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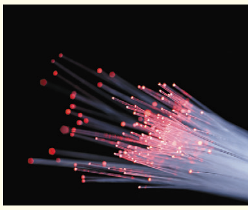
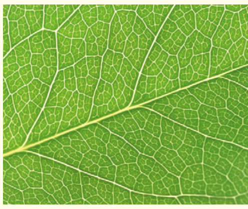
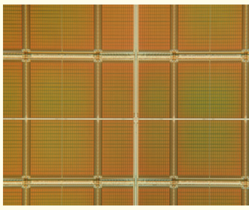

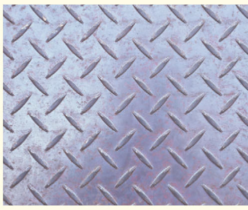

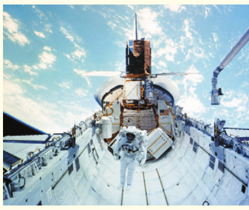

Foreword

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

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

STFC has conducted regular surveys with support of around 3000 experts in the industrial, academic and public sectors who provide us with their information and opinions through STFC's expert network system. STFC has been publishing "Science and Technology Trends" (Japanese version) every month since April 2001. The first part of this monthly report introduces the latest topics in life science, ICT, environment, nanotechnology, materials science etc. that are collected through the expert network. The second part carries insight analysis by STFC researchers, which covers not only technological trends in specific areas but also other issues including government R&D budget and foreign countries' S&T policy. STFC also conducts foresight surveys such as periodical Delphi surveys.

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

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

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Executive Summary

Life Sciences

1 Fostering of Researchers and Education in Life Science

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The 21st century has been called the "Century of Life." In Japan's science and technology policy, life science is positioned and advanced as one of four major fields in the Second Science and Technology Basic Plan. In the FY 2003 scientific and technology-related budget, the estimated budget request for the life science field is ¥209.1 billion, a 28% increase from the year before, so funding of the field is increasing.

Compared to the United States, however, the number of life science researchers is overwhelmingly low, and there is a shortage of researchers. Fostering researchers in life science is a vitally important issue, and it is necessary to improve life science education and research of universities. Because life science has become a multidisciplinary field and has come to have an impact on society as a whole, graduate schools must be prepared and curricula developed to teach life science systematically and comprehensively.

Individuals and society will debate and judge issues such as bioethics that arise from life science. Raising of society's life science literacy is therefore vital. In the United States and the United Kingdom, science education reform that includes the goal of increasing national scientific literacy is underway. Japan also needs educational policies that address scientific literacy from a long-term perspective.

Through the advancement of molecular biology, life science has developed systematic understanding of diverse biological phenomena and the mechanisms of life primarily through principles such as genetics. The future of life science will develop around those principles. Life science must therefore be properly positioned in education so that knowledge can be added in developmentally appropriate stages. This requires an examination of the structure of science education.

(Original Japanese version: published in October 2002))

Information and Communication Technologies

2 Trends in R&D and Standardization on Accessibility in the Information and Communications Field

— Toward Barrier-Free Equipment and Services of Information and Communications —

p.19

Our everyday life is filled with a variety of devices and services of information and communications. These devices and services currently available, however, do not always provide ease of use for all possible users. Solving such problems is in technical terms referred to as "improving accessibility." To realize a highly information-oriented society, improvement of accessibility is an inevitable task.

With a view of enhancing accessibility concerned with input and output, special hardware and software aids have been developed, while functions to improve accessibility have become available at the operating and application system levels.

Movements have started in many nations throughout the world toward standardization of accessibility functions provided by all equipment and services of information and communications. In Japan, the Ministry of Public Management, Home Affairs, Posts and Telecommunications and the Ministry of Economy, Trade and Industry jointly lead efforts to create a JIS standard by integrating existing accessibility guidelines in individual areas. The activity has been conducted with an eye on proposals to ISO. Similar standardization activities are in progress in Europe as well. In the U.S., a law that requires devices and services of information and communications procured by the government be accessible to people with disabilities was instituted, a move that prompted industries to seriously address the issue. Aside from this, there is a new approach which intends to establish a standard interface (AIAP) between personal input/output aids customized for individual users and machines such as ATMs.

In terms of accessibility, Japan is behind the U.S., where accessibility as a requirement in government procurement has invigorated R&D even in the private sector and is leading to the emergence of new technologies such as AIAP. However, thanks to the JIS and other standardization initiatives, the foundation on which highly accessible equipment and services can spread is being secured. One of the most effective first steps toward penetration is to adopt the JIS standard on accessibility as a consideration in the procurement by the government. This will give birth to a market through which accessibility-conscious devices and services can gradually spread into private markets.

(Original Japanese version: published in November 2002)

Environmental Sciences

3 Study of Influence on Global Warming by Aerosols

— Present Investigation and Remaining Issues —

p.28

Scientific knowledge obtained so far indicate the influence of greenhouse gases such as carbon dioxide on global warming — specific measures against which are being discussed through the Conference of the Parties to the U.N. Framework Convention on Climate Change (COP). With respect to aerosols (fine particles measuring 0.001~10 micrometer in diameter), however, the influence has yet to be evaluated globally, though they are regarded to be one of the causes of global warming.

The study of aerosols in relation to global warming consists of three categories — i.e., observations and monitoring of substances causing global warming; mechanism analysis using climate models; and forecasts based on large-scale simulations. These three categories are interdependent with one another, where achievements in one category may contribute to the progress of the other categories — each relation that has yet to be fully developed.

On the observation and monitoring researches of aerosols, laser technologies for measurement of the spatial particle density distribution have been established, but the chemical characteristics of aerosols have yet to be clarified due to complex composition. As for possible collaboration between the study of observations/monitoring and that of mechanisms, several research groups are making use of their own observation and monitoring results in conducting each specific study of mechanisms. In the field of forecasts, meanwhile, there is a need to collect a large amount of default data for accurate simulations with the earth simulator, whereas global observation data obtained within the brief period are not available.

There are thus several issues to be addressed in promoting the study of aerosols — e.g., obtain observation data that will improve the accuracy of models; secure qualified researchers who can take part in a variety of studies concerning global-warming, when the first commitment period expires at 2012; and increase the number of researchers who can actively report on their own and other Japanese findings at the related international conferences such as IPCC.

(Original Japanese version: published in November 2002)

Nanotechnology and Materials

4 Trends in Ecomaterials
— Approach of Materials Science to Global Environmental Problems —

p.36

"Ecomaterial" was a concept created in Japan in 1991 in advance of the world, and is defined as "substances and materials that serve the sustainability of human society in harmony with the global environment." There are four types of ecomaterials characterized by the kind of environmental burden in the life cycle to which the material contributes: materials free of harmful substances; materials with high material efficiency; materials with a history of low environmental burden; and recyclable materials. And, various efforts are being made to realize these ecomaterials.

Considering the fact that environmental problems derive from mass consumption and mass disposal, the essential keywords for the development of ecomaterials in the future are "improvement of resource productivity." In order to cope with the expected drastic increase in demands for materials and energy in developing countries, resource productivity must be improved dramatically.

It has only been 10 years since the research on ecomaterials started. But as a result of continuous research works mainly supported by promotion expenditure, the concept; in the design of practical materials, environmental conformity must be taken into consideration in addition to high performance and functions that have been the main targets of material development in the past, has been promulgated among researchers and engineers in materials science. In this sense, efforts in the past can be highly appreciated.

Fortunately, Japan is leading the world in the field of ecomaterials. However, efforts at the national level must be strengthened since it takes a long time to establish materials technology and to put it to practical use. Since research on ecomaterials covers wide and interdisciplinary areas, it is necessary to carry out continuous research works with the collaboration of all Japanese researchers related to this subject and with hub organizations as the cores. In addition, it is not necessarily the best way to optimize the total environmental efficiency by separately improving the environmental efficiency of each material. It is most important to continuously consider the relationship between materials and society.

(Original Japanese version: published in October 2002)

5 Trends in the Research on Single Electron Electronics

— Is it possible to break through the limits of semiconductor integrated circuits? —

p.47

Semiconductor devices based on silicon and computers using these devices have drastically grown. However, it is said that these devices are approaching their limits due to device operation problems caused by miniaturization and heat evolution derived from the high degree of integration.

Under such circumstances, research on integrated circuits using device systems that operate with single electrons is attracting attention. These device systems have the possibility to realize further miniaturization compared to conventional integrated circuits, and also the possibility to solve the problem of integrated circuits malfunctioning due to heat evolution because the power consumption is reduced to ten-thousandth to a hundred-thousandth of that required for conventional integrated circuits. The principle of these devices is the "Coulomb Blockade" phenomenon, which occurs in nanometer size materials.

Although trial single electron transistors that operate at room temperature have already been manufactured, it is technically difficult to replace all conventional transistors with these devices for integration. For this reason, research works are being undertaken to solve this problem by combining conventional transistors and these new devices, and by introducing new materials such as carbon nanotubes. As long-term research targets to break through the limits of integration, studies to develop new architectures (basic design) for the logic circuit and those to develop new information processing methods that do not require electrical wiring (i.e., a new structure that operates with single electrons) are being carried out.

Japan, together with the U.S., leads the world in the field of research on these subjects. We should recognize that for research on the establishment of device systems based on new principles such as "single electron electronics," it is necessary to provide more enhanced research resources, invested continuously from a long-term point of view.

(Original Japanese version: published in November 2002)

6 Research & Development Trend of Drug Delivery System (DDS)

p.54

In recent years, as a measure to conduct safer and more effective drug treatment by inhibiting excessive drug use and adverse reactions, researches on a drug delivery system (DDS), that aims to supply the necessary minimum drug to the necessary site at the necessary time, are in the active. The DDS has two types of methods; one is a method to dissolve a drug slowly in the living body, and the other is a method to deliver a drug to the affected target site through the blood flow. To achieve the practical use of these methods, only the modification of drug is not enough. It is in need to develop matrix materials such as polymer materials or ceramic materials as carrier of drug.

In addition, according to the deeper understanding of the bio-mechanism and the advancement of material design technology, DDS is expected as a technique to provide more effective and safer treatment also in new therapies such as gene therapy and regenerative medicine, as well as treatment using genome products.

For the treatment of cancer and regenerative medicine, utilization of polymer micelle (aggregate) and liposome (cellule consisting of lipid membrane) as drug carrier shows a significant advancement, leading to a number of clinical studies. Japan places at higher than, at least as high as, the United States and Europe in this field. A practical micro-electro-mechanical system (MEMS) was also developed for gastrointestinal DDS. At present, activities in the research and development of DDS have begun to bear fruit. Moreover, the research and development of DDS was taken up in the "Development and Application of Advanced Science Technology" (Nanomedicine Project) in the science technology policy of the Ministry of Health, Labour and Welfare in 2002, that is one example showing that it reached a breakthrough stage.

The research and development of DDS is an interdisciplinary study, requiring the close cooperation of various fields. Cooperation in such fields cannot be achieved by the effort of only one corporation, one university, or one institute. Therefore, followings are necessary to maintain and raise the level of Japan's high technological competitiveness: constructing an organization that will play a key role for this cooperation under the strong leadership of the government as soon as possible, gathering highly competent researchers, arrangement of an environment and system, and advancing the research and development of DDS through a joint industry-university-government project.

(Original Japanese version: published in December 2002)

7 Current Status and Foresight of Photocatalysts

p.66

Photocatalysts are activated to a higher energy level by absorbing light energy, and give the absorbed energy to reactants that in turn accelerates chemical reactions. Since photocatalysts utilize photons with higher energy than the band gap, they can accelerate chemical reactions requiring highly excited states that cannot be realized by thermal energy.

This characteristic of photocatalysts enables the decomposition of water and harmful substances. Since the Honda-Fujishima Effect based on this phenomenon was confirmed in titanium oxide in the 1970s, intensive research on photocatalysts has been conducted aiming at the creation of clean energy resources and decomposition of harmful substances.

In the 1990s, diversified materials that utilize the defogging, stain-proofing, and antimicrobial properties of photocatalysts were proposed, and research and development for practical applications started on a full-scale. In the progress of the research and development, it has become apparent that there are various problems to be solved such as the low quantum efficiency, light sources, insensitivity to visible light and so on. Although studies on the improvement of quantum efficiency and search for materials sensitive to visible light are being made, many of them are based on titanium oxide. Regarding the light sources, various devices using the recently developed blue-color light-emitting diode have been proposed. The sensitivity to visible light is essential for the application of the blue-color light-emitting diode, and currently the addition of nitrogen and transition metals is being tried to solve this problem. Improvement of quantum efficiency is still a remaining problem.

In order to achieve breakthroughs in these problems and expand the industry and market related to photocatalysts, it is necessary to elucidate the mechanism of photocatalysis and find a material superior to titanium oxide. It has been pointed out as well that the qualities of current products fluctuate due to the incomplete standardization. Because the production process of titanium dioxide is rather simple, it appears to be easy to enter the industry. However, to supply products that have a certain level of quality, a technical base including patents and technical know-how is required. Such a base can be established by the standardization of products used for diversified applications.

(Original Japanese version: published in December 2002)

Energy

8 Non-fossil-resources-based Hydrogen Production Technology

— Key to Sustainable Hydrogen Energy Systems —

p.80

As there is a growing need to overcome global energy and environmental problems, hydrogen-energy-based systems such as fuel cells are receiving widespread attention.

This article will: focus on the “non-fossil-resources-based hydrogen production technology” as a key technology in creating a sustainable hydrogen energy system; review its significance in solving the “3E” problem; and analyze trends in the development of mainstay technologies.

Fuel cells are energy-efficient in their nature. Take fuel cell vehicles for instance: they both significantly conserve fossil resources and reduce greenhouse gas emissions, even if they use hydrogen derived from fossil resources. As far as the results of the analysis in this article are concerned, however, fuel cells do not outperform other competing technologies (hybrid vehicles, city gas cogeneration systems, etc.) in these respects. When using hydrogen derived from non-fossil resources, meanwhile, fuel cells virtually eliminate fossil-resource consumption and greenhouse gas emissions.

The non-fossil-resources-based hydrogen production technology is thus significant for Japan, whose energy self-sufficiency rates remain at low levels. Japan needs to pursue this particular technology on a long-term basis, placing emphasis on its research and development. At the moment, all the methods excluding water electrolysis are still in their basic-study or demonstration stages. It is important that potential methods be explored widely and the feasibility of each method be assessed.

Moreover, in designing energy systems including hydrogen energy, which is secondary energy, it is indispensable to bring up specialists well versed in energy-related technologies and policies. In this context, exchanges of human resources in the energy field and cooperation among academia should be promoted.

There is great potential in hydrogen production based on renewable energy, particularly in developing countries. From the viewpoint of technological development and international cooperation, therefore, it should be of benefit to Japan to actively develop technologies to be transferred to developing countries, while promoting local joint projects.

(Original Japanese version: published in October 2002)

Infrastructure

9 Trends in Research Toward Integrated Water Management Based on the Water Cycle

p.92

Human activities of realizing social and economic development affect flood control, water utilization and the environment from various aspects in river basins especially in urban areas in Japan.

Water recharge in wooded areas, farmland and bare ground has plunged in highly urbanized river basins, and environmental burdens such as small- and middle-sized floods and water quality deterioration damage the water cycle.

The water problem is in fact a global issue occurring not only in Japan. Water problems were widely discussed and various reports on them were presented in the World Summit on Sustainable Development (Johannesburg Summit 2002) held in August 2002.

In the meantime, the Promotion Strategy of Prioritized Areas of the Second Science and Technology Basic Plan of Japan's Cabinet Office emphasizes and vigorously promotes research and development for creating a sound water cycle in river basins and realizing integrated water management.

Acquiring and maintaining the balance between flood control, water utilization and environmental conservation with the water cycle as their center are crucial in integrated water management focusing on urban rivers. In order to realize this, not only application of technologies for environmental conservation but also establishment of environmental estimation methods such as setting of environmental indicators and estimation standards is essential.

Meanwhile, in carrying out measures for integrated water management, we need to improve analysis models for accurately grasping water cycle dynamics. Moreover, establishment of macro level models for understanding global demand and supply of water will help to tackle the impacts of climate change.

Finally, advancement in research and development related to water cycle dynamics and estimation of water resources in Asia, which has complex landscapes and undergoes frequent sediment movements caused by orogeny, is pivotal in supporting sustainable development in Asian countries.

(Original Japanese version: published in November 2002)

Others

10 The Need for Competitive Research Grants to Promote the Vitalization of Young Research Scientists

p.102

The Second Science and Technology Basic Plan suggested the prioritized expansion of research funding for young research scientists as a means to increase their independence. In response, the Ministry of Education, Culture, Sports, Science and Technology and other government agencies are expanding their research grants for young scientists. The history of research grants for young scientists in Japan is a brief one, and it is vital that we understand the conditions faced by young research scientists in Japan as we consider the necessity of upgrading research grants for the future. In this article, we will examine grants for young scientists in the U.S., with its well-developed grant system, compare them with grants for young scientists in Japan, and consider what elements should be incorporated into Japanese grants.

The importance of grant support for young research scientists is reflected in the fact that Nobel Prize winning research is concentrated in the 30 to 44 age group, the 10 to 15 years after most scientists obtain their doctorates. Research grants offer young research scientists opportunities to test their own unique and flexible ideas during this vital period.

In the U.S., the National Institutes of Health (NIH) is the primary grant maker, considering scientists with less than five years of research to be in a position for career development and offering research grants to support them at various stages of that development. Japanese research grants, in contrast, do not include this concept of "career development grant." Research grants in the U.S. are also vital to the careers of scientists, making them different from the existing Japanese grant system, in which grants are often thought of as merely a sort of financial supplement.

We utilized the results of a 2001 survey of scientists in academia, government, and the private sector by the Research Division of the Ministry of Education, Culture, Sports, Science and Technology's Science and Technology Policy Bureau. We found that the attitudes of young research scientists in Japan (between ages 30 and 34) vary depending on the type of research institution they are affiliated with, as do the issues facing them.

Because the U.S. with its system of intense competition for grants is at the top of many scientific and technical fields, increasing and sustaining the interest of young Japanese research scientists in obtaining grants is considered important for Japan's scientific and technical development. We propose that in order to achieve this, "diversity" must be incorporated into Japanese research grants for young scientists.

(Original Japanese version: published in December 2002)

1

Fostering of Researchers and Education in Life Science

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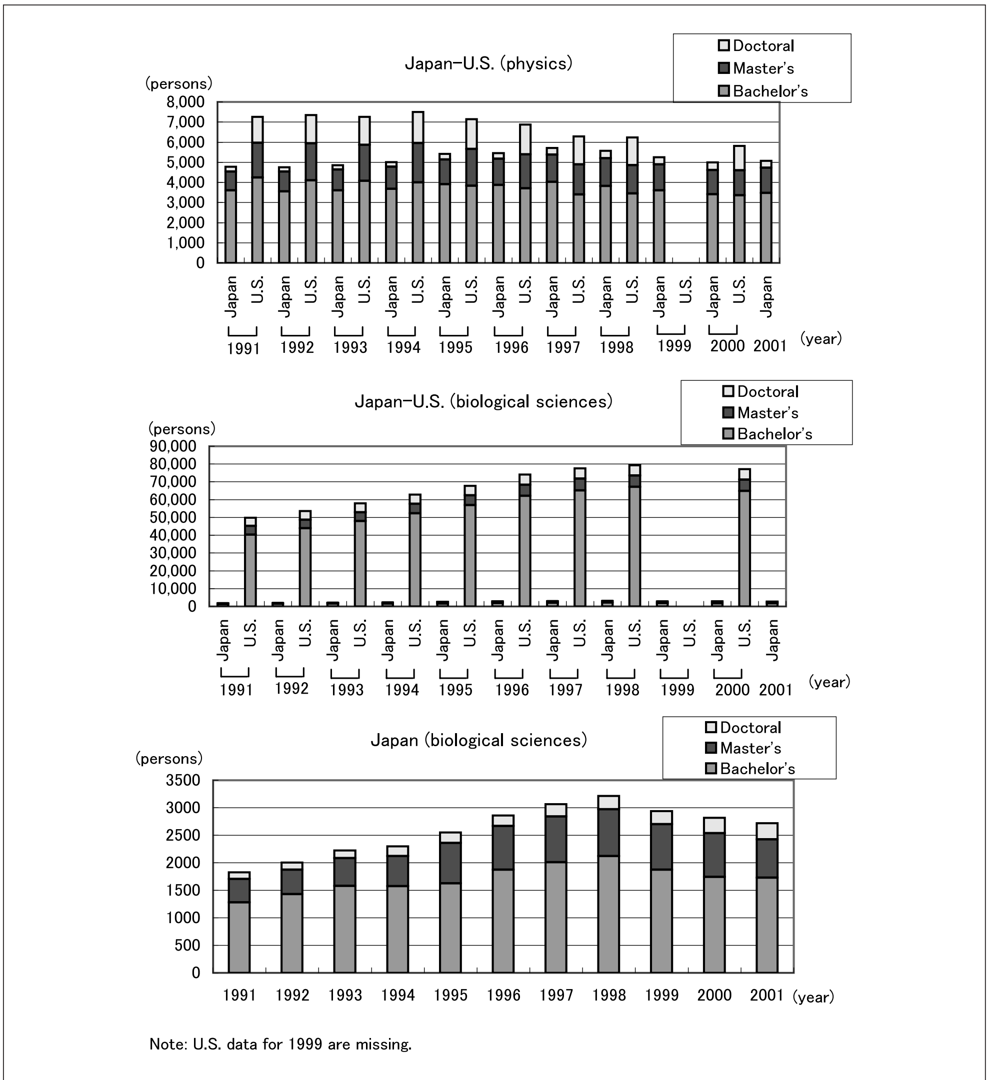
1.1 Science and technology policy in life science

The 21st century has been called the "Century of Life." As that name implies, life science is the most watched and rapidly developing scientific field today, both in and out of Japan.

