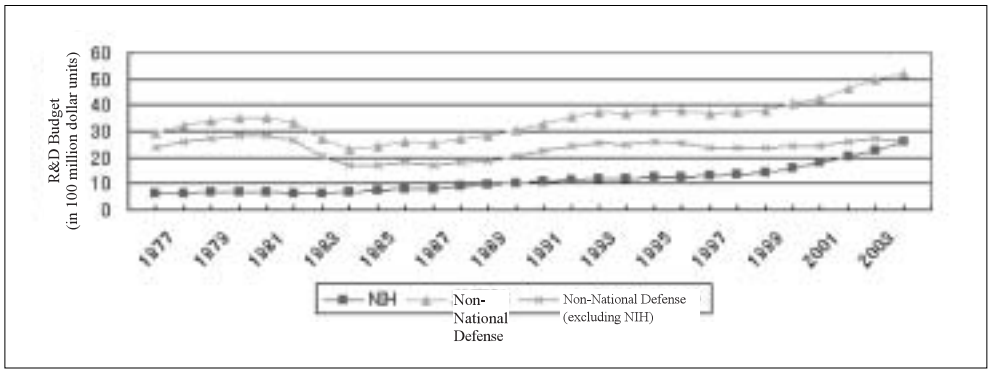
Furthermore, in an AAAS address, Advisor Marburger mentions promotion of the National Nanotechnology Initiative (NNI) as one of the priority themes of FY 2003 science and

Figure 1: Changes in NNI budget



Source: AAAS Report XXVII: Research and Development FY 2003

Figure 2: Changes in NIH share of non-national defense budget



technology policy. Specifically the FY 2003 Budget Request lists the following themes anew.

— Manufacturing processes on the nanoscale
— Detection and treatment of chemical, biological and nuclear bombs employing nanotechnology
— Development of measuring methods and measuring instruments for nanoscale

In addition said Budget Request also seeks reinforcement of standardization, development of human talent and cooperation between industry, academia and bureaucracy that has been tackled so far in the NNI.

And in the federal government, it is thought field concepts concerning "nano" are still in a fluid state. For example, the "N" that appears in the middle of NNI generally represents "Nano-technology," but the "National Nanotechnology Investment in the FY 2003 Budget Request by the President," announced by the NEST (Nanoscale Science, Engineering and Technology) working party[5] of the NNI secretariat, notes that it also may refer to "nanoscale science, engineering and technology." Advisor Marburger raises the concept of nanoscience, and comments that this is a domain comprised of organic nanoscience (biotechnology) and inorganic nanoscience (nanotechnology).[6]

(2) Life science

FY 2003 corresponds to the final year of the 5-year campaign to double the NIH budget that began in FY 1999, and precisely the same target is achieved by the FY 2003 Budget Request. Director Koizumi of the AAAS R&D Budget and Policy Program comments, "It is easy to gain the country's support for NIH. In particular the Federal Congress is holding off an election in fall of this year, so there is little possibility of reducing the NIH budget sought in the Budget Request; if anything they'll probably increase it."

Consequently, the share that NIH accounts for in the non-national defense R&D budget will increase (Figure 2), and a problem of balance between areas is occurring.

11.4.3 Problem of balance between areas

With the end of the campaign to double the NIH budget close at hand, there are calls from the NSF and some in Congress for a campaign to double the NSF budget, with an aim to increasing the budget for engineering and physics fields. However Advisor Marburger has expressed his opposition to said campaign to double the NSF budget, even while advocating the necessity of redressing the imbalance between areas[4].

Behind this is the Advisor's idea that, "The problem is not that if we increase the life science budget we should also increase the budget for physics areas in the same way. In the way that the development of IT is advancing genome analysis in leaps and bounds, and the development of nanotechnology is drawing out new functions from materials and has clarified the mechanism of new life phenomena, a variety of fields are developing while being intricately interwoven. Seen from such a viewpoint, it is important that we continue to aggressively invest in R&D for life science. Similarly, it is important that we make priority investment into nanotechnology and IT as well in the same way.

In regard to said policy, Director Peterson of SRI

International comments, "...it shows great foresight, and I am looking forward to future developments in science and technology."

