Science & Technology Foresight Center of NISTEP

Science & Technology Trends

Quarterly Review

No.3
November
2002

Life Sciences

➤ *Recent Trends in Regenerative Medicine*
— Regenerative Medicine Utilizing Stem Cells

➤ *Trend Report on Bioinformatics*

Information and Communication Technologies

➤ *Recent Trends in Supercomputers*

➤ *Cyber security measures*
— How to protect the nation's critical infrastructure from cyber attacks

Nanotechnology and Materials

➤ *Trends in Material Simulation, Centering Around Ab Initio Calculation*

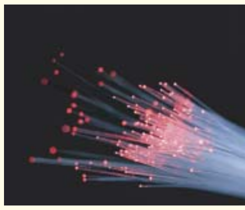
Energy

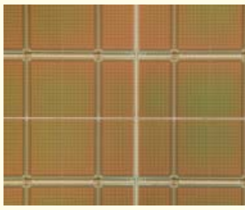
➤ *Trend and Prospects of Bioenergy Utilization*

Others

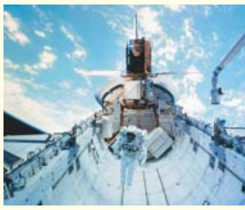
➤ *Trends in Science Communication*
— Circumstances Enveloping Science Journals —

➤ *International Appraisal of Japanese Research Results (Research Papers)*
— Increase of "First-class Papers" Produced in Japan —







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.

TERUTAKA KUWAHARA
Director
Science and Technology Foresight Center

Contact us: Science and Technology Foresight Center
National Institute of Science and Technology Policy
Ministry of Education, Culture, Sports, Science and Technology (MEXT)
1-3-2, Kasumigaseki, Chiyoda-ku, Tokyo 100-0013, Japan
Telephone +81-3-3581-0605 Facsimile +81-3-3503-3996
URL http://www.nistep.go.jp/index-e.html
E-mail stfc@nistep.go.jp

Executive Summary

Life Sciences

1 Recent Trends in Regenerative Medicine
— Regenerative Medicine Utilizing Stem Cells

p.7

In the Second Science and Technology Basic Plan, life science was selected as one of the fields having high priority. In the plan, regenerative medicine was referred to as one of areas in which various challenges should be strategically pursued with high priority in order to tackle national and social problems. In addition, heated arguments about bioethical issues coming up in regenerative medicine and regenerative therapy have been made by the Council for Science and Technology Policy, Cabinet Office, etc.

In light of such realities, this article summarizes the contents of the lecture delivered by Shinichi Nishikawa, professor at the Graduate School of Medicine at Kyoto University, about the recent trends in regenerative medicine and regenerative therapy, especially about regenerative medicine utilizing stem cells, at the National Institute of Science and Technology Policy on September 12, 2001, with data incorporated from our study.

At first, this report introduces; i) the progress in research using somatic stem cells and embryonic stem cells from the viewpoint of regenerative medicine. Then, from the viewpoint of regenerative therapy, this article describes; ii) the impact of regenerative therapy on health care cost; and iii) significance of the establishment of foundations on which to conduct regenerative therapy; followed by, iv) bioethical issues concerning research using human embryonic stem cells; and finally, v) the relationship between the "knowledge possessed by the people in the scientific community" and the "knowledge which can be shared in society," which often has great significance especially in studies in the field of regenerative medicine.

(Original Japanese version: published in November 2001)

2 Trend Report on Bioinformatics

p.15

Now that the outline of the human genome sequence was reported (February 2001) and the genome sequencing of 60 or more living species have been determined, the post-genome sequencing studies are getting into full swing. Since the needs for efficient organization and analysis of a vast amount of diverse biological information produced in the course of elucidating its biological and medical implication have increased, the importance of bioinformatics has been brought into bold relief.

In this report, we first describe the current state of researches on databases, data analysis methods, and hardware, and discuss the issues to be tackled. At present, re-organization and refinement of databases and analysis methods are in progress mainly for the purpose of DNA sequencing and protein structure analyses, and, in the future, it might be required that the research and development on cell functions and ontogenetic functions be strategically advanced. In addition, issues surrounding database management such as annotation updating and database

integration must be solved. With respect to hardware, high-performance computers need to be improved further. On the other side, software satisfying the requirements for integrating applications running on high-performance computers into one parallel system should be developed.
Second, we describe the actual state of political activities taken on bioinformatics and discuss the issues to be solved. In Japan, formation of bases for propelling bioinformatics and implementation of programs for training human resources have just been initiated. In the near future, considering the importance of bioinformatics in the life science area, it is preferable that continuous advancement of policies be made.

(Original Japanese version: published in December 2001)

Information and Communication Technologies

3 Recent Trends in Supercomputers

p.23

To report on trends in supercomputer hardware, the Earth Simulator and the ASCI, ongoing projects in order to develop the fastest supercomputers in Japan and the U.S., respectively, are described. The two countries have different development strategies. Japan focuses on developing vector parallel computers for large scale scientific and technological computations; while the U.S. is developing massively parallel scalar computers which can be applied to business use. Meanwhile, affordably-priced PC clusters have emerged. Their cost efficiency is attracting attention. However, application programs are carefully tuned to be taken in account their parallel architecture and data transfer method.
Discussed next are the various application fields of supercomputers. Their use is outlined in respective areas including Climate changes, Global environment prediction, Bioinformatics, Materials simulation, Structural analysis, Fluid analysis, Celestial mechanics, Elementary particle physics, Nuclear fusion simulation, Data mining, and Economic forecasts and Financial engineering. Bioinformatics is a new field launched through the progress of supercomputers. This report shows how supercomputers and their applications have become basic technologies those are crucial for baisc science research as well as for industrial applications.

(Original Japanese version: published in October 2001)

4 Cyber security measures
—How to protect the nation's critical infrastructure from cyber attacks

p.32

This report provides a discussion on what the government can do to protect critical infrastructure for energy, communications, finance and other services from cyber attacks. As the retaliatory strikes against the terrorist attacks in the U.S. continue, there is greater concern about possible further counter-attacks by terrorists not only in the U.S. but also elsewhere in the world. Since anthrax infected patients were found in the U.S., bio-terrorism has drawn closer attention, throwing the threat of cyber attacks into the shadow. However, cyber strikes, which can be carried out online, are highly probable under the circumstances where physical security is extremely tight in every place. Therefore, the government should immediately take actions to enhance the nation's cyber security. In particular, critical infrastructure, which is often owned by the private industry, needs higher-level protection through partnerships between the government and private sector, because damage to such infrastructure is likely to cause nation-wide chaos.

(Original Japanese version: published in October 2001)

Nanotechnology and Materials

5 Trends in Material Simulation, Centering Around Ab Initio Calculation

p.41

It is expected that contributions of simulation to Materials Research will be advanced, as supported by such moves in the background as drastic improvements in the performance of computers, advancement of simulation methods, and betterment in experimenting techniques on the nano-meter scale.

It is further expected that contributions of simulation to material design will remarkably increase in the future as the scope of application of the ab initio calculation, as precision simulation, is expanded by means of further improvements in computer performance, etc. It is furthermore anticipated that when material design by means of simulation is put to practical use, "whether material simulation can be fully utilized" will lead to the formation or expansion of a gap in the capability of research and development. It is important to improve the rate of utilization of simulation in the research and development of new materials and devices, and at the same time to establish collaborative practices of theoretical study and experimental study.

(Original Japanese version: published in December 2001)

Energy

6 Trend and Prospects of Bioenergy Utilization

p.47

Although up to now, various economic and technical options have been proposed for the global warming problem, each of them can individually produce only limited effects, leaving Japan in the position that it needs to pour continuing research and development efforts into diverse global warming countermeasure technologies to secure the bases for unerring, flexible policy implementation.

In the meantime, bioenergy is drawing attention as a clean energy source that does not emit carbon dioxide, and, in addition, the Japanese government is considering revising the provisions of the "New Energy Law" to include bioenergy among the types of new energy eligible for introduction support available under the said law.

In this report, brief explanations are given on the overview of bioenergy, its meaning as a global warming countermeasure, the states of its introduction in Japan and overseas, bioenergy conversion and utilization technology, and available biomass resources in Japan and overseas.

Furthermore, proposals are made with respect to the following five objectives to promote the introduction and spread of bioenergy in Japan: i) Enhancement of fundamental research; ii) Institutional design that gives consideration to the externality; iii) Construction of an extensive and effective biomass collection system; iv) Promotion of R&D for co-firing of coal and biomass; v) Joint efforts and cooperation with developing countries.

(Original Japanese version: published in December 2001)

Others

7 Trends in Science Communication
— Circumstances Enveloping Science Journals —

p.61

Science journals are one of the most important communication means among researchers, and extremely important for researchers to progress their researches. Circumstances surrounding them are rapidly changing as seen in the steep rise of their subscription prices, severe circumstances of earned societies publishing them and their publication firms, and accelerated progression of online computerization of their publication. In addition, there are new efforts addressing preprint servers, which complement science journals.

Under such circumstances, there is a move afoot to advance reforms of the journal systems in Japan, the United States, and Europe, and it involves not only learned societies publishing journals and publication houses but also libraries, which are institutional subscribers of journals and intermediate agents. An approach through comprehensive cooperation and appropriate burden sharing is required in order to build new and attractive journal systems by using the great potential of online computerization.

It is vital to the promotion of science communication to advance computerization of science journals, maintain objective, fair, and speedy peer review systems, and continuously provide science information.

(Original Japanese version: published in November 2001)

8 International Appraisal of Japanese Research Results (Research Papers)
— Increase of "First-class Papers" Produced in Japan —

p.72

We analyzed the degree research papers produced in Japan are appraised internationally by using data of "the shares of research papers in first-class journals" and "the number of times to be cited," etc. As a result of this analysis, the following points have become clear.

— The shares of Japanese research papers among all papers printed in first-class journals (Science and Nature) have tended to increase year by year, and the number of international-class research results is increasing in Japan.

— Japan has taken great interest in the fields of Physics, Material Science and Chemistry over the past 10 years, and there are world-leading institutes in these fields in Japan.

— In the field of nanotechnology, Japan has produced research papers watched internationally over the past 10 years.

(Original Japanese version: published in November 2001)

1

Recent Trends in Regenerative Medicine
— Regenerative Medicine Utilizing Stem Cells

HIROKO EBIHARA AND SHIN-ICHI MOGI
Life Science and Medical Research Unit

1.1 Introduction

In the second Science and Technology Basic Plan, life science was selected as one of the fields having high priority. In the plan, regenerative medicine was referred to as one of the areas in which various challenges should be strategically pursued with high priority in order to tackle national and social problems. In addition, there have been heated arguments about bioethical issues arising in regenerative medicine and regenerative therapy at the Council for Science and Technology Policy, Cabinet Office, etc. In this article, "regenerative medicine" is defined as a term referring to both research and therapy ("regenerative therapy") with the use of regenerated tissues.

1.2 Enlarged possibility of applying regenerative medicine

Various regenerative therapies have been conducted so far, including transplantation of regenerated skin and bone marrow as well as transplantation of regenerated dopamine-producing cells into the brains of patients with Parkinson's disease. However, there is a crying need for every type of tissue to be transplanted.

Use of stem cells is one of the solutions for this problem. Stem cells are the cells that have the ability both to self-replicate and to differentiate into progenitor cells, which then differentiate or develop into many different "mature" cell types that have characteristic shapes and specialized functions. Among the stem cells, somatic stem cells, which are thought to have the ability to differentiate into cells of specific tissues or organs, as well as embryonic stem cells, which have the ability to differentiate into any types of cells in tissues and organs, are expected to create cells, tissues or organs for transplantation and contribute to health care in the future. Moreover, possibility has been suggested that stem cells, in combination with cloning technology, will be applied to the creation of tailored organs for transplantation not causing rejection reactions.

Among the two types of stem cells, embryonic stem cells are harvested by extracting the inner cell mass (a mass of cells that will develop into the baby's tissues and organs) from the center of a human embryo in the first week of life, resulting in the destruction of the embryo. Therefore, deliberate arguments have been made about the bioethical aspects of the use of embryonic stem cells for experimental or therapeutic purposes.

At first, as shown in Table 1, this article introduces; i) the progress in research using somatic stem cells and embryonic stem cells from the viewpoint of regenerative medicine (Section 1.3). Then, from the viewpoint of regenerative therapy, this article describes; ii) the impact of regenerative therapy on health care cost (Section 1.4); and iii) significance of the establishment of foundations

Table 1: Contents of this feature report

Contents of this article
i) Progress in research using somatic stem cells and embryonic stem cells (Section 1.3)
ii) Impact of regenerative therapy on health care cost (Section 1.4)
iii) Significance of the establishment of foundations on which to conduct regenerative therapy (Section 1.5)
iv) Bioethical issues concerning research using human embryonic stem cells (Section 1.6)
v) Relationship between the knowledge possessed by the people in the scientific community and the knowledge which can be shared in society (Section 1.7)

on which to conduct regenerative therapy (Section 1.5); followed by, iv) bioethical issues concerning research using human embryonic stem cells (Section 1.6); and finally, in Section 1.7, v) the relationship between the "knowledge possessed by the people in the scientific community" and the "knowledge which can be shared in society," which often has great significance especially in studies in the field of regenerative medicine.

1.3 Progress in research in the field of regenerative medicine

Even in this postgenome era, no viable cells can be artificially created from scratch. In any event, some diseases require treatment using viable cells. For example, even in this era of postgenome research, blood transfusion and bone marrow transplantation cannot be replaced by therapy without using viable cells.

While the applicability of cell transplantation as regenerative therapy for the treatment of deficiency (loss) of cells or for tissue damage is currently expanding, cells for use in such therapy is desperately lacking. If intended cells can be prepared in vitro, such shortage will be alleviated.

Under these circumstances, new findings and technologies have come into the world, which seem to promise to expand the applicability of regenerated cell transplantation. Specifically speaking, the following studies are being pursued.

1.3.1 Recent studies on somatic stem cells

(1) Studies aiming to develop therapeutic methods for Parkinson's disease

Parkinson's disease is linked to the death of brain cells that produce dopamine in the substantia nigra. With the purpose of treating Parkinson's disease, fetal brain cells have been transplanted to affected patients to complement the function of dead brain cells. However, because cells to be transplanted should be collected from several fetuses for the treatment of one patient, and because it is technically difficult to extract specific cells exclusively from brain tissues removed from aborted fetuses, fetal brain cell transplantation has not gained popularity as a therapy for Parkinson's disease.

With this being the situation, many universities, companies, etc., are exploring proteins (markers) specifically expressed in progenitor cells for dopamine-producing neurons, which can be transplanted to Parkinson's disease patients for therapeutic purposes, in murine models of Parkinson's disease. It is expected that enough dopamine-producing neurons to be infused to Parkinson's disease patients for therapeutic purposes will become harvestable if marker proteins specific to such neurons are identified and utilized.

(2) Studies targeting the recovery of impaired neural functions

In a study using a rat model of spinal cord (cervical cord) injury (associated with decreased mobility of forelegs), a group led by Professor Hideyuki Okano at Keio University transplanted neural stem cells into the injured part of the spinal cord, and observed that the cells differentiated into neurons, etc., and that the neural network was reconstructed, resulting in the recovery of the mobility of the forelegs (Figure 1).

(3) Studies on plasticity of differentiated cells

It has been shown that hematopoietic stem cells are capable of differentiating into neural, muscle or liver stem cells, and that neural or muscle stem cells have the ability to differentiate into hematopoietic stem cells (Figure 2).

If intended cells become able to be prepared in vitro by utilizing the plasticity of stem cells, i.e., by reprogramming a specific kind of stem cells to

Figure 1: Recovery of neural function after the transplantation of somatic stem cells

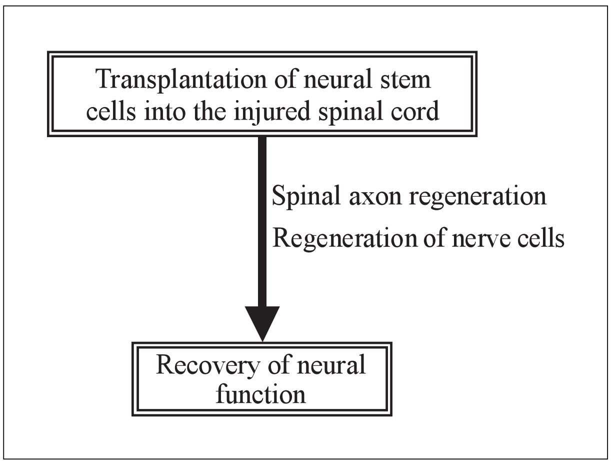
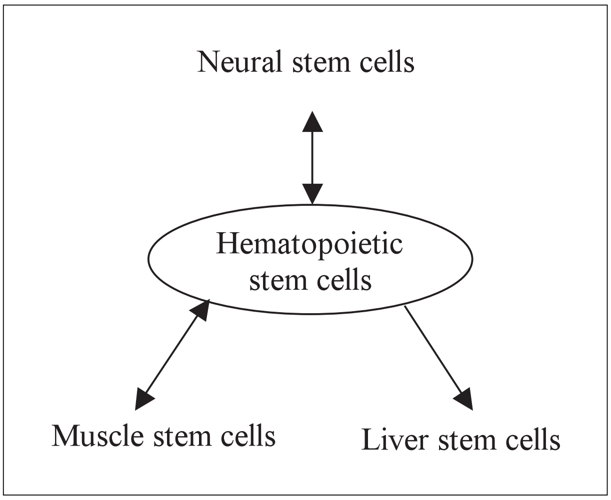


Figure 2: Plasticity of hematopoietic stem cells



Source: Authors' compilation by making reference to the materials provided by Professor Nishikawa

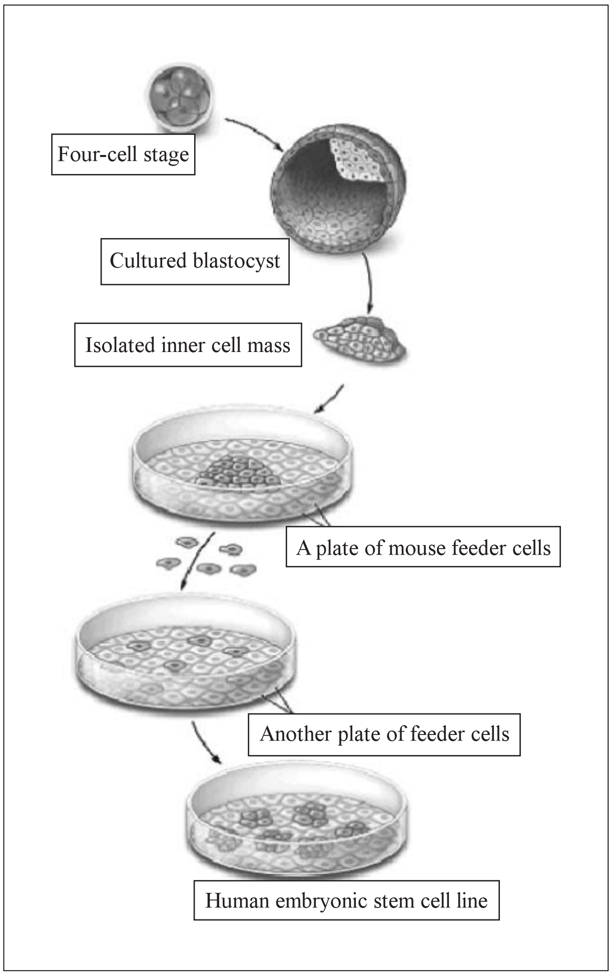
become another kind of stem cells, somatic stem cells are expected to have greater value in the treatment of diseases.

1.3.2 Recent studies on embryonic stem cells

(1) Establishment of embryonic stem cell lines

In 1998, the University of Wisconsin developed the first human embryonic stem cell line with monetary support from Geron Corp., which had a great impact on regenerative therapy (Figure 3).
Studies on embryonic stem cells have been conducted mainly on mice and Primates (Rhesus monkeys and marmosets). The first embryonic stem cell line was established in 1981, 1995 and 1998 for mice, Rhesus monkeys and marmosets, respectively.

Figure 3: Establishment of human embryonic stem cells



Source: Authors' compilation by making reference to a figure in the June 2001 issue of the NIH report "Stem Cells."

Table 2: Number of established lines of human embryonic stem cells

Goeteborg University (Sweden)	19
CyThera, Inc. (United States)	9
Reliance Life Sciences (India)	7
Monash University (Australia)	6
Karolinska Institute (Sweden)	5
Wisconsin Alumni Research Foundation (United States)	5
BresaGen, Inc. (United States)	4
Technion-Israel Institute of Technology (Israel)	4
National Center for Biological Sciences (India)	3
University of California (United States)	2
Total	64

Number of human embryonic stem cell lines reported to the National Institutes of Health (NIH)

Source: Authors' compilation by making reference to the materials provided by Professor Nishikawa

As mentioned above, the first human embryonic stem cell line was established in 1998. To date, 64 lines of embryonic stem cells have been established in the world (Table 2).

(3) Challenges to be addressed in studies using embryonic stem cells

While it has been shown that embryonic stem cells have pluripotency, i.e., capability to differentiate into various kinds of cells in vitro including nerve cells, muscle cells, blood cells and insulin-secreting cells, the mechanism of differentiation control remains under investigation. The challenges to be addressed in studies using embryonic stem cells include the exploration of factors that induce the differentiation of embryonic stem cells into cells for intended functions, development of techniques for extracting a specific kind of cells from a mixture of various kinds of differentiated cells, as well as the development of technology for inducing the efficacious proliferation of cells in vitro.

With regard to the achievements in recent studies on mouse embryonic stem cells, it has been shown that a certain transcription factor (Oct-3/4) is involved in the maintenance of undifferentiated state of embryonic stem cells. In addition, a group led by Professor Yoshiki Sasai at the Graduate School of Medicine at Kyoto University has developed a technique called the SDIA (stromal cell-derived inducing activity) method and succeeded in frequently inducing and culturing the development of mouse embryonic stem cells into dopamine-producing nerve cells in vitro, which can be used to treat Parkinson's disease.

1.4 Impact of regenerative therapy on health care cost

General concerns are rising that widespread introduction of advanced medicine into clinical practice including regenerative therapy might lead to an increase in health care cost, but there are some cases where introduction of regenerative therapy does not seem to increase health care cost.

Dr. Ron Mackay at the National Institutes of Health (NIH) in the United States has developed a technique for inducing the differentiation of embryonic stem cells into pancreatic cells, which could be successfully administered to diabetes mellitus model mice to treat the disease (This technique presents some problems in that the process of differentiation of embryonic stem cells into pancreatic cells cannot be completely controlled, and requires further study).

Patients with type I diabetes mellitus, whose pancreas (β-cells in the pancreas) cannot synthesize or secrete insulin, develop the disease at the age of less than 15 years old almost without exception, and should receive the administration of insulin throughout their lifetime after the onset of the disease. If type I diabetes mellitus can be completely treated with only a single shot of cells, health care cost will be cut. As this example illustrates, application of regenerative medicine to actual clinical practice may not always result in an increase in health care cost.

From this time forward, discussions will take place in various quarters about the impact of the introduction of regenerative therapy on health care cost.

1.5 Significance of the establishment of foundations on which to conduct regenerative therapy

1.5.1 Pittsburgh in the United States as an example

Pittsburgh is one of the cities that succeeded in industrialization though the introduction of regenerative medicine. About a half of the cases of liver transplantation in the United States is conducted in Pittsburgh. In Pittsburgh, health care, education, etc., are provided under the leadership of the organ transplantation centers, and service industries have been actively developed in a wide variety of fields including organ transplantation (Table 3).

Factors which have contributed to the success of Pittsburgh as a tissue engineering industry city include; i) powerful motivation has been shared among Pittsburgh citizens to resurrect the city's faltering economy in the wake of the decline in the steel industry as well as, ii) the city's established intellectual infrastructure (For example, Dr. Starzl, a world-renowned

Table 3: Tissue engineering industry in Pittsburgh

	Total value for regenerative therapy-related companies in Pittsburgh
Number of related companies	26
Total market capitalization or valuation (estimated)*	4.3 billion dollars
Annual gross sales (estimated)	0.774 billion dollars

Source: Authors' compilation by making reference to the materials on the investigation conducted by the Pittsburgh Tissue Engineering Initiative in 2000, http://www.pittsburgh-tissue.net/industry/pdf/industry.pdf.

transplantation surgeon is a citizen of Pittsburgh, and many Japanese transplantation surgeons have visited him to receive training in transplantation techniques).

1.5.2 Trends in Japan —creation of foundations in the Osaka area

In Osaka and Kobe areas, there are universities, institutions and companies that have first-rate experts in the fields of research on physiologically active substances, research in embryology, research in regenerative medicine, transplantation medicine, research on cloning, research on tissue engineering, etc. Therefore, a project for health-care industrialization of the areas, under the initiative of Kobe City, has been proposed. This project has been contracted out as one of the district-oriented collaborative research projects funded by the Japan Science and Technology Corporation (JST), which is due to be completed in 5 years starting from 2000, and is aiming to build up comprehensive technological foundations for research on, and application of, regenerative medicine.

At present, collaborative efforts are being put forth by the Institute of Biomedical Research and Innovation (IBRI) of the Foundation for Biomedical Research and Innovation, which holds the core facility of the Kobe medical industry development project, the Center for Developmental Biology of the Institute of Physical and Chemical Research, the Tissue Engineering Center of the National Institute of Advanced Industrial Science and Technology, the Institute for Frontier Medical Sciences of Kyoto University, the Exploratory Medical Center at the Kyoto University Hospital, the Center for Future-oriented Medicine of Osaka University, and other related hospitals, etc. Under the current circumstances, the challenge to be addressed from now on is to let the collaboration system continue to function efficiently.

In addition to the project mentioned above, efforts shown in Table 4 are being made with the aim to establish international foundations for research in life science in the Osaka area.

Table 4: Efforts aiming to establish international foundations for research in life science in the Osaka area

(1)	**Establishment of integrated foundations in the northern area of Osaka and the Kobe area.** Enhancement of the functions as foundations for research, intensive enforcement of measures to support industrialization, etc.
(2)	**Facilitation of cooperation among integrated foundations for research in life science under the initiative of the Osaka and Kobe areas.** Development of a system to promote research though collaboration among government, academia and industry, and construction of high-capacity, high-speed information networks, etc.
(3)	**Provision of opportunities for deliberation by the authorities concerned, etc., to intensively facilitate comprehensive support.**

1.6 Bioethical issues concerning research using human embryonic stem cells

As discussed, in countries with advanced medicine including Japan, ardent expectations are placed on the application of embryonic stem cells for health care, while, deliberate arguments have been made about the bioethical aspects of the use of embryonic stem cells for experimental or therapeutic purposes.

Because human embryonic stem cells are derived from the inner cell mass removed from blastocysts, which have developed from fertilized embryos, early embryos are inevitably destroyed to obtain human embryonic stem cells (Figure 3).

Therefore, some researchers feel that an early human embryo intended to be destroyed to obtain embryonic stem cells is a mere cluster of cells, but other researchers believe that a human embryo should be regarded as a human being at the time of fertilization or at a certain stage of embryonic development, and that harvesting of human embryonic stem cells equals intentional destruction of a human being (Figure 4).

The clue to addressing the bioethical problem is given by the construction of an appropriate decision-making system. For example, such decision-making system can be built up by the disclosure of detailed information by researchers to the public as well as the provision of opportunities for discussions by people with different values agreeing to disagree, followed by the formulation of fixed rules. Concerning the disclosure of information by researchers to the public, discussions are held in the following chapter.

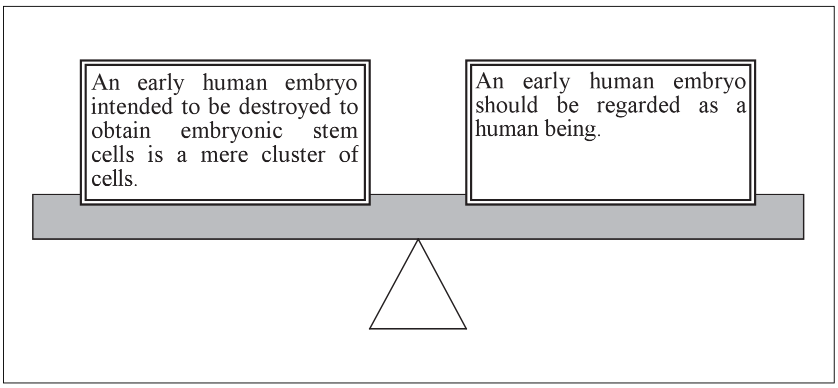
The first public discussion about ethical issues concerning research using human embryonic stem cells was held at the Human Embryo Research Subcommittee meeting under the Bioethics Committee of the Scientific Council. During the discussion, opinions were exchanged about bioethical aspects of studies using human embryos, mainly human embryonic stem cells, and the "Ethical Principles of Research on Human Embryos, Mainly Human Embryonic Stem Cells " were formulated.