Life science comprises "comprehensive sciences and technologies that explain the complex and subtle mechanisms of biological phenomena and apply the results in fields such as medicine, the environment, food production, and industry. It is an important contributor to the improvement of national living standards and the development of the national economy (2002 White Paper on

Figure 1: No. of people receiving degrees in biological sciences and physics in Japan and the USA



Source: Japanese data is derived from "Physics" and "Biology" under "Science" in the Basic Survey Report on Schools. U.S. data is derived from "Physics" and "Biological Sciences" in the National Science Foundation's Science and Engineering Degrees: 1966-2000.

Science and Technology).”

In Japan’s science and technology policy, life science is positioned and advanced as one of four major fields in the Second Science and Technology Basic Plan (determined by the Cabinet on 30 March 2001). At the meeting of the Council for Science and Technology Policy in September 2001, the life science branches that in FY 2001-2005 should be given priority for promotion by Japan and their research goals were made clear.

In the FY 2003 science and technology-related budget,[1] the estimated budget request for the life science field is ¥209.1 billion, a 28 % increase from the year before. This is a large amount compared to the ¥128.8 billion for the information and communications field (an 11.5 % increase), ¥64 billion for the environmental field (a 26.2 % increase), and ¥23.1 billion for the nanotechnology and materials field (a 100.9 % increase).

Even as the budget expands, however, we must point out that there is a shortage of research personnel in life science. Regarding the status of researchers in life science, Figure 1 shows the number of people receiving degrees in physics and in biological sciences in the United States of America and Japan. Although these statistics do not give a complete picture because in the case of Japan only biological sciences are included and agriculture, pharmaceutical sciences, and medicine are excluded, there is a large gap between the two countries. In 2000, only 1/37 as many people received bachelor’s degrees, 1/8 as many received master’s degrees, and 1/21 as many received doctoral degrees in Japan compared to the USA.

The number of physics degrees awarded in the United States has been declining over the past several years. In 2000, there was no longer a large gap between Japan and the USA.

The Second Science and Technology Basic Plan says the following about recent issues in the life science field.

- To promote the life science field, the national government should promote increased understanding of the field among the Japanese people.
- Scientific and technological progress is having an increasingly great effect on human beings and society. As exemplified by bioethics, the ethical issues raised by science and technology are important ones.
- The number of issues of great concern to ordinary people, such as clinical trials, transplants, and regenerative medicine, is expanding. Bioethics is an issue that must be debated by the Japanese people as a whole.
- As life science and information science continue to develop, they will have great influence on individuals and on society. It is therefore essential to seek a social consensus and to create rules of ethics.

The plan includes the following strategies to promote the various branches of life science.

- From the perspective of bioethics, along with the promotion of advanced research in life science, it is necessary to obtain the understanding of a large majority of the nation’s people by strengthening the active sharing of information, education, public relations, and the exchange of ideas.
- To establishing and foster multidisciplinary human resources to support new developments in life science, universities and other research organs must flexibly adjust their education and research bases and organizations, and policies to advance high school science education must be adopted.

Regarding life science literacy, a February - March 2001 study of science and technology awareness (National Institute of Science and Technology Policy, NISTEP Report No. 72) included a survey of understanding of science and technology terms.

Regarding the word DNA, 74 % of people surveyed responded that they understand “well” or “fairly well.” This is a large increase over the approximately 20 % responding so in November 1991 survey and 45 % in February 1995. However, of those responding that they understand “well” or “fairly well,” only 28 % were able to correctly answer the question “Where is DNA found in the body?” The report stated that, “Understanding of science and technology terms is closely related to the frequency with which they are used in the mass media.”

Based on the perspectives above, this report will examine the following two points.

(1) The future development of life science requires sufficient funding, as well as further promotion of the development of researchers. This requires a reexamination of the university education system.

(2) The 21st century is the "Century of Life," and a long-term perspective requires increased life science literacy for society as a whole. This requires an examination of the role of education.

1.2 Fostering life science researchers in universities

Universities play the most important role in fostering researchers. Universities foster the human resources who will carry the field of life science into the future. To expand that foundation, an educational system that promotes life science is required.

During recent years in life science fields, research and development based in molecular biology, such as genomes and genes, have rapidly developed into the mainstream. The content of such research and development is multidisciplinary and often impacts society as a whole.

However, as has been pointed out in "Regarding the Promotion of Bioscience Research (Proposal)," a February 2000 report by the Science Council, current education and research systems in university and graduate school departments of medicine, pharmaceutical sciences, science, agriculture, and so on are unable to fully respond to such rapid innovative and multidisciplinary developments in life science. The report therefore suggested that life science teaching and research departments undertake improvements, including reorganization of existing structures, to provide systematic education in life science.

Underlying this report is the fact that when research in molecular biology began to flourish in the mid 20th century, science departments in Japanese universities did not necessarily become the home of such research and education. Instead, medicine, agriculture, and other departments often adopted such fields as methods for applied research. This is because when new disciplines such as molecular biology were born, science departments were not flexible enough to create space for them.

Aware of this problem, several national universities have formed graduate research departments integrating life science fields such as science, agriculture, pharmaceutical sciences, and medicine (see Table 1).

Professor Mitsuhiro Yanagida, dean of the Kyoto University Graduate School of Biostudies, says "The fostering of outstanding life scientists requires the establishment of life science departments at the undergraduate as well as the graduate level. The Life Science Research Faculty accepts graduates from departments such as science, agriculture, pharmaceutical sciences, medicine, and engineering, but that does create some confusion in graduate education. To produce outstanding life scientists, we must implement life science education at the undergraduate level." Further

Table 1: The graduate school of Life science in national universities in Japan

	Kyoto University Graduate School of Biostudies	Tohoku University Graduate School of Life Sciences	Osaka University Graduate School of Frontier Biosciences
Established	April-99	April-01	April-02
Structure	2 divisions, 13 departments	3 divisions, 12 departments	1 divisions, 7 departments
Features	Forms research groups in science, agriculture, medicine, pharmaceutical sciences. Fosters human resources who will utilize new life science for preservation of the global environment and human welfare and happiness, and who will understand various vital phenomena of living things as a systemic function, and pursue these systemic functions.	Integrates life science fields such as science, medicine, dentistry, pharmaceutical sciences, agriculture, and engineering. Undertakes extremely wide-ranging research and education, from the molecular to the individual level, with the aim of understanding, maintaining, and protecting biological systemic function.	Gathers life science related fields of medicine, engineering, science, etc. Undertakes research and education to elucidate how elements of life from the sub-nano scale to the cell level form living organisms through dynamic processes and these pervasive structures and principles give rise to biological functions.

Source: Authors' compilation based on university web seites

Table 2: Life science standards in the National Science Education Standards in USA.

Year	Content standards	Overview of guide to the content standards
Kindergarten-4th	Characteristics of organisms	The basic needs of organisms. The structures of plant and animal bodies in proportion to various functions. The signals of internal and external behaviors.
	Life cycles of organisms	The plant and animal life cycle of birth, development, reproduction, and death. Plants and animals resemble their parents. Many of characteristics in organisms are inherited from parents or result from interaction with the environment.
	Organisms and environments	All animals depend on plants. An organism's behavior is related to the characteristics of its environment. All organisms cause changes in their environments. Humans depend on natural and constructed environments.
5th-8th	Structure and function in living systems	All organisms are made of cells, the basic unit of life. Cells have many functions, and produce more cells by growing and dividing. Specialized cells form tissues, and tissues form organs. Human beings have systems for digestion, respiration, reproduction, circulation, excretion, movement, etc., and these systems interact with each other.
	Reproduction and heredity	Reproduction is a characteristic of all living systems, and is necessary to continue species. Many species combine ovums and sperms to produce new individuals. The new individual receives genetic information from its mother and father. Genetic information is included in genes. A cell of human may include hundreds of thousands of genes.
	Regulation and behavior	Organisms regulate their internal environments by sensing the internal environment and regulating physiological changes therein. Behavioral response requires regulation and communication at the cell, organ, and organism levels. A behavior of organisms evolves through adaptation to its environment.
	Populations and ecosystems	All individuals living together and the physical factors they interact with constitute an environment. Food webs describe the relationships among producers, consumers, and decomposers in an ecosystem. The number of organisms that can be supported by an ecosystem depend resources that can be used and on abiotic factors such as the amount of light and water, temperature range, and soil conditions.
	Diversity and adaptations of organisms	Millions of species of plants, animal, and microorganisms are alive today, and all organisms share a certain unity. Biological evolution accounts for the diversity of species gradually developed over many generations. Species extinction occurs when its environment changes and species characteristics are insufficient to ensure survival.
9th-12th	The cell	Each cell has a structure appropriate to its functions. Many cell functions involve chemical reactions. Genetic information stored in DNA is used to direct the synthesis of the thousands of proteins needed by cells.
	Molecular basis of heredity	In all organisms, the instructions for their characteristics are transmitted by DNA, which is composed of four subunits (A, G, C, T). Most human cells contain two copies of 22 chromosomes, and one pair that determines sex. Changes (mutations) in DNA occur spontaneously at low rates.
	Biological evolution	Species evolve over time. The diversity of organisms is the result of more than 3.5 billion years of evolution that has filled the available niches with life forms. The millions of species of animals, plants, and microorganisms now living on Earth are related through common ancestors.
	Interdependence of organisms	The atoms and molecules on the earth cycle among the living and nonliving components of the biosphere. Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores to carnivores and decomposers. Human beings live within the world's ecosystems. Humans are gradually modifying ecosystems as a result of population growth, technology, and consumption.
	Matter, energy, and organization in living systems	The chemical bonds of food molecules contain energy. The distribution and abundance of organisms and populations in ecosystems are limited by the availability of matter and energy and the ability of the ecosystem to recycle materials. As matter and energy flows through different levels of organization of living systems - cells, organs, organisms, communities - and between living systems and the physical environment, chemical elements are recombined in different ways.
	Behavior of organisms	Multicellular animals have nervous systems that generate behavior. Organisms have behavioral responses to internal changes and to external stimuli. Behavioral biology has implications for humans, as it provides links to psychology, sociology, and anthropology.

Source: Reference [2].

study of how to prepare graduate schools and other institutions for comprehensive life science education and research remains necessary.

As we have said above, life science will continue to have important impacts on society as a whole. Completion of curricula including relevant classes at the university general education level is also necessary. At the Massachusetts Institute of Technology (MIT) in the United States, for example, life science is a requirement for all students. This precedent-setting requirement has been widely discussed in the USA as well.

1.3 Life science literacy and education

Life science will be increasingly important in social communication. It is therefore necessary to attempt to raise the life science literacy of society as a whole. From a long-term perspective, education has the most important role to play in any attempt to increase scientific literacy.

Through the advancement of molecular biology, life science has developed systematic understanding of diverse biological phenomena and the mechanisms of life primarily through principles such as genetics. The future of life science will develop around those principles, and life science education must add such knowledge in developmentally-appropriate stages.

Here we will introduce recent education reforms in the United States and the United Kingdom, and the position of life science in those reforms.

• **United States of America** [2],[3]

In 1980 in the United States, the National Science Teachers Association (NSTA) began a major campaign regarding the so-called crisis in science education. Since then, academic societies, organizations such as the American Association for the Advancement of Science (AAAS), states, and communities have all taken individual actions to reform science education. In 1991, the NSTA asked the National Research Council (NRC) to coordinate the development of National Science Education Standards. Funds for the development of the standards came from the U.S. Department of Education and the National Science Foundation (NSF). The standards were developed with the participation of numerous science teaching organizations led by the NSTA and the AAAS, as well as government organizations. The standards were announced in December 1995.

Rather than what are commonly thought of as standards, the U.S. National Science Education Standards are intended as ideals and goals for science education that will enable all Americans to be scientifically literate during the 21st century. Scientific literacy is defined as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity."

National science education standards in the USA comprise the following six standards.

(1) Science teaching standards
Facts that teachers of science at all grade levels should understand and be able to do.

(2) Standards for professional development for teachers of science
Standards for science teacher's professional development and for the maintenance of the teaching profession.

(3) Assessment in science education
Standards for determining the quality of assessment practices used by teachers and state and federal agencies to measure student achievement. Assessment is a primary feedback mechanism in the science education system

(4) Science content standards
An outline what students from kindergarten to grade 12 should know, understand, and be able to do in natural science.

(5) Science education program standards
Necessary conditions for high-quality school science programs.

(6) Science education system standards
Standards for judging the performance of the components of the science education system as a whole.

Of these, (4) Science content standards provide points of emphasis and perspectives to help states and communities develop their own curricula. Science content standards comprise the following eight categories. [1] Unifying concepts and processes in science covers kindergarten through 12th grade (ages 6-18), while the other seven categories are each divided for kindergarten through 4th grade, 5th through 8th grade, and 9th through 12th grade.

[1] Unifying concepts and processes in science
[2] Science as inquiry
[3] Physical science
[4] Life science
[5] Earth and space science
[6] Science and technology
[7] Science in personal and social perspectives
[8] History and nature of science

In these, life science is one of the categories. Standards and guidelines for life science are shown in part in Table 2. The adoption of current developments in life science can be seen in, for example, "Biological Lifecycles" for kindergarten through 4th grade, which includes the concept of heredity, and "Structure and Function in Living Systems" for 5th through 8th grade presents life in terms of systems.

The interaction of science with society, a point that is vital to life science, is covered in [7] Science in personal and social perspectives.

• **United Kingdom** [4],[5]

Declining academic skills among students and academic levels that vary by community and school are serious problems in the United Kingdom (England and Wales), and active debate regarding reforms have been taking place since the 1970s. Concerning curricula, the establishment of national standards has been a point of contention, and national government bodies have made numerous public policy statements.

Based on the 1988 Education Reform Act, a National Curriculum (NC) for all publicly-operated schools was introduced. The NC was revised in 1991 and 1995, and the current version is a September 2000 revision.

Under the Education Reform Act, science, along with English and mathematics, is a required or core subject among the foundation subjects. Underlying the requirement that all children learn about science are an effort towards a shared national scientific literacy and society's need for preparatory education to respond to rapid changes in science and technology. In addition, the reforms are intended to efficiently produce human resources who can compete internationally using science and technology.

The NC is set as a ministerial ordinance, and includes content and goals for learning. However, the NC differs qualitatively from Japan's national curriculum in that students are evaluated through national tests based on the NC (external evaluation) as well as by teachers (internal evaluation), in that publicly-operated schools but not all schools are subject to it, and in it not being a complete school curriculum.

Under the NC, primary and secondary education are connected and integrated, with compulsory education divided into Key Stage 1 (age 5-7), Key Stage 2 (age 7-11), Key Stage 3 (age 11-14), and Key Stage 4 (age 14-16).

The NC includes goals and study programs in each subject. The study program for science includes "scientific enquiry," which covers skills (techniques and abilities) and attitudes; "life processes and living things," "materials and their properties," and "physical processes" which covers knowledge and understanding. In addition to natural science fields such as life science, the NC also includes study related to science and society and everyday life through concepts like "nature of science" and "science in an everyday context."

Life science is covered under "life processes and living things." As can be seen in Table 3, life science education in the NC is designed to be continuous and integrated, with categories increasing and content becoming more advanced as children move through the stages. Children also learn about health and the functioning of the human body here.

Increasing national scientific literacy is a goal of the science education reforms in the United States and the United Kingdom. To achieve that goal, science education has been reexamined from a long-term perspective, and the resulting new structure can be seen in the National Science Educations Standards and the National Curriculum. It is also apparent that even with the differences in the content of life science

Table 3: Life processes and living things program of the United Kingdom's (England and Wales) National Curriculum.

	Key Stage 1 (5-7)	Key Stage 2 (7-11)	Key stage 3 (11-14)	Key stage 4 (14-16)※
Content	Life processes	Life processes		
			Cells and cell functions	Cell activities
	Humans and other animals	Humans and other animals (Nutrition, circulation, movement, growth and reproduction, health)	Humans as organisms (Nutrition, movement, reproduction, breathing, respiration, health)	Humans as organisms (Nutrition, circulation, breathing, respiration, nervous system, hormones, homeostasis, health)
	Green plants	Green plants (Growth and nutrition, reproduction)	Green plants as organisms (Nutrition and growth, respiration)	Green plants as organisms (Nutrition, hormones, transport and water relations)
	Variation and classification	Variation and classification	Variation, classification and inheritance (Variation, classification, inheritance)	Variation, inheritance and evolution (Variation, inheritance, evolution)
	Living things in their environment	Living things in their environment (Adaptation, feeding relationships, micro-organisms)	Living things in their environment (Adaptation and competition, feeding relationships)	Living things in their environment (Adaptation and competition, energy and nutrient transfer)

Note: Key stage 4 includes single science and double science; a majority of students choose double science. The table shows the double science program.

Source: Reference [5] and The National Curriculum for England.

education, in both countries emphasis is being placed on understanding life science in a systematic way.

Japan also needs to undertake long-term efforts to increase scientific literacy. The 21st century is the "Century of Life." Systematic life science centering on molecular biology must be properly positioned in education so that knowledge can be added in developmentally-appropriate stages. This requires an examination of the structure of science education.

1.4 Conclusion

The fostering of researchers is one of the most vital issues ensuring the advancement of life science, which is expected to support Japan's industrial base in the future. Life science education and research of universities must be improved to accomplish this. Furthermore, because life science has become an multidisciplinary field and has come to have an impact on society as a whole, graduate schools must be prepared and curricula developed to teach life science systematically and comprehensively. What type of education system should be developed is a question that will be asked of universities as the national universities become more independent of the central government, and will require government support as well.

Individuals and society will debate and judge issues such as bioethics that arise from life science. Education will play a vital role in raising of society's life science literacy from a long-term perspective. Systematic life science centering on molecular biology must be properly positioned in education so that knowledge can be added in developmentally-appropriate stages. The time has come for an examination of the structure of science education.

Acknowledgements

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Professor Yanagida graciously provided us with relevant literature as well as offering overall

Appendix.: Professor Mitsuhiro Yanagida's suggestions for advancing life science research

(1) Improving life science education A. Change in primary and secondary education is required. ● A two pronged-teaching approach through natural history style biology and through life science. ● Early education regarding genes. ● Training of life science educators B. Establishment of new departments and graduate schools in universities is required for the training of students in life science fields. ● Establish life science departments separate from existing current science, agriculture, pharmaceutical sciences, and medical departments. ● Establish life science research departments in graduate schools.
(2) Training outstanding people A. A system that maintains continued outstanding research must be built. ● Improve the quality and objectivity of research evaluation. ● Relax retirement age restrictions for outstanding researchers. ● Provide economic support including scholarship systems to help graduate students. B. Leadership training is needed. ● Young (in their 30s) research leaders. ● National leaders with international status. C. Necessary elements to train human resources ● An environment that welcomes foreign researchers and foreign research leaders. ● An environment that welcomes female researchers and allows them to become leaders. ● Improved English ability for Japanese researchers.
(3) Conditions and issues in Japan's life science policy A. National unique sense of values is necessary for determinining policy. ● Policies should not be determined to oppose to the U.S. and Europe. ● Japan should cooperate with the U.S. and Europe where possible. B. National policy (funding flow) must be scrutinized. ● Outstanding grant systems should be continued in a good direction. ● Results obtained by the public corporations that carry national policy must be scrutinized. ● Outside evaluation of funding flow as national policy is necessary.

Source: "The critical situation of life science research and education in Japan's universities," National Institute of Science and Technology Policy Lectures No. 90.

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2

Trends in R&D and Standardization on Accessibility in the Information and Communications Field

— Toward Barrier-Free Equipment and Services of Information and Communications —

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2.1 Introduction

Our everyday life is filled with a variety of devices and services of information and communications, ranging from PCs, personal digital assistants (PDAs) and Internet-enabled mobile phones to automatic teller machines (ATMs) at financial institutions, ticket-vending machines at train stations, kiosk information terminals for tourists and interactive digital satellite broadcasting TVs. As our society grows more information-oriented into the future, our lives will become increasingly dependent on such equipment and services.