11.5 Revision of government R&D management

The Bush Administration places importance on R&D management, and through the OMB (Office of Management and Budget) ordered every department and agency to i) develop criteria of R&D investment; ii) evaluate each R&D project using said criteria; and iii) reflect said evaluation results in the annual budget request.

President Bush already ordered the Department of Energy (DOE) to conduct this work in the National Energy Policy (NEP) announced in May, 2001, and the investment criteria of practical research and development that the DOE developed are also being applied by other department and agencies, and each department and agency is expected to independently develop investment criteria for basic research. The DOE's evaluation results were expected to be reflected in the FY 2003 budget request, but since the DOE took time in developing investment criteria of basic research, reflection of evaluation results was postponed until the FY 2004 budge request.

In respect to this, the National Academy of Sciences (NAS) gathered persons connected with the DOE and OMB, and persons of learning and experience from industry and academia, and held a workshop to discuss the development of investment criteria of basic research, and while participants supported OMB demands in general, they showed concern as to whether the effect of investment in long-term, high-risk basic research could be evaluated with simple criteria, and that perhaps it might kill off rudimentary research.

In an AAAS address, Advisor Marburger expressed enthusiasm for developing and setting in place evaluation criteria in order to effectively carry out peer reviews, which are used in the examination of each department's and agency's R&D projects, but fears are growing in the scientific community that "..setting detailed criteria in peer reviews will lead to the ruining of evaluations."

11.6 Conclusion

The impact of the terrorist attacks on United States science and technology policy is considerable, and a variety of counter-terrorism R&D programs are being planned and implemented, but they are quite complex and urgent coordination is being sought.

Furthermore for FY 2003, the Bush Administration is expected to prioritize nanotechnology and life science, and this trend is predicted to continue for the time being. However, if we consider the growing deficit economy, revising and increasing the efficiency of government R&D investment are necessary, and the direction of R&D management, on which the Bush Administration places great importance, will be watched with much interest.

References and notes

[1] Composed of researchers, etc., who represent the US scientific community.
[2] "Federal Research and Development for Counter Terrorism: Organization, Funding, and Options", November 26, 2001, CRS Report for Congress
[3] Committee that was set up in the White House. Mainly coordinates allocation of the federal government's R&D resources. Its members include the Vice-President, the President's Science Advisor, secretaries of departments and agencies connected with science and technology, directors of relevant bureaus, other White House high officials, and persons of learning and experience that the President has appointed.
[4] "Statement of The Honorable John H. Marburger, III, Director, OSTP", December 5, 2001, House Committee On Science
[5] Established under the NSTC
[6] "Speech of Dr. John Marburger; Science Based Science Policy", February 15, 2002, Boston, Massachusetts
[7] "University Research in the News", 02-04 February 8, 2002, Association of American Universities

(Original Japanese version: published in April 2002)

12

Outline of Drawing up the FY2002 Budget for Science and Technology — Technical and Social Aspects —

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12.1 Introduction

Year 2002 is the second year for the Second Science and Technology Basic Plan (hereinafter, "Basic Plan"). As the newly established science and technology administrative system began running smoothly, the Japanese government started full-scale efforts to accomplish the Basic Plan.

In this report, I would like to overview how the government drew up the FY2002 S&T related budget by focusing on the activities of Council for Science and Technology Policy (CSTP). This is the first budgetary process under the new administrative structure and also regarded as the prototype for future budgetary processes. In addition, I would like to present an outline of the FY2002 S&T related budget.

12.2 Budgetary process under new administrative structure — activities of the Council for Science and Technology Policy

The CSTP council meeting submitted its recommendation number 1, "Comprehensive Strategy to Promote Science and Technology," in March 2001. Based on this recommendation, the Japanese government determined the Second Basic Plan.

After its establishment, CSTP holds monthly council meetings to discuss and decide important mattes for science and technology fields.

In this report, I would like to overview how the government drew up the FY2002 budget by focusing on CSTP's policy discussions and decisions.