Under the principles, it is specified that establishment of human embryonic stem cell lines should be conducted with great care, and can be performed only within a strictly constructed conceptual framework in consideration of both the benefit of research using human embryonic stem cells and the problems associated with the harvest of those cells, i.e., destruction of the early embryo as early human life. With regard to the use of established embryonic stem cell lines, it is specified that a conceptual framework should be developed because uncontrolled use could lead to the indiscriminate use of human embryonic stem cells, accelerate the destruction of human embryos in vain, and give rise to ethical issues derived from the pluripotency (capability to differentiate any kinds of cells) of such cells. Concerning the clinical study using human embryonic stem cells, it is specified that due consideration should be taken in terms of safety of clinical practices with the use of such cells, and that clinical studies on the introduction of human embryonic stem cells, or cells or tissue differentiated from such cells into an individual human body, should not be conducted until guidelines on clinical application of embryonic stem cells are developed.

In response to the formulation of the "Ethical Principles of Research on Human Embryos, Mainly Human Embryonic Stem Cells," the Ministry of Education, Culture, Sports, Science and Technology prepared the draft of the "Guidelines for the Establishment and Use of Human Embryonic Stem Cells" and invited comments about the guidelines from the public. Thereafter, the Ministry sought the advice of experts participating in the Council for Science and Technology Policy, Cabinet Office, about the draft guidelines in September 25, 2001. Then, following repeated discussions held under the leadership of the Bioethics Review Panel of Experts, which is a subordinate organization of the council, a report on the opinions of experts was submitted to the Ministry of Education, Culture, Sports, Science and Technology.

In this context, the "Guidelines for the Establishment and Use of Human Embryonic Stem Cells" was put into effect by the Ministry of Education, Culture, Sports, Science and Technology in September 25, 2001. These guidelines specify that human embryonic stem cells shall be handled with integrity and care lest the sanctity of human life should be violated. In addition, the guidelines provide that the establishment and use of embryonic stem cell lines shall be restricted to basic research for the time being (Article 2, Section 2). Furthermore, it is also stipulated in the guidelines that practical application of human embryonic stem cells such as the manufacturing of pharmaceutical products derived from such cells for use in clinical practice as well as the

Figure 4: How should the human embryo be interpreted?



Source: Authors' compilation by making reference to the materials provided by Professor Nishikawa

Table 5: Moves to address bioethical issues about the establishment and use of human embryonic stem cells in major industrialized nations

Country name	Date	Moves to address bioethical issues about the establishment and use of human embryonic stem cell lines
Japan	September 2001	According to the "Guidelines for the Establishment and Use of Human Embryonic Stem Cells," the establishment and use should be restricted to basic research for the time being.
Germany	1990	Under the Embryo Protection Law, people are absolutely prohibited from conducting any research using human embryonic stem cells.
United Kingdom	January 2001	Under the Human Fertilisation and Embryology Act, people are allowed to establish human embryonic stem cell lines from cloned human embryos.
United States	August 2001	Under an executive order, public monetary support may be provided to studies using human embryonic stem cells, but establishment of a new human embryonic stem cell line is prohibited.
France	———	Under the Bioethics Law, research on human embryonic stem cells excluding observations of such cells is prohibited. An amendment to the Bioethics Law is planned to be submitted to allow scientists to establish human embryonic stem cell lines from spare embryos.

massive supply of such cells to be used in drug toxicity tests, shall not be conducted for the present time.

Table 5 provides a summary of moves to address bioethical issues about the establishment and use of human embryonic stem cells in major industrialized nations.

1.7 Conclusion

To date, scientists have provided the general public with knowledge derived from scientific evidences they acquired in their research activities. In other words, scientists have

Figure 5: Process of the development of knowledge possessed by the scientific community into that shared among the public

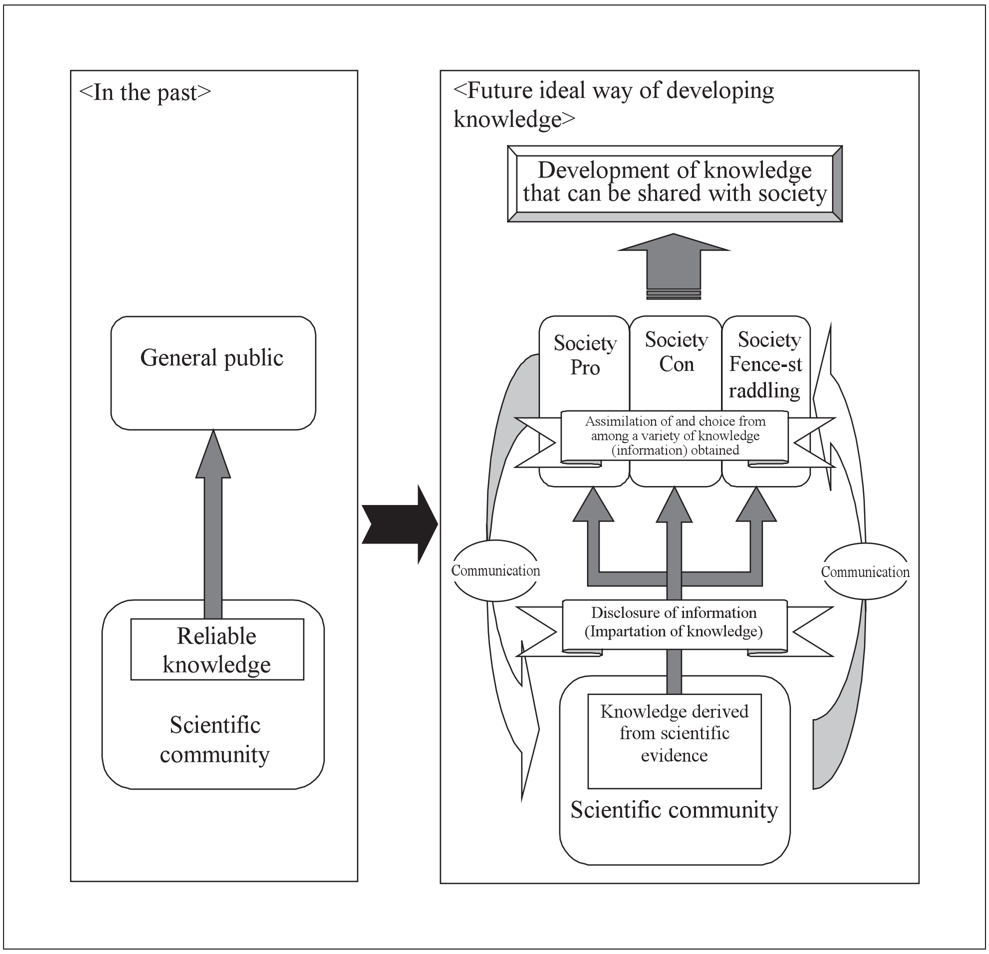


Figure 6: Requirements for the promotion of the development of knowledge within scientific circles into that shared among the public

Candid disclosure of information is required from experts in the field of life science

1. Sense of responsibility as, and candid disclosure of information by, scientists.
   - Establishment of the system of on-site observation tours to laboratories intended for people in the mass media, economic world and judicial world.
   - Improvement in communication between the scientific community and society.
2. Establishment of institutions as providers of life science-related information, which are accessible to everyone.

Source: Authors' compilation by making reference to the materials provided by Professor Nishikawa

conferred a benefit on society in that they have provided information that can be accepted as "reliable knowledge" by the general public, which will eventually bring profit to society by way of practical application.

Future challenges to be confronted by scientists, particularly in researches in the field of regenerative medicine, are to; build up and accumulate knowledge that can be shared among the general public, disclose information (knowledge) derived from their studies with high transparency, and communicate with the general public, which may have various opinions and may favor or oppose a certain subject in question or take a fence-straddling position (Figure 5).

In addition, it is desirable that institutions be established from which information digested into a more easy-to-understand form is continuously disseminated among the general public (Figure 6) (For example, at the Center for Developmental Biology [CDB] of the Institute of Physical and Chemical Research, discussions have been held by the Institutional Review Board (IRB) not only about various bioethical issues but also about how information obtained in research activities at the institute should be disclosed from the viewpoint of outsiders).

Acknowledgements

This article summarizes the contents of the lecture delivered by Dr. Shin-ichi Nishikawa, professor at the Graduate School of Medicine at Kyoto University under the theme "Recent trends in regenerative medicine-Impact of regenerative medicine" at the National Institute of Science and Technology Policy on September 12, 2001, with data incorporated from our study.

We are deeply grateful to Professor Shin-ichi Nishikawa who, on the occasion of the making of this article, willingly provided us with guidance and related materials. In addition, our profound thanks go to Professor Hideyuki Okano at Keio University, as well as Professor Yoshiki Sasai and assistant professor Hiroshi Kawasaki who provided us with valuable related materials.

(Original Japanese version: published in November 2001)

2

Trend Report on Bioinformatics

MARIKO SHOJI AND SHIN-ICHI MOGI
Life Science and Medical Research Unit

2.1 Introduction

In February 2001, the outline of the human genome was individually reported by the International Analysis Team and Celera Genomics. Now that the genome sequencing of 60 or more living species have been determined, the so-called post-genome sequencing studies are getting into full swing including gene expression analysis, protein structure analysis, proteome analysis, and intermolecular interaction analysis. These studies are intended to efficiently organize and analyze a vast amount of diverse biological information for elucidating the biological and medical implications. To fulfill such a mission successfully, bioinformatics is essential technology.

In this article, we give an overview of bioinformatics, focusing on the human genome studies, and list the challenges in this region.

2.2 Definition of Bioinformatics

Originally, the term "bioinformatics" has been used to refer to a specific region of study, in which the viewpoints and philosophy of informatics were incorporate into bioscience, although the meaning of it has been steadily extended.

Prof. Toshihisa Takagi of the Institute of Medical Science, Tokyo University defines bioinformatics as follows.

> "Information technology allows a boundless searching space (for example, the number of genes or proteins, or combinations of interactions between them), which has required manual examination or experiments for verification so far, to be narrowed down and its basic principle"

In the United States, the Biomedical Information Science Technology Initiative (BISTI) consortium of the National Institutes of Health (NIH) differentiates the term "bioinformatics" from the term "computational biology."

> **Bioinformatics**
> Research, development, or application of computational tools and approaches for expanding the use of biological, medical, behavioral or health data, including those to acquire, store, organize, archive, analyze, or visualize such data
> **Computational biology**
> The development and application of data-analytical and theoretical methods, mathematical modeling and computational simulation techniques to the study of biological, behavioral, and social systems.

Both of the two terms have almost the same underlying concept and NIH, perhaps, differentiates between them to represent immediate challenges specifically.

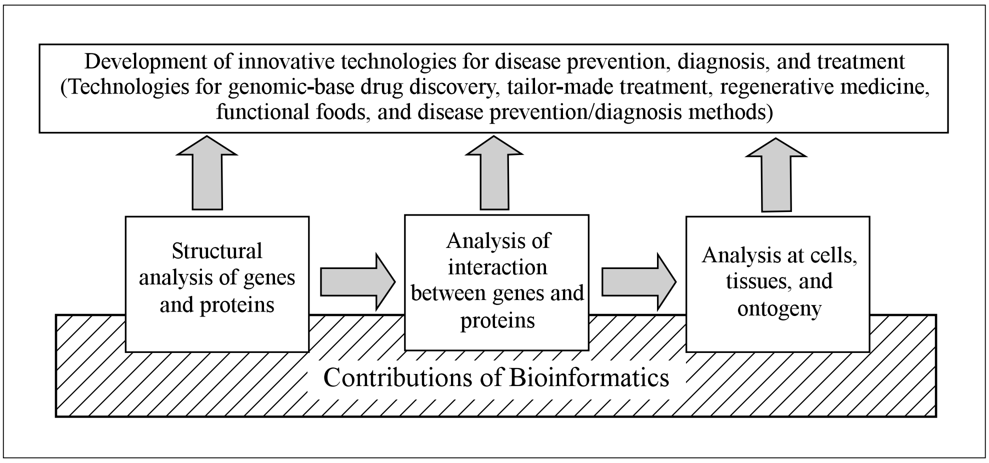
This section describes "What is bioinformatics?," closely focusing on the concept of bioinformatics defined by NIH.

2.3 Positioning and Categorization of Bioinformatics

2.3.1 Positioning of Bioinformatics

Bioinformatics plays an important role as one of basic technologies supporting researches in the life science area, mainly using genome analysis (Figure 1).

Figure 1: Positioning of bioinformatics in the life science area



2.3.2 Categorization of Bioinformatics in the Post-genome Research Area

Table 1 shows the direction of the post-genome researches, the database of bioinformatics supporting it, and the data analysis methods. The post-genome researches have been shifted from those on the "structure field" into the "relationality field" and oriented toward researches on cellular and ontogenetic functions (the "function field") for the systematic elucidation of life.

In the "structure field", various types of analyses including the DNA sequences and protein structure analyses are categorized. Homology search is one of data analysis methods commonly used in this field. This method compares DNA sequences, and extract knowledge of gene structures, functions from those homologies. Furthermore, another methods have been developed, which allows us to estimate the specific sites of genes based on the statistical characteristics observed in the gene sequences.

On the other hand, in the "relationality field," the gene expression analysis, which determines whether genes are switched on or off, and the intermolecular interaction analysis, which detects any interactions among proteins and others, are categorized. These analyses treat gene classification based on gene expression information under various conditions and intracellular localized site prediction, which predicts how proteins behave in the cells based on the physiochemical characteristics of proteins estimated from amino-acid sequences.

In the "function field", the analysis methods are grouped and include those for elucidating signal transmission among the cells and the ontogenetic mechanism.

Table 1: Categorization of bioinformatics in the post-genome research region

	Subject	Database	Data analysis
Structure	Sequence, Structure	DNA sequences, Gene polymorphism, Protein-amino acid sequences, Protein structure, etc.	Homology search, Gene discovery, Motif extraction, Protein structure Prediction, etc.
Relationality	Expression, Localization, Interaction	Gene expression information, Intermolecular interaction, Proteome, etc.	Intracellular localized site prediction, Intermolecular interaction prediction, Gene expression clustering, etc.
Function	Cell function, Ontogenetic function	Signal transmission, Ontogenetic/ Physiological function, Immune function, Brain function, etc.	Pathway comparison, Computer simulation, etc.

R & D is under progress.

Some type of future strategic motivation is critical.

Source: Authors' compilation based on materials from Prof. Toshihisa Takagi, the Institute of Medical Science, Tokyo University

In this field, however, few useful data analysis methods have been developed.
At present, public funds are invested almost exclusively in researches and developments in the "structure field", and its infrastructure is being consolidated. As opposed to this field, almost no large-scale attempts have been made toward database arrangement and development of data analysis methods with respect to the "relationality" and "function field". This is true, especially, of the latter field. To facilitate the evolution of these out-of-stream fields, some type of strategic policy for motivation must be developed in the near future.

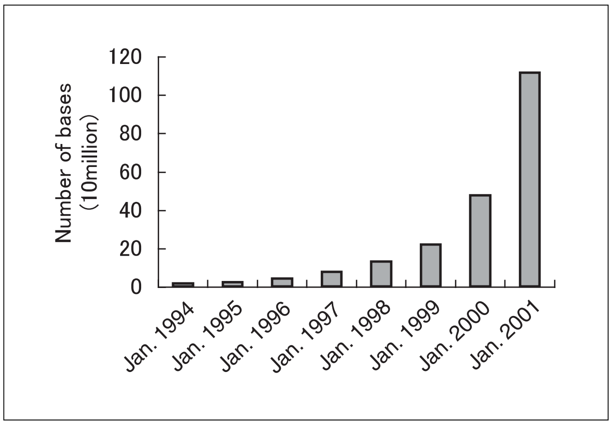
2.4 Current Status of Bioinformatics

2.4.1 Database

(1) Rapid increase in data amount

The parties concerned are obligated to register any obtained information on decoded DNA sequences and others into any of the public databases of GenBank (U.S.), EMBL (Europe), and DDBJ (DNA Databank of Japan). These three databases maintain consistency in data generation with each other, because they exchange data among themselves. In recent years, the data amount has drastically increased as can be seen from the fact that a vast amount of DNA sequences were registered, for example, 11.1 billion in January 2001 and 14.1 billion in October 2001, all of which reflect the recent, rapid progress in this area, which include registration of a large number of partial mRNA sequences (EST) into the databases and un-intermitted elucidation of the DNA sequences of various species of organisms (Figure 2).

Figure 2: Transition in the number of bases registered in DDBJ



Source: Authors' compilation based on DDBJ data

In data organization, not only base strings are enumerated but they are also annotated with various data clarified by analyses, such as the locations of gene information coding regions as well as the structures and functions of genes, and with the literatures related to these genes, all of which are registered together into the databases. In the future, it is important to make annotation attached to sequence data both qualitatively and quantitatively complete, as sequence data described here increases.
Additionally, the data structures come into the complex phase as data on gene expression under various combinations of conditions and on intermolecular interaction are added. For this reason, various requirements constantly would arise such as further speed-up and increased disk capacity of information system devices. Besides, another important challenge to be solved is to store high quality data in the databases through researcher's updating of annotation.

(2) Examples of databases

Table 2 shows typical databases commonly used in the genome research region and others. Generally, DNAs are easier to be purified than proteins and their sequences can be determined with less difficulty using a DNA sequencer, which makes the database consisting of DNA sequences the largest of all the databases. In addition to those described in section (1), the public databases include the databases containing DNA sequences of human genes and Single Nucleotide Polymorphisms (SNPs).
Additionally, there exist various types of databases containing gene information such as amino-acid sequences of proteins, motif sequences useful in predicting gene functions, and protein structures. It is said that about 400 types of databases can be found throughout the world.
Note that the journal "Nucleic Acids Research," published on January 1 every year, features these databases.
In Japan, for most of the databases, frequent access from abroad is not authorized except for some, as example, the pathway database. For us, Japanese researchers, to lead the post-genome researches in

Table 2: Examples of databases

Content in database	Database name (country)	Content in database	Database name (country)
DNA sequences	GenBank (U.S.) EMBL (Europe) DDBJ (Japan)	Amino-acid sequences	SWISS-PROT (Europe) PIR (U.S.)
DNA sequences of human genes	UniGene (U.S.)	Amino-acid sequence domains	Pfam (Europe)
Single Nucleotide Polymorphisms	dbSNP (U.S.) JSNP (Japan)	Amino-acid motifs	PROSITE (Europe) BLOCKS (U.S.)
Genetic diseases	OMIM (U.S.) Mutation Database (Europe)	Protein structures	PDB (U.S.), SCOP (Europe) CATH (Europe)
General human sequence informations	HGREP (Japan) Ensembl (Europe)	Pathways	KEGG/PATHWAY (Japan)
General human informations	LocusLink/Refseq (U.S.) GDB (Canada)	Literatures	MEDLINE (U.S.)

the world, it may be required to build original databases on a larger scale to deliver gene information to the countries throughout the world.

(3) Integration of databases

To successfully perform data analysis using bioinformatics, combinations of various databases and searching systems are often used instead of only one kind of database. For this reason, systems, which link various databases and searching systems into one integrated system, have been developed. Table 3 shows examples of typical integrated database searching systems.

One problem about database integration to be solved lies in that no standardization and coordination have been made for the methods for displaying database data and for describing searching conditions. In other words, it is important that a systematic theory (ontology) be built using the refined lexis system and describing method rather than using the concept and terminology specific to each subject of search.

For example, in the United States, Interoperable Informatics Infrastructure Consortium (I3C), which consists of more than 40 biochemical businesses and information system and/or service providers such as INCOGEN and Oracle, was founded in January 2001 and has commenced activities on propelling standardization efforts for data exchange, management, and others in the life science area. At present, I3C is working on the standardization task of XML data description and the communications protocol.

Table 3: Examples of typical database searching systems

Integrated system	Service provided from
DBGET (Japan)	Institute for Chemical Research, Kyoto Univ., Institute of Medical Science, The Univ. of Tokyo
Entrez (U.S.)	National Center for Biotechnology Information (NCBI)
SRS (Europe)	European Molecular Biology Laboratory (EMBL)

2.4.2 Hardware

As described in 2.4.1 (1), in the bioinformatics, it has been increasingly required that a high level information system, based on a series of high performance computers (super computers), be built to address the rapid increase in data amount.

Table 4 shows the estimation of computer performance needed for genome analysis. Assuming some possible evolution in the technologies for describing and simulating the complex systems such as the life system, a parallel computer system with a performance ranging from several-ten to several-hundred Tera flops,

Table 4: Computer performance needed for major genome analyses

Genome analysis	Performance (flops)
Protein family classification	1 Tera
Phylogenetic diagram	10 Tera
Sequence assembly	10^2 Tera
Sequence comparison	$>10^2$ Tera
Gene modeling	10^5 Tera

Source: Authors' compilation by making reference to the materials provided by Professor Nishikawa based on the data of the 2000 Report "Advanced Computational Structural Genomics", U.S. DOE Scientific Simulation Initiative (SSI) which consists of several thousands or even several-ten thousands of processors, may be required ("Strategy for Genome Information Science in Japan"—the Genome Science Committee, Life Science Working Group, Council for Science and Technology Policy, November 2000).

For example, ASCI white, which was ranked first out of the "TOP 500 worldwide high-performance computers" announced in November 2001, has 12.3 Tera flops of peak performance.

In the bioinformatics, parallel processing systems and parallel computers are under development. On the other hand, software development lags behind, for example, delays due to difficulties in integrating applications running on high-performance computers into the parallel system. (Note: flops is a measure of calculation performance indicating the speed a computer can calculate floating-point calculations. Tera=10^{12})

2.4.3 Data Analysis Methods and Software

Table 5 lists the data analysis methods for identifying the desired knowledge from databases and software executing these methods.

2.4.4 Industrialization of Bioinformatics

In recent years, bio-related venture businesses have proactively developed their activities centering around developed countries in the world; as of 2000, about 160 in Japan, about 1,300 in U.S., and about 700 in Europe.

In the bioinformatics, such bioinformatic businesses actively participate in this industry

Table 5: Main data analysis methods and software

Method	Descriptions of analyses and example software
Homology search	Compares among sequences to extract knowledge based on their homology and is most commonly used. BLAST, FASTA, and Smith-Waterman, as well as high-sensitive programs, which can extract even weak homology, such as PSI-BLAST, SAMT99.
Gene discovery	Estimates genes based on statistical characteristics observed in gene sequences and is used to extract unknown genes, which cannot be discovered by homology search. GENSCAN and DIGIT.
Motif extraction	Identifies characteristically short sequences (motif), which are found in DNA binding sites and functional sites such as an oxygen active center. Compares sequences against the databases containing motifs of amino-acid sequences, such as PROSITE.
Intracellular localized site prediction	Based on hydrophobicity indexes of amino acids, physicochemical properties of electric charges, and the sequences of localized signals, etc., predicts where biosynthesized proteins go within cells. Signal P, which predicts the positions of signal sequences, PSORT, which predicts localized positions, and SOSUI and TMHMM, which predict membrane-penetrating regions.
Protein structure prediction	Swiss-Model and MODELLER homology modeling software, which predict protein structures based on homology among sequences. DALI and MODBASE, which determine similarities based on the results of comparison among protein structures.

Source: Authors' compilation by referencing the "Genomic Medical Science and Introduction to Bioinformatics", Experimental Medicine Vol. 19, No. 11 (extra number) P. 61-66, P. 73-81

Table 6: Main bioinformatics-related venture businesses in the United States and Europe

Company	Business
Incyte Genomics (U.S.)	cDNA database, gene expression (DNA chips), etc.
Human Genome Sciences (U.S.)	Secretory protein database, membrane protein database, gene drug development, etc.
Celera Genomics (U.S.)	Genome database (human, mouse, and Drosophila), proteome, SNP, etc.
Gene Logic (U.S.)	Gene expression database, etc.
CuraGen (U.S.)	Gene expression database, SNP database, etc.
Genset (France)	Disease analysis using SNP database, etc.
deCODE genetics (Iceland)	Clinical database, genealogy database, polymorphism database, etc.

Source: Authors' compilation by making reference to the materials provided by Professor Nishikawa based on the "Genome Information Ventures (P. 96-102), Leading Edge of Genome Medical Science and Worldwide Bio-Ventures, Yodosha, 2001 such as those providing the databases and software, which are customized for user requirements. To successfully perform research and development using genome information, any data management system and search assistance system, which can satisfy the requirements including higher security, faster analysis, and adaptation to individual researches, are essential in addition to public databases and software commonly available. Table 6 shows main bioinformatics-related venture businesses in the United States and Europe.

2.5 Activities for Propelling Bioinformatics

2.5.1 Political Principle

Recently, political emphasis has been laid on bioinformatics in many countries throughout the world, assuming that it is critical to propel researches on genome. Table 7 shows the main propelling bases for bioinformatics in the United States and Japan. Besides, active measures are conducted mainly in the laboratories of universities.

In Japan, bioinformatics was listed as one of the challenges to be exclusively and strategically tackled in the life science area in the 2nd-stage Science and Technology Basic Plan (decided by the Government of Japan, March 2001). In addition, it was listed as one of the emphasized issues in the "2001 Emphasized Guideline on Advancement of Science and Technology" (Policy Committee, Council for Science and Technology Policy, June 2000), with 10.4 billion yen budgeted for 2001. In 2002, the Ministry of Education, Culture, Sports, Science and Technology founded the Institute for Bioinformatics Research and Development (Chiyoda-ku,Tokyo) and the Ministry of Economy, Trade and Industry formed the Japan Biological Information Research Centre (Kohto-ku, Tokyo) and the Computational Biology Research Center (Kohto-ku, Tokyo), respectively. The Japan Biological Informatics Consortium (JBiC), consisting of 87 businesses in the private sector, is making great efforts in bioinformatics research and development.

In the United States, from an early stage, bioinformatics actively advanced under the leadership of NIH. NLM, which has jurisdiction over NCBI, playing a core role in bioinformatics in the United States, was budgeted about 246 million dollars (about 29 billion yen) for 2001.

In addition, in 2001, the Center for Bioinformatics and Computational Biology (CBCB) was founded as an organization, which fosters bioinformatics

Table 7: Main bases for propelling bioinformatics in Japan and the U.S.

Japan	Ministry of Education, Culture, Sports, Science and Technology	Center for Information Biology and DNA Data Bank of Japan, National Institute of Genetics Human Genome Center, Institute of Medical Science, Tokyo Univ. Bioinformatics Center, Institute for Chemical Research, Kyoto Univ. Genomic Sciences Center, Institute of Physical and Chemical Research (RIKEN) Institute for Bioinformatics Research and Development, Japan Science and Technology Corporation(JST)
	Ministry of Economy, Trade and Industry	Computational Biology Research Center (CBRC), National Institute of Advanced Industrial Science and Technology(AIST) Japan Biological Information Research Centre (JBIRC), National Institute of Advanced Industrial Science and Technology (AIST)
		Japan Biological Informatics (JBiC), etc.
U.S.	Department of Health and Human Services (DHHS) National Institutes of Health (NIH) ├ National Library of Medicine (NLM) │ └ National Center for Biotechnology Information (NCBI) ├ National Institute of Biomedical Imaging and Bioengineering(NIBIB) ├ National Institute of General Medical Sciences (NIGMS) │ └ Center for Bioinformatics and Computational Biology (CBCB) ├ National Human Genome Research Institute (NHGRI) └ Biomedical Information Science and Technology (BISTI) Consortium Department of Energy (DOE) Office of Biological and Environmental Research (BER) National Science Foundation (NSF), etc.	

researches, and will subsidize about 10 million dollars (about 1.2 billion yen) to universities and other institutes during its the initial year. Furthermore, DOE, NSF, DARPA(Defense Advanced Research Projects Agency) and others propel researches in the bioinformatics area.

In Europe, EMBL(European Molecular Biology Laboratory) and EBI(European Bioinformatics Institute ; one of the divisions of EMBL) as well as Sanger Center (U.K.) are playing core roles in developing bioinformatics. The public bioinformatics budget of Europe for 2000 is 100 million Euro dollars (about 10 billion yen), among which 10 million Euro dollars is allocated to EBI.