Currently available devices and services, however, do not always provide ease of use for all possible users. The standard input method for the PC through a keyboard and mouse, for example, is not friendly to people with limb disabilities. Web pages containing many images also pose a challenge to people with vision impairments. Solving such problems is, in technical terms, referred to as "improving accessibility." Accessibility represents the product's ease of use and understanding for those who try to utilize it, which is similar to concepts such as "barrier-free information" and "universal access to information."

Typical groups that have poor accessibility are elderly and people with disabilities. However, they are not the only ones who are experiencing difficulty in operating information and communications devices such as PCs. Improved accessibility will have an impact on a greater range of users, and allow devices and services of information and communications to penetrate deeper into our daily lives. To realize a highly information-oriented society, improvement of accessibility is an inevitable task. This report focuses on the accessibility of equipment and services of information and communications, and presents trends in R&D and standardization activities in the field.

In relation to this subject, there is another approach in which accessibility is studied from the viewpoint of how information is created. Examples are research on a Web page structure that is easier to understand and research on a technique to select the necessary information from a large source and arrange the results to suit the user's needs. The former concerns the human's process of understanding information, while the latter is about how to enable machines to understand the meaning of information. As these studies are still in their early stages and have yet to develop, this report does not mention the issues of how to create information.

2.2 Accessibility market scale

There is no doubt that Japan is turning gray. According to the 2001 edition of the White Paper on the Aged Society, Japanese aged 65 years or older account for 17% of the entire national population and the figure is expected to top 25% in 10 years. Also, the statistics of the Ministry of Health, Labor and Welfare (MHLW) show that the number of adults and children with disabilities totals to 3.34 million as of fiscal 2001.

Elderly and people with disabilities in legislative and statistical terms are defined based on certain criteria. In practice, however, there are people who face accessibility problems but do not meet the criteria. People with hearing difficulties, for example, are counted only when the person's hearing ability levels of both ears are 70dB or worse, whereas it is said that people often start experiencing difficulties in their everyday activities at around 40dB.

Even those who can use equipment and services of information and communications without any problems may experience inconvenience depending on his/her situation. Take a person with a broken arm, who is likely to feel uncomfortable dealing with a keyboard and mouse. Such people who have temporary disabilities should also be taken into consideration when discussing accessibility. If these people are added to the population of elderly and persons with disabilities, the total number of people with poor accessibility is enormous.

Discussions on accessibility for elderly and people with disabilities are often held from the standpoint of social welfare. Yet the target population is on the order of several tens of millions, when assuming the description above. This can be seen as a huge and certain market. In addition, given the massive population scale, it is not realistic to treat these people as a mere target of protection. Through improved accessibility to equipment and services of information and communications, elderly and people with disabilities will be encouraged to participate in society and their ability can be made good use of, both of which are essential to energize and develop the entire society.

2.3 Three approaches to improvement of accessibility

There are three approaches to improving the accessibility to equipment and services of information and communications:

The first approach is to have the person use a special aid suited for his or her disability to enhance the usability of equipment and services.

The second approach is to provide functions to change the input/output method or multiple input/output options, so that a person with any kind of difficulty can use the equipment or service. For PCs, some operating systems and popular software applications come options with such capabilities.

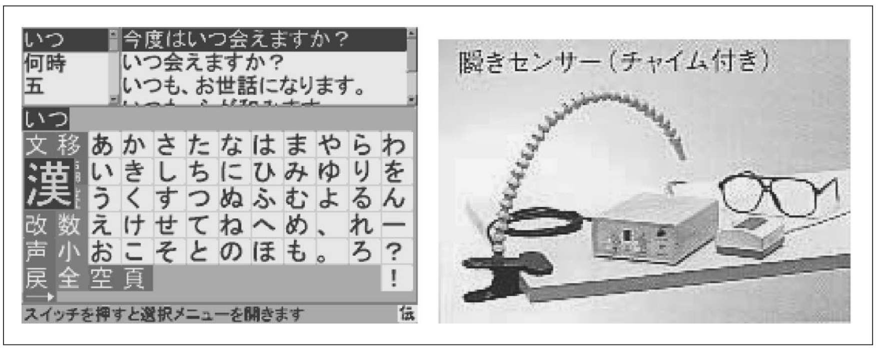
The third approach, an expansion of the second one, intends to ensure that accessibility is built into every information and communications device and service. In other words, this represents standardization of equipment and services. There are a number of activities under way throughout the world toward the development of standards on how to provide equipment and services of information and communications with consideration given to the needs of elderly and people with disabilities.

2.4 Trends in technological development

2.4.1 Current status of technological development

Here is an example of the first approach. People with amyotrophic lateral sclerosis (ALS) are profoundly disabled and have difficulty even speaking. To assist with their communication, a

Figure 1: A communication device designed for ALS patients ("Den-no-shin," Hitachi, Ltd.)



sensor system that can detect the movement of their eyes and eyelids (blinking), the parts of the body they can manage to move slightly, has been developed. The system displays a large table of characters on its screen on which the user can move the cursor through eye movements and select a character by blinking. Figure 1 shows a communication device designed for ALS patients.

Aside from this, a round-shaped push-type input device is offered to allow disabled persons who do not have sufficient muscular power to perform complicated operations to enter characters in Morse code. Other products available are software that enables the numeric keys to substitute for mouse operations and alternative technologies to the mouse such as track balls and touch panels. This is also the case with output devices. Text reading software, a program that generates audio output of Web pages, is a typical product in this area, in addition to Braille output devices (Braille displays and printers). These represent parts of the efforts to provide input/output devices specifically designed to address the needs of persons with varied types and levels of disabilities.

Many recent operating systems and software products for PCs permit users to change the view scale, the font size and color, background colors, the response speed of the keyboard and mouse, and so on. This can be viewed as an example of the second approach, since such functionality for customization improves accessibility for people with any kind of difficulty.

While the above cases are all related to PCs, they are not the only technology with poor accessibility. ATMs at post offices and banks, for example, now often employ touch panels, which are unfriendly to people with visual disabilities. To cope with the problem, models that accept entry from both the touch screen and keys have appeared. This move can be categorized into the second approach for its provision of alternative input/output methods. Yet, these ATMs still have plenty of room for improvement such as standardization of the key layout among different models.

Speech synthesis is used for communicating text information to people with hearing difficulties, while speech recognition technology is applied when communicating audio information to such people. The aforementioned Web text reading software exploits speech synthesis technology. The weakness here is that some Web pages contain two-dimensional information such as graphical images. Even a page consisting only of text may include a table, where the two-dimensional placement of text elements delivers significant information. How to communicate such complicated content is still in the stage of basic research. In NHK's news programs, the voice of announcers are automatically recognized and displayed as captions. While speech recognition works well where grammatically correct sentences are read with clear pronunciation, its function is not reliable in a conversation involving a number of people in a noisy environment. This is another fundamental research subject.

In Web text reading, audio output for a link to "http://www.nistep.go.jp," for instance, should not be literally pronounced, since it would be so long as to cause confusion and result in an unfriendly way of communication. A preferable sound for this element would be "a link to the National Institute of Science and Technology Policy," for which the creator of the Web page can prepare alternative HTML text in place. Likewise, an image should be accompanied by a text description. "Web Content Accessibility Guidelines 1.0," a document that explains how to create a highly accessible Web site, was published in 1999 by the Web Accessibility Initiative (WAI) committee of the World Wide Web Consortium (W3C), an international forum on Internet technologies, and has become the de facto international standard.

In Japan, in relation to this initiative, the Ministry of Posts and Telecommunications (MPT) and the Ministry of Health and Welfare (MHW) (both as they were called then) jointly issued in 1999 a guideline for the creation of Internet Web content accessible by people with disabilities based on the W3C guidelines. In a field trial on Web accessibility, the Ministry of Public Management, Home Affairs, Posts and Telecommunications (MPHPT) has been developing Web Helper, a system that allows Web site creators to check their sites' compatibility with this guideline and to make the necessary modifications semi-automatically. The program is slated for distribution to local public organizations by the end of 2002.

2.4.2 Government support for technological development

The Ministry of Economy, Trade and Industry (METI) has been promoting a program for the development of information systems for people with disabilities. The goal is to build, in the near future, an environment in which elderly and people with disabilities can actively take part in the information-oriented society by supporting the development and field/evaluation testing of information and communications equipment and systems friendly to such people.

The program rendered aid to 14 R&D projects in 2000, including "communications/telephone equipment for people with hearing/speech disabilities" and "PDA with Bluetooth interface for people with visual disabilities," and to another 14 projects in 2001, such as "development and field testing of e-mail software for disabled children with varied kanji reading skills" and "collection and utilization of barrier-free information through the application of IT technology." For 2002, "development and field testing of user-adaptive USB information input devices" (development of PDA-type input devices that can compensate for disabilities and be connected via USB) and "communication software for people with multiple disabilities (limbs and vision)" are among the eight projects which won grants. These are not large-scale projects, as the amount of grant per project is ¥30 million or less (may be raised up to ¥50 million depending on the content).

Developed in the project on "the communications/telephone device for people with hearing/speech disabilities" is a machine that has capabilities such as indicating an incoming call with a loud sound, vibration or lighting, letting the user choose a desirable communication method from either audio (voice) or text, for which a pen or keyboard is used, and adjustable audio volume and pitch. Through the "PDA with Bluetooth interface for people with visual disabilities" project, the participants have been working on the development of special hardware for people with vision impairments that has, instead of a regular PDA touch screen, a double-action keyboard that functions by first lightly pressing a key to produce a voice output of the assigned character or function, then firmly pressing the key to confirm entry.

A similar initiative has been taken by MHLW, which supports development of aids in the area of information and communications as part of the grant program for the development of welfare equipment carried out by the Association for Technical Aids, Inc. One of the three projects that earned the grant for 2002 was "research and development of a '3D mouse' that is easy and flexible to use for people with disabilities."

Furthermore, information on equipment and software that assist computer operations is available through such Web sites as "Kokoro Web (www.kokoroweb.org)," aided by METI, and "NORMANET (www.normanet.ne.jp)," supported by MHLW. One of the products listed on these sites is software featuring "word prediction" capabilities, a program designed for people having difficulty with keyboard typing. The software adds words and sentences entered by a user to its dictionary, so that the next time the person begins typing the same word or sentence, a box containing a list of selections appears when the first letter is entered.

2.5 Trends in standardization activities

2.5.1 Trends in ISO

In 1998, in response to a proposal from Japan, the Committee on Consumer Policy of the International Organization for Standardization (ISO) at its general meeting adopted a resolution to set up a task force for the development of a policy statement on general principles and guidelines for the design of products and environments addressing the needs of older persons and persons with disabilities. This is based on "universal design," a concept of making all facilities, products and services accessible to anybody, whether the person is or is not older or disabled. The working group, led by Japanese, actively carried out the task and finalized the general principles as the ISO/IEC Guide 71 (Guidelines for standards developers to address the needs of older persons and persons with disabilities) in early 2002. The document serves as a comprehensive guide, applying to all standardization activities.

Table 1: Development of guidelines in two technological fields

Information Processing Devices (led mainly by the MITI)	
1974-1976	Japan Electronic Industry Development Association (JEIDA) "Investigation of the Contribution Plan of Rehabilitation toward People with Disabilities"
1988	JEIDA "Investigation for the Preparation of Electronic Products Accessibility Guidelines"
1990	JEIDA "Computer Accessibility Guidelines"
1995	Notice No. 231 "Accessibility Guidelines for Use of Computers by People with Disabilities"
2000	Revision and announcement of "Accessibility Guidelines for Use of Computers by People with Disabilities and the Elderly"

Telecommunications Facilities (led mainly by the MPT)	
1998	Notice No. 515 " Accessibility Guidelines for Use of Telecommunication Equipment by People with Disabilities"
1998	Establishment of the "Telecommunication Access Council"
1999	MPT and MHW "Guidelines for the Creation of Internet Web Content Accessible by People with Disabilities"
2000	Telecommunication Access Council "Accessibility Guidelines for Use of Telecommunication Equipment by People with Disabilities"

Following this, ISO sought to develop accessibility standards to be met by every device and service in respective areas such as information and communications. As described later, there are a variety of ongoing activities in Japan as well, partly because of its intention to take the lead in the world by making technical proposals to ISO.

2.5.2 Trends in Japan

In Japan, separate guidelines have been established for information processing devices and telecommunications facilities as shown in Table 1.

Each guideline provides abstract requirements for equipment and services rather than concrete standard specifications. As an example, the Accessibility Guidelines for Use of Computers by People with Disabilities and the Elderly is outlined below.

(a) Promotion of the standardization of common functions

To address the wide range of barriers in the operation of equipment as far as possible, functions to be used in common should be standardized and built into general-purpose information processing devices. To be more specific, capabilities such as adjustable keyboard sensitivity, navigation through keys instead of a mouse (keyboard navigation) and adaptable response speed for mouse movement and clicking should be standardized and made available on all applications.

(b) Promotion of the development of dedicated functions

To eliminate operational barriers that are specific to individuals and are yet to be overcome only through existing common functions, special functions for further customization should be developed. More specifically, alternative devices such as a Braille keyboard and Braille display and voice input/output systems should be provided.

(c) Enhanced services

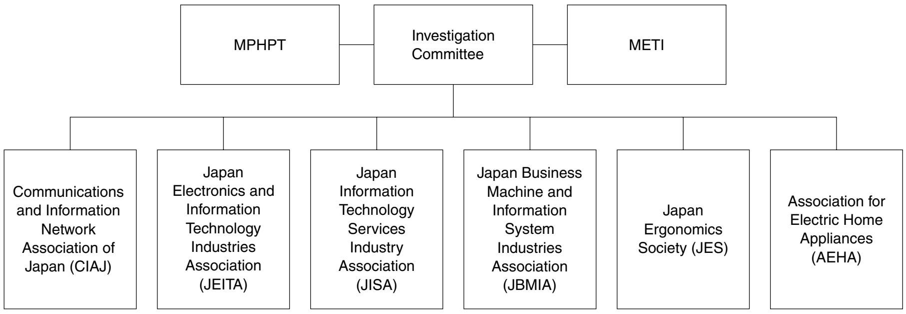
To encourage use of accessibility products and development of special functions, services should be enhanced for elderly or disabled users, their supporters, and developers of special functions. To be more specific, exposure of interface specifications to the public and creation of easier-to-understand content and manuals are demanded.

(d) Consideration to system openness

Emphasis should be placed on openness of systems to ensure compatibility, such as ease of connection with accessibility-conscious information processing devices commercially available.

Guidelines for information processing equipment and telecommunications facilities, which have been independently developed in each field, should preferably be consistent with

Figure 2: Structure of the Investigation Committee



each other as far as possible. The reason is because the distinction between information processing and telecommunications is becoming increasingly blurry with technological advancement, and also because products in compliance with close but different standards may confuse consumers.

It was 2000 when the activities toward the creation of common guidelines in the information and communications field were initiated. In September 2000, an internal organization of the Japan Standards Association, the Information Technology Research and Standardization Center (INSTAC), on a voluntary basis formed the Standardization Investigation Committee for Realizing Barrier-Free Access to Information. In response to the conclusion submitted by the committee, a new organization, the Standardization Investigation Committee for Improvement of Accessibility Common to Areas of Information Technology and Software Products, was established within INSTAC in April 2001 to serve as a body to carry out research entrusted by the government.

The new committee's structure, shown in Figure 2, shows various characteristics. The first point to be noted is that MPHPT and METI jointly support the activities. The fact that the committee has successfully acquired the understanding and cooperation of both ministries for its goal of providing Japan Industrial Standards (JIS) for elderly and people with disabilities is particularly noteworthy, considering the frequent disputes arising between ministries in Japan.

The second characteristic is participation of many organizations (industry associations, etc.) that have been engaged in the development of accessibility guidelines or in the promotion of relevant activities for the respective product groups.

In addition to these ministries and organizations, accessibility experts, people from enterprises, and disability groups comprise the committee. Currently, they are working toward the preparation of a draft JIS, which is expected to become a JIS standard by the spring of 2003.

Producing such JIS standard will contribute to wide availability of accessibility-conscious devices and services. In 1995, the government announced standard guides for the general evaluation and method of contracting of computers and services supplied to the government, as an agreement among the concerned ministries and agencies. Contained in the announcement is this sentence: "Items to be evaluated shall be established in conformity with the international and national standards." According to this rule, accessibility as a design consideration will become a requirement for government procurement, once the planned JIS standard is adopted. And if this effort by the government successfully expands the market, it is likely that the spread of such equipment and services will spark off interest in the private sector as well.

The JIS standard being prepared is a design guideline to be applied in common to all devices and services in the information and communications field and to be positioned above the existing guidelines for individual devices. After the adoption of the standard, guidelines in the respective areas will need to be reviewed in line with the common design guidelines and reestablished as JIS standards.

With respect to Web accessibility, as mentioned before, MPT and MHW (both are former name in that time) published in 1999 a guideline for the creation of Internet Web contents accessible by people with disabilities. Based on this document, a basic concept for providing administrative information through electronic means was approved through inter-ministry meetings in 2001. Following this, Web sites of administrative organizations are required to conform to the guideline.

The JIS draft, which is slated to become a JIS standard by 2003, is being prepared in accordance with the above guideline on Web content creation as well as W3C guidelines.

2.5.3 Trends in the U.S.

In the U.S., the basic law stipulating the rights of people with disabilities was instituted in 1990 as the Americans with Disabilities Act. This law was epoch-making in that it abandoned the conventional protection-oriented welfare for people with disabilities and instead identified employment, accessibility and other rights of these people. The concept was reflected into the 1998 revision of the Rehabilitation Act. In the revision, an article was added to Section 508 requiring that information and communications equipment and services which purchased or leased by Federal agencies must be accessible to employees and citizens with disabilities.The newly revised Section 508 also stipulates that Federal agencies must ensure that device and services of information and communications they procure are accessible to employees and the public to the extent it does not pose an undue burden. And employees and citizens are permitted to file complaints regarding any lack of accessibility.

In other words, computers, software and office equipment procured by the government, as well as Web sites and services provided by the government, must be accessible to both employees and citizens. Since June 2001, the Federal government has been applying Section 508 to its procurement activities.

Accessibility standards in the U.S., published in 2000, are based on a concept similar to the one for the guidelines in Japan. The U.S. version is, however, more specific and broader, as it provides such details as the height and positioning of the navigation panel of an information kiosk to be used at an administrative organization to ensure accessibility for a person who uses a wheelchair.

Section 508 is bringing a significant change to industry in the U.S. Considering the enormous amount of procurement by the Federal government, U.S. companies have begun to think in this way: if accessibility is a requirement in the public sector, why not add accessibility to all products to be marketed? Even Japanese businesses, which are large exporters of information and communications equipment into the U.S., must address this issue.

When a standard is compulsory, all devices and services available throughout the country must be compliant with it. An example is a standard on how to ground electrical machinery, which was established to prevent electric shock. Since the U.S. accessibility standards, set in accordance with Section 508, are applicable only to Federal government procurement, it is not officially compulsory. However, due to the massive scale of its impact, U.S. firms have started considering the standard as semi-compulsory.

Furthermore, according to a hearing from the people who were involved in the development of the accessibility standards, the U.S. intends to "export" them worldwide to nations such as Canada and Mexico. While U.S. companies are advanced in accessibility, with their products and services compliant with Section 508, Japanese counterparts may not be ready for the change, a situation where the latter group may suffer considerable trade disadvantages.

There is a new movement in the U.S. after the launch of government procurement compatible with Section 508. It is a fresh approach in which individuals with disabilities are provided with a specifically designed input/output device, through which the person is given access to all devices and services of information and communications. Although its direction may be completely opposite to that of Section 508, this is an interesting initiative.

The activity is led by a group called the International Committee for Information Technology Standards. Their scheme is explained like this. As an interface between the personal input/output device and information equipment such as an ATM or ticket-vending machine, the Alternative Interface Access Protocol (AIAP) was developed. Via the protocol, communication is established between the input/output device and an external machine to which the user's request can be transferred. An input/output device designed to assist each person's specific difficulties may be offered. Twenty leading companies in the information and communications industry participate in this project, and are ready to disseminate AIAP.

A critical question in developing an accessibility strategy is whether to make all equipment and services of information and communications accessible for everybody or to use intermediary devices customized to individual users for enabling their access to such equipment and services. The fact that the latter approach has started in the U.S., where the former approach was at one time dominant, may indicate the limitations of the former. The best solution is probably to improve accessibility of equipment and services as far as possible before further enhancing usability through intermediary devices.

2.5.4 Trends in Europe

In Europe, each nation's policy and the European Union's policy are interacting with each other to promote activities toward barrier-free information. The R&D program driven by the European Commission was launched in the 1990s, with a view to building a large accessibility market across Europe. Before the new movement, discussions were held solely from the viewpoint of equal opportunities, however, people began talking about technical aspects once the program started. The initiative also helped in calling attention to standardization.

Meanwhile, European efforts toward an information society were embodied as the eEurope plan. With the aim of giving special consideration to people with disabilities and acting against the digital divide, the plan requires the European Commission and each member state to identify the following actions.