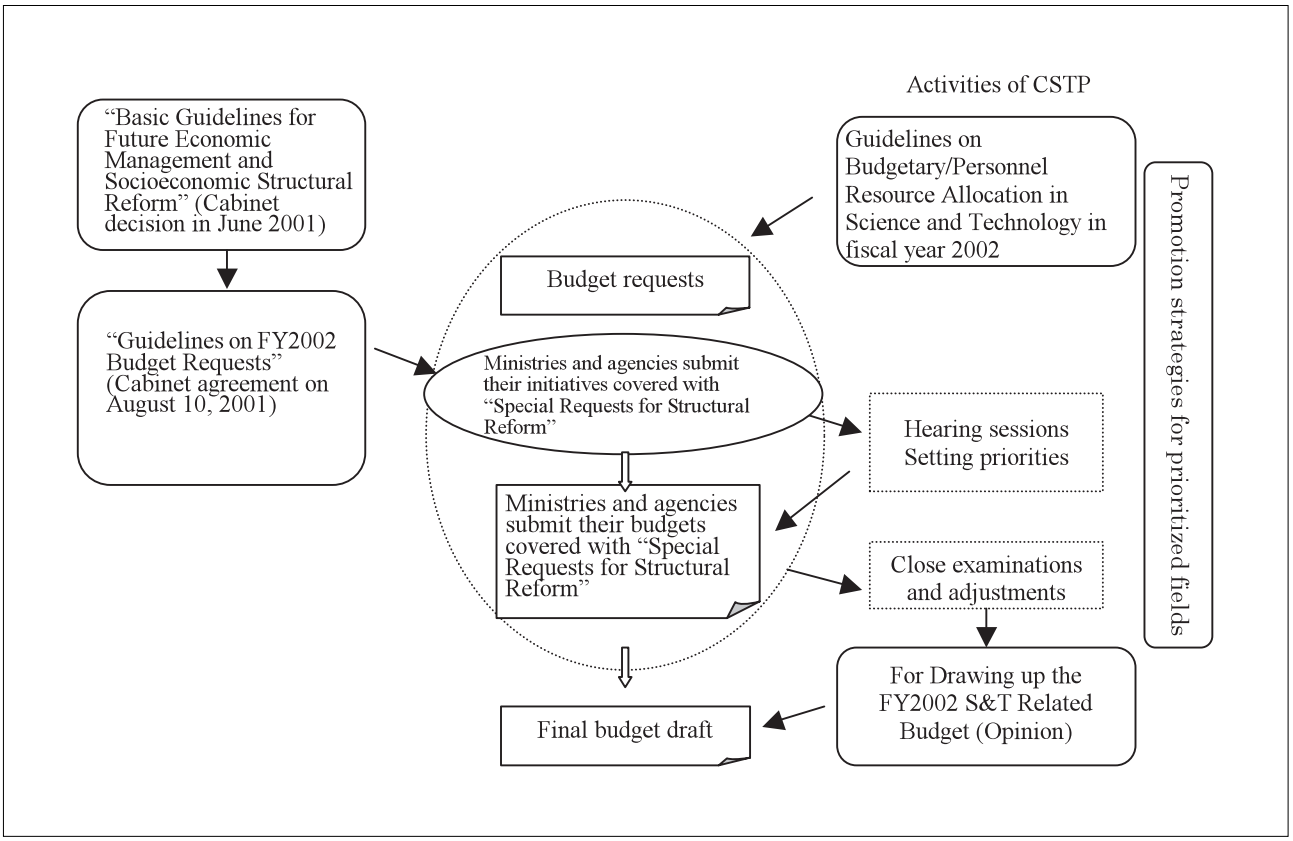
In drawing up the FY2002 budget, CSTP (i) examined promotion strategies for each prioritized area, (ii) proposed guidelines on budgetary/personnel resource allocation, and (iii) reviewed how the government actually incorporated CSTP's resource allocation guidelines into the related programs.

In May, the council meeting discussed important matters for the FY2002 budget. The council meeting also made two decisions: (i) CSTP would prepare the resource allocation guidelines well in advance so that ministries/agencies could request the budgets in line with it, and (ii) CSTP would evaluate budget requests of the related ministries/agencies, set priorities and ensure proper resource allocation in cooperation with Ministry of Finance.