2.5.2 Activities for Training

With respect to recent researches in the life science area, the quality and performance of bioinformatics tools to be used and techniques for making full use of them are the main factors contributing to the progress of research and development. For this reason, the need for talents who can use these sophisticatedly tools and people who can develop superior algorithms and software, has rapidly increased. However, since this bioinformatics is a new study, a sufficient amount of personnel has not been trained and training has become a major problem to be solved in many countries.

"Strategy of Genome Information Science in Japan" (November 2000, Genome Science Committee, Life Science Working Group, Council for Science and Technology Policy) defines the tentative requirements for training as follows.

1) Training of adaptable talents: Development of education and training programs to make full use of existing talents, as well as provision of training opportunities and incentives.
2) Training near-future and future talents: Formation of bases for giving places where communication of research information and experiment of test and fault is achieved by reorganizing graduate school courses and major subjects of universities.

With respect to requirement 1), for example, Institute for Bioinformatics Research and Development, Japan Science and Technology Corporation(JST), commenced the "Genome Literacy Course," a practical training program, in cooperation with the Human Genome Center, Institute of Medical Science, Tokyo University, in 2001. In this course, a training program is provided for researchers to learn the methods of using databases and analytical software.

With respect to requirement 2), a new business for training was started in 2001 ,by allocating the 2001 Special Coordination Funds for Promoting Science and Technology (SCF), and four themes were adopted. For example, Keio University's "System biologist education and training program" was initiated, in which a new life information course will be established in the Department of Science and Engineering. This program is intended to help students learn about experiments and computer science as one method for understanding biology based on chemistry, physics/information, and mathematics. This program has as its target that about 40 graduated students and about 25 masters will be provided to pharmaceutical and computer companies and consulting firms.

In the United States, the subject of training is actively attacked as well. The divisions of NIH include the Fogarty International Center (FIC), the National Cancer Institute (NCI), the National Institute of Aging (NIA), the National Institute of General Medical Sciences (NIGMS), the National library of Medicine (NLM), and the National Human Genome Research Institute (NHGRI). Out of them, for example, NLM invested funds in 12 training programs such as those in Yale University and Columbia University.

2.6 Conclusion

Bioinformatics can be viewed as not only a basic technology supporting the researches in the life science area but also as a new region bearing the life science aera, a fused interdisciplinary area.

At present, to analyze DNA sequences and protein structures, databases and data analysis methods are being reorganized. In the future, research and development of databases and data analysis methods needed for researches on cell functions and ontogenetic functions must be strategically advanced.

Since databases are the foundation for data analysis, it is necessary to always attain high quality data. It is important that appropriate data management, such as update of annotation data, is maintained.

With respect to hardware, even the current highest-performance computers are insufficient for various types of genome analyses, and further improvement of performance is required. Similarly, software must be improved so that applications running on high-performance computers can be integrated into one parallel system.

In Japan, efforts in forming the bases for propelling bioinformatics and in developing and implementing programs for training have just started. Considering the importance of bioinformatics in the future life science area, it is desirable that further continuous policies are implemented.

Acknowledgement

We would like to express our deep thanks to Prof. Toshihisa Takagi of the Institute of Medical Science, The University of Tokyo for his valuable advice and the provision of the related materials.

(Original Japanese version: published in December 2001)

3

Recent Trends in Supercomputers

MASAO WATARI
Information and Communications Research Unit

3.1 Introduction

After the first supercomputer was developed in the 1970s as high-end computers having fastest computing capabilities, supercomputers have been steadily improving in their performance as shown in Fig. 1. According to the TOP500, the list of the world's fastest supercomputers* released in June 2001 (refer to our August, 2001 issue of Science and Technology Trends), ranking No. 1 was ASCI White, which was developed in the U.S. as part of the ASCI project and has a peak speed of 12.3 teraflops*1. In Japan, on the other hand, the Earth Simulator, a supercomputer with a 40 teraflops speed, is expected to start running in early 2002.

Meanwhile, driven by the growing PC market, development of general-purpose processors is vigorously pushing forward, showing remarkable performance improvements. Today's workstations and PCs have computing power equivalent to that of supercomputers ten years ago. For their cost advantages, workstations and PCs are often used even for scientific and technological computation recently.

However, supercomputers are still playing important roles as massive-scale computations are required in many basic science research fields, where supercomputer performance enhancement is the key for the area's research advancement. Supercomputer technology is vital not only for advancing a computer technology but also for providing an essential tools to advance basic science research.

Thus the environment surrounding supercomputers is changing rapidly. This report describes trends in performance and applications of supercomputers and then, discusses the future roles and prospects of supercomputers with a view of the trends in their applications

3.2 Supercomputer hardware trends

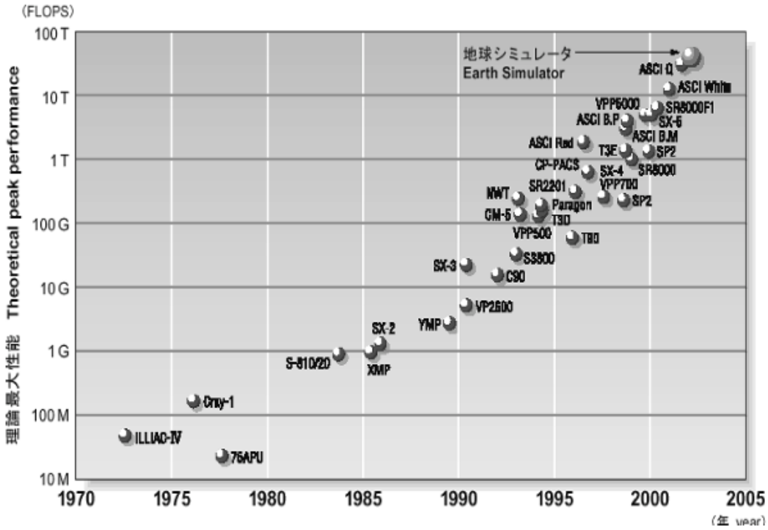
3.2.1 Supercomputer performance developments

The history of supercomputers started in 1971, when ILLIAC IV was developed at the University of Illinois, followed by the shipment of the first commercial model Cray-1 by Cray Inc. in 1976. In the early 1980s, supercomputers began their rapid development in the U.S., and Japanese makers followed. In the U.S., in the 1990s, vector supercomputers declined*5, and scalar parallel supercomputers were developed by adopting general-purpose processors which are used for workstations and PCs. On the other hand, in Japan, performance of vector supercomputers was further enhanced, because processor speed was more important than massively parallel processing for fastest computers.

Since the supercomputer market is not very large despite high development costs for supercomputers, the market is affected by large impacts from funds granted through national projects. Described below are the latest, ongoing supercomputer development projects in Japan and the U.S.

* While supercomputers are often referred to as high performance computers (HPC) these days, the more popular term "supercomputer" is used in this report.

Figure 1: Supercomputer performance developments



Source: Earth Simulator Research and Development Center

(1) The ASCI (Accelerated Strategic Computing Initiative) project in the U.S.

Through the ASCI project, which started in 1995, three laboratories under the umbrella of the Department of Energy (DOE) are working on developing the highest-performance supercomputers while providing support for hardware manufacturers.

By investing about ¥140 billion over ten years, they are aiming to realize a peak speed of 100 teraflops by 2004. In October 1996, the ASCI Red system achieved 1.8 teraflops, followed by the ASCI Blue, which achieved 3 teraflops in October 1998, and the ASCI White, which provided a 12.3 teraflop performance in June 2000. Furthermore, in 2002, ASCI Q, a supercomputer aiming at 30 teraOPS (about 24 teraflops), is scheduled to be delivered.

To achieve such high processing speeds, the ASCI project employs a large number of general-purpose processors connected in a parallel configuration to build a massively parallel scalar supercomputer. For ASCI White, as many as 8,192 processors are connected in parallel. Because of their system's massively parallel structure, emphasis is also placed on the development of software that can efficiently execute parallel processing.

(2) The Earth Simulator project in Japan

The Earth Simulator, a five-year project with a ¥40 billion budget, was started in 1997. In this project, a 40 teraflop supercomputer is being developed to elucidate and predict global climate changes such as global warming, unusual weather, and meteorological disasters. The project seeks to find solutions to global environmental problems as well as to contribute to developing measures against natural disasters by creating a "virtual Earth" model on the computer.

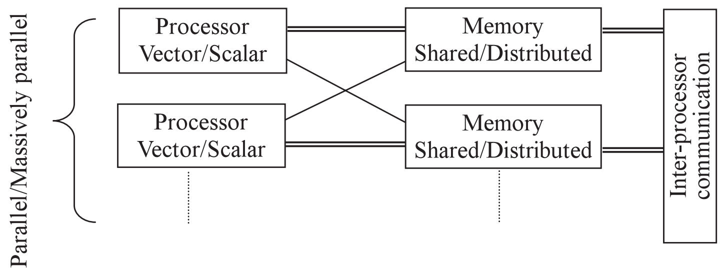
The Earth Simulator uses 5,120 vector processors connected in parallel, shared memory, and a high-speed network interface technology. Vector processors are adopted, because vector parallel computers have five to ten times the efficiency of massively parallel scalar computers, and Japan is leading the vector technology field. As of the beginning of 2002, when it starts operating, the Earth Simulator will be the supercomputer with the world's highest performance.

(3) Difference in strategies for development between Japan and the U.S.

The U.S. is focusing on increasing throughput by parallel processing rather than improving per-processor computing speed, because in the high-performance computer (HPC) market, the business sector (for transaction processing, etc.) market is larger than the scientific and technological computing market. The overall performance has been enhanced by implementing more than 1,000 general-purpose scalar processors in parallel. On the other hand, Japan is focusing on enhancing vector processors

Figure 2: Supercomputer performance factors and features

Vector processors	Designed specifically for scientific and technological computing to allow high-speed calculations.
Scalar processors	Low-priced general-purpose processors. Their performance has been remarkably enhanced.
Parallel architecture	Higher-class supercomputers having multiple processors in parallel.
Massively parallel configuration	Massively parallel configuration has more than 1,000 processors. Development of software for massively parallel processors is crucial.
Shared memory	Multiple processors shares the same memory. Memory access is high speed and a broad range of data can be accessed.
Distributed memory	Each processor has its own memory. Access to other processor's memory is made via inter-processor communication, and thus slow. PC clusters use the distributed memory system.
Inter-processor communication	High-end supercomputers adopt dedicated high-speed networks, and on the other hand PC clusters adopt general-purpose LAN.



continuously, which are more suited for scientific and technological computing. This leads to enhance computing capability with suppressing increase of number of processors in parallel. This superior vector processor technology is viewed as one of the few computer technologies that Japan has a leading edge over other countries.

However, performance of a supercomputer is determined not only by the processor speed but also by the memory architecture and data transfer method between processors. There are many components which may cause high price. Also note that as every supercomputer has processors in parallel with various scale, development of efficient parallel processing method is crucial. Figure 2 summarizes supercomputers' performance factors and their features.

3.2.2 Emergence of the PC cluster system

As the computing capabilities of PC processors increase, PC clusters, which are enabled by connecting a large number of high-performance PCs via a high-speed network, have emerged. A PC cluster reaches the same performance level of a supercomputer at a lower investment because it allows massive PCs running simultaneously in high speed network. The technology has already been commercialized in the U.S, while in Japan the Real World Computing Partnership (RWCP) is working on research and development with a plan for commercialization.

As a PC cluster with 1,000 processors that achieves 550 gigaflops*1 on the Linpak benchmark has already been realized, further performance upgrades are expected as processor performance increases. While PC clusters are not yet as fast as high-end supercomputers, their excellent cost effectiveness is worthy of attention. However, their performance is enabled only when applications allow parallel processing and limiting data transfer between PCs. Therefore, PC cluster systems will find a wide range of applications in areas where parallel processing gives an effective solution, for example, genome information processing or web search engines.

3.2.3 Dedicated computers

A processor specifically designed to perform specific computations at a high speed can contribute to building a low-cost computer that has performance equivalent to or beyond a supercomputer. For example, there is a computer with a dedicated LSI to calculate inter-particle dynamics and data matching. It can execute celestial simulations, protein structure analysis, and other complicated calculations at a high speed.

Challenges concerning this technology are the need for specifically developed software and continuous competition with general-purpose processors whose performance continues to improve.

3.3 Grid computing: a new move in networked computing technology

As an example of widely distributed computing system over the Internet, there was a demonstration to prove the possibility of large-scale computing by gathering participating PCs' idle time through the peer-to-peer technology*2. In the case of a project led by the American Cancer Society and others with a mission to discover candidate substances to cure leukemia, 900,000 PCs took part to achieve effects equivalent to a world's top-class supercomputer (4 teraflops) in terms of provided CPU hours during a six-month period, assuming the average participating computer performance was 50 megaflops. While attracting attention as an attempt to compete with expensive supercomputers, this effort showed the limitations of such systems: a computation must be completed inside a participating PC and it must need a large number of contributors who are willing to offer their computing power for free or at a low price.

Meanwhile, a concept of providing unified computing power by connecting multiple computing centers was proposed in 1995. This scheme is called as grid computing in analogy to a power grid in which people can use energy without knowing where it is generated. It allows use of a supercomputer via a network but does not enhance the original computing power. The advantage of this technology is that scientists can form a networked community through exchanging and communizing their computing resources (computing power and data), so that their research projects can be accelerated through the use of shared software and data. There are many projects underway in the U.S. and Europe. U.S. examples include the National Technology Grid for NSF infrastructure construction, the Grid Physics Network to create a huge physics database, and the Information Power Grid to provide NASA with a seamless computing environment. EU has established its European Data Grid designed for high-energy physics, earth observation, and biotechnological research. The British government is, as part of its e-Science program, pushing forward a number of joint projects focusing on applying grid technologies, together with a project to build an infrastructure to support them. Meanwhile, the Global Grid Forum is taking the initiative in international standardization of grid technologies.

These grid technologies are not a mere application technique of supercomputers but a scheme that, in the future, will allow any person to access and use networked information resources from anywhere, anytime. They can be the next-generation Internet technology, if challenges such as resource management, security, privacy, and copyright problems are successfully overcome.

3.4 Supercomputer application fields

To provide an overview of the future needs for supercomputers, how they are currently used in major application fields, and what are their future goals will be discussed. The overview is summarized in Table 1.

(1) Prediction of Weather, Climate changes, and the Global environmental change

Today's weather forecasts are significantly improved in accuracy by using supercomputer simulation in addition to the conventional empirical method. For the further improvement, it needs a computer simulation using a finer mesh model. For example, local-level forecasts for concentrated heavy rains require the description of cumulous clouds with a resolution down to a few kilometers. If the mesh resolution is refined by one tenth, required computing power increases 1,000 times.

Regarding climate changes, it is known that global-level weather phenomena, such as the El Nino, Asian monsoon, and Aleutian low, have a large impact on the climate changes in Japan. However, due to the limit of computing capability, the current simulation is performed on individual or regional models of the atmosphere, ocean, earth's surface, and cryosphere. If a global model or an integration model of the atmosphere and ocean can be created, the accuracy of climate change prediction is expected to dramatically increase.

Elucidating the mechanism of global climate changes such as global warming and diminishing forest is a critical issue for the entire world. This research requires massive-scale simulations by using worldwide data. Rendering with a resolution of about 10 kilometers will allow examination of model of the global warming mechanism.

The Earth Simulator, the world's fastest supercomputer that will start operation in 2002, is expected to dramatically facilitate progress in research in this area by allowing scientists to create a "virtual Earth."

(2) Bioinformatics

In the bio technology field, analysis of gene information is making rapid progress supported by supercomputers. In particular, bioinformatics, a combination of bio technology with information technology, is drawing big attention recently. Now that most of the human genome*3 has been analyzed, scientists are shifting their focus to solving protein structures. Their future targets include elucidation of cell differentiation and proliferation, development of medicine to cure malignant diseases, and analysis of biochemical reactions.

Research in bioinformatics requires massive data processing and analysis, for instance, deciphering 35,000 genes from 3 billion base pairs of the human genome, or performing three-dimensional structural analysis to identify 10,000 basic structures and functions of protein generated from genes. While most of such computations can be done through parallel processing, some complicated analyses can not run in parallel. In general, a parallelising such computation may be up to 1,000 elements. In order to use more parallel processors simultaneously, a breakthrough at parallel processing algorithms is awaited.

Protein's chemical reaction mechanism is being partly analyzed, and it can be solved through molecule chemical simulation based on quantum mechanics. Its computation volume is defined in proportion to the fourth power of the molecule size so that approximation methods are being researched in order to reduce the computation volume. Current supercomputers can simulate 100 atoms behavior during a period of nanoseconds. However, analysis of chemical reactions requires computer simulation of phenomena that last some microseconds to milliseconds, scientists are looking forward to seeing petaflop*1 computers.

(3) Materials simulation

In the field of nanotechnology, the structure and properties of materials can be derived by computer simulation. In a quantum mechanical method called First Principle simulation, specific atoms are combined inside a computer to virtually create new materials or structure for investigating new properties. Since this method does not use empirical parameters, a researcher can investigate the characteristics of completely new materials through computer simulations without the need to conduct a preliminary experiment to obtain parameter data.

The latest supercomputers can provide computing power to simulate up to 100 level atoms, standing at the entrance to the nano-scale world. A next challenge is to design a system that needs more atoms to simulate, while allowing more macroscopic analysis of properties and development of new methods for materials generation. As the computing volume increases in proportion to the third or greater power of the atomic mass, research and development to find techniques to reduce the volume is underway.

So far, due to insufficient computing power, computer simulation is limited in its applicable field and thus further development of supercomputers is looked forward greatly.

(4) Structure analysis and Fluid analysis

Structure analysis or fluid analysis is conducted through a numeric analysis where the subject is divided into fine meshes. When the number of meshes becomes huge in case of complicated form, a supercomputer is needed for its calculation.

As a structure analysis example, a car's structure is rendered on a computer to simulate a collision in order to analyze what happens. A supercomputer can complete such collision analysis in a short time (overnight) so that result of analysis is reflected into designs. A supercomputer simulation enables to speed up the overall process of designing a car with enhanced safety.

Fluid analysis examples include simulation of strong winds blowing through tall buildings and analysis of air resistance to a car or high-speed train. Since recent high-end PCs have enough computation power to simulate simple-shaped subjects, this technique is widely used in the industry applications.

For an accurate analysis of real world phenomena, coupled simulation[*4], in which structure analysis and fluid analysis can be simultaneously performed, is often required for the use of a supercomputer. As examples, coupled simulation are required for design of an aircraft wing (fluid mechanics + structural mechanics), analysis of engine combustion (heat + chemical reaction + fluid dynamics + structural mechanics), and simulation of blood flow in a blood vessel or a heart (fluid mechanics + structural mechanics). Analysis of fluid noises such as those generated by winds against pantographs or by a train entering into a tunnel requires more than one billion grids. Its computation can be done by a supercomputer equivalent to the Earth Simulator. In general a vector supercomputer works more efficiently for fluid analysis. In the case of simple fluid analysis without requiring many computations among remote grids, parallelizing processors is expected to be up to 10,000.

(5) Celestial mechanics and Elementary particle physics

The secrets of the universe, such as formation of the Galaxy from fluctuation in the early universe, and creation of a black hole and planets in the solar system, are researching through computer simulation. By modeling the universe as multiparticle gravitational interaction, scientists are carrying out simulation on a supercomputer or a dedicated computer having high-speed gravity computation capability.

On the other hand, in the area of basic physics that deals with atomic nuclei and elementary particles, supercomputers are used to simulate their behavior in each of a vast number of microscopic grids, to elucidate new properties of atomic nuclei and elementary particles.

Whether the subject is the universe or the atom, researchers use a supercomputer for simulating basic theoretical models to understand phenomena that are extremely difficult to observe. The supercomputer is an essential research tool for them.

(6) Nuclear fusion

Simulation by supercomputers plays an important role in the study of fusion energy, which is expected to become a future energy source. Since there is no complete established theory for fusion plasmas, scientists must analyze simultaneously both particle and fluid level phenomena for a collection of a huge number of particles. They are now building the theory of plasma on the basis of their knowledge obtained through experiments and computer simulations. Simulating behavior of within seconds of several tens of millions of particles takes a few days for a supercomputer. For realizing complete simulation of plasma, electron analysis should be taken into account in addition to the current simulation. To meet this end, computing power will be required as tens of thousand times than the current supercomputer.

(7) Data mining

Data mining technology can derive to find useful knowledge from large volumes of data. It is based on learning models or language processing models developed through the research of artificial intelligence. When data volume is enormous, a high-speed computer is required. For example, the Web search engines collect ever-changing Web site information over the Internet in order to find user required web site by keywords. A supercomputer is used to perform large-scale similarity calculations to figure out. It is rather easy to parallelize the calculations for this kind of applications. Small-scale data mining can be handled by high-performance PCs.

(8) Economic forecasting and Financial engineering

It is widely known that mathematical theories are applied for developing models for stock and derivative trading. Also, there are many studies that attempt to provide macro-economic forecasts by simulating interactions among many economic factors on a computer. However, the complexity of economies makes it extremely difficult to verify and justify their theoretical models. In addition, economy is heavily affected by electronic transactions systems worldwide, an event is transferred very quickly, easily causing an unexpected chain reaction.

While leading securities firms used to perform simulations on a supercomputer, their demand for supercomputers has weakened as they began to question the cost efficiency of investing a large

Table 1: Supercomputer application fields and their features

Supercomputer application field	Current applications	Future visions	Computing requirements	Needs
Prediction of Weather and Global environmental change, Geological prospecting	Weather forecasts based on atmospheric models and empirical parameters; Prediction of oil reserves based on geological studies	Elucidating global warming; Predicting unusual weather and other climate changes; Forecasting local-level weather such as concentrated heavy rains.	Vector processing work better on climate computations. Large-scale computation for a fine mesh is required because a local phenomenon affects the overall results.	Mesh refinement is needed to improve the accuracy of prediction. If the grid resolution is refined one tenth, computing power requires 1,000 times (equivalent to a teraflop computer).
Bioinformatics	Gene analysis; Protein structure analysis	New medicine development from the genome data; Customized remedies; Protein's chemical reaction by using quantum theories (computational chemistry).	Calculation of matching, energy and so on sometimes allow for parallel processing, but at times require more complicated computations.	A 1,000-fold increase will enable only microsecond-level analysis. An additional 1,000-fold upgrade is needed for chemical reaction simulation.
Materials simulation	Analysis of structure and properties of materials through first principle simulation on a 100-atom level	Designing and creating new materials and nanostructures; Analyzing their functions and properties (computational physics).	Complete theoretical computation is possible only in a small area. The computing volume is the third or greater power of the atomic mass.	Shared memory systems are suitable as access to a wide range of data is required. The demand for upgrading computing power is strong.
Structure analysis and Fluid analysis	Virtual experiment of car crashes; Analysis of air resistance to aircraft and many other industrial applications	Coupled simulation to solve multiple theoretical models in a unified manner. e.g., engine combustion and biodynamic simulation.	High-performance PCs or workstations can be used for simple structure / fluid simulation.	A petaflop computer is needed for coupled simulation. Easier 3D data entry is called for.
Celestial mechanics and Elementary-particle / nuclear physics	Simulation of Galaxy formation and elementary- particle / nuclear simulation	Finding the secrets of the universe such as formation of the Galaxy and creation of a black hole	Gravity computations for large-scale particles require a teraflop or faster computer.	Dedicated computers are sometimes used.
Nuclear fusion simulation	Simulation of nuclear fusion plasma based on theoretical models and the knowledge obtained through experiments	Gaining energy from nuclear fusion by real-time control based on theories and simulations.	Macroscopic fluid analysis and microscopic inter-particle dynamics are simultaneously calculated.	Complete simulation integrated with electron analysis requires tens of thousands times the computing power.
Data mining	Web search engines; Analysis of customer information or product popularity	Extracting knowledge (meaning, characteristics) from large volumes of data.	Large-scale data calculation based on leaning models and language processing models.	HPCs are required when the data volume is large. Parallel processing is applicable.
Economic forecasts and Financial engineering	Macro economic forecasts; Stock quotation projection	Establishing superior models to forecast economic fluctuations by large-scale complex simulation.	Calculating various interactions based on mathematical theories and probability models.	Price performance is essential for computer simulation. Many users moved to PC systems.

sum of money into a supercomputer when enhanced-performance PCs are widely available.

3.5 Computer simulation trends

In industries, supercomputers are typically used for simulations of structure or fluid analysis in the many fields such as machinery, civil engineering, construction, and electronics. They often contribute to the production design process. A small-scale analysis can be run even on a high-performance PC. In the fields of biotechnology, chemistry, materials and energy, a supercomputer usually serves the research and development section for simulations but not yet for product design.

The capabilities of computer simulation are expanding as supercomputer performance improves. In particular, supercomputers are indispensable when studying something hard to experiment with (high temperature/pressure) or to obtain (new materials), something dangerous to handle (collisions, poisons), and something difficult to observe (elementary particles, atoms, and molecules). Conventional simulation systems provide only simple idealized simulation based on a single phase or steady state model, the next developmental goal for the computer simulations is to enable more realistic or accurate simulation such as coupled simulation, in which a multi scale process is simulated in a unified manner. To achieve this goal, further upgrading of supercomputer performance is anxiously anticipated.

3.6 Software development trends

Software developed for supercomputers is partly dependent on supercomputer types. Science and technological computations often use vector processing, and programs for vector processors are easier to develop while providing efficient operations. However, software developed for vector processors does not deliver full performance on scalar processors. In the U.S., where vector computers have become unavailable, many applications are being rewritten for massively parallel scalar computers.

On the other hand, a parallel computer can achieve its full performance only on a program designed for parallel processing. Thus there are many researches in software for parallel processing such as parallel compilers and parallel communication processing programs that support parallel computing. While the U.S. started working on parallel architecture early, Japan is generally behind in this field.

3.7 Conclusion

Application of supercomputers is more often seen in the area of basic scientific research in addition to industrial fields. In particular, the latest supercomputers are contributing to basic scientific research in producing new developments. For example, as a new field Bioinformatics is emerged combining biotechnology with information technology in the U.S. Supercomputers are playing an essential role in Bioinformatics. Venture businesses are being fostered aiming at even launching a new industry.

Also supercomputers help predict global environmental changes, promoting embodiment of an enriched society. Simulation by supercomputers is a basic technology crucial for both science and industry as a means to quickly and safely solve complicated phenomena occurring in various areas including natural science, engineering, and socioeconomics.

Demand for supercomputers is still strong. Especially in simulation for biotechnology and physics, petaflop supercomputers, that are 100 to 1,000 times faster than the current super-computers, are awaited. So far, supercomputer performance has been upgraded 10-fold in every four to five years. Assuming this trend continues, a petaflop computer is expected to come out by 2010. Of course extensive development of relevant technologies must continue in order to realize this projection. In the U.S., discussion is already taking place about a plan to develop a petaflop computer. This is because they consider supercomputers not only as a key technology for science but also as a defense technology for the nation. Also they recognize that the market is not large enough to provide sufficient funds for development of supercomputers and thus government support is required for nurturing supercomputer technologies.

Japan maintains unique technologies for supercomputer hardware, which are different from those of the U.S. This superiority should be taken into account when we discuss our strategy for the next-generation supercomputer. Aside from the hardware aspect, application-oriented approaches to identify demands for and uses of supercomputers should also be considered. We must realize that if supercomputers become an exclusive technology of the U.S, it may affect not only the computer field but also the basic science research field.

Japan also has been failed to acknowledge the importance of software, posing a major challenge for us. Dr. Pople won the Nobel Prize for his development of the famous molecule chemistry software called Gaussian, together with Dr. Kohn who established the theory for it. In Japan, where software is not recognized as highly valued, a researcher in science cannot gain a doctor's degree by new software development alone. This makes us realize the need for adding a new point of view to our research evaluation system.

Glossary

*1 gigaflops, teraflops, and petaflops

Giga (G) represents 10^9, tera (T) 10^{12}, and peta (P) 10^{15}. Flop, which stands for floating-point operations per second, is an index to indicate the computing power of a computer. Linpack, a program to solve liner equations, is often used for benchmark tests.

*2 peer-to-peer technology

A technology that enables individuals on the Internet to directly exchange information each other. By using this technology, many computers can be interconnected to share their computing power and files through network.

*3 human genome

The entire human genetic information that provides the basic blueprint of human life. There exist 3 billion base pairs in DNS contained in chromosomes within a cell nucleus, and genes are said to account for 3% of them.