The first action is to publish "Design for all" standards for information technology (IT) products by the end of 2002, in order to enhance employment opportunities for people with special needs and to encourage their participation in society. The second is to check whether laws and standards are compatible with the concept of accessibility by the end of 2001. In addition, eEurope also spells out improvements for public organizations' Web sites by the end of 2002, in line with the W3C guidelines.

With "Design for all" and "eAccessibility" as slogans, regional standardization bodies embarked on activities toward the development of guidelines in the area of information and communications. The European Commission, which asked for the movement, supports the activities with a small grant on the order of 10,000 Euro. The outcome is expected to be made public within 2002.

2.6 Provision of information to users and improvement of IT literacy

Before highly accessible equipment and services of information and communications can be disseminated, users must first know of their presence. Particularly important is to offer a place where people, especially elderly, who often express distaste for IT devices without ever trying or believe they cannot use such devices, can experience the benefits of such technologies and learn to accept them. Moreover, certain hands-on training should be provided, since, unfortunately, operating today's PC usually requires some getting use to. Education on threats such as computer viruses and exposure of personal information should also be given as needed. These are what "improvement of IT literacy" means.

For example, the mobile telephone is rapidly spreading among people with hearing difficulties. While at first these people did not show much interest in the technology, considering it as a kind of telephone, once they realized its capability of sending and receiving e-mail messages, the device started to prevail among them. This example suggests how important it is to provide information on the service itself.

In Japan, the e-Japan Program promotes education aiming at improvement of IT literacy. In this area, the program sets the following objectives.

(1) With the aim of far exceeding the forecast rate of 60% in 2005 for Internet penetration by individuals, information literacy of all Japanese shall be promoted.

(2) The IT education system in elementary,

Table 2: Structure of the Investigation Committee

Information Processing Devices (led mainly by the MITI)	
Initiatives	Number of Attendants
Basic IT skill training to learn the basics of operating PCs, making documents, accessing the Internet, and sending/receiving e-mails.	Approx. 5.5 million
IT training, etc., for managers of SMEs to understand the effects of IT on management.	Approx. 290,000
IT training, etc., for consumers to learn the skills to freely obtain and utilize information concerning everyday life.	Approx. 180,000
IT training, etc., at prefectural women's centers, etc.	Approx. 20,000
IT training, etc., for supporting corporate officers' planning of strategic information investment.	Approx. 15,000
IT training, etc., toward people working in agriculture, forestry and fisheries industries.	Approx. 10,000

lower- and upper-secondary schools and universities will be strengthened in addition to enhancing lifelong information education for the general public.

(3) By increasing the number of people with master's degrees and doctorates in IT-related fields, the availability of advanced IT technical experts and researchers shall be ensured in the private, academic and public sectors. In addition, some 30,000 distinguished foreign human resources will be accepted. In total, our nation will exceed the U.S. standard of human resources regarding IT technical experts and researchers.

To promote the understanding of IT among adults, the ministries concerned, including MPHPT, the Cabinet Office, METI and the Ministry of Agriculture, Forestry and Fisheries, have been implementing the measures as shown in Table 2.

Since improvement of IT literacy among older persons and people with disabilities is of the same importance, these people should be given opportunities to receive fundamental education on IT. he 2002 White Paper on "Information and Communications in Japan" mentions various ongoing efforts in this direction, such as seminars for these people. One such seminar is conducted by a group called Access Support Volunteer (ASV). The support offered by ASV includes: (1) on-site technical assistance, such as installation of text-to-speech synthesis software that works with on screen text and web pages, by dispatching a volunteer to the home of a sight-restricted person, (2) IT training for people with visual disabilities under commissions from local governments, and (3) monthly open consultations for people with visual disabilities.

Toward the future, it is hoped that even more educational opportunities will be offered to all citizens, including older persons and people with disabilities, to allow them to make the most of information and communications technologies.

2.7 Conclusion

In the domain of accessibility, Japan is behind the U.S., where accessibility as a requirement in government procurement has invigorated R&D even in the private sector and is leading to the emergence of new technologies such as AIAP. Japan and Europe stand almost at the same level, in a state an expert described as "proceeding, if at a snail's pace."

Thanks to the JIS and other standardization initiatives, the foundation on which highly accessible equipment and services can be spread is being secured. Wider availability of these products is expected to increase the user population, whose feedback will further improve the accessibility of the original equipment and services, resulting in a perpetual cycle.

One of the most effective first steps toward penetration is to adopt the coming JIS standard on accessibility as a consideration in procurement by the government, a high-volume purchaser of technology. This will give birth to a market through which accessibility-conscious devices and services can gradually spread into private markets.

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3

Study of Influence on Global Warming by Aerosols
— Present Investigation and Remaining Issues —

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3.1 Introduction

The concept where human activities increase the amount of greenhouse gases in the atmosphere, thereby having a long-term impact on the global climate is becoming well known across the world. Greenhouse gases consist primarily of carbon dioxide (CO_2), along with methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbon (HFC), perfluorocarbon (PFC) and sulfur hexafluoride (SF_6).[1] As climate modeling incorporating the effects of these greenhouse gases becomes more elaborated, variations in the simulation results derived from a number of forecasting models for temperature increases are becoming less distinct – i.e., the impact of greenhouse gases on global warming is being proved scientifically. Based on the accumulation of such efforts in quantifying global warming effects, the Intergovernmental Panel on Climate Change (IPCC) has prepared evaluation reports, forecasting increases in CO_2 concentrations and mean temperatures over the next century; it has released its first, second and third reports [1]-[3] so far.

In response to the efforts of IPCC in accumulating scientific findings on the global warming phenomenon, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (COP) began discussing numerical targets and other related issues in 1995 for reducing greenhouse gases. In the COP7, which was held in 2001, political agreement was finally reached on the “rule book” for the implementation of the Kyoto Protocol; each country has been gearing up for the upcoming enforcement of the protocol. If enforced, Japan will be obliged to reduce greenhouse gas emissions by 6% from the 1990 level during the first commitment period, namely from 2008 to 2012. [4], [5] In response to this, the Japanese government set the “Guideline for Measures to Prevent Global Warming” [4] in 2002, presenting specific measures against global warming that are being promoted nationwide.

However, greenhouse gases are not the only causes of global warming. Fine particles in the atmosphere have a significant impact on global temperatures. For instance, volcanic ash in the atmosphere reflects sunlight, thereby decreasing temperatures. Fine particles (measuring 0.001~10 micrometer in diameter) emitted into the atmosphere by the combustion of fossil fuels and the eruption of volcanoes are generally called “aerosols.” The effects of aerosols in promoting or suppressing global warming, [6], [7], [8] as well as the effects of clouds in decreasing the range between maximum temperatures and minimum temperatures [9] — a phenomenon that is difficult to certify — have yet to be proved scientifically. A variety of studies are thus going on to collect scientific findings in these areas.

This report addresses the three study fields designed to secure the scientific credibility of the impact assessment of aerosols – i.e., observations and monitoring of substances causing global warming; analysis of climate-model-based mechanisms; and forecasts based on global simulation models. Chapter 3-2 classifies the study of global warming and interrelates the three study fields with one another. Chapter 3-3 reports on the present status of observations/monitoring of phenomena centered on aerosols. Chapter 3-4 discusses the ideal collaboration between the study of observations /monitoring and that of mechanisms. Chapter 3-5 suggests approaches to promote the study of forecasts. And Chapter 3-6 summarizes challenges to be addressed in the study of global warming in relation to aerosols.

3.2 Classification of the study of global warming and the interrelation between each study field

In the international framework for global warming, scientific findings serving as the basis of IPCC's scientific assessments are summarized by START (Global Change System for Analysis, Research and Training), which is being promoted jointly by the following three international research projects: WCRP (World Climate Research Programme, which analyzes the global climate system); IGBP (International Geosphere-Biosphere Programme, which accumulates scientific findings in biological and chemical processes regarding global climate changes); and IHDP (International Human Dimensions Programme on Global Environmental Change, which addresses the human dimensions of global environmental changes.

The accumulation of scientific assessments by IPCC is correlated with political decisions to be made within the international framework set by UNFCCC. The results of those assessments are closely related to policy trends regarding: (1) observations and monitoring of substances causing global warming; (2) analysis of climate-model-based mechanisms; (3) forecasts based on global simulations; (4) assessments of the impact on the natural and the living environments; and (5) development of measures against global warming. Specifically, scientific approaches constitute the major part of (1), (2) and (3), covering most of the studies regarding the impact assessment of aerosols.

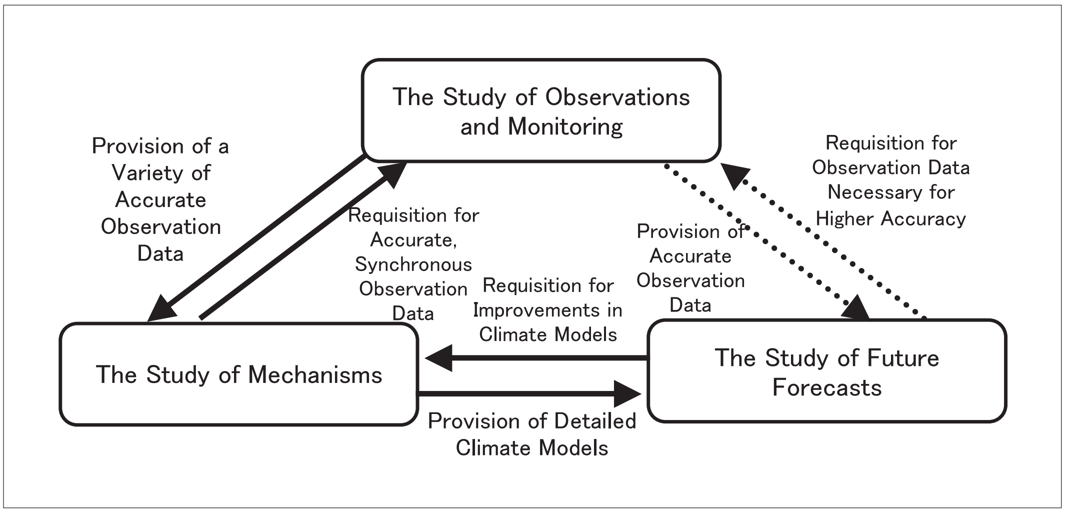
The scientific studies of aerosols can be categorized into (1), (2) and (3) mentioned above, with each category correlated with one another as shown in Figure. 1. In general, climate-model researchers may be able to improve the accuracy of climate models by applying a set of high-precision data (obtained through multiple observation/monitoring methods) to the models. In other words, this relationship between provision and requisition is necessary to improve the scientific studies.

It should be noted that there is no data set observed globally at one time. Moreover, the credibility of simulation models to be used for forecasts has yet to be established. The present situation is such that models are verified by confirming the reproducibility of climate changes that took place in the past.

3.3 The present status of the study of observations and monitoring

There are many observation and monitoring methods involved in global warming problem, according to principles/models to be adopted, as well as the target, location, time and frequency of observations. Aerosols are made up of sulfate, soot,

Figure 1: Correlation between the three study fields comprised primarily of scientific approaches



and mineral dust such as Asian dust (called Kosa in Japan, and which means "yellow sand") and volcanic ash. Several methods for observing/monitoring these substances have been established for the scientific studies.

3.3.1 Significance of aerosol observations

Coupled with greenhouse gases, substances such as ozone and aerosols also contribute to the global warming. "Radiative Forcing*1" is a physical value that indicates the effects of various substances on global warming and cooling; a positive radiative forcing means a warming effect, while a negative one indicates a cooling effect. The radiative forcing of various substances causing global warming has been evaluated based on the scientific findings accumulated by IPCC. [2], [3], [6], [7] Figure. 2 shows the estimates of radiative forcing released through the IPCC Third Assessment Report. IPCC evaluates the scientific credibility of each estimate subjectively. In evaluating the scientific credibility, meanwhile, assumptions required for evaluating radiative forcing, the level of understanding regarding physical and chemical mechanisms determining radiative forcing, and uncertainties (the margin of error) associated with the quantitative estimate of radiative forcing are taken into account. While the credibility with respect to greenhouse gases and ozone is relatively high (with low uncertainties), that of aerosols remains at low levels. In particular, uncertainties associated with tropospheric aerosols are extremely high – scientific findings in aerosols have yet to be established.

The complexity of the mechanism of aerosol generation as well as the difficulty in figuring out their amount on a global scale makes it difficult to evaluate the amount of aerosol radiative forcing. As far as the movement of aerosols in the atmosphere is concerned, understanding their large-scale distribution is also difficult because of the effects of rainfall on them. Due in large part to the complexity of their chemical and physical characteristics, moreover, how much the atmosphere containing aerosols reflects or absorbs the sunlight can hardly be estimated – a fact that makes the estimate of large-scale distribution through observations all the more difficult. For these reasons, most of the existing climate models incorporate simplified versions of

Figure 2: Evaluation results of the radiative forcing of various substances

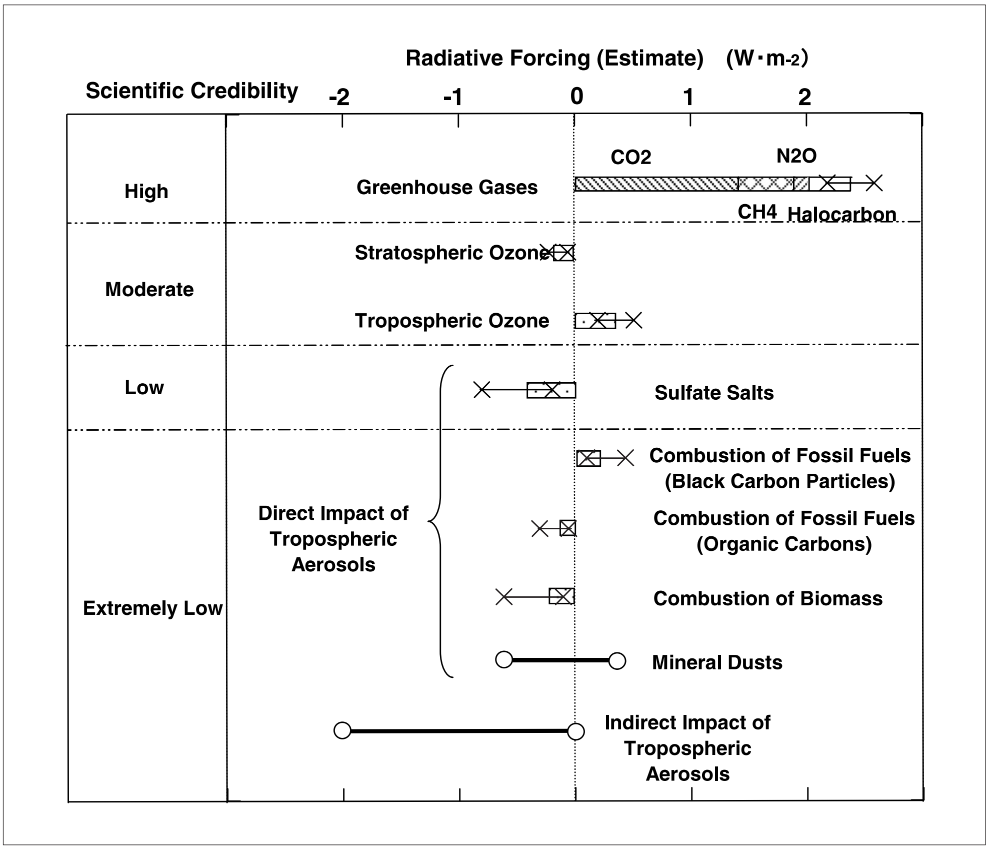


Table 1: Classification of aerosol observation technology

Observation Equipment	Observation Method	Physical Value to be Estimated	Installation (Satellite)
Radiometer (Imager and Spectrometer)	(1) Analyze radiation from the cloud, earth and ocean (2) Analyze the sunlight reflected from the cloud and earth	(1) Diameter and type of particles (2) Horizontal distribution of particle density (3) Physical value (4) Characteristics and distribution of the cloud	(1) Satellite - Advanced high-performance microwave radiometer / AMSR-E (Aqua) - Advanced high-resolution radiometer / AVHRR radiometer (NOAA series)
Scatterometer	Analyze the reflection of light and microwave emitted	(1) Wind velocity on the water (speed of aerosol transportation) (2) Wind direction (direction of aerosol transportation)	(1) Satellite Conical scan scattering meter / SeaWinds (QuickSCAT)
Cloud Radar	Analyze the reflection of microwave emitted	(1) Conditions of cloud particles in the troposphere	(1) Earth (2) Aircrafts
LIDAR	Analyze the scattering light of laser emitted	Vertical and horizontal distribution of the following in the troposphere and stratosphere: (1) Particle density (2) Particle diameter (3) Substances	(1) Earth (2) Aircrafts (3) Vessels (4) Space Shuttle (experimental)

the chemical and physical characteristics regarding aerosols. The mechanism of climate change attributable to aerosols has yet to be fully resolved. It is thus indispensable that scientific knowledges on aerosols be accumulated.

3.3.2 The present status of aerosol observation technology

The primary purpose of observing aerosols is to identify their chemical and physical characteristics; observations are conducted from the ground, at sea and in the air, using several types of equipment. High-precision data are becoming available thanks to increased observation stations on the ground and to satellites equipped with high-performance observation equipment (observation area at a time is expanding).

Hand in hand with advances in information technology, moreover, research and observation institutes across the world are improving the quality and accessibility of their observation data. For researches, therefore, observation data at a given time are becoming more and more accessible.

(1) Observation technology for physical characteristics

Observation technology for the physical characteristics of aerosols can be classified in terms of mode (active or passive), wavelength range, and subject and method of observations. Table 1 shows the classification of observation technology, based on common aerosol-observation equipment.

In creating models in the study of mechanisms, it is indispensable that the physical characteristics of aerosols (e.g., the three-dimensional distribution of the density and diameter of particles) be observed. "LIDAR" (Light Detection and Ranging) [10] is an observation system that can meet this particular requirement. LIDAR is made up of a short-pulse laser oscillator and a detector sensing the scattering light from aerosols. The principle: short-pulse laser beam that is emitted up into the air scatters in all directions in accordance with the physical characteristics of target aerosols, which can be diagnosed by the light scattered back to the laser side; various physical characteristics can be diagnosed by selecting the wavelength of the laser beam. In addition, an intense laser beam accommodates observations of aerosols in the stratosphere. Because of these advantages, expectations are large for LIDAR. As the achievements of avid studies conducted so far, (1) a compact low-power LIDAR for observing urban aerosols, Asian dust and aerosols in the troposphere and stratosphere, and (2) a scanning LIDAR for observing the movement of clouds (where the three-dimensional images of observation targets are obtained by sweeping a laser beam) have been developed and established for use in observations from the ground, at sea (vessels) and in the air (aircrafts). Moreover, other studies are underway to develop a LIDAR system that can measure the distribution of temperatures and wind speeds by means of changes in the wavelength of scattered light, though they are still in the stage of demonstrating their principle.

Although full-scale observations using satellites equipped with LIDAR have yet to be conducted, there has been the LITE experiment, in which the vertical distribution of aerosols was observed through LIDAR aboard the Space Shuttle. On the other hand, institutes in and outside Japan are pushing ahead with observations from the ground and aircrafts. The Japan Meteorological Agency, for instance, set up an atmospheric environment observatory in Iwate prefecture (Ryori, Ofunato-shi); the station is using LIDAR to observe the vertical distribution of Asian dust (few hundred meters to 10km or 5km to 35km above the ground) and its temporal variations on a regular basis, while exchanging observation data with other countries including China.[11] Using a relatively compact LIDAR system, the Atmospheric Environment Division of the National Institute for Environmental Studies conducted round-the-clock observations of Asian dust in the atmosphere up to 3km above the ground, and succeeded in obtaining temporally accurate data on its vertical distribution.[12] The division is also accumulating data on the horizontal distribution by setting observation points at other locations such as Tsukuba, Nagasaki, Amami Oshima and Beijing. A number of universities including Chiba University are likewise conducting observations using LIDAR. LIDAR can be considered an established technology.

(2) Observation technology for chemical characteristics

Observations to obtain data on the chemical characteristics of aerosols are conducted primarily through aircrafts. Specifically, the types of aerosols are identified and their chemical characteristics are determined by analyzing the air introduced into an aircraft or by analyzing substances filtered out. The technology for identifying the types and chemical makeup of aerosols, the structures of which are relatively simple, has been established, and a large amount of data has been collected so far through observations using analyzers aboard aircrafts and vessels. In addition, a broad database of chemical reactions associated with those aerosols is available, which is utilized for creating models necessary for forecasting changes in the atmospheric constituents. However, quite a few factors have yet to be elucidated – e.g., the rate constant of chemical reactions of aerosols, and the chemical characteristics of compounds made up of aerosols and other chemical substances such as sulfides (for example, soil particle with SO_4, soot with H_2SO_4, etc.). Equipment for analyzing these compounds is still in the development stage.