Based on its council meeting's decision in March, CSTP established the expert panels to examine sectorial promotion strategies for prioritized fields described in the Basic Plan. These expert panels planned and examined projects for each prioritized fields and reported their findings to the monthly council meetings, mainly focusing on where the government should put more emphasis in each prioritized fields. The expert panels also surveyed and examined the resource allocation guidelines in cooperation with the expert panel on S&T system reformation and the expert panel on evaluation.

Based on these activities, the council meeting in July determined the "Guidelines on Budgetary/Personnel Resource Allocation in Science and Technology in fiscal year 2002" (hereinafter, "Resource Allocation Guidelines"),

Figure 1: Flowchart of budgetary process



which describes basic concepts for budget requests. "The Resource Allocation Guidelines" proposed more strategic fund allocation to prioritized fields mentioned in the Basic Plan, as well as more drastic system reforms to build proper environments that would create the highest-level R&D results in the world. Each of the related ministries and agencies was supposed to sufficiently incorporate the guidelines into their budget requests. CSTP also would work with the treasury authorities as necessary in the budgetary process.

In August, the government determined the "Guidelines on FY2002 Budget Requests" (Cabinet agreement on August 10, 2001). This Cabinet agreement approved "Special Requests for Structural Reforms" to prioritize budget allocation for seven important issues, such as policies for environmental problems, countermeasures for the aging society with fewer children, revitalization of local communities, urban regeneration, science and technology promotion, human resource development/education/culture, and for an IT nation. In terms of the special requests, CSTP decided to examine planned promotion initiatives based on "Resource Allocation Guidelines" and to review prioritized public investment initiatives from viewpoints of enhancing science and technology.

In September, after ministries and agencies submitted their initiatives covered financially with the special requests, the Minister of State for Science and Technology Policy and CSTP council members held hearing sessions and set priorities on these initiatives from the viewpoints of accomplishing the Resource Allocation Guidelines and structural reforms. After having examined other issues, the Cabinet Secretariat offered its final plan to the related ministries and agencies. Based on this final plan, ministries and agencies requested their budgets through Special Requests for Structural Reform.

Then, CSTP carefully examined its budget requests as a whole. Based on "Resource Allocation Guidelines" as well as "Promotion Strategy of Prioritized Areas" decided by its September council meeting, CSTP systematically sorted out the related initiatives and examined which initiative should be aggressively promoted or should be carried out in cooperation with other ministries/agencies. In November, the CSTP council meeting compiled "For Drawing up the

FY2002 S&T Related Budget (Opinion)," which describes important issues for budgetary process. According to this opinion, although the importance of science and technology was generally emphasized in the budget request process, the budget request failed to incorporate other important initiatives, such as greater fund allocation to national university/institutions. In addition, the opinion pointed out important matters for more strategic science/technology promotions and system reforms.

After such process, the government determined the FY2002 budget. As some policy initiatives might require comprehensive implementation, continuous examination and clear strategies, CSTP decided to keep track of and adjust the related initiatives in order to ensure consistency with the Resource Allocation Guidelines and Promotion Strategy of Prioritized Areas.

12.3 Outline of the FY2002 budget for science and technology

12.3.1 Total amount of budget for S&T

Budget for S&T refers to the national budget portion that contributes to science/technology promotion, such as expenses for research activities at universities, expenses for government research institutes (including independent administrative institutions and research institutes of public corporations), subsidies for R&D activities, grants/contract charges, and other necessary expenses for R&D-related administrative activities. (In this context, expenses mean all budgetary items, such as personnel cost, gratitude, travel expense, research expense, agency expense, equipment expense, facility expense, contract charge, subsidy and investment.) S&T promotion expenses refer to the general account budget portion that mainly aims at science and technology promotion. The budget for S&T is the sum of S&T promotion expenses, other R&D-related expenses in the general account budget (e.g., energy-related policy expense) and S&T-related expenses in special account budgets (such as the Special Account Budget for National Educational Institutions and the Special Account Budget for Electric Power Development Promotion Measures). The Ministry of Education, Culture, Sports, Science and Technology (MEXT) is in charge of compiling the S&T related expenditures.