*4 coupled simulation

Also known as multi-disciplinary or multiscale simulation, this term refers to simulating multiple theoretical models in a unified manner. Examples include blood flow simulation, which analyzes fluid and structures at the same time, and fracture analysis, which is simultaneously finding solutions for both the microscopic quantum mechanics theory and macroscopic classical physics.

*5 a decline of vector supercomputers in the U.S.

In the U.S., where mainframe manufacturers did not make supercomputers, specialized producers such as Cray led the supercomputer market as well as the technology. Japanese computer manufacturers, who entered the market in the 1980s, over took their U.S. counterpart by the late 1980s because of their total technological strength that covered even the semiconductor field. In the early 1990s, as mainframes were downsized, no additional companies moved into the vector supercomputer market, while Cray, which was suffering from unstable operation, lost their competitive edge in technology development. At the start of anti-dumping duties in 1996, top-end vector supercomputers became unavailable in the U.S. Under the duties, which were lifted in May 2001, U.S. computer makers focused on development of massively parallel scalar supercomputers.

(Original Japanese version: published in October 2001)

4

Cyber Security Measures
—How to protect the nation's critical infrastructure from cyber attacks—

TOMOE KIYOSADA, *Information and Communications Research Unit*
HAJIME YAMADA, *Affiliated fellow*

4.1 Introduction

The terrorist attacks on September 11, 2001, targeting the U.S., have driven not only the country but also the world into turmoil. Terrorism carried out by only a few tens of people caused a major disaster involving thousands of casualties, which resulted in chaos in the city for several days.

Under U.S.-lead retaliatory strikes, the possibility of further counter-attacks by terrorists is posing a greater threat to us. What type of measures would they take? What can our government do to prevent damage?

By focusing on cyber terrorism, this report provides information on how the U.S. has been developing cyber security policies from an early stage, which will contribute to our policymaking to improve cyber security.

4.2 Cyber Attack Threat

4.2.1 Will there be further retaliatory attacks?

On October 11, the Federal Bureau of Investigation (FBI) officially warned that there was a probability of additional terrorist attacks within a few days ("Immediate Release," FBI National Press Office). The Washington Post also reported on October 5 that officials from the FBI, CIA (Central Intelligence Agency) and DIA (Defense Intelligence Agency) unofficially stated to the members of the Senate and House Intelligence Committees, "there is a 100 percent chance of an attack should the United States strike Afghanistan." ("FBI, CIA warn Congress of more attacks as Blair details case against Bin Laden," Washington Post.)

4.2.2 Further retaliation through cyber attacks

Assuming terrorists are planning retaliations, what measures would they take? Taking their presumably scarce resources into account, they are likely to use biological, chemical or cyber weapons, which can be developed and executed with limited labor and cost, instead of missiles for armed attacks.

Actually, in the U.S., anthrax infected patients turned up one after another, increasing the threat of bio-terrorism. However, as security against terrorism becomes extremely tight throughout the country, cyber attacks, which can be carried out from a remote place, are no less serious a threat than bio-attacks. In fact, Infrastructure Defense (iDEFENSE), an information provider dedicated to cyber security, pointed out that supporters of either terrorism or anti-terrorism have already organized hacker groups, through which cyber attacks have started against targeted Web sites such as those operated by U.S. corporations or by Islamic nations (iDEFENSE Report #105540, #105551).

4.2.3 Terrorists' capability of cyber attacks

Next, how terrorists are capable of cyber attacks is discussed.

It is reported that Bin Laden is likely to have been secretly sending instructions for attacks by using a technology known as steganography ("Terror groups hide behind Web encryption," February 6, 2001, USA TODAY).

Steganography is the technique of embedding secret messages, images, or data in ordinary file formats sent over or displayed on the Internet such as texts, images, and audio. Professor Johnson, George Mason University shows on his

Web site (http://www.jjtc.com/stegdoc/sec313.html) the comparison of an image with data embedded by using steganography and the same image without the hidden data. There is virtually no visible difference between the two. Secret information is typically sent by using an encryption technique, and thus it is clearly known something is hidden within the encrypted data. On the other hand, steganography does not allow others to readily recognize if there is masked information or not, thus enhancing confidentiality. In addition, while encrypted data is often detected by data traffic interception systems online, this is not likely to occur with steganographic data.

Dr. Hunker, who led the cyber security division of the National Security Council (NSC) under the Clinton administration, pointed out that the September 11 attacks must have been well-prepared by well-educated people probably with abundant financial resources. He also said if these people had carried out a cyber attack, the result would have caused as great damage to the U.S. ("U.S. Networks Run Big Risk of Cyber-strikes," Experts Assert, October 3, 2001, Mercury News.)

The above chapter showed an analysis of; i) Cyber attack threat, and ii) Terrorists' capability of cyber attacks. With attention to how the U.S. developed their cyber security policies from an early stage, the following chapters outline the policies as well as the background that made the country address this field.

4.3 Enhanced Cyber Security Awareness in the U.S.

Development of information technology (IT) facilitated the connection of the critical infrastructure of defense, electricity, natural gas, telephone networks, and transportation to the Internet. While improving convenience, this has increased the vulnerability of these systems. Meanwhile, there has been a growing number of unauthorized entries into key infrastructure systems in the U.S. over the past few years ("Emerging Challenge: Security and Safety in Cyberspace," Ver. 14, No. 4, Winter 1995-1996, IEEE Technology and Society Magazine). Thus, cyber strikes on critical infrastructure are being recognized as a new national security threat.

4.3.1 Exercises assuming cyber attacks

On March 23, 1996, the Defense Advanced Research Projects Agency (DARPA) of the Department of Defense (DOD) conducted an exercise called "The Day After...," assuming a variety of damage that could be caused by a cyber attack targeting key infrastructure (Strategic information warfare: a new face of war," Roger C. Molander, Andrew S. Riddile, and Peter A. Wilson, Rand Corporation). The cyber strike scenario developed for the exercise is described in Table 1.

Now that a terror attack beyond our imagination occurred, the cyber strikes described in the above scenario sound more realistic. The following section outlines an experiment conducted to examine the feasibility of such cyber attacks.

4.3.2 Computer system vulnerability study

In June 1997, DOD conducted an experiment called "Eligible Receiver" to examine the vulnerability of DOD key infrastructure, such as networks, communications systems, and the power grid, against cyber attacks (Testimony by Mr. Richard C. Schaeffer, Jr., October 6, 1999, Senate Judiciary Committee, Subcommittee on Technology, Terrorism and Government Information). For this experimental exercise, 30 officials at national security organizations acted as hackers with the following mission.

— Shutting down the control systems for key infrastructure such as communications networks and the power grid.
— Entering DOD computer networks without authorization.

The participants were also told; i) while simulating an attack on key infrastructure, they should leave a sigh in the system they penetrated, instead of actually shutting down the system, and ii) with respect to the unauthorized access experiment, they should clearly indicate how deep they penetrated.

The acting hackers followed these terms:

— Do not use knowledge obtained through their jobs.
— Buy and use any computers available off the

Table 1: Cyber strike scenario

Date and Time (EDT)	Proceedings
Evening, May 11	NCC reports to the White House that; (1) the public telephone network system for Northern California and Oregon suffered a failure due to a Trojan horse, and (2) the base phone system for Fort Lewis had been subjected to a DoS attack and their communications system had been paralyzed for several hours.
Later at night, May 11	In Cairo, Egypt, the electricity supply system failed, leaving 90% of the nation's households without power for several hours.
4:00, May 13	A large oil refinery in Southeast Sandi Arabia suffered a control system failure, causing an explosion and fire.
18:12, May 14	In Maryland, a logic bomb embedded in the transportation system network exploded, causing a collision between a freight train and a high-speed train. Maryland State Police estimate 60 dead and 120 injured.
6:00, May 16	Scotland Yard reports to the British Prime Minister that the Bank of England detected three failures in their funds transfer system and the Bank leaders, considering this serious, suspended the funds transfer service.
Morning, May 20	Joint Chiefs of Staff (JCS) information warfare planning cell announced that their computer program for time phased execution control is infected with an unknown worm.
12:10, May 20	The automatic tellers of the two major banks in Georgia started to malfunction causing a bank run. These banks were forced to shut down their ATM systems.
12:25, May 20	The CNN news center feed out of Atlanta was off the air for 12 minutes.
15:30, May 20	CNN aired a special report focusing on the vulnerability of the U.S. to cyberspace warfare, dwelling on the series of incidents including; (1) the crash of the express train linking Boston, New York and Washington D.C., (2) the telephone outage in the Northwest, (3) the malfunction of the ATM systems in Atlanta, and (4) the still-unexplained interference with CNN's signal transmission.
Evening, May 20	Local and national evening programs reported that U.S. military deployments to the Gulf were experiencing delays due to cyber attacks on the LANs and phone systems of key Army and Marine bases.
19:44, May 22	The pilot of a Continental Airline's Airbus-340 making a final approach to O'Hare International Airport reported to the control tower that his flight deck avionics had suffered a malfunction and that the aircraft was out of control.
Night, May 22	After receiving a preliminary British report concluding that all late model AB-330 and 340 flight control software may be infected by a sophisticated logic bomb, the administrator of the FAA recommended that all late model AB-330s and AB-340s be immediately grounded until the nature of the flight deck malfunction can be ascertained.
12:57, May 23	The Saudi public switched network began to fail apparently due to unauthorized modification of the system through trap doors.
16:10, May 23	The Secretary of Defense was informed by the JCS Chief that a full-scale IW attack by unknown sources was underway at almost every military base in the U.S. and Europe.
19:00, May 23	Several radar aircraft operating in the Gulf region were plagued with a computer worm.
10:30, May 24	The entire phone network system in the Washington/Baltimore region including local cellular systems failed due to trap doors.
13:30, May 24	The Chicago Commodity Exchange experienced some of its wildest fluctuations in history. There was widespread suspicion that the Exchange was being subjected to a form of electronic manipulation by parties unknown.
Afternoon, May 24	In Washington D.C., an emergency NSC meeting was called by the President but the arrangement was difficult because of the phone system shutdown.

Notes:
NCC: National Communications Center
Trojan horse: A program set on a computer system that allows the program developer to take control of the system.
Trap door: A technique that permits designated third parties to access a targeted program or network, bypassing passwords or other security procedures.

Source: "Strategic information warfare: a new face of war," Roger C. Molander, Andrew S. Riddile, and Peter A. Wilson, Rand Corporation

shelf.
— Carry out an attack over a commercial Internet service.
— Use hacking tools available and downloadable from Web sites.

Prior to the exercise, the participants had a three-month preliminary period. During the exercise, they gained unauthorized access to key infrastructure and left signs showing their ability to turn off the systems. They also successfully broke into DOD computer networks. There were 40,000 attempts of unauthorized access to the networks, out of which 36 were successful. However, it was only two of them that DOD system administrators could detect. Some hackers even succeeded in obtaining a system administrator's authority, which allowed them to access any desired DOD network.
This experiment showed that as few as 30 people who do not have any special skills could have paralyzed critical communications networks and the power grid, and could have taken control of DOD networks, which are protected with one of the most sophisticated security systems in the world. In other words, it was proven that a small number of people could cause a national security crisis in the U.S. The result shook the U.S. government so violently that the government officials could not help starting to seriously address cyber security issues.

4.4 Critical Infrastructure Protection in the U.S.

The critical infrastructure protection policy the federal government is now working on is based on the scheme announced by then- President Clinton in January 2000, "The National Plan for Information Systems Protection Version 1.0" ("The National Plan for Information Systems Protection Version 1.0," January 2000, The White House).
This plan is often referred to by governments of other nations, when they formulate their own cyber security policy.
In this chapter, we will look at how this plan was developed in the first section 4.4.1, and then outline the plan in section 4.4.2.

Table 2: Recent changes in the U.S. critical infrastructure protection policy

Month / Year	Description
7 / 1996	Then- President Clinton established the President's Commission on Critical Infrastructure Protection (PCCIP).
10 / 1997	PCCIP released a report.
5 / 1998	Then- President Clinton signed the Presidential Decision Directive (PDD) 63.
1 / 2000	The National Plan for Information Systems Protection Version 1.0 was announced.

4.4.1 *How the National Plan for Information Systems Protection Version 1.0 was developed*

In response to the result of the Eligible Receiver exercise, an intrusion detection device was installed on every DOD network in addition to 24-hour monitoring. Other government agencies also began to take cyber security measures.
On the other hand, the industry was not paying as much attention as the government to their critical infrastructure protection.
Therefore, the government, which had been leaving the private sector to take care of their own key infrastructure protection and provision of stable service, changed their attitude and decided to collaborate with them to protect critical infrastructure according to the series of policies shown in Table 2.

(1) Recommendations by PCCIP
July 1996, then-President Clinton signed Executive Order 13010 to initiate:

— Establishment of the President's Commission on Critical Infrastructure Protection (PCCIP)
— Definition of critical infrastructure by the above organization
— Discussion on protective measures for the above critical infrastructure

PCCIP designated the following systems, which are crucial to national security and people's lives, as critical infrastructure:

— Power supply systems
— Gas/oil production systems
— Financial systems

— Transportation systems
— Water supply systems
— Emergency care service systems
— Public administration service systems

After studying protective measures for these systems, PCCIP issued the following recommendations in October 1997.

— Develop a wide range of programs to enhance cyber security awareness in the private sector.
— Facilitate collaboration and information sharing between the government and the private sector.
— Review the current legislation to eliminate elements that may hinder critical infrastructure protection.
— Promote research and development programs to develop technologies applicable to critical infrastructure protection.
— Expand national-level efforts to effectively make important resolutions and recommendations concerning critical infrastructure protection.

Table 3: The structure to implement PDD 63

Structure	Person or organization in charge	Responsibility
Assigning a National Coordinator	The First National Coordinator was Clarke (the current chair of the National Commission onTerrorism)	— Assist the President in implementation of PDD 63, and in charge of critical infrastructure protection as well as with domestic and foreign terrorism.
Establishing the National nfrastructure Protection Center (NIPC)	— Established within the FBI as a body to fuse together representatives from DOD, USSS (U.S. Secret Service), DOE (Dept. of Energy), DOT (Dept. of Transportation), the intelligence community, and so on, to promote collaboration among agencies and the private sector that are dealing with computer crimes and infrastructure protection. — Linked via networks with the federal government's monitoring center, private information centers and other facilities dedicated to countering cyber attacks.	— Provide warnings, analyses, and countermeasures in response to cyber threats, coordinate the effort of concerned organizations, mitigate attacks, and support recovery in the case of damage.
Establishing Information Sharing and Analysis Centers (ISACs)	— Established in each critical infrastructure industry. — The first ISAC, which was founded by the financial industry, started operation in October 1999.	— Report and exchange information about; (1) threats and damage from cyber attacks and computer crimes, (2) countermeasures and best practices, and (3) system vulnerabilities.
Establishing the National Infrastructure Assurance Council (NIAC)	— The chairperson is designated by the President. — The national coordinator serves as the executive director of the NIAC. — The members of the NIAC are appointed by the President, based on the recommendations of the major agencies and the National Economic Council (NEC), from private sector entities representing the critical infrastructure and from local governments.	— Meet periodically to enhance the partnership of the public and private sectors in protecting our critical infrastructure.
Establishing the Critical Infrastructure Assurance Office	— Organized within the Department of Commerce.	— Provide support to the national coordinator's work in developing a national plan for protecting critical infrastructure. — Integrate the security measures developed by critical infrastructure industries into the national plan. — Analyze the federal government's dependence on critical infrastructure. — Help coordinate national education and awareness programs for cyber security, and legislative affairs.

Source: PDD 63, May 22, 1998, The White House

This was the first time that the government mentioned the private sector activities related to critical infrastructure protection.

(2) Presidential Decision Directive 63

In response to the recommendations by PCCIP, then- President Clinton, following additional discussions in NSC, signed Presidential Decision Directive (PDD) 63 in May 1998. The Directive prescribes:

— To build a reliable, interconnected, and secure information system infrastructure by the year 2003, and significantly increase security of government systems by the year 2000.
— To immediately establish a national center to warn of and respond to cyber attacks.
— To address the cyber and physical infrastructure vulnerabilities of the federal government by requiring each department and agency to work to reduce its exposure to new threats.
— To require the federal government to serve as a model to the rest of the country, including state governments and enterprises, on how infrastructure protection is to be attained.
— To seek the voluntary participation of private industries to meet common goals for protecting our critical systems through public-private partnerships.
— To protect privacy rights and not to hinder free competition in the market while implementing cyber security policies.
— To seek full participation and input from Congress, in terms of overall cyber security protection.

In addition, PDD 63 orders the setting up of a structure as shown in Table 3 to deal with the challenge.

To implement PDD 63, the following National Plan for Information Systems Protection Version 1.0 was developed.

4.4.2 Outline of the National Plan for Information Systems Protection Version 1.0

Based on PDD 63, then- President Clinton set the National Plan for Information Systems Protection Version 1.0 in January 2000.

(1) Goals of the National Plan Ver. 1.0

The goals set up for the National Plan Ver. 1.0 are as shown in Table 4.

(2) Programs for the National Plan Ver. 1.0

To achieve the above goals, the programs shown in Table 5 were developed for the National Plan Ver. 1.0.

(3) Government organizations to carry out the National Plan Ver. 1.0

Figure 1 shows the government organizations that will carry out the National Plan Ver. 1.0. As indicated, the government is addressing critical infrastructure protection from a variety of viewpoints, including national security, R&D, standardization of technology and methods, human resource development, and information provision and analysis.

(4) Toward Version 2.0

As explained above, the National Plan Ver. 1.0 focuses on critical infrastructure protection activities initiated by the federal government. The version number is added because the Plan, which is now in the initial phase, is supposed to evolve in the future. The focus of attention toward the following phase is how private, public and local organizations are involved and expected to play

Table 4: Goals of the National Plan Ver. 1.0

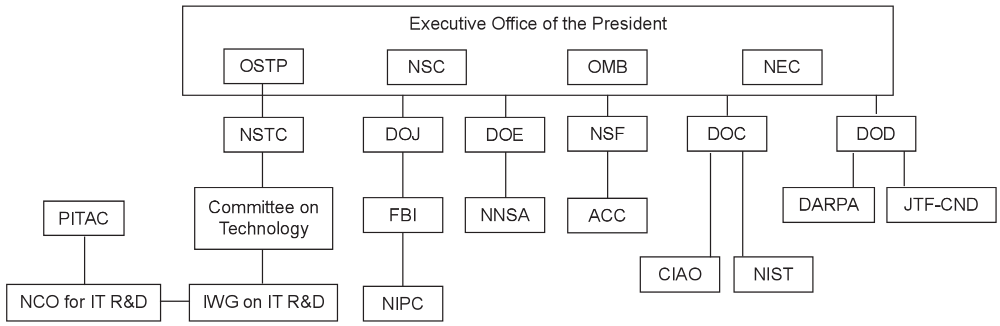
Category	Outline
Prepare and Prevent	— Minimize damage in case of a cyber attack on critical infrastructure. — Allow the attacked infrastructure to keep functioning without suspension of service.
Detect and respond	— Timely isolate, analyze, and confine cyber strikes, so that the affected system can be quickly restored and reconstructed.
Build strong foundations	— Develop a structure, human resources, and legislation, so that national-level prevention and detection of cyber attacks on critical infrastructure are provided.

Table 5: Programs to achieve the goals of the National Plan Ver. 1.0

Category	Program#	Outline
Prepare and prevent	1	Identify critical infrastructure assets and shared interdependencies and address vulnerabilities
Detect and respond	2	Detect attacks and unauthorized intrusions
	3	Develop robust intelligence and law enforcement capabilities to protect critical information systems, consistent with the law
	4	Share attack warnings and information in a timely manner
	5	Create capabilities for response, reconstitution, and recovery
Build strong foundations	6	Enhance research and development in support of Programs 1 - 5
	7	Train and employ adequate numbers of information security specialists
	8	Outreach to make Americans aware of the need for improved cyber-security
	9	Adopt legislation and appropriations in support of Programs 1 - 8
	10	In every step and component of the plan, ensure the full protection of American citizens' civil liberties, their rights to privacy, and their rights to the protection of proprietary data

Source: The National Plan for Information Systems Protection Version 1.0, January 2000, The White House

Figure 1: Organizations related to critical infrastructure protection policies in the U.S.

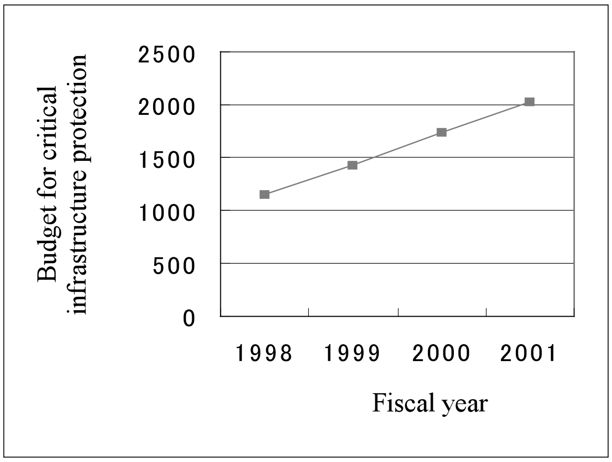


Organization names

OSTP: Office of Science and Technology Policy
NSTC: National Science and Technology Council
IWG: Interagency Working Group,
PITAC: President's Information Technology Advisory Committee
NCO: National Coordination Office
NSC: National Security Council
OMB: Office of Management and Budget
NEC: National Economic Council
DOJ: Department of Justice,
FBI: Federal Bureau of Investigation
NIPC: National Infrastructure Protection Center
DOE: Department of Energy
NNSA: National Nuclear Security Administration
NSF: National Science Foundation
ACC: Advisory Committee for Cyberinfrastructure,
DOC: Department of Commerce
CIAO: Critical Infrastructure Assurance Office
NIST: National Institute of Standards and Technology
DOD: Department of Defense
DARPA: Defense Advanced Research Projects Agency
JTF-CND: Joint Task Force on Computer Network Defense

certain roles independently or in collaboration with the government in order to protect their own critical infrastructure. The Bush administration is now working on the next version of the National Plan, which is being developed based on the previous version by integrating a wide range of opinions from Congress, state governments, industries, and local communities as well as from the public at large.The National Plan Version 2.0 will be released this fall.

Figure 2: U.S. government budgetary trends (critical infrastructure protection)



Source: Budget of the United States Government, Fiscal

4.5 The U.S. Government Budget to Protect Critical Infrastructure

Figure 2 shows the trend in the U.S. government budge to protect critical infrastructure.
Figure 2 indicates that the U.S. government budget to protect critical infrastructure has been on a steady rise.

4.6 Cyber Protection after the September 11 Attacks

On October 9, President Bush assigned Richard Clarke, who is the current chairman of the National Commission on Terrorism, as the special advisor to the President on Cyberspace Security. His mission was; i) immediately create a highly secured information system, and ii) establish a system that minimizes damage caused in case of cyber attacks ("Fact Sheet on New Counter-Terrorism and CyberSpace Positions," October 9, 2001,The White House).
Immediately after the assignment, Special Advisor Clarke announced a plan to develop GOVNET, a network dedicated to government organizations ("Top Cybercop Wants New Net," October 10, 2001,Associated Press).
The House Committee of Science held a public hearing on cyber security protection on October 10 ("Committee hears sobering news on nation's cyber security," October 10, 2001, Committee on Science, US House), where lawmakers, who were seriously concerned about the threat of cyber strikes, and invited experts actively discussed what the U.S. government was expected to do in the short, medium and long ranges.
Following this, Associate Press reported on October 11 that the federal government was planning a cellular system that would allow priority communications by emergency crews and government officials during a crisis. According to the report, the government was going to secure priority circuits for 500 users in the following two months and for 50,000 users by the end of 2002 (U.S. Plans New Cellular System," October 11, 2001,Associated Press).
On October 16, President Bush signed an executive order on critical infrastructure protection from cyber attacks that demands; i) continuous protection of critical infrastructure, ii) development of emergency communication networks, and iii) establishment of the President's Critical Infrastructure Protection Board.The Board is positioned as the highest-level authority to oversee planning and coordination of efforts to protect the private sector's critical infrastructure, public sector's information systems, and critical information systems for national security.
On the other hand, in Japan, the Cabinet decided to establish the Emergency Anti-Terrorism Headquarters, which on the same day, released emergency measures to combat terrorism. Among these measures, top priority items were identified on October 12, one of which was "enhancing the capability to counter cyber terrorism." More specifically, it was required to enhance the ability to counter cyber terrorism through reinforcing and expanding personnel involved, gathering information, increasing more sophisticated detection, analysis, and examination devices, strengthening protection of critical infrastructure,

and so on.

Meanwhile, on October 10, the IT Strategy Headquarters convened the IT Security Promotion Committee to discuss and formulate a policy to deal with cyber terror attacks, which emphasized closer partnerships between the government and private sector.

4.7 Conclusion

This report provided an overview of the U.S. effort to develop cyber security policies from an early stage to address the increasing cyberspace threat.

Ahead of other countries in the world, the U.S. government has developed the National Plan for Information Systems Protection Version 1.0. While establishing a structure to carry out the plan, they are actively tackling measures in areas such as R&D, development of human resources, legislation, privacy protection, and governmental funding. In particular, their emphasis on protection of critical infrastructure owned by private and public sector entities, based on the awareness that malfunction of these systems can cause a nation-wide crisis, provides us with a lot of useful information.

Meanwhile, we should also be aware of the risk that our cyberspace vulnerabilities can cause damage not only to our country but also to other countries. Cyber attackers often make use of third-party computers to prevent backward tracing. If an attacker carries out a strike via a computer in Japan, the victim may take our country as the home of the criminal.

So far, even the U.S., the country most prepared for cyber strikes, does not seem to provide perfect critical infrastructure protection. Besides, as they often compare it to dog years, information technology is advancing so rapidly that a newly developed technology to enable higher security can soon become obsolete.

Therefore, it is important for us to immediately strengthen cyber security and to keep our countermeasures up to date.

From this point of view, we must have been quick enough when, in the wake of the terrorist attacks in the U.S., we started taking actions to combat cyber terrorism, lead by the Emergency Anti-Terrorism Headquarters and IT Strategy Headquarters.

The U.S. government is expected to announce the National Plan for Information Systems Protection Version 2.0, an upgrade from Version 1.0, in this fall. While making use of it as a helpful guide, the Japanese government should develop its own policy to protect the nation's information systems.

(Original Japanese version: published in October 2001)

5

Trends in Material Simulation, Centering Around Ab Initio Calculation

JUN-ICHIRO TAKANO
Materials and Manufacturing Technology Research Unit

5.1 Introduction

Simulation has increasingly been used in Materials Research. Tens of years ago, instances of applying simulation to Materials Research were rare, and few of them were practically useful to Materials Research. The situation, however, has been changing, due to the rapid improvement in the performance of computers (refer to the special feature, "Trends in Supercomputers," in the October 2001 issue of Science and Technology Trends), advancement in simulation methods, and enhanced experimental technologies in the micro regions as is called Nanotechnologies (nano is equivalent to one-billionth).

In fact, in "Promotional Strategy for Nano Technologies and Materials Field (September 2001)" laid down by Council for Science and Technology Policy, Cabinet Office, "basic technologies, such as instrumentation/evaluation and numerical analysis/simulation, and the fields on which they have impact" is listed as one of the five key areas. Also, the following is listed as one of the performance goals to be achieved in this area in the coming five years:

> Establishment of the utilization of simulation in the development of new materials and devices

In this article, I would like to comment on the current level of Material Simulation as one of the basic technologies of nanotechnologies, and propose the necessity of making efforts towards acceleration of utilization rates of simulation in syntheses for new materials.

5.2 Roles of Simulation in Materials Research

Material Simulation is a "tool" and also a method of Materials Research: "computer experiment (imitative experiment)". Researchers carry out, as required, computer simulations instead of conducting real experiments using precision equipment to "examine (try, verify, experiment) ideas".

Now, some merits of simulations dealing with nano-meter scale materials and their respective instances are listed below:

Merit 1) Speeding up and Cost Reduction in Materials Development

Out of all conceivable experiments, minimum necessary ones are selected after prediction of the structure, physical properties and phenomena of a material by use of simulation. In this way, the number of experiments necessary for research and development can be reduced, thus contributing to speeding up as well as the cost reduction of materials development.