3.4 Collaboration between the study of observations/monitoring and the study of mechanisms

The first step in the study of aerosol mechanisms is to create models that can simulate climate changes at a given period of time based on observation data collected through satellites and observatories on the ground. Aerosol radiative forcing can be evaluated by using models simulating climate changes that took place in the past.[13] In this particular case, it is very important to unify the times (or periods) and targets of observations to ensure the time consistency of data. In conducting aerosol observations on a global basis, therefore, relevant research institutes across the world need to collaborate and cooperate with one another in unifying observation methods, exchanging/sharing observation data and analyzing observation results.

Based on several frameworks, research activities are ongoing at a number of institutes conducting aerosol observations, each of which is engaged in forecasts. [14] As an organization responsible for meteorological observations, the Japan Meteorological Agency is creating relevant databases including those of aerosols in line with the GAW (Global Atmosphere Watch) Programme initiated by WMO (the World Meteorological Organization) in 1989. [11] The atmospheric environment observatory in Ryori, which was mentioned in Section 3-3-2, is registered with

WMO as a local observatory conducting aerosol observations. In addition, the Japan Meteorological Agency established a group responsible for observations, monitoring and modeling within its organization, with the Meteorological Research Institute taking the initiative. The agency is addressing the study of forecasts in an integrated manner.

Aside from the framework of the GAW Programme, researchers at research institutes (the National Institute for Environment Studies, etc.) and universities in Japan are developing observation equipment, collecting observation data and creating models with a view to more accurate study of aerosols. For instance, the National Institute for Environment Studies has organized a group dedicated to these particular efforts. From the standpoint of public facilities, meanwhile, the Center for Climate System Research, the University of Tokyo is pushing ahead with a series of studies centered on modeling, while obtaining part of the required data through its own observations.

3.5 Measures to promote the study of forecasts

The IPCC Fourth Assessment Report is expected to place particular emphasis on the studies for some part of atmospheric constituents – a subject that was not addressed in the Third Assessment Report. Specifically, the studies in short-lived substances (aerosols, tropospheric ozone, etc.) will be emphasized and evaluated rather than those in long-lived greenhouse gases, the scientific studies of which are considered sufficient in amount. Of these short-lived substances, suppressing anthropogenic aerosols is considered one of the important measures against global warming. Aerosols are short-lived because they readily combine with water vapor in the atmosphere, thereby falling to the ground with rain, and are chemically unstable, properties of which change through a variety of chemical reactions. In estimating the effects of aerosols on global warming, there is a need to address changes in their chemical properties during their lifetime, using a function of particle densities and locations, the calculations of which could be enormous. In conducting the study of forecasts in consideration of the effects of aerosols, therefore, it is indispensable that calculations based on an enormous amount of data be carried out in a short period.

While simulations using supercomputers have been the mainstream of the study of forecasts, a global simulator has been developed as a new science tool.[15] With the use of this global simulator, the study of forecasting the effects of atmospheric constituents (aerosols, the tropospheric ozone attributable to exhaust gases, etc.) on climate changes is expected to make a great leap forward.

As far as the study of aerosols based on the global simulator is concerned, the development of a “chemical meteorological chart” (where unknown chemical properties mentioned in Section 3-3-2 are evaluated in detail and temporal changes in the distribution of aerosols are mapped out) as well as the forecast of global changes in climate and carbon circulation due to temporal changes in the distribution of aerosols are expected to emerge as important subjects. In forecasting global warming using the global simulator, a mesh (10km square or smaller) that serves as a point of calculations can be set, the range of which is capable of incorporating the behavior of clouds. In other words, the generation of clouds attributable to aerosols as well as their extinction can be incorporated into the global warming forecast.This development is expected to shed light on the effects of clouds on global warming, which have been considered too complicated a process that exceeds the capacity of supercomputers.

With the conventional supercomputers replaced by the global simulator, the performance of calculations has improved dramatically: the size of a grid, which was one hundred to several hundred kilometers square, has been downsized to 10km square or smaller. This enables models to incorporate the lifecycle of clouds, namely the process of their generation, development and extinction. The major challenge, however, is to prepare a data set of the default value of each smaller size grid. Although observation/monitoring equipment such as LIDAR is now available, the amount of global observation data on aerosols is far from being sufficient. When using given observation/monitoring data as default values, moreover, the data set must have time consistency. Under the present situation, preparing such data set is extremely difficult even if the observation area is limited to East Asia centered on China. To improve the study of forecasts, therefore, it is indispensable that the time consistency of data be ensured. Specifically, there is a need to establish a partnership between organizations engaged in observations/monitoring and those preparing data set for forecasts out of observation/monitoring results. In other words, a partnership in the three study fields shown in Figure. 1 should be established between relevant organizations in and outside Japan, and a mechanism where models are elaborated and observation/monitoring data are improved should be in use.

3.6 Challenges in promoting the study of aerosols

Since aerosols have yet to be fully addressed in the study of global warming, there is a need to push ahead with observation/monitoring efforts and elucidate their mechanisms, the achievements of which will be used for promoting the study of highly credible forecasts. However, there is no specific framework for addressing these efforts – scores of challenges remain untapped.

First of all, the present study of mechanisms is too primitive to create models that can accommodate quantitative assessments – the amount of observation data is insufficient for creating any substantial models. Despite the efforts of a number of research institutes, observation data showing the detailed distribution of aerosols in the atmosphere above Japan have yet to be collected. Under the present situation where observations and monitoring through satellites are not feasible, year-round observations extending over a wide area should be conducted through aircrafts. Since there are not many observatories that can observe the distribution of aerosols near the earth's surface, there is also a need to establish an on-the-ground observation network that would improve the accuracy of models. As far as the Asian region is concerned, moreover, Japan should take the initiative in improving the regional data - the amount of data on the vertical distribution of aerosols remains insufficient in many areas including China.

Secondly, researchers well versed in several study fields are hard to find in Japan, and so are modeling researchers who have sufficient physical and chemical knowledge. While universities are the major source of researchers engaged in the study of global warming, study of the climate system (including aerosol observations) is underway at only a handful of research centers and laboratories in Kyoto University, Chiba University, University of Tokyo, Tokyo University of Mercantile Marine, etc. Naturally, there is a limit to the number of researchers who can be trained by these institutes. Discussions about measures against global warming to be adopted after the expiration of the first commitment period under the Kyoto Protocol are expected to start in the near future - there is not much time left, but only a limited number of researches are likely to become full-fledged in such a short period of time. If Japan is to contribute to accumulating scientific findings in the future, those limited number of junior researchers should be trained so that they can take an active part in the study of both observations/monitoring and modeling, or for that matter, participate in the study of forecasts. What is needed above all is the framework for an inter-organizational relationship where researchers can play an active role in various study fields.

Lastly, it should be pointed out that Japan-originated quality findings are not well communicated to other countries as far as the studies of observations/monitoring and mechanisms are concerned. Since most of the research papers concerned are written in Japanese, only a few of them have been referred to in the IPCC Third Assessment Report and other overseas documents. Underlying this regrettable situation is the absence of a system where relevant institutes and research groups in Japan can communicate their findings in various study fields to other countries in a comprehensive and effective manner. Top-notch researches in Japan should thus take part in a number of international projects including IPCC in the future; they must take the leadership in those projects, while acting as a go-between to build a partnership between domestic research groups and promote the transmission of information.

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Glossary

* 1 Radiative Forcing

An index for measuring the force of one given factor to change the energy balance of the atmosphere, or an amount that indicates the probability of changing climate.

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4

Trends in Ecomaterials
— Approach of Materials Science to Global Environmental Problems —

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4.1 Introduction

The year of 2002 is the 10th anniversary of the Environmental Summit, formally the United Nations Conference on Environment and Development that was held in Rio de Janeiro in June 1992. This year is also the 30th anniversary of the United Nations Conference on the Human Environment, commonly called the Stockholm Conference, at which various environmental issues such as global environmental problems and sustainable development and growth are raised. After such initial calling of attention, environmental problems have been widely recognized, preceding attempts have been made, the framework has been discussed, and now we are at the stage where concrete measures for solutions will be taken. In this very year of 2002, the "World Summit for Sustainable Development" (Environmental Development Summit) was held in Johannesburg from August 26 to September 4. It was also resolved in a conference of the United Nations to request all the countries of the world to depart from mass consumption, mass production and mass disposal, and to change the industrial structures.

Under such circumstances, it goes without saying that we must recognize the responsibility and roles in terms of the global environment regarding the materials technology that has sustained the life and industry of human beings since old times, and that we must actively propose how the materials technology should be developed as a basic technology for the future society. "Ecomaterial" is a concept that was proposed by Japan for the first time in 1991 in advance of the Rio de Janeiro Summit.[1] Since the volume of material flow on the earth is enormous, the impact of ecomaterials on the environment is expected to be significant. Therefore, it is no exaggeration to say that success in obtaining ecomaterials largely affects the fate of global environmental issues. Taking such circumstances into consideration, we would like to review the technical trends in ecomaterials (approach of materials science to global environmental issues) and present an outlook for the future.

4.2 Ecomaterials cover a wide area

4.2.1 Definition of ecomaterial

"Ecomaterial" was a concept created in 1991 as a conclusion of the discussion in the Rare Metals Forum of The Society of Non-Traditional Technology on what the next-generation structure materials should be. The term was defined as "substances and materials that serve the sustainability of human society in harmony with the global environment." Figure 1 shows the performances of ecomaterials in terms of the three axes.[2] The axis of Innovation Frontier

Figure 1: Carbon nanotube transistor

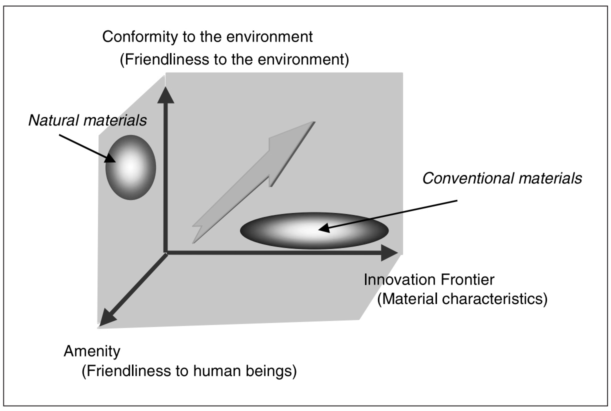
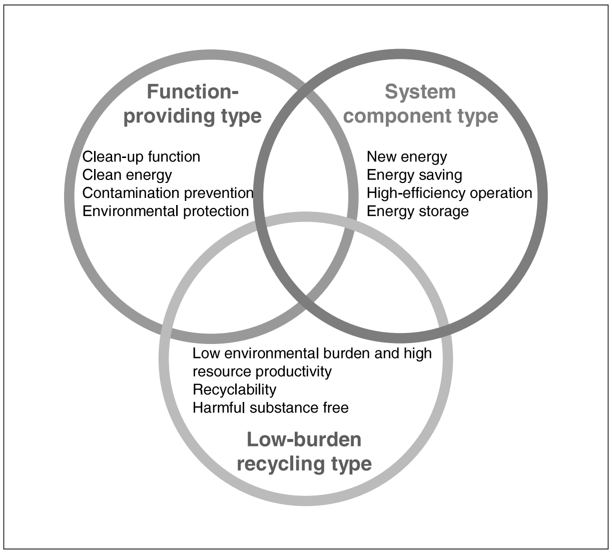


Figure 2: Classification of ecomaterials



indicates conventional material performances. Conformity to the environment represents how small the burden is to the environment, indicating the friendliness of materials to the environment from the viewpoint of sustainable development. Finally, the Amenity axis represents the index showing the friendliness to human beings (biocompatibility, non-allergic, and feeling of warmth are good examples). While conventional materials have pursued only performances, ecomaterials seek for the optimization in this new coordinate system. At present, those materials that have higher values of environmental efficiency represented by equation (1) in comparison with similar conventional materials are considered to be ecomaterials.[3]

Environmental efficiency (EE) = material performance (P) / environmental burden (BL)··················(1)

Therefore, in all the material groups including superconducting materials, semiconductors and magnetic materials, there are groups of ecomaterials and those with low environmental efficiency.

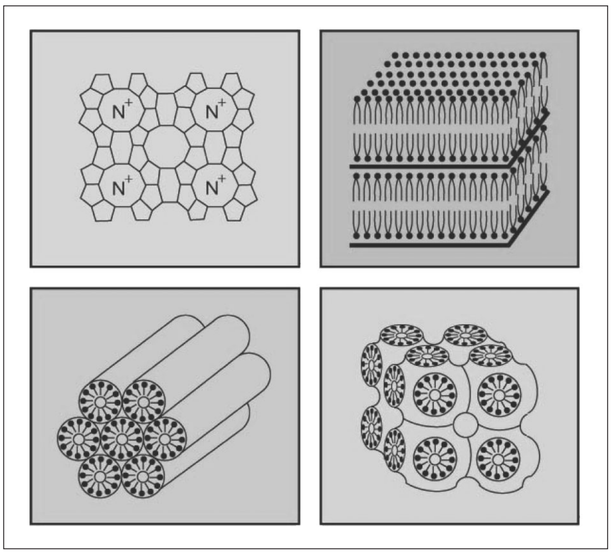
4.2.2 Classification of ecomaterials

From the viewpoint of behavior toward the global environment, ecomaterials are classified into three major groups as shown in Figure 2.[4] The first group is the function-providing type in which mainly the chemical functions of materials such as cleaning function and catalytic function are directly utilized. The second group is the system component type, which is required for the realization of highly efficient, clean energy systems. And the third group is the low-burden recycling type, in which materials themselves are not actively used in environmental systems but contribute to the conservation of the environment through their friendly characteristics such as recyclability. This classification is not overly strict, and the more practical the materials become, the more it is required for the materials to have combined characteristics. That is, materials corresponding to the overlapped portion in Figure 2 are required. Furthermore, although “free of harmful substance” is a characteristic of the low-burden recycling type, it goes without saying that all the materials must aim for this characteristic. The following is a brief introduction of typical materials and research topics for each group.

4.2.3 Functioning directly to the environment — Function-providing type —

A typical example of the function-providing type is catalyst. The success of the three way catalyst for the auto exhaust developed in the 1970s had a large impact by making it possible to simultaneously reduce hydrocarbons, carbon monoxide, and nitrogen oxides. One catalyst attracting particular attention at present is the photocatalyst. There are two directions of approach to the catalysts of this type, which are

Figure 3: Structure of zeolite



Source: Web site of Ecomaterials Center [10] activated by the energy of sunlight to decompose water. One direction is to make it possible to respond to visible rays so that water is efficiently decomposed producing hydrogen, and the other direction is to utilize the reaction in the range of ultraviolet rays so that cleaning functions are obtained.

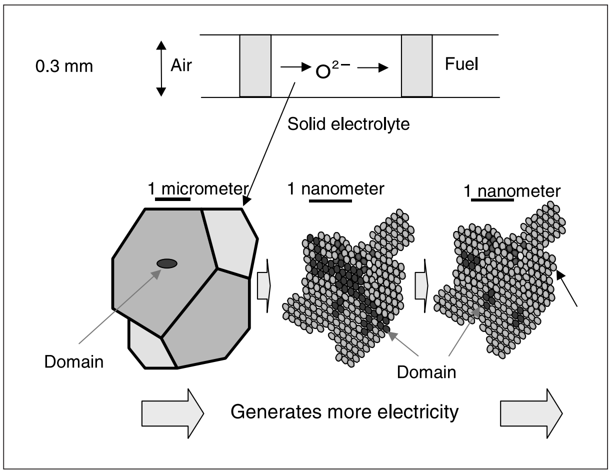
Regarding cleaning functions, the function that removes harmful substances such as environmental hormones and heavy metals is important. Many of the harmful substances now causing serious problems remain toxic even in diluted concentrations or are very difficult to decompose. To cope with such situation, technologies to decompose and separate harmful substances using large equipment in special fields (such as supercritical regions and strong magnetic fields) are being developed. On the other hand, research on systems of soft reactant substances that utilize the reaction at the solid-liquid interface such as absorption and desorption in materials having fine pores is being conducted simultaneously. Zeolite derived from natural resources is a typical example of such materials (Figure 3). Zeolite systems are expected to play an important role especially in the case where in situ clean-up function is required in the future living space.

The environmental materials of the function-providing type that make use of the chemical characteristics of materials further include a wide range of materials such as those for fixing carbon dioxide and catalysts to decompose dioxin and organic chlorine compounds. Regarding the above-mentioned three way catalyst, deterioration of catalyst activity has become a problem because the oxygen concentration in the exhaust increases in lean burning engines. Consequently, the development of catalysts that function under such lean burning conditions are demanded. In order to cope with these various environmental problems, innovation in materials technology is being sought for.

4.2.4 Core components of energy systems — System component type —

Heat resisting materials for high efficiency power generation are typical examples of the system component type. Since the efficiency of heat engines increases as the temperature

Figure 4: Solid electrolyte having nanostructure



difference of heat sources increases, in order to efficiently convert heat to electricity with less generation of carbon dioxide, it is necessary to obtain conditions that enable operations at high temperatures. Under such conditions, as it is required to rotate turbine blades at high temperatures and speeds, it becomes the key point for raising the temperature of the combustion gas of natural gas and other fuels to develop heat resisting materials for the turbine blades. Therefore, for the construction of environmentally friendly energy systems, materials technologies that support the systems construction are required, and those materials that provide such mechanical, thermal, chemical, or electrical characteristics are grouped as the ecomaterials of the system component type.

Also in the development of fuel cells that are attracting particular attention now, materials for separators and solid electrolytes are considered to be the key to constructing fuel cells systems. For example, solid electrolytes consist of micro fine regions called "domains," and the penetrating power of ions increases significantly improving the electrical performances as these domains are uniformly distributed (see Figure 4). Such control of nanostructures is essential for improving the materials of the system component type, so that losses in the processes of energy generation and conversion are eliminated.

Hydrogen, which is also used for fuel cells, is considered to be the key material for the 21st century as the secondary energy, and it requires various materials for purification, transportation, storage and energy conversion. For example,

Figure 5: Diagram showing the principle of the metallic hydrogen saparation membrane

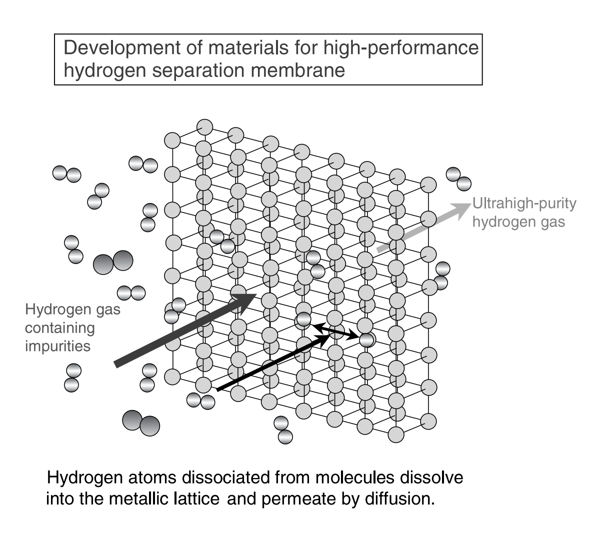


Figure 5 shows a metallic separation membrane used for purifying hydrogen by permeation. This membrane dissociates hydrogen to the atomic state on its surface, and only the dissociated hydrogen atoms can permeate through the membrane. As a result of the elimination of impurities and catalyst poisons, it becomes possible to operate hydrogen energy systems effectively. At present, the main material used for the metallic separation membranes is palladium of the platinum group, but it is now being attempted to obtain satisfactory results utilizing the vanadium recovered from petroleum combustion ash.

Other ecomaterials of the system component type include superconducting materials that are expected to significantly contribute to the efficient transport of energy, thermoelectric materials that enable recovery of energy from low-quality waste heat, and, in addition, heat resistant, abrasion resistant, and corrosion resistant materials required for power generation from waste.

4.2.5 Materials that support our daily life — Low-burden recycling type —

While the above-mentioned two types of ecomaterials actively serve environmental systems based on the characteristics and functions of the materials involved, materials of the low-burden recycling type are those used for everything that supports our daily life including buildings and household electric appliances. These are the materials that conform to material selection based on environmental consciousness.

The expression, "low environmental burden," means that products or materials bring about a low environmental burden in their total life cycle beginning with the resources recovery through the disposal after use and ending with waste treatment. And the method of assessing the environmental burden is called LCA (Environmental Life Cycle Assessment).

4.3 How are materials evaluated by LCA?

The environmental burden for a life cycle, BL, consists of the environmental burden of manufacturing, BP, the environmental burden of use, BU, the environmental burden of disposal of waste at the end of life, BE, and the deduction of burden due to recycling, BR.[5] Therefore, BL is given by the following equation:

$$\mathbf{BL = BP + BU + BE - BR} \quad \cdots\cdots (2)$$

If the performance of the material at the stage of use is P, by combining equation (2) with the aforementioned equation (1), the following equation (3) that expresses the environmental efficiency (EE) is obtained as follows:

$$\mathbf{EE = P/(BP + BU + BE - BR)} \quad \cdots\cdots (3)$$

Equation (3) enables the characterization of materials according to the term to which a particular material contributes.