The total amount of the FY2002 general account budget is ¥81 trillion (down 1.7% from FY2001). General expenditures are ¥47.5 trillion (down 2.3% from FY2001). Despite such tight budget, S&T promotion expenses reached ¥1.2 trillion (up 5.8% from FY2001) and enjoy significant growth. The total amount of the budget for S&T is ¥3.5 trillion, increasing by 2% from FY2001 (Table 1). The government allocated ¥2.7 trillion to the structural reform special requests for more strategic fund allocation. Out of this sum, the government allocated about ¥0.9 trillion to "Promotion of S&T, Education and IT." The S&T-related initiatives are as follows.

- Establishing top-level universities in the world: ¥18.2 billion
- Enhancing educational/research activities at private universities [new project due to amending the system]: ¥64.5 billion
- Promoting life science through the Protein 3000 Project: ¥20.5 billion
- Groundbreaking advanced medical

Table 1: S&T related expenditures in the FY2002 budget draft

(in ¥100 million)

	FY2001	FY2002	Increase / Decrease (%)
General account budget	18,376	18,513	0.7%
S&T promotion expenses	11,124	11,774	5.8%
Others	7,252	6,739	– 7.1%
Special account budgets	16,309	16,874	3.5%
Total	34,685	35,387	2.0%

Source: Press release from the Research and Coordination Division, Science and Technology Policy Bureau, MEXT

Table 2: Budget amount by ministry / agency

	Expenditure (in ¥100 million)	Percentage	Increase / decrease (%)
MEXT	22,644	64%	2.4%
METI	5,972	17%	6.4%
Defense Agency	1,435	4%	– 3.7%
MHLW	1,281	4%	3.4%
MAFF	1,224	3%	–0.1%
Total	35,387	100%	2.0%

Source: Press release from the Research and Coordination Division, Science and Technology Policy Bureau, MEXT

technology promotion R&D activities: ¥2.8 billion

— Developing/testing fuel cell technologies: ¥5.2 billion
— Nanotechnology comprehensive support project: ¥3.8 billion
— Creating industry-university and industry-government joint research activities: ¥5.0 billion
— Intellectual cluster formation project, etc.: ¥8.6 billion

12.3.2 Budget by ministry / agency

When we look at the budget amount for each ministry/agency, MEXT has ¥2.3 trillion and accounts for 64% of the total amount, followed by the Ministry of Economy, Trade and Industry (METI) at ¥597.2 billion, the Defense Agency at ¥143.5 billion, the Ministry of Health, Labor and Welfare (MHLW) at ¥128.1 billion, and the Ministry

Table 3: S&T related expenditures for each field

(in ¥100 million)

	Main policies	Related policies	Independent administrative agencies (for reference)	Competitive funds (for reference)	Total (for reference)	Percentage (main purpose)	Increase / decrease % (main purpose)	Increase / decrease % (Total)
Life science	1,663	254	635	1,815	4,366	11%	8%	4%
IT	1,155	677	292	332	2,456	8%	– 1%	– 2%
Environment	507	6,647	267	222	7,643	3%	33%	6%
Nano-tech/ materials	115	384	286	447	1,232	1%	58%	13%
Energy	6,841	42	59	92	7,033	45%	2%	2%
Manufacturing	26	376	21	170	594	0.2%	– 43%	– 1%
Social infrastructure	2,005	240	558	45	2,848	13%	– 4%	– 2%
Frontier technologies	2,780	341	5	58	3,184	18%	– 7%	– 7%

Source: Press release from the Research and Coordination Division, Science and Technology Policy Bureau, MEXT

(Notes) 1) After adjustments with the Cabinet Office, METX compiled these figures based on data submitted by the ministries and agencies.
2) "Main policies" column refers to expenses spent for research activities or other original purposes, except for the independent administrative agency and competitive fund expenses.
3) "Related policies" column refers to expenses spent for, if any, secondary research activities other than original purposes, except for the independent administrative institution and competitive fund expenses.
4) "Independent administrative agencies" column refers to expenses that MEXT calculated based on its questionnaire. With this questionnaire, MEXT asked independent administrative agencies to comment on their budget plan for each field. MEXT calculated these figures for your reference. (MEXT calculated FY2002 figures proportional to the FY2001 actual fund allocation.)
5) "Competitive fund" means expenses that qualify for competitive funds. MEXT calculated these figures based on the actual budget allocation in the immediately preceding fiscal year (FY2000 for this survey). MEXT calculated these figures for your reference.
6) Other than the funds mentioned above, there are ¥1,580 billion budget funds as expenses for cross-sectional projects, expenses that remain unallocated in the budgetary process as well as some expenses in the National Educational Institution Special Account Budget.