•Example of merit 1)

A phenomenon called "electro-migration," in which metal atoms migrate as high-density current runs through the metal wiring, can be a problem for the preparation of semiconductor devices. A certain electric company, who applied an atomistic simulation to the selection of additive elements to prevent breaking down of metal wiring and also to the selection of substrate material to prevent removing, succeeded in shortening the period for material design down to 4 months from 1 year, which would normally be required when relying totally on repetition of experiments on a trial-and-error basis. (Source: Professor Takayuki Kitamura, Graduate School of Engineering, Kyoto University)

Merit 2) Electronic / atomistic understanding of phenomena that are difficult or impossible to verify by means of experiment

It is possible to analyze the electronic or atomic mechanism of phenomena by direct atomistic observation the behaviors of the atoms at every moment through simulation. It is also possible to obtain various information such as the inside conditions of the material, and a phenomenon of chemical reaction that takes place in an extremely short period of time.

•Example of merit 2)

What role does the Ziegler-Natta catalyst, which is indispensable for the manufacture of high strength polyethylene and polypropylene for use in various moldings and fibers, play in chemical reactions and how the reaction progresses? Its mechanism has been made clear on the basis of the ab initio calculation (see comments in Section 5.4) made as a result of a joint research program between the Joint Research Center for Atom Technology (JRCAT) and the Max Planck Institute for Solid State Research (Germany). JRCAT is a centralized industry-government-academic joint research organization, with Angstrom Technology Partnership (ATP), technical research partnership commissioned by the New Energy and Industrial Technology Development Organization (NEDO), and the National Institute of Advanced Industrial Science and Technology (AIST) as parent bodies.

It was not possible to directly verify this chemical reaction mechanism by experiment, as it is very fast and progresses in an extremely short time, so that details of the reaction process have hardly been known. It is expected that such results can be utilized for upgrading and improvement of manufacturing technologies.

Since a lot of behaviors of the atoms and molecules in such a complicated chemical reaction cannot be analyzed by experiments alone, material simulation play a big role in analyzing the chemical reaction mechanism.

Next, I would like to review the trends in academic lectures presented at annual academic meetings for an overview as to what extent Material Simulation is used in Materials Research and which features are attracted for utilization. While presentations on study results concerning Material Simulation are made at a lot of meetings, here I would like to introduce the case of the Japan Institute of Metals (JIM) as one of examples showing a cross-sectional view of the current status of Materials Simulation studies.

More than 1,000 presentations are made at each of the spring and fall Annual Meetings of the JIM. "Ten years ago, presentations of studies relating to simulation which numbered several at the most. But it has come to account for about 10% of the total in recent years," says Professor Yoshiyuki Kawazoe of the Institute for Materials Research, Tohoku University.

Also according to an investigation by the Science and Technology Foresight Center, presentations of study results, which have a close relationship with Material Simulation, in the 2001 JIM Fall Meeting of the academic lectures numbered 120 out of 1,388 presentations in total, accounting for 8.6% of the total.

5.3 Material Simulation in the 7th Technology Foresight

The National Institute of Science and Technology Policy, under the Ministry of Education, Culture, Sports, Science and Technology, has continued to conduct a large-scale and exhaustive "Technology Foresight" almost every five years since 1971, to investigate the courses of development of science and technology from a long range perspective. The latest 7th Technology Foresight, which was published in July 2001 and covered more than 1,000 survey topics in 17 different fields, was carried out with the cooperation of almost 4,000 experts in the respective fields.

Out of 103 survey topics in total, in the field of "Materials and Processing" of the above survey, 4 topics relating to Material Simulation are shown in Table 1.

Out of the 4 topics in Table 1, attention was paid to the topic (3) relating to the "Ab Initio

Calculation" (refers to the comments in Section 5.4), which is expected to make a contribution particularly to the area of below nano-meter scale. Results on comparison between the average of responses to the various survey items on all the topics in the Materials and Processing Field and those to the topic (3) are shown in Figure 1 below.

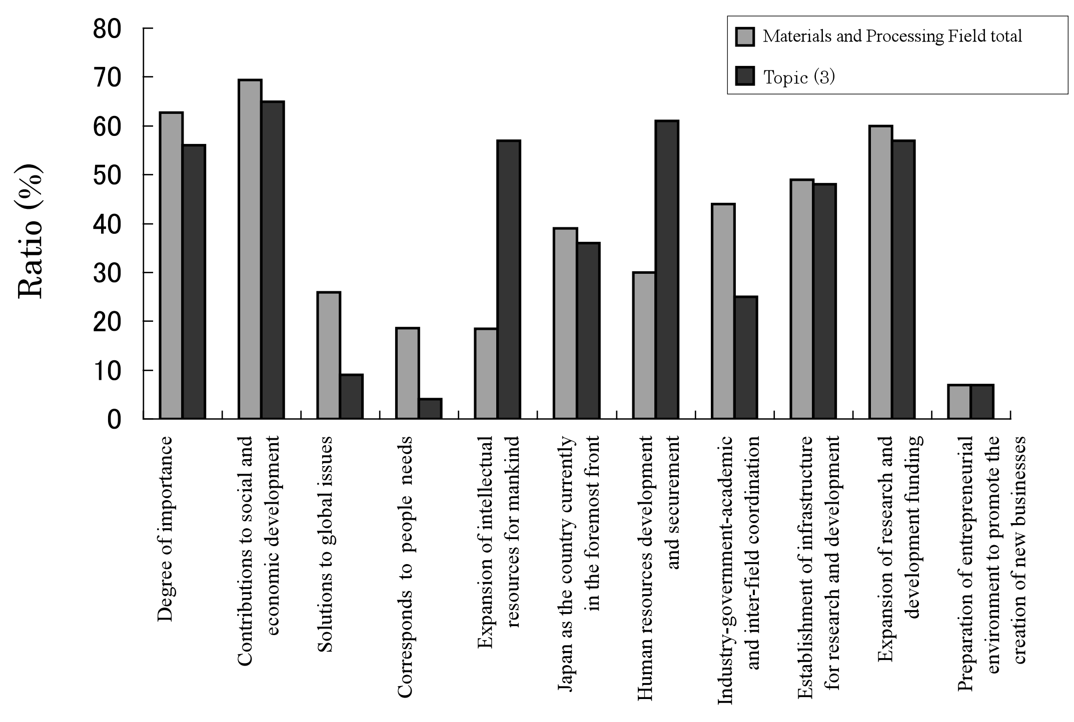
Also, the following survey results were obtained:

- While it is estimated that it will be in the year 2016.6 on the average when all the topics in the Materials and Processing Field are realized, it will be in the year 2018, comparable to the above average, for the topic (3) to be implemented.
- The countries the respondents selected as those that took the lead concerning the topic (3) were the United States (86%), Japan (36%) and EU (26%), in the order of score. (Since the responses are collected as "check all that apply", the total is not 100%.)

Table 1: Topics Related to Material Simulation in the 7th Technology Foresight

Topics related to Material Simulation		Importance index	Forecasted realization time
(1)	Theoretical design of performance using computers for metallic materials becomes possible.	55	2016
(2)	Computer-aided material designing method is put to practical use for solid catalysts having the necessary composition, structure and physical properties.	54	2017
(3)	Technology of designing a material of prescribed features is put to practical use by means of simulation based on the ab initio calculation.	56	2018
(4)	Computer simulation technology enables to estimate strict structures and physical properties in thermal equilibrium state of multi-element material, once elementary composition is provided.	49	2018

Figure 1: Comparison between average response to the topics in the Materials and Processing Field in total and that to the topic (3).



5.4 Current Level of Ab Initio Calculation in Materials Research

In Materials Research, it is an important subject of study to clarify how the functions of materials, as aggregates of atoms, are developed through understanding of the electronic states, locations, and interactions of individual atoms and their changes with time, etc., and to create materials of innovative functions by means of positively controlling their mechanisms.

Regarding Material Simulation on the nano-meter scale, studies have now been carried out for establishment of the method called "ab initio calculation" and for its application to real Materials Research.

While it is the basic equation of classic mechanics that describes the world we see routinely, it is the basic equation of quantum mechanics that describes the world of around 30 nano-meter or less. It is known that various physical properties are obtained on the nano-meter scale by changing conditions to solve the basic equation of quantum mechanics. This method represents a study method of performing nonempirical calculations without using experimental results as parameters of calculation to obtain the required information, and it is called "ab initio calculation".

The reason why ab initio calculation is highly attracted among various methods of simulation is that it is considered to be almost the only method enabling to predict quantitatively the structure, electronic state and physical properties of various materials by obtaining their electronic density distribution functions based on the basic equation of quantum mechanics, as different from conventional simulation methods that contain empirical parameters to be determined by experimental results.

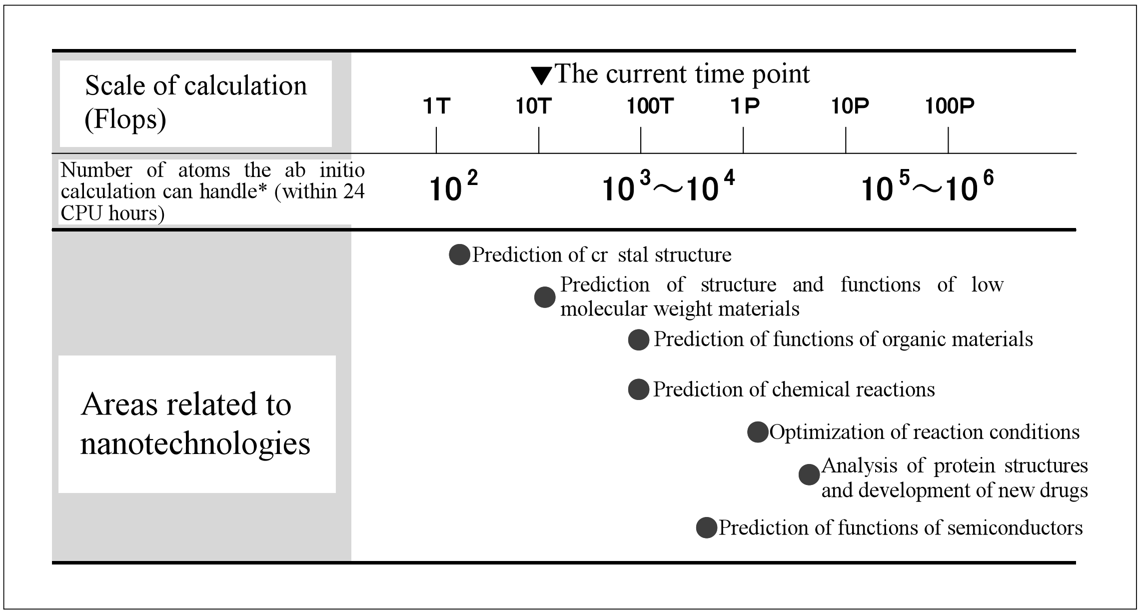
Then, what is the current level of the ab initio calculation?

The ab initio calculation is at such level as is applicable to clarification and analysis of structure and electronic properties of a material having a crystal structure.

For example, with regard to calculation concerning the lattice and elastic constants of silicon, simulation can be done with accuracy of within 1% of the experimental result.

On the other hand, there is an example in which the experimental value came to match the value obtained from simulation as accuracy of experiment has been enhanced and preparation of ideal single crystals and artificial lattice has been made possible, though it was initially said that such magnetic momentum of artificial lattice

Figure 2: Scale of calculation of the ab initio calculation, and examples of industrial applications



* It is assumed here that such high-speed algorism as computing amount is proportional to the number of atoms or its square comes into practical use.

Source: Mechanical Engineering Research Laboratory, Hitachi, Ltd.

made of aluminum and iron, as was obtained from simulation, did not agree with the experimental value.

Figure 2 shows a summary of the scale of computation, the number of atoms that the ab initio calculation can handle, etc., when a supercomputer of the highest performance level currently available is operated for 24 hours.

It is highly difficult for a researcher to exclusively use a large, high-performance computer at a research site. Assuming such exclusive use should be made possible, if it takes one month to carry out a simulation for selection of an optimum material for design of a new device, it necessitates operating such a high-performance computer for one year without interruption only for the purpose of selecting an optimum material out of 12 different materials. Thus, it cannot be said to be realistic. In fact, in view of the performance of the computer assigned to each individual researcher and the limitation in the environment of use, the ab initio calculation could be conducted to handle several hundreds of atoms at the most.

Namely, when a three-dimensional material is considered, one thousand atoms (10 x 10 x 10 = 1000) should be handled, assuming that 10 atoms exist on one side. However, under the current performance of computers and the environment of use, it is not realistic to conduct the ab initio calculation on all of such one thousand atoms, and, in reality, it could be applied only to a material smaller than a cube consisting of 10 atoms on one side.

Therefore, the advent of "Peta Flops Computer (its computing scale is described as 1P in Figure 2)" is awaited, so as to conduct ab initio calculation useful to such real Materials Research as shown in the column of areas related to the ab initio calculation in Figure 2.

(Peta Flops computer is capable of executing 1,000 trillion times per second of calculations.)

As to the time when this Peta Flops computer is appear, it was forecasted in the Information and Communication Field of the 7th Technology Foresight that a "parallel computer system with one million processors connected and having a computing speed of 1 Peta Flops class will be put to practical use" in the year 2013.

Not only improvement in the performance of computers but also development of "the methods of reducing the amount of computation necessary for simulation" are required to cover a larger spatial scale (necessary for research of such structure, physical properties and phenomena, as a larger number of atoms are involved) and a longer time scale (necessary for study of phenomena over a longer time). Thus, studies on such issues are urged.

Now, assuming that the number of atoms to be handled by the ab initio calculation is N, the amount of computation is roughly in proportion to N^m. While m varies depending on simulation method, m = 2 ~ 7 applies. When the number of atoms to be handled is increased ten-fold, the resulting amount of computation increases from 100 times to 10 million times. In reality, the number of atoms to be handled in simulation cannot be easily increased.

Many researchers are therefore engaged in the development of a method called "Order N Method" (a method of curbing the increase in the amount of computation up to around ten times that of the original computation).

Basic theories as prerequisite for simulation, are also important so as to increase the number of atoms the ab initio calculation can handle.

For instance, it is not currently possible to predict structure, constituent elements or physical properties such as superconductive transition temperature of a superconductor. However, once a theory that can handle a strongly correlated electron system is established, there is the possibility of predicting the structure and physical properties of a superconductor on the basis of the ab initio calculation with such a theory incorporated. Study is in progress based on such assumption.

5.5 Conclusion

Concerning study on such ideal systems containing no impurity and are free from disorder in the structure on the atomic scale, as represented by carbon nanotube, theoretical study by use of simulation has preceded due partly to the technical difficulties of experiment.

However, owing to advancement in micro fabrication and other nanotechnologies in recent years, experimental technologies of handling extremely clean systems where a single impurity atom is found out of 10 billion of silicon atoms have been increasing in number among others in the semiconductor industry. With the development of experimental technologies enabling the preparation of materials extremely free of impurities, it is now becoming possible to compare the result of simulation with the experimental result.

Hereafter, as direct comparisons between the experimental results and the simulation results increase in volume, improvement in quality such as accuracy and reliability of simulation is expected through feedback from such comparisons.

Also as illustrated in the example shown below, support by high-precision, high-reliable simulation is indispensable for upgrading of experimental technologies and establishment of theories, in order to achieve steady progress of nanotechnologies in the future.

- Scanning tunneling microscope (STM) and atom force microscope (AFM) provide important means of experiments in nanotechnologies. Atomic scale images of surface conditions can be obtained with STM and AFM. By comparing the result of high-precision simulation of quantum mechanical interaction between the atom located at pointed top of the probe of STM or AFM and the atom on the substrate with corresponding atomic scale images obtained from real STM or real AFM, more precise information can be obtained on the substrate observed.

  Thus, simulation can play a great role in experimental methods on the nano-meter scale.
- Contributions of Material Simulation to establishment of various theories including clarification of the mechanism of a chemical reaction that can not be observed by current experimental technology as it takes place in an extremely short time, which provide the basis for progress of nanotechnologies, are also highly important.

However, according to Table 1 and Figure 1, which show the result of the 7th Technology Foresight, the topics related to Material Simulation are regarded to be slightly lower in importance than the average of the Materials and Processing Field in total. This fact seems to indicate a situation that even researchers in the Materials and Processing field are not fully aware of the significance of simulation as basic technology to advance nanotechnologies.

In the near future, when material design by simulation becomes practicable due to the realization of the Peta Flops computer, etc., it is suspected to have not just a small effect on the gap in "research and development capability" among various research organizations based on "how well they can utilize Material Simulation".

It is necessary to try from now on to direct efforts toward Material Simulation by increasing the rate of utilization of simulation in research and development of new materials and devices, and on establishing collaborative practices between theoretical and experimental studies for the purpose of maintaining and enhancing research and development capability and competitiveness in the area of nanotechnologies and materials studies in the individual research organizations.

(Original Japanese version: published in December 2001)

6

Trend and Prospects of Bioenergy Utilization

RYOTA OMORI, *Environment and Energy Research Unit*
AKIHIRO HASEGAWA, *Life Science and Medical Research Unit*
MASAHIRO NEMOTO, *Environment and Energy Research Unit*

6.1 Introduction

Today, we are faced with global energy and environmental problems and required to find solutions satisfying the requirements of the three E's, namely energy, environment and economy.

For the global warming problem, among other things, although various economic and technical options have been proposed, each of them can individually produce only limited effects and in fact, we have no choice but to deal with the issue by using appropriate combinations of them, giving due consideration to their cost vs. performance characteristics. Under these circumstances, Japan also needs to advance research and development of diverse global warming countermeasure technologies to secure the bases for unerring, flexible policy implementation.

In this article, bioenergy, which is one of the available options in addressing the global warming problem, will be discussed. Recently bioenergy has been paid much attentions and the Japanese government is also considering revising provisions of the "Special Measure Law for Promotion of New Energy Utilization, etc." (Enforced in March 1997. Hereinafter called the "New Energy Law") to include bioenergy among the types of new energy that will be supported with government's subsidies.

In Japan, bioenergy utilization was actively studied after the oil shocks, but interest subsided with the continued downtrend of oil prices. Bioenergy, like other new energy, can contribute much in a society where externality such as energy security, environmental preservation, is highly respected.

6.2 Biomass and Bioenergy

6.2.1 Bioenergy

Plants produce hydrocarbons from water and carbon dioxide, using energy of sunlight (photosynthesis). The chemical energy held in hydrocarbons is the source of bioenergy. In a chain of plant utilization as food or a material for various products, energy held in them will be passed onto various agricultural and industrial products, and then to agricultural wastes, animal dung, waste timber and kitchen refuse.

These plant-origin organic resources are called biomass and energy extracted from them are bioenergy. Those that are not practical for utilization as energy such as foods, timber and fertilizer are not included in biomass in a narrow sense.

6.2.2 Classification of biomass

Table 1 shows the classification of biomass as a source of bioenergy. Biomass is grouped into two categories, the production resource group (energy crop plantation group) and the unutilized resource group (residue group). Production resource group biomass is mainly plants cultivated for the purpose of utilization as an energy source. Brazil's sugar cane cultivation as a supply of raw material for automobile fuel ethanol is one typical example of this group. On the other hand, unutilized resource group biomass comprises of unutilized resources left as agriculture, forestry and fishery residues after processing, and biomass found in urban wastes.

When unutilized resource group biomass is used for energy, the benefits are not limited to the energy obtained, but also include waste disposal and environmental preservation. Meanwhile,

Table 1: Classification of biomass

Categories		Example of biomass resources
Production resource group	Terrestrial resources	Sugar cane, beet, corn, rapeseed, etc.
	Aquatic resources	Seaweeds, microorganisms, etc.
Unutilized resource group	Agricultural residues	Rice straw, rice husks, wheat straw, bagasse*, vegetable wastes, etc.
	Cattle grazing residues	Cattle manure, butchery residues, etc.
	Forestry resources	Logging residues, saw mill wastes, construction wastes, etc.
	Fishery resources	Residues from fishery processing
	Urban waste resources	Household wastes, sewage sludge, etc.

*Bagasse: residues remaining after the pressing of sugar cane.

conflicts with other forms of land use should be taken into account in the case of production resource group biomass utilization.

6.2.3 Bioenergy as a renewable energy

The amount of biomass stock existing in the world is estimated between 1.2 and 2.4 trillion tons, or between 24,000 and 48,000 EJ (exa joule: $1EJ=10^{18}J$)[*1]. This represents mostly trees growing on the ground, and the amount of oceanic biomass is only one three hundreds of this[*2].

The annual primary production (flow) of biomass, in the meantime, is estimated at 128.9 billion tons[*3]. This amount converts to about 2,580 EJ/year, or seven to eight times the amount of annual primary energy consumption of the world.

Bioenergy can be regarded as renewable energy as long as biomass resources are utilized in a sustainable manner within the limits of the amount of its annual primary production. Disorderly exploitation of forest resources or their destruction will deplete the biomass stock.

Of course, biomass resources available for energy production are quite limited due to both technical and economical reasons, and there are also conflicts with other uses. Rather, they normally produce higher added value when they are utilized for other uses such as food, timber or paper. Estimation of the amount of biomass resources actually available for energy production will be discussed later in Section 6.7.

6.3 Prevention of global warming and bioenergy

The reason why bioenergy is drawing attention as a promising option among global warming countermeasures is that it is a carbon-neutral energy source that does not emit carbon dioxide as the net balance.

Of course biomass generates carbon dioxide in the course of utilization as energy such as combustion, but the amount of carbon dioxide generated is equivalent to the amount of carbon dioxide fixed from air in the growth process of the plants that provided the source of biomass. In other words, no carbon dioxide is generated as the net balance. Essentially, the same will apply to the cases where biomass is used as liquid fuel such as ethanol, methanol, biodiesel, etc.[*4].

Furthermore, biomass, even if it is unutilized as energy, will sooner or later be decomposed by microorganisms in soil into carbon dioxide and water, so the eventual carbon dioxide emission remains constant whether it is utilized as energy or not.

From the above-mentioned reasons, bioenergy, unlike fossil fuel use of which means unilateral release of carbon dioxide fixed underground to air, can be regarded as a clean energy source compared to other natural energy. Effectiveness of introduction of bioenergy as an option for global warming prevention is also mentioned in IPCC's third report on global warming released this year[*5].

6.4 Trend in Japan

6.4.1 Bioenergy's position in the New Energy Law

In this section, the position of bioenergy in the law system will be briefly reviewed. Article 2 of the New Energy Law provides for utilization of new energy, etc. The specific items of new energy implied in "Utilization of new energy, etc." are considered to be the 12 items defined in the enforcement ordinance (Article 1 of the ordinance) of the said law, which include solar energy and wind power generation, with items referring to waste power generation and thermal utilization thought to include bioenergy in part, but reference to bioenergy utilization is not explicit as far as the wording of the provision is concerned.

A report compiled by the New and Renewable Energy Subcommittee of the Advisory Committee for Natural Resources and Energy in June this year *7 refers specifically to this point and states as follows: "While in its opinion, the current law system does not explicitly mention that utilization of biomass energy is regarded as one form of new energy utilization nor provides for any administrative measures to encourage its utilization, the Subcommittee considers it appropriate to include biomass in a distinctive manner as one category of the new energy defined in the New Energy Law and encourages its active introduction and promotion. ("III. Review of the scope of new energy" of the said report.)

In response to this recommendation, revision of the relevant provision is being considered to include bioenergy in the scope of the New Energy Law. More specifically, granting the following privileges to enterprises approved by the minister having jurisdiction (approved enterprises), among those that are planning to utilize bioenergy, is being considered: loan guaranty provided by NEDO (New Energy and Industrial Technology Development Organization), which is a measure stipulated under the New Energy Law, or application of the exception rule of the Small and Medium-scale Enterprise Investment Foster Company Act (subscription of shares or convertible bonds issued by an approved enterprise by the Small and Medium-scale Enterprise Investment Foster Company).

6.4.2 State of bioenergy introduction

Table 2 shows the actual state and future prospects*6 of Japan's new energy introduction. The combined new energy accounts for about 1.2% of the entire primary energy supply, while two thirds of it are brought by the utilization of black liquor and waste timber in the pulp and paper production process, which is also recognized as a form of bioenergy utilization.

Although the absolute quantity of energy obtained from biomass power generation is small when

Table2: Energy supply records and prospects of new energy

	Supply records in 1999 (converted equivalent crude oil volume in 10,000 kl)	Forecasts for 2010 / objectives (converted equivalent crude oil volume in 10,000 kl)	
		Forecasts based on current trends	Objectives
Power generation sector			
Solar power generation	5.3	62	118
Wind power generation	3.5	32	134
Waste power generation	115	208	552
Biomass power generation	5.4	13	34
Thermal utilization sector			
Solar heat utilization	98	72	439
Unutilized energy (including snow and ice coldness)	4.1	9.3	58
Waste thermal utilization	4.4	4.4	14
Biomass thermal utilization	—	—	67
Black liquor, waste timber, etc.	457	479	494
Total new energy supply (composition in the total primary energy supply)	693 (1.2%)	878 (1.4%)	1910 (About 3%)
Total primary energy supply	about 590 million kl	about 620 million kl	about 600 million kl

Source: Quoted from a report compiled by the Comprehensive Resource and Energy Survey Committee*6 compared with the utilization of black liquor and waste timber, it is almost equivalent to power generation using solar energy or about 1.6 times the quantity of wind power generation. The objective figure for introduction of biomass power generation and biomass thermal utilization combined in 2010 is about 1 million kl as the converted equivalent crude oil volume (about 5% of the new energy).

6.4.3 Incentives for introduction

Granting approved enterprises, which are planning for power generation or thermal utilization using wastes among the sources of bioenergy, special privileges in the form of loan guaranties provided by NEDO (the limit of guaranty: 90% of the amount of eligible loans; the rate of guaranty fee: 0.2% per annum; the annual cap of guaranty offered in FY2000 (available guaranty amount): ¥30 billion) under the New Energy Law or application of the exception rule of the Small and Medium-scale Enterprise Investment Foster Company Act (subscription of shares or convertible bonds issued by an approved enterprise by the Small and Medium-scale Enterprise Investment Foster Company) is being practiced.

Furthermore, NEDO is offering approved enterprises a subsidy covering part of the expenses incurred in introducing bioenergy (percentage of subsidization: one third of the expenses; total amount of the subsidies paid in FY2000: ¥11.49 billion) and enterprises utilizing combustion heat of wastes including paper sludge and waste timber have enjoyed the subsidies. Besides, NEDO and enterprises are jointly conducting field tests to introduce waste power generation, etc., though they are not direct supporting measures for bioenergy introduction.

In the meantime, Japan Natural Energy Co., Ltd., a company established with capital contributions made by eleven major electric power companies in Japan in November 2000, has institutionalized a green power certificate system, under which the company takes an order from an enterprise desiring utilization of natural energy such as wind force, selects an appropriate natural energy power provider to commission it to construct and operate a plant, and supplies electric power generated at such a plant through a local electric power company. The company has so far promoted wind power generation alone as a power generation means utilizing natural energy due to its acceptance by society and the cost, and is supplying to about 20 enterprises power from such sources with a contract to supply 1 to 4.5 million kW per annum per enterprise. The company is planning to expand the scope of its activities to include bioenergy, and to promote it actively in the future.

Furthermore, a study to find a desirable form of the RPS system (renewable portfolio standard: a standard system to promote the introduction of renewable energy by using certificates) is now underway at the New and Renewable Energy Subcommittee of the Advisory Committee for Natural Resources and Energy to promote the introduction of new energy including bioenergy. Under this system, if introduced, the government will issue certificates to enterprises based on the levels of their utilization of new energy in power generation and obligate electric power companies, etc., to acquire a certain number of certificates. Certificates may be traded on the market.

6.5 Overseas Trends

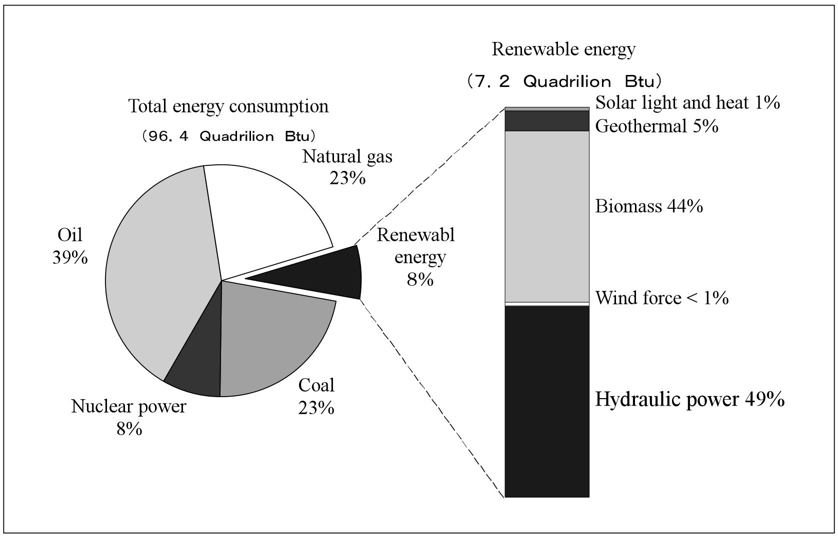
6.5.1 U.S.