Whereas ecomaterials were classified into three groups according to the way of action toward the environment in the preceding chapter, here in this chapter they are characterized by the type of environmental burden.

(1) Materials free of harmful substances (= materials with low BE)
(2) Materials with high material efficiency (= materials with high P or low BU)
(3) Materials with a history of low environmental burden (= materials with low BP)
(4) Recyclable materials (materials with high BR)

In the following section, the present status of materials development and the main points for each type are described.

4.3.1 Materials free of harmful substances

There are a group of materials widely spread in our daily life due to their special functions such as bondability, performance as film, and electric properties. These materials often contain components that turn out to be harmful when disposed. This occurs as a result of the attempt to keep the production cost at a low level. Now it is demanded to develop safe materials that provide the desired functions such as lead-free solder and dry cells containing no mercury. It is also hoped to develop materials that do not cause pollution by generating dioxin or environmental hormone. When attempting to replace harmful materials or structures intended for particular functions, it is necessary not only to avoid materials containing directly harmful materials but also to avoid materials that may generate harmful components at the stage of disposal. In addition to solder, although lead is widely used in plating, additives for lubrication, additives in metals for improving machinability, etc., now lead-free materials that provide such functions are being developed.

The use of cadmium and mercury is now almost limited to within controllable areas, and, although highly functional chromium plating is still being used, chromium-free plating technology is being developed.

Light emitting devices using gallium arsenide, widely used for cellular phones and CD-ROM drives, are another typical example of harmful material widely spread in the environment. When a harmful material cannot be replaced with other materials, it is necessary to thoroughly control the products. In the case of gallium arsenide, however, this is difficult to carry out, and, as such, the direction that should be taken in the development of materials is to aim at achieving high performance without using harmful substances.

4.3.2 Materials with high material efficiency

Examples of materials with high material efficiency are those related to the transmission, conversion and transportation of energy, that is, those used for the transmissions and light bodies of automobiles. In the case of these materials, the environmental burden caused by the energy flow during use is much larger than that in the production stage. Although it is important for these materials to have low environmental burden, it is still more important to achieve the intended role. Therefore, materials that provide effective accomplishment of intended services must be developed. Especially for raw materials, the environmental burden during use is often neglected, but results of LCA indicate that the environmental burden of materials used for automobiles during use is ten times or more compared to that of material production. Therefore, it is essential to select such materials that promote effective transmission or generation of energy by providing high-temperature, high-efficiency action based on weight saving and enhanced heat resistance, or by reducing energy loss in transmission operation caused by abrasion.

Many attempts have already been made to develop such materials from the viewpoint of energy saving, and the attempts must be positively enhanced from the viewpoint of reducing the environmental burden.

4.3.3 Materials with a history of low environmental burden

Materials with a history of low environmental burden are defined as those materials having a low environmental burden from the mining of resources to the production stage. Materials based on wood are ecomaterials in the sense that wood is regeneratable, whereas resources such as ores and fossil fuels are exhaustible. Plant-origin plastics synthesized from biomass without using petroleum also belong to this group. Materials made from the byproducts generated in the activities of human beings are another example of materials with a history of low environmental burden, and such materials contribute to reducing the burden for waste treatment. Eco-cement produced from industrial wastes, which are artificial resources such as incineration ash and polluted sludge, is a typical example. Another successful example is steel TULC cans. Steel sheets for TULC cans are polymer-coated so that lubricants are eliminated in the production process, thus reducing the generation of waste fluid to zero and drastically lowering the environmental burden of such production process. It is more than just process saving and energy saving to lower the environmental burden in the production process. New process technologies that reduce the environmental burden by utilizing low-grade resources and regenerated resources are now required.

4.3.4 Recyclable materials

Attempts for materials recycling are being made intensively with the establishment of the Basic Law for a Recycling-oriented Economic Society in 2000 as a turning point.

Recycling tends to be considered as an issue relating to the social system, process technology for recycling, and product designing. But materials themselves must not be neglected as the fourth aspect of the issue. As materials are usually composites with delicate differences in composition and complex treatments such as surface finishing, which cause degradation in the recycling process.

In his book,[6] Professor Kunihiko Takeda of Shibaura Institute of Technology describes the problems caused by contamination and degradation during recycling and the methods for assessment of recycling costs, and points out that at present the environmental burden increases as the number of recycling increases. Although this is a fair-enough point, we must construct a recycling-oriented society in the future because we live in a closed society on the earth in terms of materials, and, therefore, we must start to move forward to achieve this goal.

At present, as shown in Table 1, the ratios of recycling of most metals, which are exhaustible resources, are low, and we must take positive actions to improve the recyclability from the viewpoint of material technology. The following are approaches that should be taken.

(a) Material designing that does not include substances that disturb recycling processes.
(b) Material systems insensitive to inevitable artificial contaminants.
(c) Imparting functions that provide identification and decomposition to help recycling processes.

In order to achieve target (a), a design technology called "recyclable material design" is being developed, in which the high performance of a material is obtained by controlling the structure of materials of simple compositions without adding elements. A successful example of such materials is thin steel for automobile application. These steel sheets feature lightweight and strength as well as recyclability, because the amount of addition elements was reduced by increasing the strength of materials through heat treatment. Such a concept is now a major premise in the steel industry. In addition, in the super steel project [7] that aims at "double strength and double life," recyclabiliby is one of the major aspects of development.

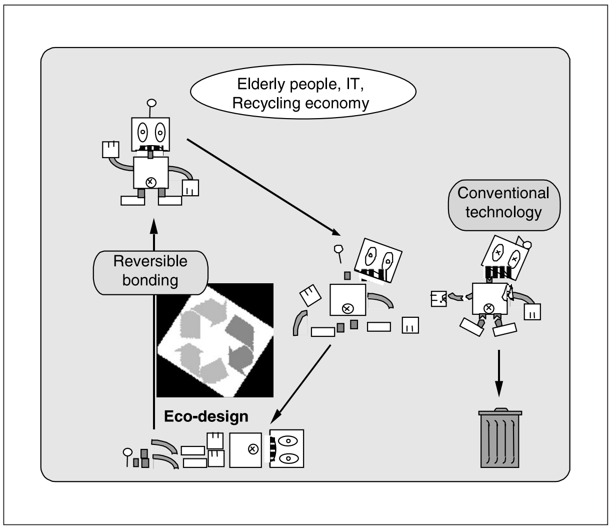
Examples of contamination relating to (b) are

Table 1: Recycling ratios of major non-ferrous metals in Japan

	Amount of consumption (tons)	Amount of discharge (tons)	Recycling ratio (%)
Copper	3,500 thousand	598 thousand	66
Aluminum	2,300 thousand	1,662 thousand	54
Zinc	1,000 thousand	364 thousand	20
Lead	300 thousand	277 thousand	66
Cadmium	2,000	1,080	28

Source: "Recycling-oriented economic system to be achieved for non-ferrous metals " 1999, the Ministry of International Trade and Industry.

Figure 6: Conceptual diagram for easily detachable bonding technology



Source: Web site of the Nanometer-scale Manufacturing Science Laboratory, Research Center for Advances Science and Technology, The University of Tokyo.[9]

copper and other materials in iron scraps derived from electric cables and metals such as tin coming from surface plating. There is also an attempt to positively utilize impurities and new research is being made to improve strength and ductility of steel by controlling fine structures through the use of impurity copper.[8]

Target (c) is a new approach of improving bonding technology that enables the recovery of usable components and the reuse of discarded parts. As an example, Figure 6 shows a conceptual diagram of easily detachable bonding technology. For detaching, a method utilizing the cubical expansion caused by hydrogen absorption has been proposed.[9]

Relating to recycling, one thing we must pay attention to is that recycling heretofore has mostly involved in-house scraps and process scraps whose origins are clear. Recycling of used materials that include scraps of various shapes, impurity ingredients, and composites is a challenging technical subject, and research is just going to be started.

4.4 National policy and organization

In "The Basic Plan for Science and Technology" endorsed by the Cabinet in 2001, four priority fields of science and technology — "life science," "information and communication," "environment," and "nanotechnolgy and materials" — are listed, so that investment and research and development are conducted strategically. Furthermore, in the "Policy for Allocation of Resources Including Budget and Human Resources Relating to Science and Technology in Fiscal 2003" prepared by the Council for Science and Technology Policy this June, "materials required for the enhancement of environmental protection and efficient use of energy" are clearly designated as related to the above-mentioned "nanotechnology and materials." "Ecomaterial" is an important concept that covers both the environment and materials, and combines them.

Japanese institutes and associations have established various study groups and special interest groups as shown in Table 2. The Society of Chemical Engineers, Japan, The Chemical Society of Japan, and other institutes and associations related to chemistry are also carrying out strenuous activities from the viewpoint of process with the "environment" as the keyword. And almost all of their bulletins feature special articles every month relating to the environment and material processing.

Many international conferences are also being held. Since "ecomaterial" is a concept created in Japan, as described at the beginning, Japan is playing a center role in the international conferences. Table 3 shows major examples of international conferences. In these conferences, stress is being laid on "what we should do to construct an integrated social system for environmental protection, whereas all the separate measures for environmental protection such as various tools including LCA, zero emission, promotion of recycling, and restriction of harmful substances have been implemented." [4]

The Ecomaterials Center was established in April of this year in the Independent Administrative Institution, National Institute for Materials Science as a parent organization for the promotion of research on ecomaterials. The center consists of four groups — Eco-Circulation Processing, Eco-Device, Eco-Energy Materials, and Eco-Function Materials — with a total of 65 members including 23 permanent researchers. Research organizations named with the term "ecomaterial" do exist hitherto at the level of laboratory or research

Table 2: Study groups and special interest groups of Japanese institutes and associations related to ecomaterials

Society of Non-traditional Technology	Ecomaterials Forum (established in 1993)
The Society of Polymer Science, Japan	Ecomaterial Study Group (established in 1992)
The Japan Institute of Metals	Ecomaterial Study Group (established in 2000)

Table 3: Major international conferences related to ecomaterials

International Conference on Ecomaterials	Held every other year since 1993, the fifth conference held last year
International Conference on EcoBalance	Held every other year since 1994, the fifth conference held this year
International Conference on Ecodesign	Held every other year since 1999, the second conference held last year

department — the Ecomaterial Group of the National Institute of Advanced Industrial Science and Technology for example. However, the Ecomaterials Center covers all the fields relating to ecomaterials as shown in Figure 2 — Eco-Circulation Processing corresponds to the low-burden recycling type, Eco-Energy Materials correspond to the system component type, and Eco-Function Materials correspond to the function-providing type — and further include the Eco-Device Group that aims to establish the technology for preparing devices harmonious with the environment. Thus, the target of the Ecomaterials Center is to become an integrated parent organization for the development of ecomaterials.[10]

4.5 Accomplishments of ecomaterials research

Since the concept of "ecomaterial" was presented to the world from Japan for the first time in 1991, research projects relating to ecomaterials have been continuously carried out mainly supported by promotion expenditure. Due to the results of these projects and increasing concern about global environmental issues, the term "ecomaterial" is now being used even in the advertisements of private companies' products as well as within manufacturing premises. Also, some departments of universities use this term for their names and the term is steadily penetrating into society. The activities in the past have a great significance in that researchers and engineers now consider, when designing practical materials, conformity with the environment in addition to the improvement in performances and functions that have been the main concerns.

One of the most important achievements of research on ecomaterials is the proposal of MLCA (Materials LCA). In the past, only LCA for products (PLCA = Products LCA) was made. In the PLCA, consideration for the environment relating to materials was at most something like "the environmental burden of a part should be reduced because the present value is high." Environmental burden of materials, that is the index of ecomaterials, is now being established with the progress of MLCA. MLCA not only provides a valuable database for PLCA but also enables grasping the flow and circulation of materials macroscopically as well as microscopically.

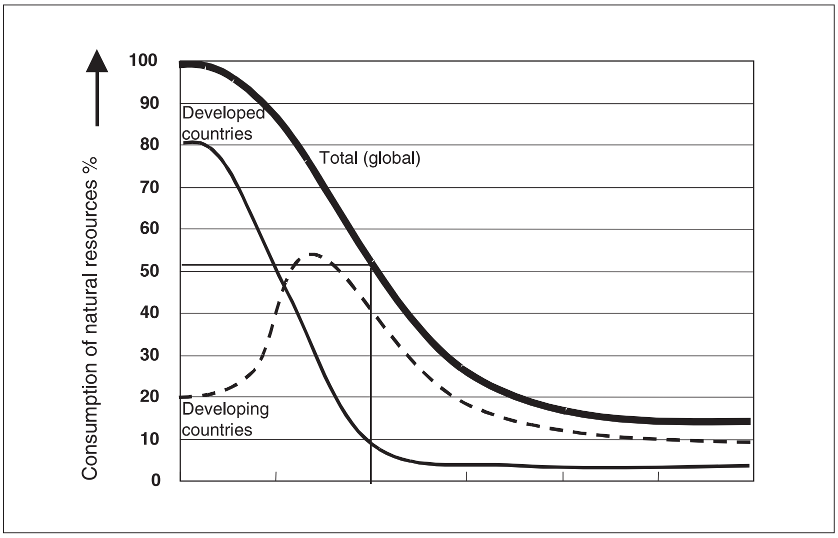
Another important achievement is the proposal of recyclable materials design. The concept of resources circulation in which properties of materials with simple composition should be improved by controlling fine structures and not by addition elements was created in the discussion of ecomaterials at the initial stage. This concept is the core idea of the "Super Steel Project" and also the guiding principle for many research projects for materials.

Since research on ecomaterials is still in the early stage, no ecomaterials in practical use have been developed. However, some structural materials including super steel have reached a stage that requires just one more effort. Furthermore, wood ceramics based on natural raw materials have been developed triggered by the project.

4.6 Keywords for the future: improvement of resource productivity

Taking into consideration that the basis of the environmental problem is the enormous consumption of materials and disposition of materials, the fundamental idea for developing ecomaterials lies in the "improvement of resource productivity." "Resource productivity" is an expression used in terms of global environmental issues, and analogous to economic terms such as capital productivity and labor productivity. Resource productivity is defined as the efficiency of performance of products and systems relative to the total input of various resources and energy. Weizacker of Germany described the importance of resource productivity in an easy-to-understand manner as "to double the affluence while reducing the material consumption to half," and propounded "Factor 4" that aims to reduce the consumption of materials per unit service to a quarter. Furthermore, Schmidt-Bleek of Wuppertal Laboratory propounded "Factor 10," claiming that developed countries must reduce materials consumption to one-tenth of the present amount.[11] They argue as follows (see Figure 7). At

Figure 7: Reason for Factor 10

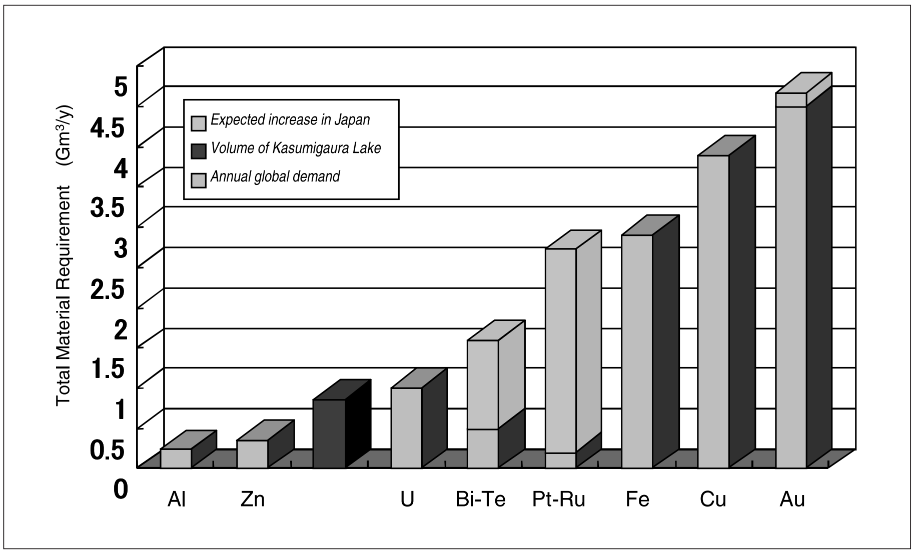


present, developed countries whose population is 20% of the world's total of six billion consume 80% of the total resources. Assuming that the resource consumption by developing countries increases by a factor of a little less than three from now forward, in order for human beings to maintain production activities for 100 or 200 years, it is necessary to reduce the consumption of natural resources to 50% of the present consumption in 50 years, keeping pace with the curve expressed by the heavy line in the figure. To realize this, developed countries must reduce their present consumption of resources to one-tenth (curve expressed by the thin line).

TMR (Total Material Requirement) is a parameter that indicates how much total resource is taken from the global environment. Figure 8 shows a graph of TMR for the annual consumption of metals in the world. The third column from the left side shows the total amount of water in Kasumigaura Lake for reference. It is seen that soil amounting to five times the volume corresponding to that of Kasumigaura Lake is dug out, generating the same amount of waste soil as an environmental burden. Likewise iron generates waste three times the volume of Kasumigaura Lake. In order to reduce this TMR, it is necessary to develop recyclable materials that reduce the burden on the earth as well as to develop materials that provide high performance using less amount of resources with low TMR — that is materials of high resource productivity.

In addition, future requirements for materials in Japan are added in Figure 8 (light-colored portions of the columns). In the case of catalyst materials used for fuel cells, which are now drawing public

Figure 8: Total material requirement for annual demands of metals in the world



attention, although the amount actually used is very small, large amounts of resources are used for their production. If all the automobiles in the future use fuel cells and the technologies to produce materials are not changed, the filled portions of TMR for Pt-Ru and Au will be increased so that the total is almost comparable to the TMR caused by iron in the world. In the case of the thermoelectric materials (Bi-Te), which is expected to be used for waste heat recovery, resource consumption equal to 1.5 times the volume of Kasumigaura Lake will be induced when 5% of the total power generation in Japan is produced using this system. This is the situation in Japan where the utilization of materials is saturated, and efforts are being made to reduce the consumption of resources by transiting to a recycling society. From now on, people of many Asian and African countries will aspire toward more affluent life bringing about enormous needs for automobiles, semiconductors, energy and so forth. Then, it will be impossible to cover all of these requirements with the present resource productivity for both structural and functional materials. It is therefore necessary to innovatively increase resource productivity, so that the expected drastic increase in materials and energy demands in developing countries can be satisfied.

4.7 Conclusion

In the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992, which corresponds to the 20th anniversary of the United Nations Conference on the Human Environment held in Stockholm, an action plan for relieving the global environment, "Agenda 21," was formulated. However, the report, "Implementation of Agenda 21," published at the end of last year points out that we are far behind the agreed target set in Rio and the situations in some fields are worse than 10 years ago.

In response to the above-mentioned report, the action plan adopted by the Environmental Development Summit clearly states, in addition to a recommendation for the eradication of poverty, the following targets: "utilization of technologies for clean and efficient energy," "prevention of the generation of industrial wastes, promotion of recycling and use of substitute materials that are environmentally friendly," restriction of harmful chemical substances and review of manufacturing methods" and "prevention of the depletion of natural resources." These items exactly represent the viewpoints of ecomaterials, which aim to conform to the environment and achieve a sustainable society.

Considering the fact that it takes a long time to establish material technologies and put them to use, actions must be enhanced at the national level. Fortunately, Japan is now leading the world in the field of ecomaterials. Deployment of ecomaterials to developing countries is an urgent task for the sake of solving global environmental problems, but it will also bring about a large economic effect to Japan.

Since the research on ecomaterials covers wide and interdisciplinary areas, it is necessary to build a network of many researchers and engineers. Therefore, research works must be carried out with the collaboration of all Japanese researchers related to this subject with hub organizations as the cores.

It is possible to obtain the environmental efficiency of individual ecomaterials based on MLCA, which indicates the grade of ecomaterials. However, it is another question whether the sum total of the efficiency values indicates the environmental efficiency of the total system, enabling optimization of the over all environmental efficiency. In order to correctly assess the over all environmental efficiency, although it is important to carry out research works with close collaboration among technical fields, it is still more important to continuously consider the relationship between materials and society.

While it is an important issue for researchers engaged in materials development and people related to policy making for science and technology to coordinate the relationship between materials development and society, it seems very difficult to find a solution. However, the relationship between the environment and society appears to be very close and realistic to us. In Chapter 4-4, it was described that "ecomaterial" is an important concept that combines the environment and materials, but it may be further amplified as a concept that combines society and materials. The perspective of ecomaterials is the key to clarifying the interface between society and materials through the viewpoint of the environment.