Table 4: Competitive funds

(in ¥100 million)

	FY2001	FY2002	Increase / decrease %
Total	3,265	3,446	5.5%
Grants-in-aid for Scientific Research	1,580	1,703	7.8%
Special Coordination Funds for Promoting S&T	343	365	6.4%

Source: "Outline of Expenditures in the FY2002 Budget," Ministry of Finance

of Agriculture, Forestry and Fisheries (MAFF) at ¥122.4 billion. In terms of an increase in ratio from FY2001, METI is the highest (up 6.4% or ¥35.9 billion) followed by MHLW (up 3.4% or ¥4.2 billion) and MEXT (up 2.4% or ¥52.3 billion). On the other hand, the Defense Agency has a smaller budget (down 3.7% or ¥5.5 billion). (Table 2)

12.3.3 Budgets for prioritized fields

Table 3 shows S&T related expenditures by each prioritized field stated in the Basic Plan.

The energy area has the largest budget (¥684.1 billion, 45%), followed by frontier technologies (¥278.0 billion, 18%) and social infrastructure (¥200.5 billion, 13%). When adding up the amounts in "related policies," "independent administrative agencies" and "competitive fund" columns, the environment area has the largest budget (¥764.3 billion, 26%), followed by energy (¥703.3 billion, 24%) and life science (¥433.6 billion, 15%).

Although nano-technology/materials only have a small budget (¥11.5 billion for main purpose and ¥123.2 billion in total), this area enjoys the significantly largest growth rate in main policies (up 58%), related policies (up 35%) and in total (up 13%). Main initiatives include MEXT's administrative cost subsidy for the National Institute for Materials Science (¥16.7 billion), METI's nanotechnology program (¥8.3 billion) and MEXT's nanotechnology comprehensive support project (¥3.8 billion). In addition, the environment field also enjoys a significant growth rate (up 33%) in its main purpose initiative expenses.

12.3.4 Competitive fund

Competitive funds increased to ¥344.6 billion, up 5.5% from FY2001. Out of the total competitive funds, Grants-in-aid for Scientific Research and Special Coordination Funds for Promoting S&T increased by 7.8% and 6.4%, respectively. (Table 4)

12.3.5 Industrial competitiveness enhancement and industry-university-government cooperation

The government allocated ¥338.4 billion to industrial competitiveness enhancement and industry-university-government cooperation for the FY2002 budget. This area enjoys significant budget growth, up 29% from FY2001.

Main initiatives include METI's industrial technology R&D contract fees (¥9.5 billion) and MEXT's industry-university-government cooperative innovation creation project (¥7.1 billion).

12.3.6 Regional science and technology promotion

In the FY2002 budget, the government allocated ¥68.8 billion to regional science and technology promotion. This area enjoys a 40% budget increase, which is larger than the industry-university-government cooperation field. Main initiatives include METI's regional emerging consortium R&D project (¥8.8 billion) and MEXT's regional science/technology promotion expenses (¥8.6 billion).

12.4 Conclusion

The Japanese government determined the FY2002 budget as mentioned above. As follow-up activities for the FY2002 budget, CSTP holds hearing sessions and compiles new findings concerning specific initiatives of the related ministries/agencies. Although this budgetary process would be the new model for drawing up S&T related budgets in the future, it is still necessary to carry out pre/post evaluations concerning a variety of research themes in the FY2003 budgetary process.

(Otriginal Japanese version: published in April 2002)

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 organizations, 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 provide 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 five 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 3000 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 network, 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. Research 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 to set priority in policy formulating.