(1) State of bioenergy introduction

The state of bioenergy introduction in the U.S. is briefly reviewed based on data published by the Energy Information Agency of the U.S. Department of Energy. As shown in Figure 1, renewable energy (including hydraulic power) accounts for 8% of the energy consumption in the U.S. Bioenergy accounts for 44%, indicating that its utilization, rather than solar energy and wind force, is widely practiced. The utilization of biomass, however, is mostly in areas other than power generation and 80% of it is consumed in the industrial sector. By form, wood-origin biomass accounts for 80%, while urban wastes-origin biomass, 17%.

To compare the sources of renewable energy utilized for power generation (1999), hydraulic power comes first with an 80% share, followed by biomass, geothermal and wind force accounting for 14%, 4% and 1%, respectively. Biomass power

Figure 1: State of renewable energy introduction in the U.S. (1999)



(DOE/IEA)

generation is mostly undertaken by non-utility power providers (such as cogeneration-based small-scale power providers and independent power providers (IPP)) and the biomass power generation facilities combined registered a capacity of 11.01 million kW in 1999.

In the U.S., automobile-use alcohol-blended gasoline (gasohol), which contains up to 10% of mainly corn-derived ethanol, is widely used and accounts for nearly 40% of the total automobile fuel consumption in some of the middle and western states. Automobile-fuel ethanol production in the U.S. has increased at a rate of 12% per year on the average since 1980, and reached 1.4 billion gallons in 1998*[7]. Today, ethanol substitutes for about 1% of total gasoline consumption.

Pollution of potable water with MTBE (methyl tertiary butyl ether), which is used as an additive in modified gasoline, has become serious recently and many states are beginning to consider banning the addition of MTBE. Ethanol is the most expected MTBE substitute and may see an explosive increase in demand in the near future*[8].

(2) Government efforts

In the U.S., bioenergy utilization is being promoted by the government through the Department of Energy and the Department of Agricultural Affairs from the viewpoints of energy security, environmental protection and agriculture promotion. The Department of Energy is promoting a biofuel-related R&D program and a biopower generation R&D program, with a view towards energy production. The Department of Agricultural Affairs, on the other hand, is engaged in the projects of biomass plant breeding and biofuel, aiming at promoting and protecting agriculture.

In August 1999, President Clinton issued presidential order 13134, "Development and promotion of bioproducts and bioenergy" with a view to tripling bioenergy-related products and bioenergy consumption by 2010.

The presidential order proposed the following as specific measures: (1) the government as a whole should invest $240 million in R&D in FY2000; (2) efforts should be made jointly with the private sector to increase production of automobile fuel ethanol; and, (3) an inter-departmental committee should be established to create bioenergy promotion strategies spanning over the Departments of Energy, Agricultural Affairs and Commerce, the Environmental Protection Agency, and the Departments of Commerce and State Affairs. It claims that implementation of this program is expected to reduce about 100 million tons of greenhouse effect gas emission and 4 billion barrels of imported crude oil, while it will create opportunities for $15 to $20 billion of additional incomes in the rural faming areas.

Some people, however, pointed out that this presidential order is a product of political ambition to win support from farmers before the presidential election. The state energy policy published by the Bush administration in June this

Table 3: Renewable energy's shares in the primary energy composition of EU member countries (1999)

	Biomass (%)	Wind force (%)	Geothermal (%)	Solar (%)	Hydraulic power (%)	Total (%)
Finland	19.0	0.0	—	0.0	3.4	22.3
Sweden	14.5	0.0	—	0.0	12.3	26.8
Austria	10.9	0.0	0.0	0.4	12.3	23.2
Denmark	7.8	1.4	0.0	0.0	0.0	9.3
France	4.5	0.0	0.0	0.0	2.5	7.0
Italy	3.9	0.0	1.6	0.0	2.2	7.8
Spain	3.3	0.2	0.0	0.0	1.7	5.2
Netherlands	2.0	0.1	—	0.0	0.0	2.0
Germany	1.9	0.1	0.0	0.0	0.5	2.6
UK	0.9	0.0	0.0	0.0	0.2	1.1
EU total	3.7	0.1	0.2	0.0	1.8	5.9

Source: Eurostat data

year*8 seems to place more emphasis on the increase of domestic fossil resource supply rather than conversion from fossil resources to natural energy. (Science and Technology Trend, a feature covered in the June 2001 issue.)

6.5.2 EU

(1) State of bioenergy introduction

As shown in Table 3, renewable energy (including hydropower) accounts for 5.9% of the primary energy consumed within the EU, while about 60% of it comes from bioenergy. By country, Austria, Finland and Sweden registered over 10% figures as bioenergy's share in the primary energy composition. On the other hand, large energy-consuming countries such as the UK, Germany and France register relatively low figures as their bioenergy's share in the primary energy composition.

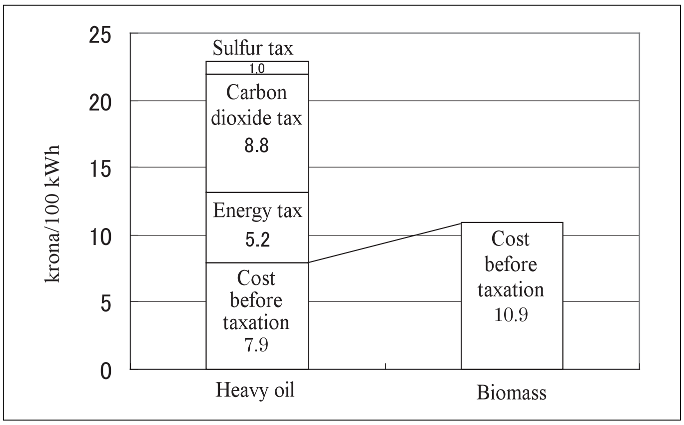
Since a greater portion of bioenergy is utilized as heat, power generation has a smaller share in the uses of bioenergy than those of other renewable energy. Nevertheless, bioenergy power generation accounts for 1.4% of the total power generation in the EU (12% in Finland, 4.5% in Denmark, and 3.3% in the Netherlands), which is greater than the 0.6% accounted for by wind power generation and the 0.2% by geothermal power generation. Incidentally, solar power generation is next to nil.

There are several reasons lying behind this wide spread of bioenergy utilization in the EU including high public interest in environmental issues, large demand for heat for heating purposes, mandatory green power purchase system obligating power distributors, introduced in many countries, and various incentives offered in the form of tax exemptions or subsidies encouraging renewable energy introduction. In the Scandinavian countries, where forest industries are prosperous, district heating and cooling systems and cogeneration systems using wood-origin biomass such as wood chips produced in sawmills and forest residues have spread widely. Carbon tax (bioenergy is exempted) has played an important role in spreading bioenergy in Sweden, where the cost of biomass fuel is lower than that of heavy oil as shown in Figure 2*9.

(2) European Commission's Efforts

In November 1997, the European Commission released a white paper referring to the European Community's strategies and action plan, "Future of energy: renewable resource energy"*10. The action plan proposed in the white paper consists of four objective areas, regional market-related actions, policy reinforcement as the EU, enhancement of cooperation among member countries and supportive measures, and defines its goal as the increase of renewable energy's share in the primary energy composition of the EU as a whole to 12% by 2010. It proposes to increase bioenergy introduction from 44.8 MTOE in 1995 to 135 MTOE by 2010, nearly triple. The breakdown of this increase is 15 MTOE by biogas utilization, 30 MTOE by forest residue and forestry residue utilization and 45 MTOE by energy crops.

Figure 2: Comparison of heavy oil and biomass costs in Sweden



Source: reference material *9, 1 krona = ¥12

The "Kick-off campaign" to realize this proposal was started in 1999. In the bioenergy area, the plan names specific objectives including bioenergy based heat supply to 1 million homes by 2003, construction of biogas plants outputting 1,000 MW and installation of bioenergy based cogeneration systems outputting 10,000 MWth heat. As bioenergy-related R&D and introduction support programs, the ENERGIE program (1999-2002) in the R&D area and the ALTERNERII project (1998-2002) relevant to law-system, administration and market environment improvement, and the promotion of investment support are now underway. The ALTERNERII project was allocated 22 million ECU for the 1998-1999 period.

6.5.3 Other countries

Brazil has promoted ethanol production from sugar cane and the introduction of ethanol cars as its national policy with a view to stabilizing sugar prices on the international market and to reduce oil imports to save on foreign exchanges. It also uses a large quantity of bagasse, residues remaining after sugar cane pressing, as industrial fuel. As of 1995, ethanol cars (running with water-added ethanol alone) accounted for 42% of all the automobiles driven in Brazil, while the rest are operated with gasohol containing 22-24% of absolute ethanol[*11]. In recent years, however, demand for ethanol cars has declined due to the lowering oil price, unstable alcohol production and a change in people's taste.

In most of the developing countries in Asia and Africa, firewood is the major source of primary energy. Although it is often observed that the use of firewood is not reflected in statistics due to its non-commercial nature, one estimation claims that 15% of the world's primary energy consumption and 38% of that by the developing countries depend on bioenergy consisting mainly of firewood[*12]. Generally, the efficiency of energy utilization is low with firewood consumption in these developing countries, which causes incidental problems including forest disruption.

6.6 Bioenergy conversion and utilization technology overview

Biomass can take diverse forms or be utilized in a variety of ways including power generation, thermal utilization and use as liquid fuel. Since biomass is chemical substances, it can be transformed into liquid fuel such as methanol, ethanol or bio-diesel to be utilized as substitution fuel or fuel for fuel cells. This is a characteristic point not found among other new energy, and adds great advantages to biomass in terms of its transportability or storability.

Energy conversion technologies applicable to biomass are roughly divided into two types; thermo-chemical conversion technology, and bio-chemical conversion technology. In this section, some major technologies belonging to the respective types will be discussed.

6.6.1 Thermo-chemical conversion technology

(1) Direct combustion

This is the most generally practiced method of utilizing biomass, and direct utilization of heat and power generation using combustion heat are included in this category. Typical plants are of a size between several MW and several ten MW. In the Scandinavian countries, wood chips, waste timber and agricultural wastes are mainly used. At coal-fired thermal plants in the U.S. and some EU member countries, mixed firing of coal and waste timber, saw dusts, wheat straw, peat and urban wastes is practiced.

In 1999, the U.S. Department of Energy released the Vision 21 plan, which aims at building a plant by 2015 that can produce not only electric power and heat but also various products including chemical substances and transportation fuel from diverse raw materials, and yet emits little substances causing an environmental load. As raw materials supplied to the plant, the plan names biomass together with coal, natural gas, petroleum and urban wastes. (All these raw materials will be gasified before they are fed to the plant.) The plant aims at reducing emission of substances causing an environmental load to almost nil, (reduction of carbon dioxide emission will be achieved through realization of high-energy efficiency, with the use of separation and fixation technologies in combination).

(2) Synthesis of liquid fuel via gasification

This is a process to gasify biomass such as wood by heating it with a gasification agent such as air, oxygen or steam, and to obtain a gas mixture (biomass gas) consisting mainly of hydrogen and carbon monoxide. The point is how to produce desirable biomass gas having low tar content, and a variety of processes using different gasification furnaces including fixed bed, fluidized bed and entrainment furnaces have been proposed. Once an adequate biomass gas is obtained, it can be easily converted into liquid fuel such as methanol, diethyl ether and gasoline with established technologies[*13].

(3) Thermal decomposition and oil conversion

Thermal decomposition is a method to obtain gases and oils by heating dried and crushed biomass in an inert gas atmosphere such as a nitrogen atmosphere. A rapid thermal decomposition method has become the mainstream of this technology in recent years. In this method, temperature is raised quickly to minimize the production of combustible gases and char, a solid combustible, and improve the production yield of oil. Meanwhile, a direct oil conversion method is the more appropriate choice, with biomass having a high moisture content. In this technology, biomass is converted into oil by simply placing it under high-temperature, high-pressure conditions without using hydrogen or carbon monoxide, and the operating temperature is rather low compared with thermal decomposition. Although the method requires a more complicated reaction system, it offers higher energy efficiency than thermal decomposition does for high moisture content biomass[*13].

(4) Biodiesel

Rapeseed oil, palm oil and sunflower oil are modified through esterification, etc., to lower the viscosity for use as diesel fuel. Biodiesel fuel can reduce particulates, polymers, SO_X, acetaldehyde, etc, contained in exhaust gas from levels normally observed with ordinary diesel fuel. On the other hand, bio-diesel, in which three fourths of the cost is taken by the production cost of plant oils, is more expensive than diesel oil[*13].

6.6.2 Bio-chemical conversion technology

(1) Ethanol fermentation

This is a long established technology for producing ethanol from sugar through fermentation using microorganisms. In the case of sugar-containing biomass such as sugar cane, etc., sugar can be obtained directly. On the other hand, ligno-cellulose-based biomass such as wood requires a sugar conversion process using hydrolysis prior to the fermentation process. Development of an efficient process to convert grass and wood, which are not sugar-containing biomass, into sugar is a key to widening the horizon of bioenergy utilization, and such technology has already reached a near practical level. In the meantime, development of microorganism enzymes that can ferment crude liquid containing sugars, other than glucose such as xylose, is underway, with gene recombination technology also employed in this area.

(2) Methane fermentation

This includes a process to decompose raw food wastes, cattle manure, agricultural wastes, etc., in an atmosphere lacking oxygen with anaerobic bacteria to fat acids, alcohols, carbon dioxide and hydrogen. Then methane is produced by using methane formation bacteria, and used as fuel at methane gas power plants.

A fermentation method used in this process can be; (1) a wet method to ferment organic materials in a liquid; or (2) a dry method to ferment solid materials conditioned to an optimum moisture level and kept under agitation. Method (2) is quite effective as a means to dispose of wastes, since it can reduce the volume and weight of raw food wastes substantially through the fermentation process.

At waste disposal facilities, natural generation of methane is normally observed and recovery of naturally produced methane is widely practiced in the U.S. Methane fermentation using cattle manure and agricultural wastes is being introduced into European countries in consideration of the prevention of environmental pollution. Biomass gas plants using cattle manure and food wastes have also been erected in Japan at Bekkai-cho, Hokkaido, and Yagi-cho, Kyoto Prefecture. Due to the enforcement of the Food Recycle Law (enforced in June 2001) and the Cattle manure Management and Recycle Law (enforced in November 1999), appropriate management and disposal of these types of wastes are expected to progress in the future. In connection with this, their effective utilization as a source of bioenergy may also be promoted at an accelerated pace in Japan.

6.7 Evaluation of the potential of bioenergy resources

6.7.1 Their potential as resources in Japan

Japan has forest rich with biomass resources covering about 70% (about 25 million ha) of its land area (37 million ha) and about 5 million ha of farming land developed mainly on plains, where biomass production is practiced through agricultural production activities.

According to Professor Shiro Saka of the Energy Science Study Course of the Post Graduate School of Kyoto University[*11], Japan is estimated to be producing about 370 million tons of biomass resources annually, about 130 million tons of which come from forest and farming land, while the remaining of some 240 million tons are unutilized waste resources.

According to his estimation, 20% of the total biomass resources annually generated in Japan or 77 million tons can be technically and economically convertible to energy. Although such estimation runs the risk of error due to the susceptibility of results to assumptions such as the forms of use and the evaluation method, the amount corresponds to 127 million tons of carbon dioxide or about 10% of Japan's 1,231 million-ton total carbon dioxide emission in 1997[*11]. In another estimation, about 4% of Japan's primary energy consumption can be saved, if the unutilized waste biomass resources that can be economically and technically usable are fully utilized[*14].

(1) Agricultural residue biomass

Since most of Japan's farming land is used for specific purposes such as food production and already assigned to some sort of actual crop production, it is difficult to secure farming land for bioenergy crop production anew. Accordingly, rice straw, wheat straw, rice husks, etc., are considered to be the only agriculture-related biomass available for energy production.

According to Professor Saka mentioned earlier[*11], among 19.62 million tons of agricultural residues generated annually, 8.55 million tons or about 40% are considered to be available for energy production. Assuming the average calorific value of agricultural residues to be 16.3 MJ/dry-kg, the calorific value of rice straw, the energy potential of agricultural residues available for energy production will be about 140 PJ (peta joule: $1PJ=10^{15}J$) or about 0.6% of Japan's primary energy consumption.

Incidentally, the following crops may be named, when devoting faming land to growing crops for the purpose of producing energy is considered: (1) crops that ensure high sugar productivity such as sugar cane, corn, sweet sorghum, potatoes, etc., to obtain liquid fuel such as ethanol; and, (2) fast growing tree or grass species that ensure high

Table 4: Forecasts of forest residues and recycled timber (Unit: million m^3)

		Current	2010
Generated volume	Forest residues	10	10
	Sawmill wastes	15	13
	Construction waste timber	16	32
	Total	41	55
Utilization volume	Energy production	7	20
	Raw material, etc.	13	24
	Total	20	44

Source: Forest and Forestry Basic Plan compiled by the Ministry of Agriculture, Forestry and Fisheries.

biomass productivity including cellulose production such as eucalyptus and Nepier grass.
A number of domestic testing or research institutions have conducted research programs to cultivate sweet sorghum in particular, because it can be grown in a relatively cold climate and is easily convertible to ethanol, and found that it can yield about 50 t/ha of raw stems*[15].

(2) Livestock grazing residue biomass

With regard to livestock grazing residue biomass, excretion from livestock such as cows and pigs, and fowls such as chickens, is a source available in Japan and the combined annual output is estimated to reach 95 million tons (60 million tons of excrement and 29 million tons of urine) (according to the Ministry of Agriculture, Forestry and Fisheries).
Among the excretion, NEDO's survey report*[16] estimates that 25% of cattle manure is available for energy production, and an available resource amount based on this assumption is calculated to be 16.5 million tons, or about 69 PJ, when converted into calories (1,000 kcal/kg is assumed), which corresponds to about 0.3% of Japan's primary energy supply.

(3) Forestry residue biomass

The annual increment of forest resources in Japan is generally estimated at 70 million m^3, and it is assumed that forest residues and waste timbers among them are available as resources for bioenergy production.
The "Forest and Forestry Basic Plan" approved by the Cabinet in October 2001 contains "Forecasts of Forest Residues and Recycled Timber" shown in Table 4.
According to these forecasts, forest residue biomass including forest residues and waste timbers used for energy production in 2010 will hit 20 million m^3. To convert these wood resources into weight with a conversion factor of 0.5 t/m^3, 10 million tons per annum of forest residue biomass can be utilized. If 20 MJ/kg, the calorific value of wood-origin biomass, is assumed, the energy potential of these resources will reach about 200 PJ, or about 0.8% of Japan's primary energy supply.
Incidentally, taking trees felled in thinning operations as an example, to examine the actual state of Japan's forestry, thinning was performed on approximately 300,000 ha of forest area in Japan in FY1999, producing about 5.14 million m^3 of logs (according the Forestry Agency's estimation), but only 2.12 million m^3 or 40% of them were extracted for use as a raw material for sawn timber, round logs and wood chips from forests where logging and hauling were relatively easy. Accordingly, it is believed to be difficult in present Japan to further increase the recovery of these forest residues as a raw material for energy production, supply of which is normally required to be at low cost, and, therefore, utilization will be promoted first with sawmill wastes and construction waste timber.

6.7.2 Medium to long-term potential of global resources

As reviewed up to here, biomass includes quite a wide range of materials and its utilization as an energy source conflicts with various other uses. Generally speaking, utilization as food, timber, fertilizer, paper, fiber, etc., should be given first priority and the satisfaction of these needs is a prerequisite for utilization as bioenergy. Then, how much of bioenergy will be available to human societies in the 21st century?

A group led by Professor Kenji Yamachi of the New Area Creative Science Study Course of Tokyo University performed an analysis of Japan's biomass flow using a biomass balance sheet, and evaluation of energy supply potential from idle arable land over the world using a Global Land Use and Energy (GLUE) Model[*1,14].

According to this analysis, an actually realizable quantity of bioenergy supply calculated from global residue-based biomass generation volume, with technical restrictions taken into account, would have been 34.4 EJ (excluding about 20 EJ generated with fuel-use wood) in 1990. In 2050, the study predicts that the total quantity of residue-based biomass in the world will be 173 EJ, with energy crops that can be supplied from idle arable land reaching 110 EJ. Combined together, they will provide about 280 EJ, or approximately 70% of the present total energy demand of the world.

In this analysis, it is assumed that all idle arable land will be devoted to energy crop production. It also states that estimation of the energy crop quantity that is supplied from idle arable land can be affected greatly by parameters such as food supply demand from developing countries, while residue-based biomass steadily shows large supply potential regardless of simulation conditions.

In the IPCC's third global warming report[*5], the supply potential of energy crops in 2050 is estimated at 396 EJ or 441 EJ when combined with residue-based biomass.

6.8 Toward introduction of bioenergy

Japan has been rather backward in introducing bioenergy when compared to other nations. In recent years, however, rapid growing interest in bioenergy has been observed among industry, government and academic circles, and necessary revision of the relevant provisions to include bioenergy in the scope of new energy to which supportive measures are applied under the New Energy Law is being studied within the government circles. It is undoubtedly a need of the times for Japan to establish effective bioenergy introduction strategies.

It has been pointed out that the economy, or collection and transportation costs of biomass in particular, is a problem in considering utilization of bioenergy. Although bioenergy has been introduced to a considerable extent in the U.S. and Europe, there is no denying that it is the result of underpinning political support along with preferential treatment in taxation, an order obligating power providers to purchase new energy-derived power, and environment taxes. Furthermore, it has been pointed out that Japan's rugged topography makes it difficult to utilize its resources, in spite of the affluence of its forest resources, and that the relatively small scale of agriculture and cattle grazing operations and small demand for heat for heating purposes, etc., would work adversely in promoting bioenergy.

In any event, except for abnormal circumstances such as an oil shock, it is hardly conceivable that the cost of bioenergy will become lower than that of fossil resource-based energy without artificial manipulation of a political nature. Since most developed countries including Japan are dependent on fossil resource-based energy for about 80% of their primary energy supply, if they are to depart from their present fossil resource dependent society, it is necessary for them to construct a society that is willing to bear a reasonable cost for development and utilization of bioenergy and other new energy.

To spread the utilization of bioenergy on a substantial scale, it is essential to have private enterprises' participate in the market and, therefore, it is believed to be of importance to provide political support that allows them to construct economically viable business models, while advancing researches that provide the bases for such political initiatives.

As stated in Section 6.7.1, even a conservative estimate of the energy supply potential of biomass, limiting its scope to economically and technically usable unutilized waste-origin biomass resources, is about 4% of Japan's primary energy consumption, and this is not a small figure by any standard.

Furthermore, it is important to note that utilization of bioenergy will bring additional benefits to society such as waste disposal and environmental preservation. In any event, the spread of bioenergy utilization depends on the construction of a society that takes benefits of the external economy such as environmental preservation and saving of fossil resources as its internal value, and the degree of spread will be determined by how much the society recognizes external benefits as its internal value. And this is something purely dependent on our own decision and choice.

The following five proposals are our recommendations to encourage introduction of bioenergy.

(1) Enhancement of bioenergy research

Because various types of materials together with varying conversion and utilization technologies are involved in biomass resources, research efforts are being made in diverse areas by industries, universities and national or public research institutions (industrial, academic and governmental research organs), and research achievements are published through a number of academic societies or technical associations. Although resources input to the bioenergy-related studies have so far been much smaller, when compared to efforts made in the solar energy-related area, another area in the same natural energy category, it is desirable to expand support to industrial, academic and governmental research organs for bioenergy-related studies in the future due to international trends connected to the international agreement on global warming prevention.

In expanding support, naturally thorough understanding of the current institutional system is required, but the first thing that must be done is to hold more detailed and fruitful discussions between the administration side and the researchers' side by releasing exhaustive and systematic information on the development, introduction and spread of bioenergy by the researchers' side.

Discussions between the researchers' side and the administration side may involve a wide variety of topics including: the desirable form and level of social burden sharing to absorb the cost of disposal and utilization of household wastes and cattle grazing wastes; the most effective system for collaboration between academic societies or technical associations in connection with industrial, academic and governmental research organs; an appropriate fund allocation plan matching the number of currently employed researchers of each research institution; and, support for human resource cultivation and so on.

Because biomass resources involve vast diversity, it is desirable to expand support while running appropriate assessment programs to rate the value of each research work for selection of the research areas that should be bolstered.

(2) Designing a system that gives consideration to the external economy

When compared with solar batteries and wind power generation, utilization of bioenergy will require absorption of much larger running costs such as fuel collection and transportation, plant operation, etc., besides the initial investments in plants.

Take cattle manure for instance, which by regulatory requirement is not allowed to be left for nature to decompose, there are disposal means including a bioenergy plant using methane fermentation that is effective in terms of prevention of offending smell. However, if such means require persons discharging wastes to bear extra costs besides normal disposal costs or provide only poor returns to plant operators, introduction of bioenergy plants will advance at only a snail's pace and a negative picture of them can stagnate research and development efforts as well.

Therefore, when utilizing wastes as bioenergy is considered to be beneficial at least for the external economy, it is necessary to design a system that asks a wider spectrum of society to share the costs of construction and operation of a bioenergy plant in parallel with the promotion of R&D.

(3) Construction of an extensive and effective biomass raw material collection system

Generation of biomass resources is not distributed evenly over regions and the effect and desirable form of introduction of bioenergy will also vary depending on regional characteristics. From a transportation cost point of view, it is more advisable to construct an energy conversion and utilization plant near the point of raw material generation.

In the meantime, it should also be noted that the scale of a biomass conversion and utilization plant will have significant impacts on its economy. For biomass conversion and utilization plants, as with typical industrial plants, the larger a plant is, the more it becomes economically viable due to the merits of scale. (Of course, construction of an energy plant of several hundred thousand kW capacity using solely biomass resources is not practical in terms of the procurement of raw materials). The IPCC's third global warming report also states that often the economy derived from the scale of a plant (to utilize bioenergy) is more important than additional transportation costs (that become necessary because a plant is constructed away from the point of raw material generation).

Therefore, it is of importance to select a location where sufficiently large quantities of biomass raw materials can be secured in promoting bioenergy utilization in Japan. At the same time, it is desired to construct recovery systems that ensure recovery of intended biomass raw materials in a sufficient quantity and improve the efficiency of sorting and recovery operations at the respective ends.

(4) Promotion of R&D for mixed firing at coal-fired plants, etc.

When dry biomass raw materials are burned in an established thermal plant together with the proper fuel, such as coal, natural gas or oil, for mixed firing, scale merits and economic benefits offered by them can be fully enjoyed, while it is not necessary to absorb the construction cost of a biomass power plant as the primary beneficiary. In fact, mixed firing is practiced in the U.S. and European countries at coal-fired thermal plants.

Such mixed firing at established thermal plants is believed to be one of the biomass utilization methods minimizing risks, and we should also place more emphasis on this form of utilization in promoting R&D efforts in Japan. Furthermore, in view of a plant operable with multifarious fuel as proposed in the U.S. Department of Energy's Vision 21, it is a research area worth paying more attention to in Japan as well.

(5) Joint efforts and cooperation with developing countries

Due to conflicts with other land uses, introduction of large-scale energy crop plantations is not regarded as practical in Japan in the foreseeable future, and expanding utilization of existing unutilized biomass resources is a more practical option for us. Meanwhile, when viewed globally, the potential of bioenergy based on energy crop plantations is quite large. Countries in Southeast Asia, Latin America and Africa in particular may find quite high potential in bio-plantations.

Accordingly, although it may take quite a long time before bioenergy produced in these countries take on an important role in the world energy supply system, it is considered to be necessary to render active support to developing countries' efforts for utilizing bioenergy by taking advantage of CDM (clean development mechanism) defined in the Kyoto Protocol.

Many developing countries depend on firewood for their main source of energy, but their present energy utilization efficiency is very low. Since support required to improve their technology to utilize this resource has little technical difficulties and is expected to produce immediate effects in terms of greenhouse gas emission reduction, we should promote it actively.