Acknowledgement

We would like to express our appreciation for the contributions of Komei Harada, chief of the Ecomaterial Center of The National Institute for Materials Science, for providing us with his valuable advice and data.

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5

Trends in the Research on Single Electron Electronics
— Is it possible to break through the limits of semiconductor integrated circuits? —

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5.1 Introduction

Semiconductor devices based on silicon and computers using these devices have drastically grown in accordance with Moore's Law. It is said, however, that these devices are approaching their limits due to device operation problems caused by miniaturization and heat evolution derived from the high degree of integration.

The Japan Science and Technology Corporation is now promoting basic research projects aiming at the creation of innovative technical seeds by establishing 13 research areas under the six strategic objectives that have been newly proposed by the government (Ministry of Education, Culture, Sports, Science and Technology) in fiscal 2002 as the "Strategy Creation Program." The total budget for these projects amounts to ¥4.4 billion. One of the six strategic objectives is the "creation of nano-devices, materials, and systems for breaking through the limits of integration and functions in information processing and communication technologies," and focused and intensive activities have been started.

Also, "Measures to promote the research and development of nano-technology and nano-materials" established by the Science and Technology Council in June 2002 points out the necessity to construct diversified device systems based on new principles that enable next generation information processing and communication. The proposal emphasizes the importance of research on devices systems, and integration technology based on a new principle that utilizes single electrons for operation instead of transistors that have been used for conventional integrated circuits.

If construction of integrated circuits using device systems that operate with single electrons are realized, power consumption will be reduced to a ten-thousandth to a hundred-thousandth of that required for conventional integrated circuits. It is also expected that the operating limits will be expanded, and that the malfunction problem of integrated circuits caused by the evolution of heat will be solved.

The device system that operates with single electrons functions based on a new operating principle called "coulomb blockade," which is inherent in single electrons. There are three major approaches for integration as follows:

(1) To break through the limits of integration by replacing the transistors that have been used for conventional integrated circuits with single electron transistors, following in the present system of the circuit architecture (aiming at realizing practical application within 10 years).
(2) To break through the limits of integration by changing the circuit architecture to a new structure called the "Binary Decision Diagrams," which is suited for operation using single electrons (aiming at realizing practical application within 10 to 15 years).
(3) To break through the limits of integration by adopting a new information processing method that does not use electrical wiring — a structure called "Quantum Cellular Automata," which utilizes single electrons

(aiming at realizing practical application later than item (2)).

This report summarizes the present situation and future prospect of research and development of such integrated circuits that function using single electrons.

5.2 Coulomb blockade Phenomenon

The operating principle of a device system that utilizes single electrons is based on a phenomenon called coulomb blockade. This phenomenon occurs when the size of materials such as metals and semiconductors is reduced.

When electrodes are connected to very small pieces of metals or semiconductor islands (called coulomb islands) through a gap on the order of nanometers (called a tunnel gap), electrons transfer to the coulomb islands by tunneling. When the islands of metals or semiconductors are large, the electrons can transfer freely; however, the motion of electrons is blocked if the islands are in the nanometer range. Nevertheless, the electrons can move if a certain level of voltage is applied to the electrodes. This phenomenon is called the "Coulomb Blockade phenomenon."

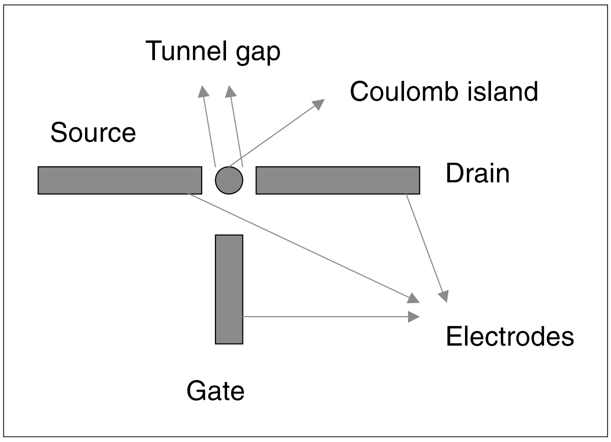
5.3 Integration of the single electron transistor

5.3.1 Single electron transistor

Conventional transistors operate based on currents consisting of one to a hundred thousand electrons. Single electron transistors, however, operate based on "one electron (single electron)" due to the Coulomb Blockade phenomenon. Figure 1 shows the structure of a single electron transistor. This transistor, like conventional transistors, consists of three electrodes — source, drain, and gate, but it differs from conventional transistors in that a fine Coulomb island is placed among the electrodes.

Regarding the single electron transistor, many studies are being undertaken all over the world, and there are diversified materials for the targets of the studies. In order to realize the practical application of the single electron transistor, it is necessary to reduce the size of Coulomb islands to the order of nanometers so that the transistor can operate at room temperature. In the early stage of research, it was difficult to realize fine Coulomb islands and the transistor could operate only at low temperatures. However, the operation of single electron transistors at room temperature has now been confirmed using some kinds of metals and semiconductors.

Figure 1: Single electron transistor



5.3.2 Integration

While the single electron transistor is suited for high-density integration because its structure itself is essentially small, research on integration is still at the beginning stage.

As a future prospect of the single electron transistor, Professor Shunri Oda of Tokyo Institute of Technology commented as follows: "It is difficult to simply replace the devices that compose conventional integrated circuits made of silicon with single electron transistors. In integrated circuits that utilize single electron transistors, it is necessary to connect single electron transistors with miniature wiring, but miniature wiring in the nanometer-scale range is still difficult to fabricate. In addition, because the single electron transistor operates with single electrons, the output can drive only a limited number of single electron transistors in the next stage. In the future, therefore, research on hybrid circuits in which single electron transistors are formed on the silicon integrated circuit chip must be conducted in order to eliminate the necessity of constructing all circuits with only single electron transistors. For this reason, the materials used for single electron transistors must be compatible with the today's silicon process. It is very advantageous if silicon is used as the material for single electron transistors, because conventional integrated circuit production lines for integrated circuits made of silicon can be used with little modification.

Recently, Doctor Uchida et al. of Toshiba succeeded in fabricating hybrid circuits consisting of single electron transistors and conventional transistors on one silicon chip. Similar hybrid circuits have been fabricated by Doctor Igawa et al. of NTT. Furthermore, Doctor Yano's group of Hitachi manufactured trial silicon memories that operate with single electrons utilizing the coulomb blockade phenomenon.

A promising material other than silicon is carbon nanotubes. Doctor Kazuhiko Matsumoto's group of the National Institute of Advanced Industrial Science and Technology recently developed an integration technology for single electron transistors using carbon nanotubes. Carbon nanotubes also enable miniature wiring. This technology is expected to grow as a promising integration technology for single electron transistors.

5.4 Logic circuit based on binary decision diagrams

In conventional integrated circuits made of silicon, transistors are connected in series so that the actions of AND, OR, and NOT are executed as the functional architecture. This requires lengthy wiring and large electric currents.

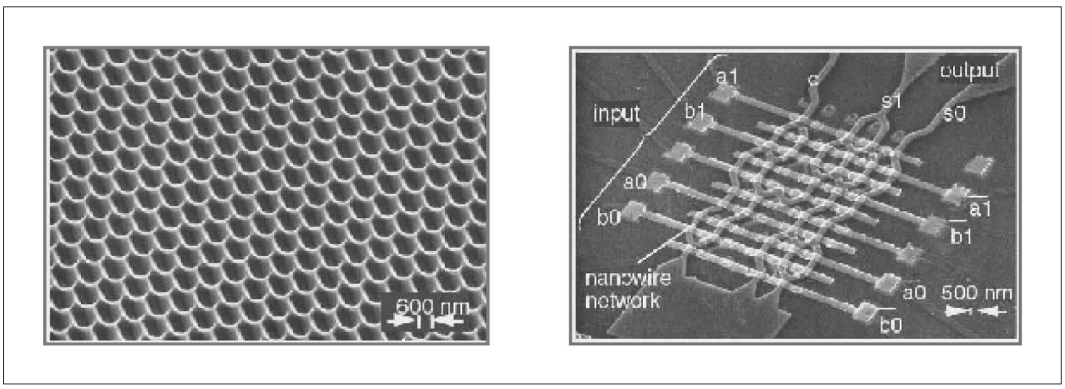
On the other hand, since the above-mentioned single electron transistor operates with single electrons, which correspond to a very small amount of electric current, the device is very sensitive to electric charges and tends to malfunction due to slight electrical changes in the environment. Therefore, it has been pointed out that the single electron transistor may not be suited for integration using conventional methods, as described in Chapter 5-3, so long as the conventional functional architecture is applied.

Therefore, to break through this limit for the integration of circuits, attempts to develop a functional architecture that is suited for operation by single electrons are being made with a different concept from the integration of single electron transistors. The new architecture being studied for integrated circuits that is suitable for operation by single electrons is based on "Binary Decision Diagrams."

It is expected that the logic circuits based on the Binary Decision Diagram will enable easier design of circuits. Since the basic action for constructing the logic circuits is a simple binary branching switch, various physical phenomena that enable switching over the transfer direction of signal media according to the input can be utilized for the construction of circuits. Above all, devices that operate with single electrons meet the requirements of high integration and low power consumption.

Figure 2 shows scanning electron microphotographs (taken by Professor Hideki Hasegawa's group of Hokkaido University) of an indium-gallium-arsenic (InGaAs) hexagonal quantum wire

Figure 2: InGaAs hexagonal quantum wire network formed on a fabricated substrate (left), and an integrated circuit based on binary decision diagrams (2-bit adding machine) using this technology.



Source: Web-site of Hasegawa Laboratory of Hokkaido University.
http://www.rciqe.hokudai.ac.jp/iede/2_naiyou_j.html

network formed on a micro-fabricated substrate in advance, and an integrated circuit based on Binary Decision Diagram (2-bit adder) that utilizes this technology.

In the integrated circuit based on Binary Decision Diagram, fine wires of nano-scale form a network of hexagonal meshes, and straight metallic microelectrodes are arranged in the network. The Y-shaped branches formed at the junctions of the nano-scale wires act as the switches for single electron transistors, and the switching action is controlled by the metallic electrodes. The logic circuit is constructed with these elements.

Professor Hasegawa, proponent of integrated circuit based on binary decision diagrams, commented as follows:

”This integrated circuit based on Binary Decision Diagram does not require a large electric current for operation because the functional architecture does not rely on the serial connection that is used for conventional integrated circuits in which the output of a transistor is used for the input to the next stage. It has also been found that this system requires less number of devices than the logic gate system to attain the same level of function. Furthermore, this system is suited for high-density integration because the problem of lengthy wiring is solved, since the structure is well regulated, the fine wire network serves as the wiring, and there are no source and drain electrodes.”

Professor Hasegawa considers that compound semiconductors are the most suitable materials for these circuits because the technology for fabricating the fine wire network structure is mature. However, not only compound semiconductors but also various materials can be applied to such circuit system, and he thinks that if silicon is used to form a fine wire network comparable to that made of compound semiconductors, it would be more practical because the present manufacturing lines for silicon integrated circuits can be used with little modification.

5.5 Quantum cellular automata

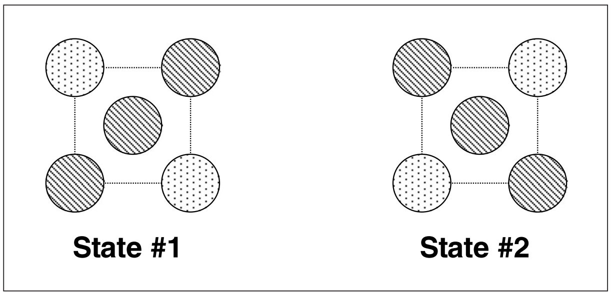
When the frontiers of integrated circuits based on single electron transistors and integration of the logic circuits based on binary decision diagrams are advanced, it is expected that the distance between single electron transistors interconnected with wiring and the size of the quantum wire networks will become less than 10 nm or smaller, making the tunnel effect of electrons prominent. When the tunnel effect becomes prominent, integrated circuits do not operate.

Cellular automata, particularly Quantum Cellular Automata (QCA), which operate by proximity interaction of single electrons without requiring lengthy wiring between devices, are expected to be effective for breaking through such limits.

Figure 3 shows cells consisting of five Coulomb islands (also called quantum dots) and two electrons.

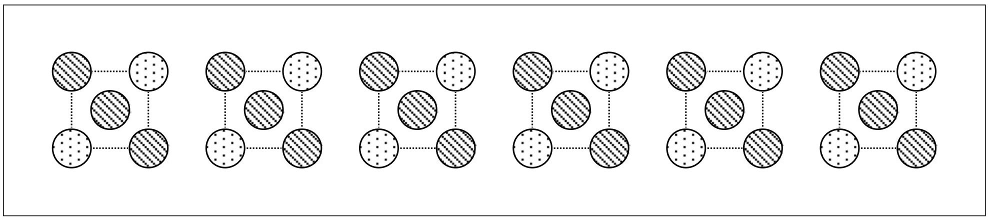
QCA functions with these cells as the operating unit. Since the total energy of a cell becomes lowest when the two electrons exist in the islands on the diagonal line declining to the left (State #1) or on the diagonal line declining to the right (State #2), electrons tend to take either of the two positions. When the direction of the alignment of two electrons in a cell is perpendicular to that of the two electrons in the adjacent cell (i.e., one cell is in State #1 and the other is in State #2), the electrons in the two cells repel each other so that they tend to align in parallel. When a number of cells are laid side by side as shown in Figure 4, electrons in all cells tend to take the same orientation in parallel. If the orientation of the electrons in the leftmost cell is reversed by 90 degrees by some means, the electrons in the

Figure 3: Schematic diagram of cells consisting of five coulomb islands.



Each of the dotted islands has one excessive electron, however the islands shaded with slanted lines do not have such excessive electrons. There are two states for stable distribution of the two electrons: on the diagonal line declining to the left (State #1), and on the diagonal line declining to the right (State #2). Tunneling occurs among the five coulomb islands.

Figure 4: Principle of cellular automata



When the cells are laid side by side, electrons in all cells tend to take parallel positions. Although static electric force acts on the electrons in the adjacent cell, tunneling of electrons does not occur.

adjacent cell tries to take the same orientation as the electrons in the leftmost cell. Thus, electrons in all cells try to take the same orientation, resulting in a domino effect. By combining many cells in this way, it becomes possible to transmit information from the leftmost cell to the cell on the opposite side without using wiring. It is now hoped that various logical operations necessary for computers can be executed by devising appropriate ways for cell arrangement.

The concept of QCA has just been introduced, and only experiments relating to its principle are being conducted. In order to realize QCA that operates at room temperature, it is necessary to develop a technology that enables the laying out of hyperfine structures such as quantum dots with good controllability making use of self-organization, etc. In addition to the so-called quantum dots of semiconductors, it has been recently proposed that a complex of ruthenium-based molecule having mixed valence, which has a much smaller structure than quantum dots, may realize QCA that operates at room temperature, and experiments are being conducted in the United States.

Doctor Tetsushi Tanamoto of LSI Laboratory of the Toshiba Research and Development Center, who conducted research on the simulated operation of QCA, commented about present status and future prospect as follows:

"QCA, devised by Lent et al. of Notre Dame University in the U.S., as an extremely miniature device, requires precise fabrication of quantum dots and accurate control of each electron. Although it is necessary to develop this method first, it will also become necessary in the future to develop various new types of Cellular Automata that are different from the QCA developed by Lent."

Although the future of QCA is still uncertain, if it is realized, the device will operate with a very small amount of energy for controlling only one electron without suffering from the problems caused by wiring, and we will be able to drastically increase the degree of integration compared to conventional integrated circuits.

5.6 Status of research and development relating to single electron electronics in foreign countries

From Figure 5 to Figure 7 summarizes the results of investigation, using the ISI database of the U.S., into the number of papers related to single electrons among the total papers reported globally over the past 21 years (from January 1981 to October 2002). There were 1,934 papers in total that were retrieved using the keywords "Coulomb Blockade," which is the operating principle of the new device system run by single electrons (Figure 5). Out of these, 631 papers were related to the single electron transistor (Figure 6). In order to search for papers oriented to the integration of single electron devices, the combination of keywords, "single electron" and "logic" or "memory" or "integrated" was used and 345 papers were retrieved (Figure 7-c). Furthermore, there were 11 papers relating to logic circuits based on the binary decision diagrams, and 81 papers relating to quantum-dot cellular automata (Figure 7-d).

As can be seen from these figures, the number of Japanese reports relating to "coulomb blockade" and "single electron transistor" is outstanding together with the U.S. and Germany. Particularly, application-oriented research aiming at integration is most actively conducted in Japan.

As not much time has passed since Professor Hasegawa et al. of Hokkaido University proposed

Figure 5: Results of retrieval using with "coulomb blockade" as the keywords.The total number of papers since 1986 was 1,934 (including 464 Japanese papers). No paper was retrieved from any country for 1985 or earlier.

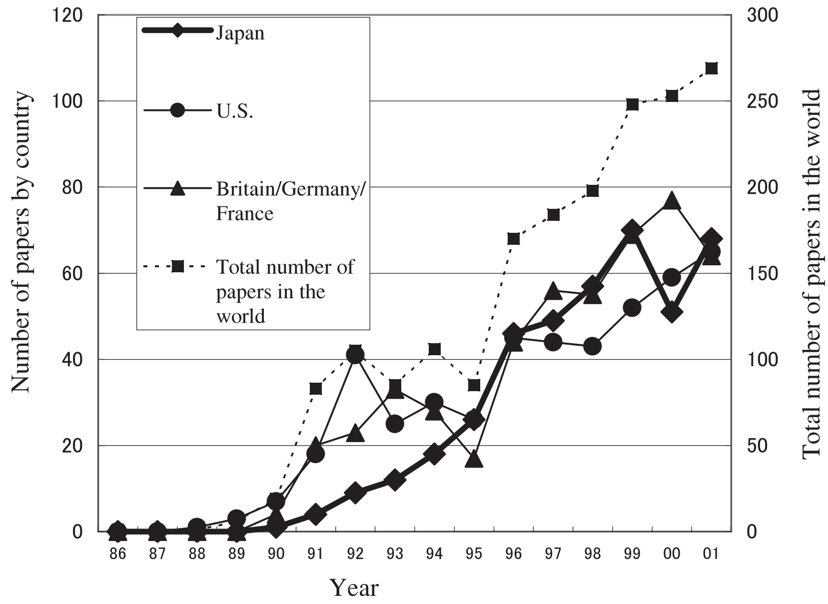
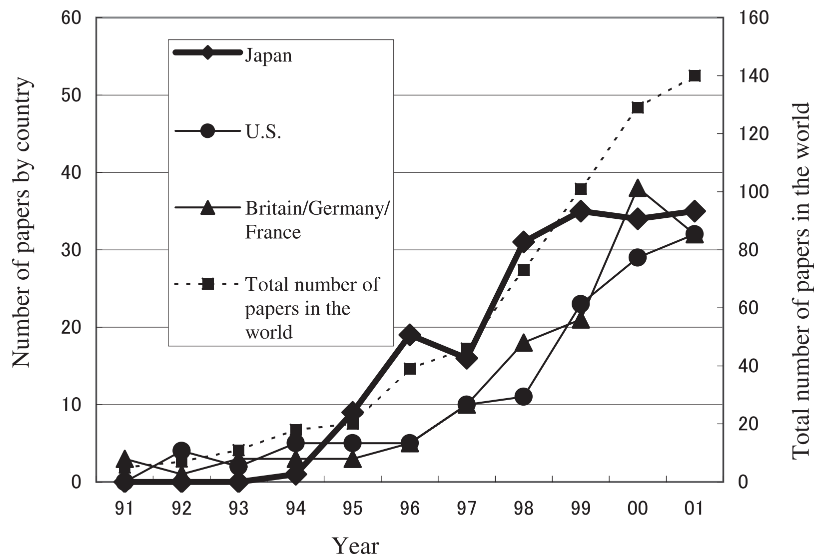


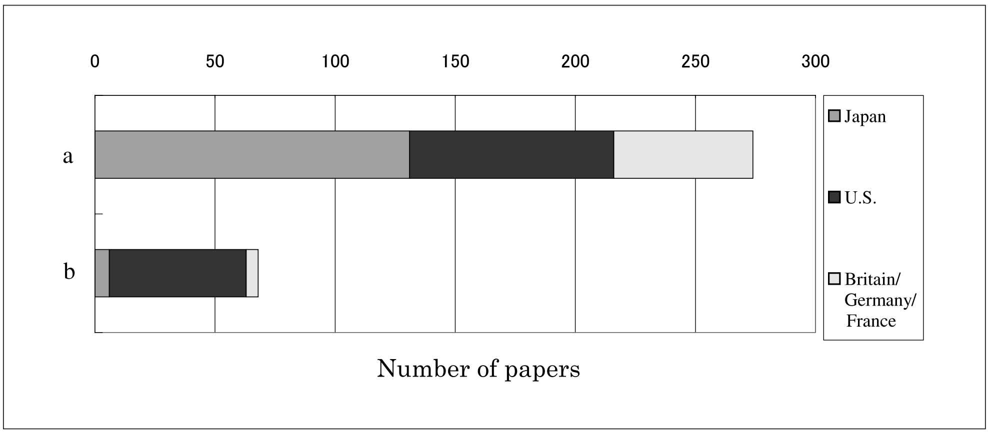
Figure 6: Results of retrieval with "single electron transistor" as the keywords.The total number of papers since 1991 was 631 (including 205 Japanese papers). No paper was retrieved from any country for 1990 or earlier.



the "logic circuit based on the binary decision diagrams," most of the papers on this subject have been reported by the Hokkaido University group. However, as this method is expected to be applied to a wide range of materials including silicon, research activities will expand in the future.