— STFC publishes the research results as feature articles for "Science Technology Trends" (monthly report).

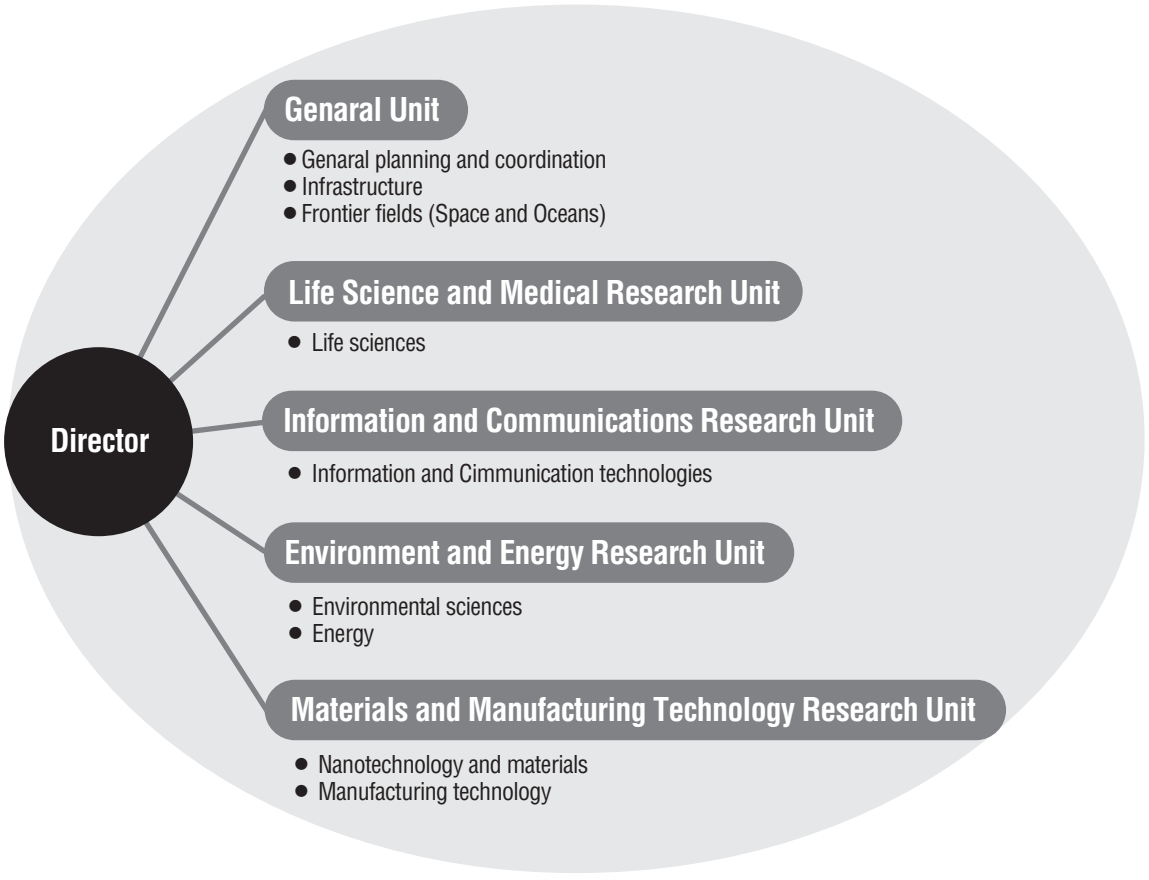
3. Technology foresight and S&T benchmarking survey

— STFC conducts technology foresight survey every five years to grasp the direction of technological development in coming 30 years with the cooperation of experts in various fields.

— STFC benchmarks Japan's current and future position in key technologies of various fields with those of the U.S and major European nations.

— The research results are published as NISTEP report.

Organization of the Science and Technology Foresight Center



* Units comprise permanent staff and visiting reseachers (non-permanent staff)
* The Center's organization and responsible are reviewed as required

- Life Sciences
- Information & Communication Technologies
- Environmental Sciences
- Nanotechnology and Materials
- Energy
- Manufacturing Technology
- Infrastructure
- Frontier
- Science & Technology Policy

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