Reference

* 1 Kenji Yamachi, "Baio enerugi" (Bioenergy), Mioshin Shuppan (2000)
* 2 H.Leith and W.Whittaker: Primary Production of the Biosphere, Springer-Verlag (1975)
* 3 Kyoji Yota, "Chikyu kagaku" (Earth science), 16(2), 78-85 (1982)
* 4 Masayasu Sakai, "Baiomasu ga hiraku 21 seiki" (21st century opened with biomass), Morikita Shuppan (1998)
* 5 IPCC Third Assessment Report: Climate Change 2001, IPCC (2001)
* 6 Comprehensive Resource and Energy Survey Committee, New Energy Subcommittee: New Energy Subcommittee's report: "Kongo no shin enerugi no arikata" (Desirable forms of future new energy development), June 2001
* 7 J.DiPardo: Outlook for Biomass Ethanol

Production and Demand, DOE Modeling and Analysis Report (2000) (http://www.eia.doe.gov/oiaf/analysispaper/biomass.html)

* 8 National Energy Policy Development Group: National Energy Policy - Reliable, Affordable, and Environmentally Sound Energy for America's Future (2001)

* 9 Tetsuya Iida, "Hokuo no enerugi demokurashi" (Energy democracy in Scandinavian countries), Shinhyoron (2000)

*10 European CommissionÅFEnergy for the Future: Renewable Sources of Energy, White Paper for a Community Strategy and Action Plan, COM(97)599 (1997)

*11 Compiled and authored by Shiro Saka, "Baiomasu, enerugi, kankyo" (Biomass, energy and environment), IPC (2001)

*12 T. Johansson, et al. Eds., Renewable Energy, Island Press (1993)

*13 Shinya Yokoyama, "Baio enerugi saizensen" (Bioenergy front), Morikita Shuppan (2001)

*14 Kenji Yamachi, "Baio enerugi heno kitai to kadai" (Expectations on and problems of bioenergy), the tenth Japan Energy Society's convention, keynote lecture, in Kita-kyushu City (2001)

*15 Compiled by the secretariat to the Agriculture, Forestry, and Fishery Technology Conference of the Ministry of Agriculture, Forestry and Fisheries, "Baiomasu henkan keikaku, Yutakana seibutsu shigen wo ikasu" (Biomass conversion plan, utilizing affluent bio resources), Korin (1991)

*16 New Energy and Industrial Technology Development Organization, FY1999 survey report, NEDO-GET-9949 (2000)

(Original Japanese version: published in December 2001)

7

Trends in Science Communication
— Circumstances Enveloping Science Journals —

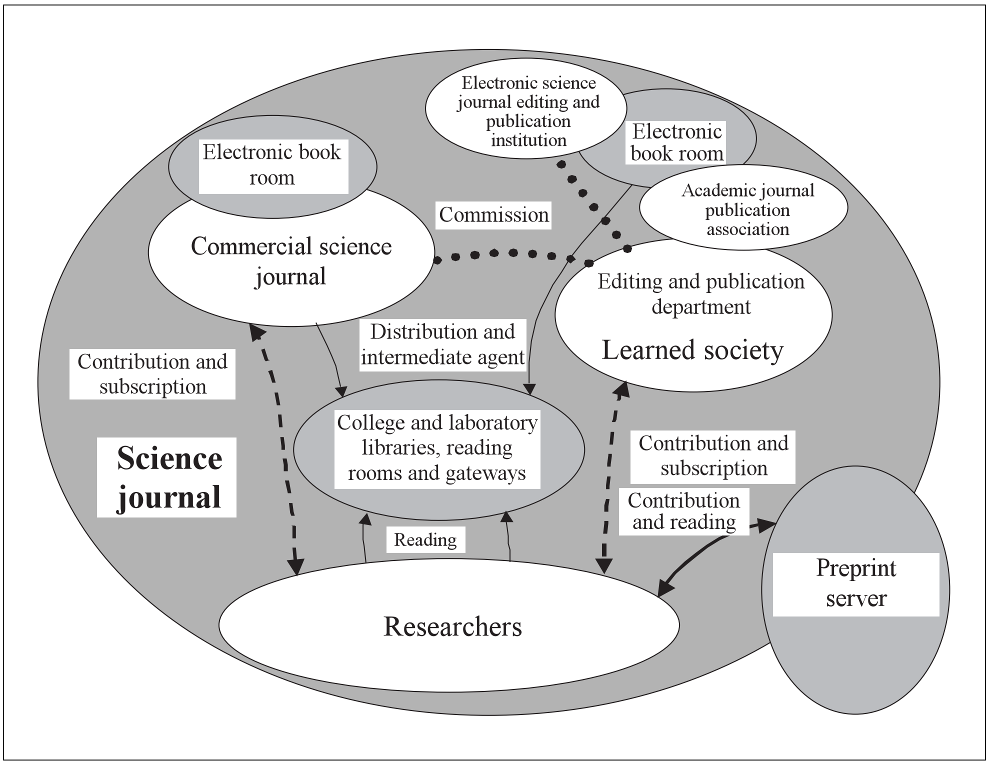
TAKASHI NAKA, *Material and Manufacturing Technology Research Unit*
TOMOE KIYOSADA, *Information and Communications Research Unit*
HAJIME YAMADA, *Affiliated fellow*

7.1 Introduction

Communication in scientific and technological studies (hereafter called "science communication") has a broad spectrum of interests including personal correspondences between researchers, presentations in study sessions and learned society meetings, paper presentations to science journals, proposal for research program, applications for research posts, and science communication as a means for linking science with society. Above all, publication of science journals, which is shouldered by researcher communities such as learned societies, is one of the most important means of communication among researchers and plays an important role in developing researches. On the other hand, libraries, which continuously collect science journals and make them available for researchers, have guaranteed to some extent that researchers and students can read not only their own literatures but also those they do not subscribe to through interlibrary loan (ILL). In general, subscription fees of a science journal paid by institutional subscribers such as libraries and corporations are significantly greater than those paid by individual subscribes, and cover a considerable part of the journal's publication costs.

Science journals have functioned as important media for scientists since the 17th century.

Figure 1: Communication through science journals



As shown in Figure 1, papers contributed by researchers are edited by the editing and publication departments of learned societies and commercial science journals for placement in their journals. Printed and published journals are bought by individual readers and libraries via intermediate agents. Libraries sort and arrange them on bookracks to make them available for readers. Over the ages, this system has supported the continuing publication and subscription of science journals, laying the basis for communication among researches. Review systems, which accomplish a peer review of papers in their editing stage by anonymous researchers in the same or similar field, are considered necessary for science journals to maintain the quality of papers placed in them through the filtering and enrichment of their information. In fact, a paper that has been subjected to a peer review and placed in a science journal is counted as one research merit for the author. In many science journals, their peer review system is supported by researchers volunteering their time.

Learned societies, publishing houses, libraries, intermediate agents, etc., which support the science journal systems, are confronted with and pressed to address problems that have materialized due to the rapid increase in science and technology information such as more papers and the development of information technology.

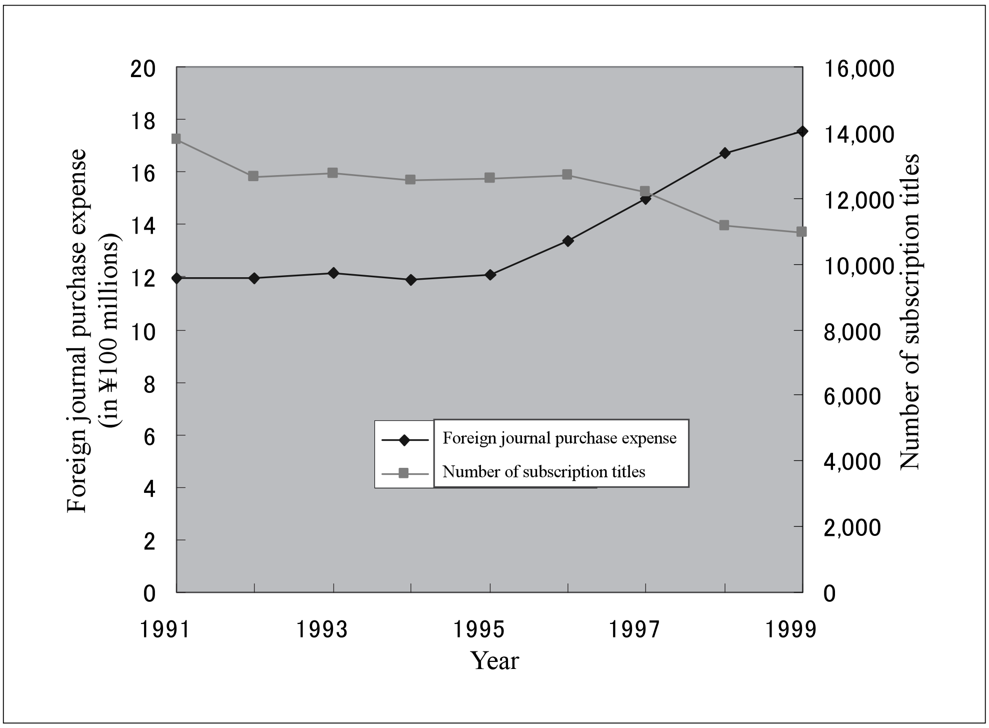
This paper first describes problems to be solved by science journals and the current state relating to them. We then introduce efforts on improving the science communication of related organizations including computerization. Finally, this paper proposes a commitment necessary for the evolution of science communication.

7.2 Science Journals and Their Circumstances

7.2.1 Decrease in science journal subscriptions by libraries

As pointed out by the Science Council of Japan, the number of subscriptions for periodical literatures by college libraries, etc., began to sharply decline from about 1990[*1]. The report by the National Diet Library said that the number of subscriptions (of foreign journals) has continued to decline since 1990, and is about 40% of the peak value at present (1999)[*2]. The cause is the rapid rise in the subscription prices of, among others, foreign journals, which is noteworthy when compared to the weak increase in journal purchase budgets of libraries. The rise in

Figure 2: Purchase by year by 40 colleges joining the Japan Pharmaceutical Library Association



subscription prices is also a serious problem in the U.S. The subscription prices are on a further upward trend recently since electronic and ordinary paper-version journals are sold in combination. As a concrete example showing this tendency, let us view the number of annual subscription titles and the amount of foreign journals purchased since 1991 by 40 colleges joining the Japan Pharmaceutical Library Association (Figure 2) [3]. Although the total literature purchase expense in 1999 is greater than that in 1991 by 47% (annual growth rate of 5.2%), the number of foreign journal titles purchased actually decreased by 23% during the nine years from 1991 to 1999 (annual decrease rate of 2.6%). Furthermore, the ratio of the foreign journal purchase expense to the total literature purchase expense climbed from 60% (1991) to 69% (1999). Such a decrease in the number of science journal titles purchased by libraries, which are major institutional subscribers, is a worrying development.

7.2.2 Computerization of science journals

The operational pattern of publication and its distribution has been dramatically changing due to the rapid development of information technology from the 1990s. Publishing firms are now able to deliver science journals directly to subscribers via the Internet. In particular, due to the increase of information such as science and technology papers and databases, it is expected that computerization of providing information and distribution (communication) will further accelerate. The merits of computerization are the possibility of obtaining recent papers immediately, obtaining papers without visiting libraries and having to find them, obtaining desired information from among enormous literatures through keyword searching, etc. An analysis said that a computerized paper is viewed more frequently and it has been pointed out that computerization can greatly contribute to improving science communication. It is also expected that libraries will suffer shortages of space for stocking their books in the future and therefore there is an active effort afoot to computerize paper literatures published in the past[*4]. Many new attempts have begun to make the most of the merits of online computerization. However, it is also revealing problems that cannot be thought of in paper document-based systems[*5].

7.2.3 Decrease in the number of members of domestic learned societies.

At present, there are many science and engineering learned societies whose members are diminishing. For example, the Japan Society of Applied Physics and the Chemical Society of Japan have undergone a 3.5% and 0.7% decrease in individual members every year, respectively. Reflecting the present economic trend, institutional members, such as corporations, of learned societies are decreasing at a much higher rate[*6]. Moreover, information science and technology learned societies suffer not only a decrease in their members but also in the numbers of participants in national conventions and study sessions, and of research presentations in these meetings; thereby, as indicated in[*7], their working cost balance deteriorates and contributed papers are scrambled for among several learned society journals. The bursting of the bubble economy is considered as a remote cause of the operational problems of learned societies. Learned societies are undergoing consolidation in order to overcome such embarrassing situation as well as to seek a new ideal situation[*7].

7.2.4 Popularity of Japanese learned society journals

As an index to indicate how often Japanese science journals are read, the citation frequencies and impact factors of their papers published in 1999 can be found in ISI company's Journal Citation Reports 1999 Science Edition.

The most frequent citation in Japan is 2,928 times/year recorded by the Japan Society of Applied Physics' English journal, "JAPANESE JOURNAL OF APPLIED PHYSICS PART-1-REGULAR PAPERS SHORT NOTES & REV", and that in the world is 39,971 times/year recorded by the "JOURNAL OF BIOLOGICAL CHEMISTRY." Although the top ten journals in terms of citation frequency in Japan are all society journals, those in the world include four commercial journals.

Next, let us consider readers' attention to papers in terms of the level of their impact factors, which show citation frequency per paper. From among the top ten journals in Japan, the journal winning the highest impact factor of 2.26 is the Society of Plant Physiologists' English journal, "PLANT AND CELL PHYSIOLOGY." From among the top ten journals in the world, the journal winning the highest impact factor of 47.56 is the "ANNUAL REVIEW OF IMMUNOLOGY." Although the top ten journals in terms of impact factor in Japan are all society journals, those in the world include nine commercial journals.

The data above reluctantly reveal that Japan has no journals corresponding to world top journals with such high impact factors.

7.3 Discussions about Science Journals

The reason why the subscriptions of science journals by Japanese libraries have been reduced is because the budgets of institutional subscribers such as libraries have not been increased despite of the rise in subscription prices. On the other hand, it seems that libraries joining the Association of Research Libraries (ARL) in the United Stated have taken action to prevent the number of subscriptions from dropping as much as possible. According to figures released by ARL, science journal subscription cost increased 2.9 times from 1986 to 2000 (annual growth rate of 8.0%) limited the decrease in the number of titles purchased during this period to 7% (annual rate of 0.47%) (Figure 3). Incidentally, whereas the average annual price increase ratio of independent books purchased during the same period was 3.7%, that of journals was 8.8%, as high as 2.4 times of the former, showing the steep rise in journal subscription cost*8. In addition, the ratio of the journal purchase cost to the total book purchase cost rose from 58% to 73% during the same period.

It is thought that the steep rise in science journal prices can be attributed to:

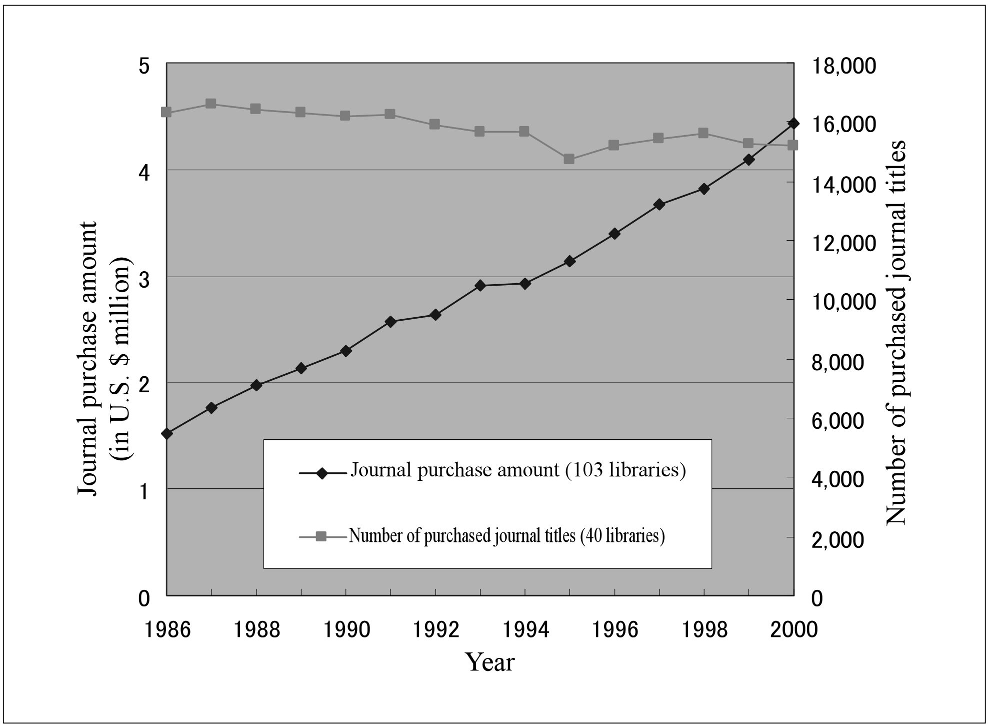
(1) Increase in the cost of editing and publication due to the increase in research results (such as papers) contributed from research institutes;

(2) Market over-concentration established through merger and acquisition in the publishing industry world; and,

(3) Computerization cost, which is increasing recently.

Let us examine concrete data supporting cause (1). According to American figures, the number of

Figure 3: Total amount of documents purchased by libraries joining the U.S. ARL.



science journals increased by 62% in the period from 1975 to 1995, during which science and technology researchers doubled and the number of pages of papers per researcher increased by 70%[*9]. In Japan, during the period from 1981 to 1999, researchers doubled and the number of papers increased by 2.6%. Such perpetual increases in the numbers of researchers and their papers is also true in Europe[*10].

Cause (2) has been pointed out by the Association of Research Libraries (ARL)[*11] and a Japanese library organization[*12]. At present, science journal problems including rises in their prices are discussed by concerned parties including Euro-American libraries, publishing houses, learned societies, journal editors, information science researchers, etc., on the Internet[*5]. The following questions other than the problem of price rises are also being discussed and the directions of these discussions should be watched carefully by those who address science journal problems in future years: "How far does intellectual property rights (especially on computerized property) of a copyright holder (such as a publishing firm) extend?," "To whom should a copyright of a paper, based on the results of research conducted under the subsidization of taxpayers and/or companies, be given?" and "Who should bear the cost of editing and computerization and how much of that cost?"

Also in Japan, many learned societies publish their journals in English, so as to widely distribute their members' research results to the world. However, if the number of their issues continues to decrease as in the present, it is thought that the publication of learned society journals will put pressure on the operations of the societies in the near future[*13]. Concerns are rising that journals on a less secure footing and with small subscriptions are experiencing decreases in their subscriptions with their increasing prices, which causes their subscription prices to rise furthermore, which in turn causes their subscriptions to decrease furthermore and such a vicious circle finally creates a situation where they can not survive. On this account, many Japanese learned societies hesitate about positively adopting computerization of their journals and information technology into their operations, while they suffer decreases in subscriptions of their journals.

7.4 Efforts of Related Organizations

This paper first introduces, as examples of the efforts on the publishing side, the efforts of the American Institute of Physics (AIP), which is well known with the advanced mode of attack and the computerization efforts of the Japanese Government which has recently established Institute of Pure and Applied Physics (IPAP) We next introduce the efforts of libraries, which are major subscribers (and intermediate agents), and a preprint server that has recently attracted a great deal of attention.

7.4.1 American Institute of Physics (AIP)

AIP is a nonprofit corporation established in 1931, which has the principal purpose of publishing and distributing learned society journals for physical and engineering learning societies. The member learned societies total 10, including the American Physic Society (APS) (these societies' members number 125,000). In addition, AIP cooperates with 22 related learned societies in their operations.

Let us explain how AIP computerizes its operation processes, while tracing the processes in which researchers present their papers for publication and wide subscription. In April 2000, AIP released a tool kit, which operates under Word 2000, to used by researchers to describe their papers. The widespread use of such a kit has increased electronic paper submissions. Computerized submissions in 2000 reached 50% of all papers submitted to AIP. Some journals see a ratio of 90%. Now, 48% of drawings in papers are presented electronically. The advantages include that manual inputting of data is eliminated, errors and costs are reduced accordingly, and the time to publication is shortened. The speedup resulting from computerization causes some papers to be published earlier than their expected issues, thus acquiring great popularity. The average number of days from adoption to publication is 30 workdays, with the shortest time being 25 workdays. Once a final copy is sent to the printing house, the paper can be read online by the next day. This means that the paper can be viewed more than one week earlier as compared to when the journal is arranged in related libraries.

If a library selects online subscription, the subscription is discounted. Whereas the discount rate was 15% in 1999, it escalated to 20% in 2000, and 25% in 2001. Overseas libraries can now save on postage and obtain papers earlier through online subscription.

Back issues are also being digitalized and provided online. A literature cited is given a digital object identifier (DOI), which is used as a link to it. All journals published in the name of AIP are given this DOI. It is felt that the introduction of the cross-reference system using DOI will be made widely available. In 2000, more than 30 publications were added to the online journal publishing service. At present, more than 100 publications of 16 learned societies are incorporated into this online journal publishing service, in which more than 210,000 papers have been accumulated and utilized.

AIP does not assume that a library making an online contract with it will allow everyone to download its papers at no charge. If a contract library belongs to a research organization or college, it may allow its staff or students to download at no charge. However, if everyone can download via the library without charge, no one would buy the related journals and that library would have to pay the costs to generate such material (U.S. $49 million in the case of AIP).

AIP does not allow a computerized paper to be placed on a homepage just as it is. Even the author of the paper is not allowed to do this. Since AIP returns the copyright of a paper to its author after having received it from him or her, he or she can use the computerized paper within the confines of fair use. However, he or she can only publish the paper on a homepage in a form other than the AIP computerized version. The reason is because an electronic paper published by AIP contains AIP's intellectual efforts in the form of editing.

7.4.2 Integration into European Physical Journal in Europe

Physical institutes in European countries have organized the European Physical Society since the European integration, which has begun to integrate traditional and authoritative journals in these countries into the European Physical Journal. At present, it has five disciplines. The European Physical Society is acting with an eye toward integration with the Institute of Physics (IOP), aiming at the integration of their physical academic journals. Under circumstances where American science journals are being internationalized, attention must be directed toward the fact that a journal competing with them has been born in Europe[*13].

7.4.3 Trend of Japanese physical academic journals

The number of recent science and technology papers is increasing considerably in Asia including Japan, in which, as with Europe and the United States, nonprofit organizations conducting academic publication operations have been established and efforts to realize online publication of science journals have started[*13].

Taking a cue from the Physical Society of Japan and the Japan Society of Applied Physics, the government began the "Online Journal Editing and Publication System (NACSIS-OLJ) (under the control of the Ministry of Education —the present Ministry of Education, Culture, Sports, Science and Technology) and the "Japan Science and Technology Information Aggregator, Electronic (J-STAGE)" (under the control of the Science and Technology Agency —the present Ministry of Education, Culture, Sports, Science and Technology) under the 1998 budget (their functions are to be integrated within this year.).

Subsequent to that, the Institute of Pure and Applied Physics (IPAP) was established mainly by physical learned societies. At present, IPAP has four member journals: Journal of Physical Society of Japan (JPSJ, published by the Physical Society of Japan with 19,000 members), Progress of Theoretical Physics (PTP, published mainly by the Fundamental Physics Research Institute of the University of Kyoto and the Physical Society of Japan), Japanese Journal of Applied Physics (JJAP, published by the Japan Society of Applied Physics with 23,000 members), and Optical Review (OR, published by the Optical Society of Japan, which is a sub-society of the Japan Society of Applied Physics with 2,000 members).

The publication costs in the year before the inception of IPAP (1998) were ¥130 millions for JPSJ, ¥95 millions for PTP, ¥300 millions for JJAP, and ¥11 millions for OR. Although at present the publication balance breaks even in each journal, it is expected that their balance will become worse due to the perpetual decrease in members, representing their subscriptions, and the gradual increase in their publication costs*13. A breakdown of their main income comprises of subscriptions, government subsidies, offprint fees (contribution fees), and individual membership fees.

At present, overseas contributions to JJAP are about 30%, with many of them from Asia. An English proofreading service is also offered. A total Web system specialized for JJAP and integrating contributions, review reading, editions, and accounting was completed in July of this year, eliminating the exchange of paper copies. However, a general-purpose online editing system has not yet been completed, since the editing method varies among joining learned society journals. IPAP recently published a virtual journal, "Novel Superconducting Materials," which selects papers on superconducting materials from several electronic journals and automatically links them to each journal with the cooperation from AIP and APS in the U.S.

The electronic journal of JJAP is released (free access) one month after the publication of its paper version. The reason the online journal is released a while after the publication of its paper version, in contrast to AIP, is because there are concerns no one will buy the paper version if the online journal is released earlier since the journal's main subscribers are paper version subscribers such as libraries. JPSJ similarly allows its electronic journal to be accessed free after its paper version is published, and makes back issues up to 1992 available. At present, the costs of publishing and computerizing in the both journals are almost covered by subscriptions paid by their institutional subscribers, but access to their electronic journals could be charged if the publication costs increase in the future. Computerization of past papers is proceeding with subsidies including the science research fund.

7.4.4 Efforts of libraries and intermediate agents

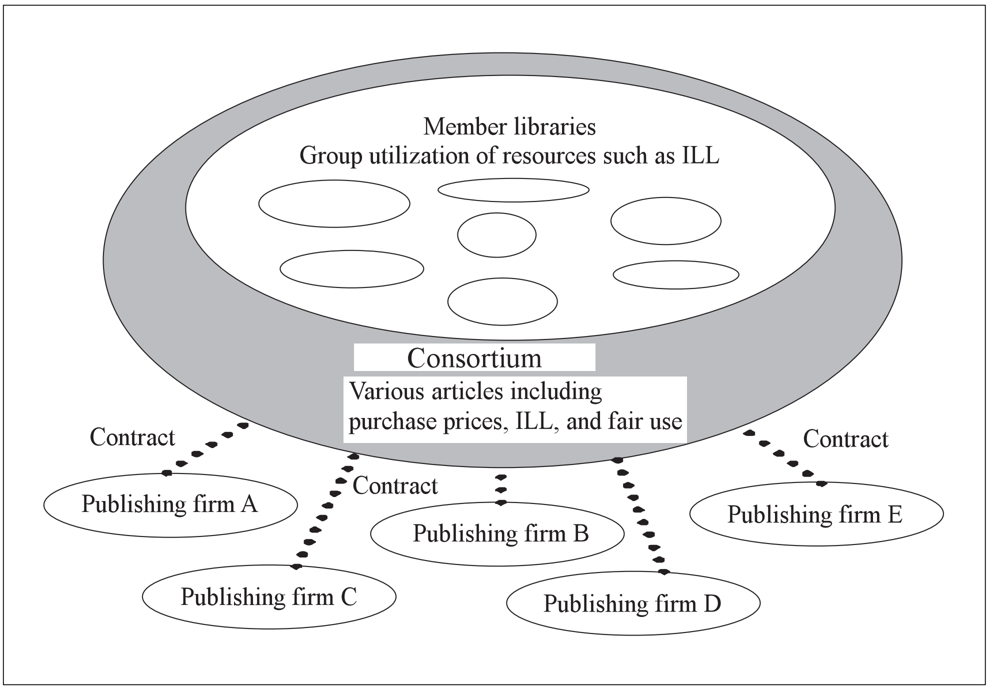
Since the 1990s, during which the number of purchased titles showed a remarkable decrease, in Japan as well, a high sense of crisis has been held by many thinking organizations including libraries, which subscribe and stock journals.

Recently, there is a move afoot by a library organization to ask the Japan Fair Trade Commission to investigate the pricing by a major overseas publication, which publishes many science journals*14. Before this time, group buying through a consortium (a group jointly collecting and utilizing academic source materials) did not take much root in Japan for various reasons. However, it is expected that efforts through a consortium will become mandatory in the future for libraries, in order to continue to provide electronic information resources such as electronic journals under the current state in which it is difficult for them to find additional funds*15. A library consortium is organized by many libraries in order to buy and jointly utilize electronic information through purchase and utilization contracts with publishing firms and database providers (Figure 4). It can be said that it serves cost-cutting goals, but poses challenges such as how to operate it, how to allocate its operation cost, etc.

Many libraries in Europe and the United States strive to continue buying journals by organizing consortia for group buying. There are about 1,000 library consortia in the world, which wrestle with group buying of journal books, electronic contents, etc., and co-ownership and joint use of resources among libraries such as ILL. It has become a general rule in Europe and the United States that a library joins several consortia*16. However, since reductions in purchase costs borne by libraries through group buying, etc., in the form of a consortium are not substantial at the present time, it can be said that it is difficult to control the decrease in the number of journal titles purchased through efforts only on the library side.

Under the present circumstances where major publishing firms, which publish journals, and their users begin to exchange information directly over

Figure 4: Example of Consortium Operation Form



the Internet, intermediate agents are forced to greatly change their missions. However it can be said that they have the possibility of shouldering important functions in order that the merits of computerization are evolved in accordance with respective and various requests from different users in the future; It is thought that they will have knowledge on editing and publication of science journals, and perform construction of editing and publishing server systems customized for every learned society. In addition, it appears that they will find much business in the future in areas other than learned societies, such as libraries, research institutes, and universities. Their new fields may include database construction, data migration, management of intellectual property such as copyrights, construction of pay-per-use systems, which charge in accordance with the amount of papers downloaded, etc.[*16].

7.4.5 Preprint server

In general, research papers are handled in the sequence of contribution, review (peer review), acceptance, printing and publication, and rarely released before their acceptance. Recently, however, many papers are released on the Internet before they are reviewed and accepted to be published, and researchers who want to pioneer in their research fields actively post their papers to computers connected to the Internet, which provide paper registration and release service and are called preprint servers. Furthermore, after the publication, they can leave their papers on the servers to make them available for everyone.

A representative preprint server is XXX in Los Alamos (http://xxx.lanl.gov/). The XXX server receives 3,000 papers every month and is accessed one million times every week. When compared to the fact that the U.S. Physical Review Letter (one of the prestigious physics journals), to which papers are contributed from around the world, receives 2,855 papers in a year (1999), it becomes clear just how many papers are posted to XXX. Assuming that a preprint paper is actually read one time among 10 connections and is read for six months after its contribution, a single paper would be read about 10 times every day. At present, the National Science Foundation (NSF) provides subsidies of U.S. $300,000 a year to XXX for its operations[*5].

The success of the XXX server shows that if a system is intended only to receive and release computerized academic papers, it can be built cheaply, moreover the chance of the papers being read are extremely high, and the evolution of such a system has the possibility of significantly changing the ideal situation of science journals[*17]. However, since a preprint server does not necessarily guarantee permanent access and filtering of information is incomplete, it can be said that it is complementary to the function of a science journal. It is pointed out that, in the field of life science, there are examples in which papers without sufficient results are early posted to preprint servers in order to gain an advantageous foothold in obtaining intellectual rights related to their researches.

7.5 Problems Arising with Computerization

7.5.1 Copyright and fair use of computerized papers

The problems are not limited to the steep rise in purchase prices. Publishing firms and publishing departments of learned societies require authors of papers to transfer their copyrights to them when they contribute their papers, in order to secure smooth publishing and distribution of their journals and management of the copyrights. Although it is thought that there are many complicated and outstanding or unknown problems about the copyright and fair use of computerized information, there is an opinion to the effect that it should be avoided to impose a significant restriction on the use of computerized science and technology information, especially when it is used for researches and education[*5].

7.5.2 Editing and computerizing costs

Simply raising the subscription fee to cover the costs of editing and computerization puts a load on subscriber libraries here and abroad, and therefore has a possibility of causing them to cancel their subscription. Under circumstances where papers are computerized and read via the Internet, since the frequency of downloading papers can be exactly measured by publishing firms, systems that charge users based on this count are being used. However, an appropriate system for charging is now being searched for and the challenge of solving the problems of costs for publishing and operating science journals including their computerization and of setting their subscription fee have not yet been cracked.

7.5.3 Electronic book room

In order that an electronic book room is maintained and accessible for a long time to come, economic and technical problems to be solved for it are being discussed among experts. As for the form of an electronic book room, a conclusion on which is advantageous between the center concentration type, which collects books in a certain center, and the distribution book room type, which functionally connects book rooms distributed all over the world, has not yet been reached and experts are still discussing about this problem. Although each of these has its merits and demerits, there are many experts in Europe and the United States who say that the distribution book room type is realistic and safe from loss of data due to an accident, reflecting the recent rapid development of distribution computing technology.

In addition, there are problems to be solved, such as who and how to save electronic media and how to update them.

7.6 Conclusion — Science Communication in the Information Age —

Communication through science journals are supported by many organizations including scientist communities, learned societies, publishing houses, intermediate agents, and libraries, etc. However, under the circumstances where science journals are forced to change significantly, the related organizations must cooperate to build a new system. For this purpose, we make the following propositions:

(1) Computerizing science journals

Following the global tide of computerizing science journals, it is thought that computerization of Japanese journals must be push forward in order to improve their information transmission power. According to a recent analysis of papers on computer science published in the last several decades, computerized papers that can be accessible online tend to have a much better chance of being read and cited[*5]. At present, publication of attractive journals for both the authors and readers are desired in Japan, justifying the promotion of advance efforts by making the most of the potential of computerization.

(2) Making necessary science information easily accessible as much as possible

In order that science journals widely propagate research results and to make the necessary information (papers) easily accessible as much as possible by lowering barriers, it is necessary to solve the problems pointed out above (7.5) and to have the related organizations cooperate toward this end. Especially, in Japan, science journals need to be reformed, taking intents of subscribers and contributors in the world into account.

Although preprint servers are becoming indispensable for researchers especially in fields in which researches are rapidly evolving, it is necessary to promote them while understanding that they are complementary to the function of science journals. It is thought that public research institutes' and the government's positive involvement in the operations of preprint servers are appropriate efforts to promote science and technology researches. For example, it may be possible that a laboratory, which furthers nanotechnology researches, hosts a nanotechnology preprint server ahead of the world to accelerate science communication, thereby contributing to the development of nanotechnology researches around the world. However, its operation requires an excellent "moderator."

(3) Maintaining objective, fair, and speedy peer review

Filtering contents of papers (science and technological information) through editing and peer review is considered to be effective for quality control. It is thought that an objective, fair, and speedy peer review not only improves the reliability of the journal itself but also eventually leads to enhancement of the authority of science communities such as learned societies engaging in the publication of journals.

Let us introduce an example related to this. Recently, a major medical journal announced that they will not place papers that are suspected of being interfered with by companies*[18]. The reason is because researches funded by companies, which make huge investments in the development of new drugs increase in number and companies deeply involve in these researches and contents of their papers published in many cases, which generates concerns that only information that is advantageous for these companies is released. Since researchers generally conduct researches under various pressure and interference as described above, although it is important to ask authors of research papers to maintain their morals, an objective and fair review will be required more than ever*[19].

(4) Continuously providing science information

On the other hand, it is thought that the role of libraries and research institutes, which build electronic book rooms and databases, and intermediate agents, which supports these organizations, will become increasingly important to establish smooth and economical communication*[20]. Maintaining an adequate number of science journal titles purchased by libraries, etc., is important in order to support and develop book rooms, which guarantee that present and past documents as well as electronic information can be read. Under circumstances where information on science and technology is increasing, maintaining and strengthening the functions of libraries, which have the mission of "providing collected documents and maintained facilities for public use" *[21], is thought to be one of the important infrastructure construction programs in science and technology development and it is desirable to make an active investment in it to equip libraries with functions adaptable to future computerization.

Reference

* 1 Scientific Council of Japan, Information Science Liaison Study Committee, Academic Literature Information Expert Committee, "Urgent Question on Collection Systems of Electronic Academic Publications", June 2000 (in Japanese).

* 2 National Diet Library, Collection-Planning Committee, Foreign Document Subcommittee, "Domestic Circumstances Surrounding Foreign Documents: Publication, Libraries, and Researchers", March 1999 (in Japanese).

* 3 "Basic Data in Japan Pharmaceutical Library Association", Journal Problem Study Committee Document, May 14, 2001; Isao Horota, "Report on 'Symposium on Price Problem of Foreign Journals'", Pharmaceutical Library, Vol. 45 (2000) 275 (in Japanese).

* 4 JSTORE, A. W. Mellon Foundation, U.S.

* 5 "Nature web debate, Future e-access to the primary literature", http://www.nature.com/nature/debates/e-access/
For Japanese and foreign electronic journal publication, the Exploratory Committee on Usage of J-STAGE MXL has also presented a detailed report.
http://xmlweb.jstage.jst.go.jp/xmlboard/

* 6 Gakkai Binran (Learned Society Directory), Japan Science Support Foundation

* 7 Information and System Society Journal, Vol. 6, No. 3, Nov. 1, 2001, Institute of Electronics, Information and Communication Engineers (in Japanese).

* 8 ARL Statistics 1999-2000, http://www.arl.org/stats/arlstat/

* 9 Tenopir and King, "Designing Electronic Journals With 30 Years of Lessons from Print", 1998, http://www.press.umich.edu/jep/04-02/king.html

*10 "Annual Report on Promotion of Science and Technology", Fiscal year 2000

*11 M. M. Case (translated by Shoichi Tokisane), "ARL Promotes Competition in Academic Publication through SPARC Project", Information Science and Technology, Vol. 49 (1999) 195.

*12 Takashi Kitakaze, "Price Problem of Foreign Journals", Library Journal, Vol. 94 (2000) 979 (in Japanese).

*13 The Publication Office of the Japanese Journal of Applied Physics (The forerunner of the IPAP), "Activity Report of Council for Electronic Publication of Physical Journal", Mar. 15, 1999 (in Japanese).

*14 Masaaki Tonozaki, "2000-2001 Yen-dominated Journal Price Problem of Elsevier Science", Medical Library, Vol. 48 (2001) 93; Asahi Shimbun, Dec. 14, 2000.

*15 Shigeharu Kousai, "Serial Publications" Version 2, 2000 (in Japanese).

*16 R. Turner, "Patterns from Chaos, The Evolution of the Journal", May 16, 2001, ASA Seminar.
http://www.usaco.co.jp/new/asas.html

*17 P. Ginsparg, "Creating a global knowledge network", Feb. 20, 2001, http://arXiv.org/blurb/

*18 Mainichi Newspapers, Sep. 10, 2001.

*19 The Economist, Sep. 15-20, 2001.

*20 Takashi Yamakawa, "Corporate and Academic Markets in Japan", ASA International Conference, "E-commerce and Future of Journal Subscription", Feb. 26, 2001.
http://www.usaco.co.jp/new/asa.html

*21 Japan Library Association, "Declaration of Freedom of Libraries", 1979.

(Original Japanese version: published in November 2001)

8

International Appraisal of Japanese Research Results (Research Papers)
— Increase of "First-class Papers" Produced in Japan —

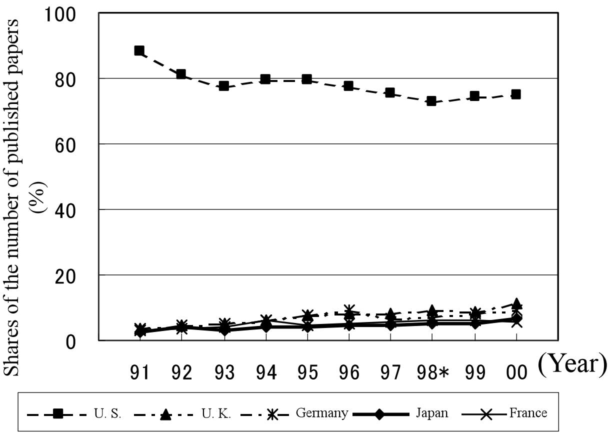
TOMOE KIYOSADA, *Information and Communications Research Unit*
HIROYUKI TOMIZAWA, *2nd Theory-Oriented Research Group*

8.1 Introduction

Dr. Ryoji Noyori, professor of the Graduate School of Science of Nagoya University, was awarded the Nobel Prize in Chemistry for 2001. In addition, Dr. Hideki Shirakawa, professor emeritus of Tsukuba University (now a member of the Council for Science and Technology Policy) was awarded the Nobel Prize in Chemistry for 2000. It is possible to say that the fact that two Japanese scientists have won the Nobel Prize for two consecutive years is evidence that scientific research activities in Japan have produced excellent results.

Based on this background, we analyzed the international appraisal of Japanese research papers using "shares of research papers in first-class journals" and "the number of times cited," etc. in this report.

Figure 1: Shares of research papers printed in "Science"



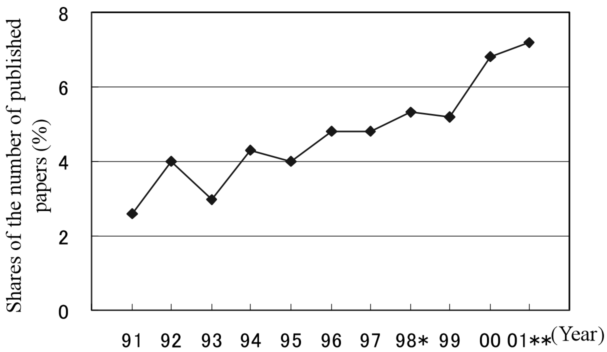
Note: — The subject papers are "Research Articles," "Reports," and "Reviews".
— For 1998, data for 11 months from January to November are aggregated.
— Legends are shown in the order of shares in 2000.

8.2 Production of research papers in the overall fields of natural science and engineering in Japan

The shares of research papers printed in "Science" among major advanced counties are shown in Figure 1, and the same shares limited to only Japanese research papers are shown in Figure 2. In addition, the shares of research papers printed in "Nature" among major advanced counties are shown in Figure 3, and the same shares limited to only Japanese research papers are shown in Figure 4.

"Nationalities" of the respective research papers are judged by the addresses of institutes the respective authors belong to. If the addresses of institutes of coauthors number more than one, the nationality of that paper is counted twice. For instance, if a research paper is written by three authors, and one author belongs to an institute in

Figure 2: Shares of Japanese research papers printed in "Science"



Note: — The subject papers are the same as Figure 1.
— For 2001, data for 6 months from January to June are aggregated.
— Legends are shown in the order of shares in 2000.

Figure 3: Shares of research papers printed in "Nature"

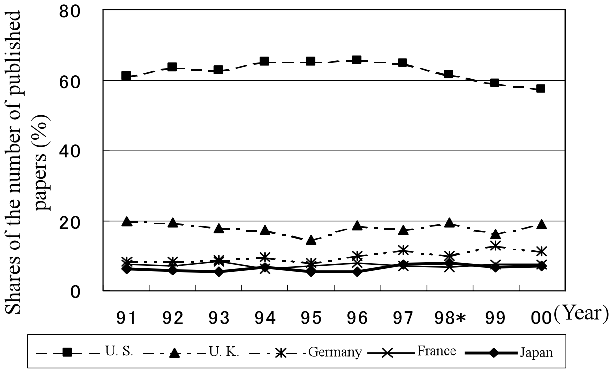
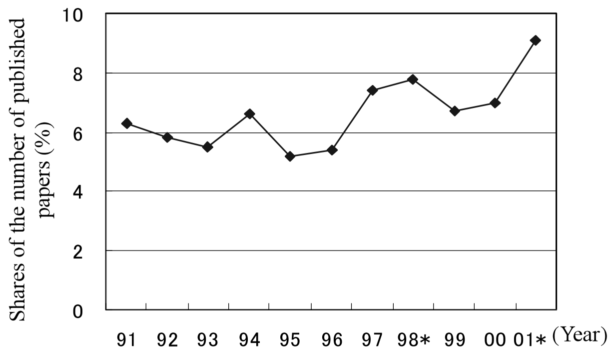


Figure 4: Shares of Japanese research papers printed in "Nature"



Note: — The subject papers are the same as Figure 3.
— For 2001, data for 6 months from January to June are aggregated.
— Legends are shown in the order of shares in 2000.

Japan and the remaining two authors belong to institutes in the U. S., the paper is counted once for Japan and the same paper is counted once for the U. S.

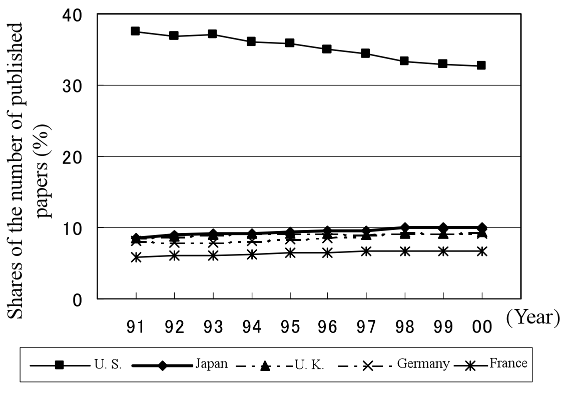
Data for the period from 1991 to 2000 are aggregated from the SCI database, while data of 2001 shown in Figure 2 and 4 are aggregated from "Science" and "Nature" independently.

Since 1991, the shares of Japanese research papers printed in "Science" and "Nature" have tended to increase, and, in particular, increased more in these few years.

The shares of research papers of major advanced countries, among journals recorded in the SCI database covering all fields of natural science and engineering, are shown in Figure 5.

Since 1991, the shares of Japanese research papers among journals in the fields of natural science and engineering have increased gradually to around 10%. It may be possible to infer that the increase of shares of Japanese papers in "Science" and "Nature" as mentioned above are approaching to the level of these shares.

Figure 5: Transition of shares of the number of published papers of major advanced

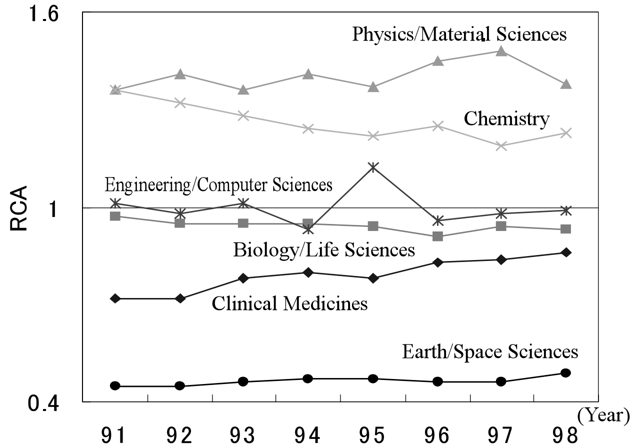


8.3 Production of research papers by field in Japan

The RCA (Relative Comparative Advantage) by field in Japan is shown in Figure 6.

The RCA is a value calculated by dividing the ratio of the number of research papers for a certain field in a certain county to the total number of research papers for the entire field of natural science and engineering, by the ratio of the number of research papers for the certain field throughout the world. For instance, the ratios of the clinical medicine field in 1997 are 22.2% for Japan and 26.4% for all over the world, respectively. The RCA of this field in Japan will be 22.2% ÷ 26.4% = 0.841. Fields of which RCA exceeds 1 can be considered as fields that Japan

Figure 6: RCA by field in Japan



Source: National Institute of Science and Technology Policy aggregated figures on the basis of the NSI database (Deluxe, 1981 - 1998)
Science and Technology Indicator (FY 2001), National Institute of Science and Technology Policy

takes great interest in.
In Japan, the RCAs in the fields of Physics/Material Sciences and Chemistry are high, while the same in the fields of Earth/Space Sciences, Clinical Medicines and Biology/Life Sciences are low.

8.4 Ranking of institutes by field according to the number of times cited

As a result of investigation executed by ISI, the ranking of institutes according to the number of times cited for the period from 1991 to 2000 in 19 fields; namely, Biology/Biotechnology, Microbiology, Molecular Biology, Genetics, Immunology, Neuroscience, Clinical Medicine, Pharmacy, Zoology and Botany, Agriculture, Computer Science, Environment, Material Science, Engineering, Earth Science, Space Science, Physics, Mathematics, Chemistry and Psychology, Japanese institutes have been ranked within the top 5 in 4 fields; namely, Biology/Biotechnology, Material Science, Physics and Chemistry (Table 1).
Among these 4 fields, RCAs of the fields of Material Science, Physics and Chemistry in Japan are high. Japan takes great interest in these fields, and there are world-leading institutes in Japan.

8.5 Tendency of research papers related to nanotechnology

In the previous chapter, we outlined institutes producing many research papers cited in the respective existing fields. However, many of the most advance research themes are progressing in boundary fields or merged fields, which cannot be categorized into the existing research fields, and thus it is difficult to analyze the tendency of cited research papers using ordinary methods.
In this chapter, we outline the tendency of cited research papers related to nanotechnology, being spotlighted recently in Japan and overseas, based on the data aggregated by ISI individually.
ISI had extracted 32,605 papers including the word "nano" in their titles or keywords described by the authors from all research papers published in the term from 1991 to 2000 registered in the SCI database, and provided a ranking of journals according to the number of times cited as shown in Table 2.
According to Table 2, we can observe that journals in the fields of Physics, Chemistry and Material Science are ranked within the top 10, except for "Science" and "Nature" covering overall natural science in general.
In the same way, the rankings of nations, institutes

Table 1: Ranking of institutes according to the number of times cited

(1) Biology / Biotechnology

Rank	Institute	No. of times cited	No. of research papers
1	Harvard University (USA)	184,786	7,325
2	University of Texas (USA)	149,017	8,009
3	UCSF (USA)	93,710	3,952
4	University of Tokyo (Japan)	79,673	5,571
5	NCI (USA)	72,923	2,966

(2) Material Science

Rank	Institute	No. of times cited	No. of research papers
1	Tohoku University (Japan)	13,889	3,231
2	IBM (USA)	13,160	1,369
3	UCSB (USA)	12,001	871
4	MIT (USA)	11,723	1,506
5	University of Illinois (USA)	9,826	1,328

(3) Physics

Rank	Institute	No. of times cited	No. of research papers
1	AT&T (USA)	98,264	4,921
2	University of Tokyo (Japan)	92,058	10,920
3	IBM (USA)	87,982	4,649
4	MIT (USA)	86,292	6,462
5	CERN (Switzerland)	85,319	5,937

(4) Chemistry

Rank	Institute	No. of times cited	No. of research papers
1	UC Berkeley (USA)	57,039	3,846
2	Kyoto University (Japan)	56,981	7,215
3	University of Tokyo (Japan)	56,860	6,781
4	University of Texas (USA)	50,919	4,052
5	University of Cambridge (UK)	48,634	4,287

Source: Science Watch Vol.12, No.4 July / August 2001, ISI

Table 2: Journals ranking of nanotechnology

Rank	Journal	No. of times cited	No. of research papers
1	SCIENCE	13,341	237
2	APPLIED PHYSICS LETTERS	12,586	1,132
3	NATURE	11,312	192
4	PHYSICAL REVIEW B	9,525	820
5	PHYSICAL REVIEW LETTERS	8,023	424
6	JOURNAL OF PHYSICAL CHEMISTRY	6,422	182
7	JOURNAL OF THE AMERICAN CHEMICAL SOCIETY	5,582	270
8	JOURNAL OF APPLIED PHYSICS	5,415	825
9	CHEMISTRY OF MATERIALS	5,392	405
10	NANOSTRUCTURED MATERIALS	4,893	1,099

Source: Essential Science Indicators of "Nanotechnology," ISI, October 2001

and authors are shown in Table 3.

Japan is ranked within the top 10 of nations, institutes and authors, respectively.

8.6 Conclusion

The shares of Japanese research papers among all papers printed in "Science" and "Nature" have tended to increase, and we can observe that the number of international-class research results is increasing in Japan. Of course, it is not enough to only analyze the shares in both magazines for appraising our research results. However, the shares by nation must be considered remarkable indicators for appraising our research results, since both magazines cover overall natural science in general and are recognized as first-class magazines internationally.

If we look at nanotechnology, Japan has produced research papers watched all over the world for these 10 years. Although it was previously difficult to analyze the tendency of research papers in interdisciplinary fields using databases constructed in accordance with the ordinary concept of research fields, we can now speculate on the international appraisal of our research papers in interdisciplinary fields (Bioinformatics or System biology, etc.) by applying the method used by ISI.

Table 3: Rankings of nations, institutes and authors of nanotechnology

(1) Ranking of nations

Rank	Nations	No. of times cited	No. of research papers
1	The U. S.	92,108	9,993
2	Japan	26,267	4,251
3	Germany	20,673	3,579
4	France	17,168	2,673
5	The U. K.	9,466	1,415
6	Switzerland	8,233	792
7	China	7,653	3,168
8	Canada	5,707	754
9	Spain	5,131	874
10	The Netherlands	4,767	514

(2) Ranking of institutes

Rank	Institute	No. of times cited	No. of researchs papers
1	UC Berkeley (USA)	6,591	393
2	MIT (USA)	5,370	366
3	Rice University (USA)	4,329	156
4	IBM (USA)	4,305	282
5	NEC (Japan)	4,016	140
6	Harvard University (USA)	3,278	155
7	Tohoku University (Japan)	3,244	485
8	University of Illinois (USA)	3,093	289
9	Ecole Polytech Fed Lausanne (Switzerland)	3,092	212
10	US Navy (USA)	3,045	302

(3) Ranking of authors

Rank	Authors	No. of times cited	No. of researchs papers
1	Smalley RE, Rice University (USA)	3,816	78
2	Alivisatos AP, UC Berkeley (USA)	3,084	97
3	Ajayan PM, NEC (Japan)	2,659	63
4	Ebbesen TW, NEC (Japan)	2,424	36
5	Thess A, Rice University (USA)	2,213	23
6	Gratzel M, Ecole Polytech Fed Lausanne (Switzerland)	1,980	79
7	Sumio Iijima, NEC (Japan)	1,959	75
8	Rinzler AG, Rice University (USA)	1,937	36
9	Dai HJ, Rice University (USA)	1,851	31
10	Akihisa Inoue, Tohoku University (Japan)	1,719	184

Source: Report of ISI / Thomson Scientific (October 2001) Essential Science Indicators of "Nanotechnology"

(Original Japanese version: published in November 2001)

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).

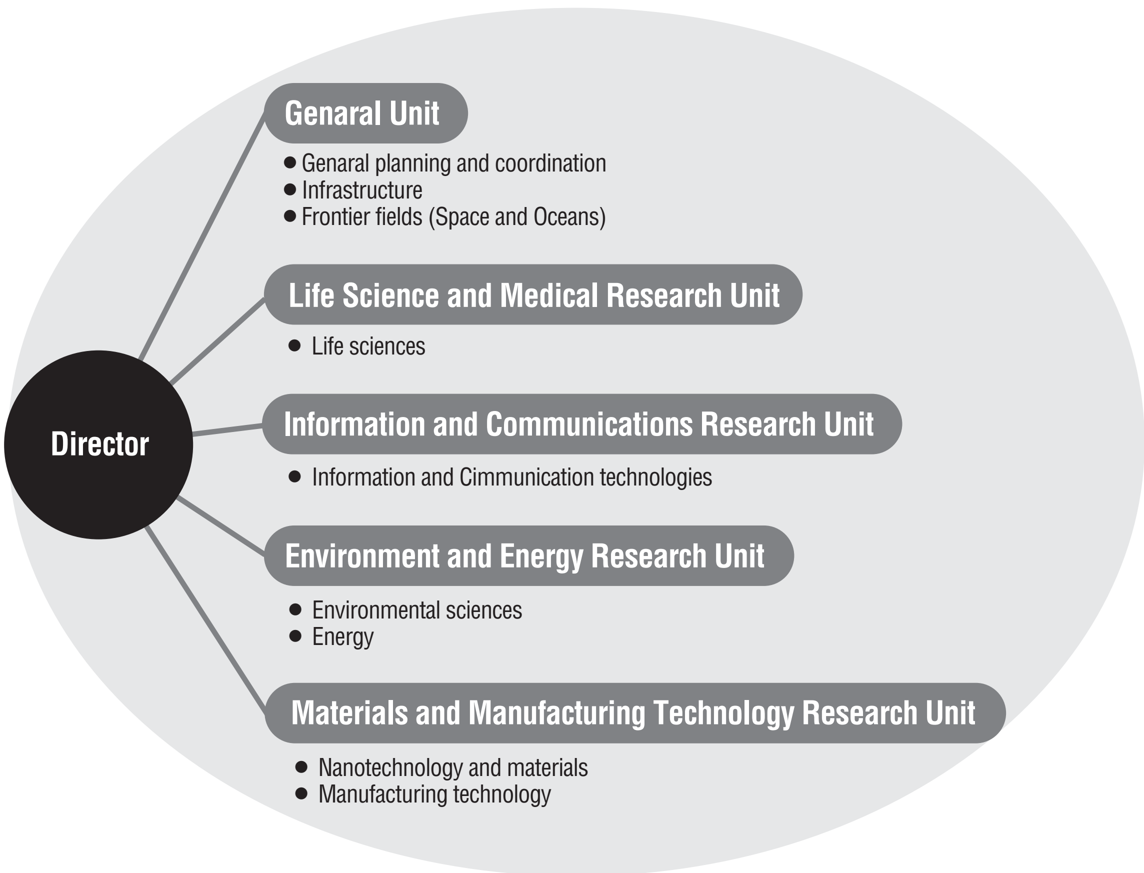
3. Technology foresight and S&T benchmarking survey

— 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

Science and Technology Trends —Quarterly Review

No.3 November 2002

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