The number of papers published in the U.S. relating to quantum cellular automata (QCA) is predominant. QCA was originally proposed by C. S. Lent et al. of Notre Dame University of the U.S., and research works are being actively carried out in the United States primarily by researchers at the university. No experimental research work has been conducted in Japan relating to QCA,

Figure 7: (a) Result of retrieval with "single electron" and ("logic" or "memory" or "integrated") as the keywords, (b) results of retrieval with "quantum-dot automata" or ("quantum cellular automata" and "dot") or "quantum-dot cells" or ("cellular automaton" and "single electron") as the keywords.



(a) The total number of papers since 1991 was 345 (including 138 Japanese papers). No paper was retrieved from any country for 1990 or earlier. (b) The total number of papers since 1993 was 81 (including 6 Japanese papers).

although some simulated operation works have been carried out.

5.7 Conclusion

Present status and future prospect of research and development oriented to integrated circuits that operate with single electrons among devices supporting next generation information processing and communication are summarized.

Studies oriented to the integration of single electron devices are more actively carried out in Japan compared to any other country in the world. Regarding the logic circuits based on Binary Decision Diagrams, research works are now getting started primarily in Japan. As for Quantum Cellular Automata (QCA), research works are being actively carried out in the United States, whereas no experimental research work related to QCA has been conducted in Japan, although some works on the simulation have been done.

The prospect of QCA is still ambiguous, but since it will drastically increase the degree of integration once it is realized, Japan will be left far behind the U.S. unless we start some kind of research now.

For research on the establishment of device systems based on new principles such as "single electron electronics," it is necessary to provide more enhanced research resources, invested continuously from a long-term point of view, in addition to the "Strategy Creation Program" sponsored by the Japan Science and Technology Corporation.

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6

Research & Development Trend of Drug Delivery System (DDS)

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6.1 Introduction

Nowadays, symptomatic therapy such as surgical operation and drug therapy are given to patients. Medification is regularly done by oral administration, and intramuscular and venous injection. Injection usually causes pain and tissue injury, and it is difficult to give oral administration based on individual differences such as sex, age and disease condition. The administered drug distributes not only to the affected site but also to the normal cells (tissue), and decreases due to hepatic metabolism. Thus, only small part of the administered dosage reaches and acts on the affected site, and the drug distributed to the normal cells may cause adverse reactions. So, one administration or injection of the drug cannot maintain an effective concentration in the blood over many hours, causing a repeated dosage with more than the necessary dosage.

In recent years, as a measure to conduct safer and more effective drug treatment by inhibiting excessive drug use and adverse reactions, researches on a drug delivery system (DDS) that aims to supply the necessary minimum drug to the necessary site at the necessary time, are in the active. The DDS has two types of methods; one is a method to dissolve a drug slowly in the living body, and the other is a method to deliver a drug to the affected target site through the blood flow. To achieve the practical use of these methods, only the modification of drug is not enough. It is in need to develop matrix materials such as polymer materials or ceramic materials as carrier of drug. In the case of drug carried to the capillaries in the affected site through blood flow, the drug particle size including the drug and matrix material must be several nm to 200 nm (1 nm = 1/1 billion m) at maximum[1] because the diameter of the capillary is approximately 5μm and the absorbency of the drug increases with the decrease in the particle size of the drug.

For the treatment of cancer and regenerative medicine, utilization of polymer micelle and liposome as drug carrier shows a significant advancement, leading to a number of clinical studies. For bio-diagnosis/treatment and DDS in the gastrointestinal system, a practical MEMS was developed. At present, research and development of DDS has begun to bear fruit like this. Moreover, the research and development of DDS was taken up in the “Development and Application of Advanced Science Technology” (Nanomedicine Project) in the science technology policy of the Ministry of Health, Labour and Welfare in 2002, that is one example showing that it reached a breakthrough stage.

Therefore, in this report, we will introduce the present status of the research and development of DDS, prospect the future picture of DDS, and discuss the necessities of research and development on it, and arrangement of a research system.

6.2 Efficacy of DDS

From the standpoint of treatment and pharmaceutical development, the following efficacies are expected from the DDS technique[2].

(1) It is possible to take out only a particular action and to suppress the onset of a particular action. (Separation of actions)
(2) The efficacy becomes more exact. Reduction of the dosage and extension of the applicability of drug can be expected. (Increase of efficacy)

(3) A dropped out compound due to adverse reactions can be revived as a drug. (Reduction of adverse reactions, increase of safety)
(4) The burden on medical staff and patients can be reduced. The problem of no time to spare can be resolved. (Improvement of the convenience in use)
(5) Extension of the life cycle of products and reduction of medical expenses become available. (Economy)

In the research and development of DDS, according to the deeper understanding of the bio-mechanism and the advancement of material design technology, DDS is expected to provide more effective and safer treatment also in new therapies such as gene therapy and regenerative medicine, as well as in the use of genome products.

6.3 DDS to date

Various DDSs are considered as shown in Figure 1[3], and several DDSs have reached the stage of practical use. The material to carry the drug is of importance in considering DDS, and particularly in the administration via blood, the material to carry the drug requires the following properties.

(1) A large drug volume with a small particle size (100 nm).
(2) High water solubility.
(3) High stability of the structure.
(4) Ability of biodecomposition and bioabsorption after playing a role.

Polymer and ceramic materials having the above properties were developed, and, to date, the following DDSs have been put into practical use. If DDSs are roughly divided into two categories, one is the slow release of drug at a certain rate in a certain period of time (sustained release of drug), and the other is targeting of drug by selectively transporting the drug to the affected target site (targeting of drug).

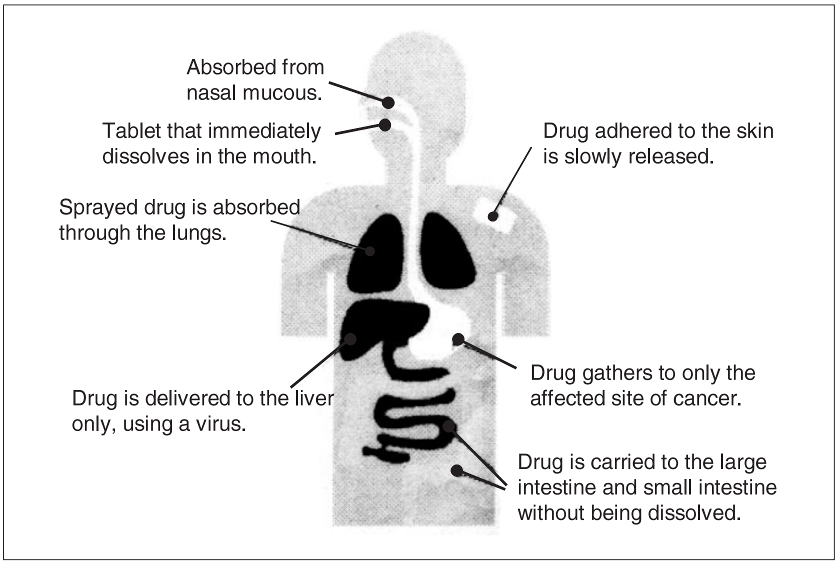
(1) Sustained release of drug

The purpose of the sustained release of drug is to keep a certain concentration of the drug in the blood over a long term. As basic principles of the sustained release of drug, there are a reservoir type and a monolithic type as shown in Figure 2.

The reservoir type uses a method to control the amount of permeated drug by utilizing the permeability of the polymer membrane covering the drug. The monolithic type uses a method to control the diffusion of drug by dispersing the drug into a polymer or ceramic matrix.

When the drug is administered by a normal method, the concentration of drug in the blood shows a serrate-shaped change depending on the time and the number of administration, as shown in Figure 3. Immediately after administration concentration of drug rapidly increases, and

Figure 1: Mechanism of various DDSs



Source: Nikkei Homepage (http://www.nikkei4946.com/today/0105/12.html)

Figure 2: Basic mechanism of the sustained release of drug

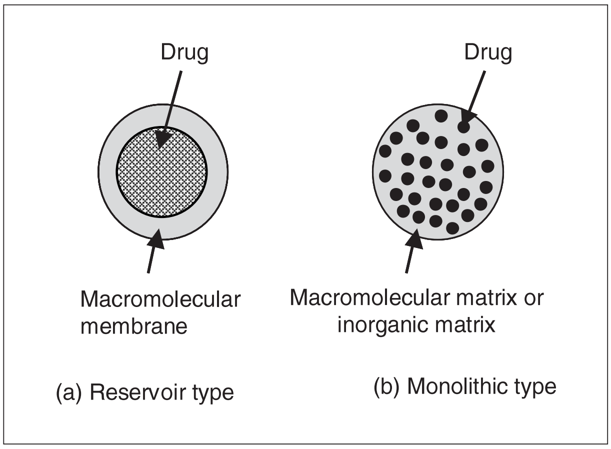
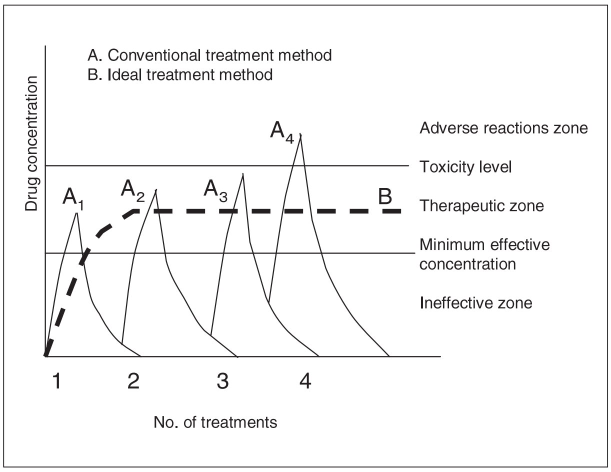


Figure 3: Temporal change of blood drug concentration



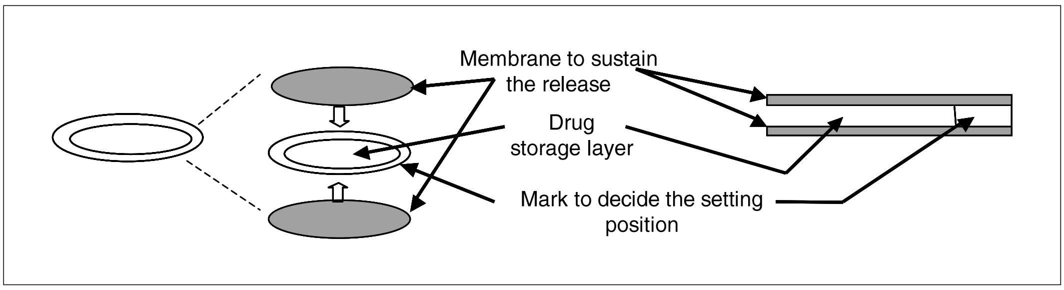
occasionally the concentration may reach a certain level with the risk of adverse drug reaction. Meanwhile, the drug in blood is metabolized in the tissues, and the concentration decreases by excretion, etc. If drug concentration becomes lower than the necessary minimum, therapeutic efficacy cannot be obtained at all[4].

T. Higuchi (Utah University), A. Zaffaroni (Alza Corp.) and others enclosed a drug for glaucoma (Pilocarpine) in ethylene-vinyl acetate copolymer (EVA) to be worn like contact lenses.As a result, an Ocusert system, which sustained the efficacy of the drug for 4-7 days, was put into practical use in 1974, and the product was launched in Japan in 1981.The annual sales of the system is more than 60 billion yen worldwide. In addition, as transdermal therapeutic systems (TTS) using PEVA membrane to control the absorption of drug through the skin just like patches, an antiangina drug Nitroglycerin and antihypertensive drug Clonidine (Catapres-TTS) were put into practical use in 1989. Recently, a TTS (Nicotinell-TTS) to assist smoking cessation was also put into practical use in 1998. This type of DDS has the advantage that it can be easily discontinued when a problem such as adverse reaction occurs. This advantage assisted the rapid progress to a practical use.

In 1992, for prostatic cancer, Takeda Chemical Industries, Ltd. put a drug named Ryuprin into practical use, which allows the retention of blood drug concentration for 4 weeks. It has been used in more than 70 countries across the world, and annual sales reached more than 150 billion yen. In addition, Ryuprin SR Injection Kit 11.25, which allows the retention of blood drug concentration for 12 weeks by changing the material enclosing a drug, was put into practical use in August 2002[5].

Diabetes patients must receive insulin injections several times every day. However, in 1953, Novo Nordisk A/S mixed two types of insulin crystals, i.e., easily soluble and hardly soluble, making it possible to decrease the number of injections to once daily. If insulin is administered excessively or blood glucose concentration decreases too much, it may lead to a life-threatening condition (hypoglycemia) such as cerebral function disorder, so it is necessary to conduct insulin treatment at an appropriate dose according to the glucose concentration. Therefore, research and develop-

Figure 4: Ocusert System (treatment for glaucoma)



ment activities are being conducted on a material and system to release insulin according to the blood glucose concentration, but the system have not been put into practical use as yet [4].

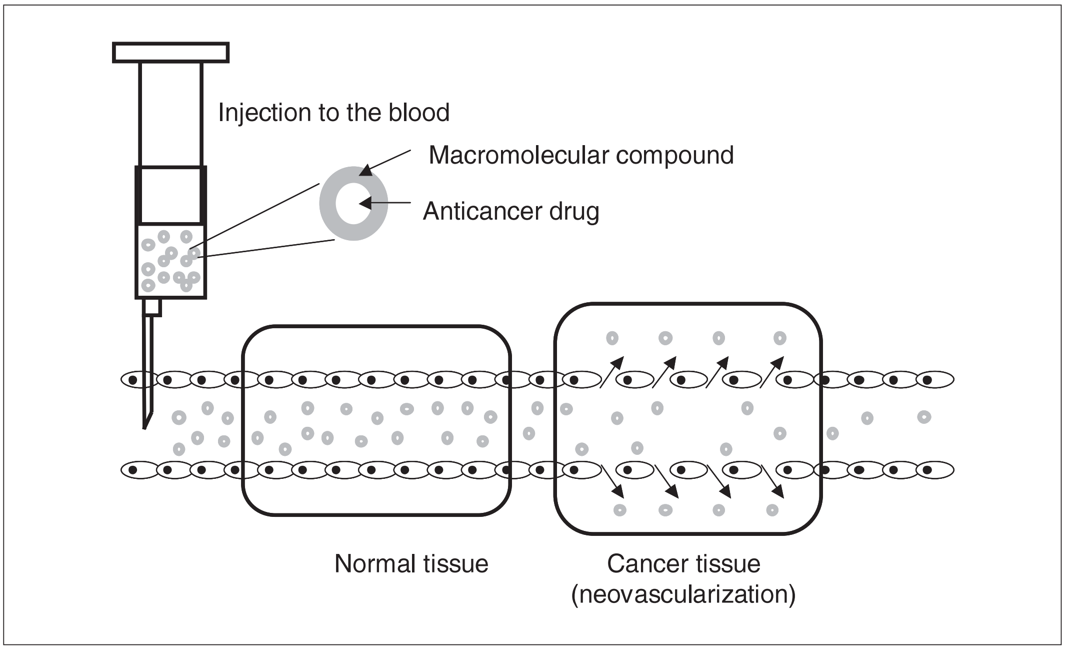
(2) Drug targeting

The targeting of drug is also called missile therapy, and it is a method of carrying a drug effectively to the targeted inflammatory site or cancer cells to demonstrate the drug's action. In 1988, Yutaka Mizushima (DDS Research Institute, Jikei University) developed a lipo product with particles (liposome) enclosing drugs within an artificial phospholipid membrane with multiple layers. This attracted people's attention as the first targeting product in the world. The lipo product utilizes the characteristics in which lipid particles often gather at the vessel having arteriosclerosis or at the inflammatory site. Lipo prostaglandin E1 (PGE1) products (first generation) enclosing PGE1, which is very effective for arteriosclerosis in lipid particles, was put into practical use. From 1992 to more recent years, annual sales in Japan of approximately 35 billion yen has been maintained. In PGE1 products, the drug is enclosed in soybean oil, and the surface is capsuled with lecithin. Except for the above products, steroid hormones and non-steroid analgesic/inflammatory drugs were put into practical use. At present, for the second-generation PGE1 product produced by esterifying PGE1, Mitsubishi Pharma Corporation is conducting phase 2 and phase 3 of the clinical studies in the United States and Japan[6].

On the other hand, research and development activities on drugs targeting cancer cells have been conducted based on a principle of active targeting to accumulate the anticancer drug to cancer, utilizing the antigen-antibody reaction with cancer cells. A certain level of achievement in the laboratory was obtained, but no success in animal tests has been obtained. The reason is because an antigen similar to the target cancer antigen exists in the blood and on the surface of other normal cells, and, therefore, the necessary amount of drug cannot be concentrated onto the target site.

Since Hiroshi Maeda (Dept. of Medical Researches, Kumamoto University Graduate School) et al. advocated the enhanced permeation and retention (EPR) effect in 1986, research on the targeting to solid cancer has significantly changed. As shown in Figure 5, new blood vessels in cancer tissue have a higher permeability than blood vessels in normal tissue, so that more polymer compound with a large molecular size permeates and transfers into cancer tissue. In addition, the recovery mechanism of polymer compounds through lymph vessels is incomplete in cancer tissue, so retention of a polymer compound within the cancer tissue may easily occur [7]. This is called an EPR effect. By this effect, passive targeting to

Figure 5: Selective delivery of anticancer drug to the site of solid cancer (EPR effect)



have cancer cells take in a drug in the blood became possible. As a result, in 1986 and after, the targeting to solid cancer made a new start as passive targeting by inhibiting the metabolism in the liver and kidney and using the sustained release, in contrast to the conventional active targeting by the antigen-antibody reaction.

6.4 Current status of research and development of DDS

As stated above, the research and development of DDS to date may be roughly divided into two; sustained release of drug and targeting to the affected target site, and these are considered individually. However, after the EPR effect was advocated for the targeting of solid cancer, the research and development came to be conducted not only for targeting to cancer cells but also for the system associated with the sustained release function.

6.4.1 Status of research and development of DDS in Japan

(1) Targeting to cancer cells

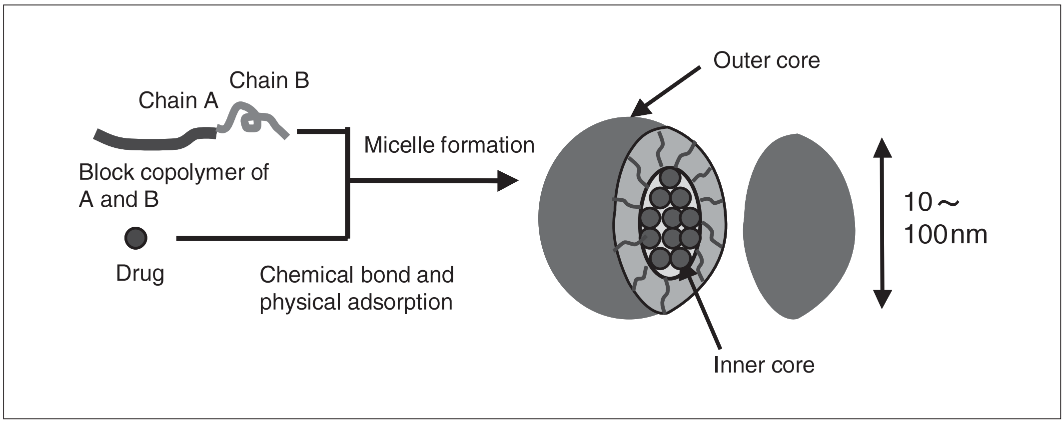
Kazunori Kataoka (Graduate School of Engineering, University of Tokyo, and the Biomaterials Center of National Institute for Materials Science, Japan) et al. obtained a significant increase in anticancer activity in the living body using polymer micelle enclosing an anticancer drug (Adriamycin), and confirmed the accumulation with a high selectivity to cancer tissue. As shown in Figure 6, in their study of a block copolymer using polyethylene glycol in chain A and poly (aspartic acid) in chain B, Adriamycin was chemically bound to the part of chain B to form polymer micelle (aggregate) of several dozen-nm uniform particle size with chain A as the outer core, and Adriamycin was also adsorbed physically to the inner core.

When aqueous solution containing polymer micelle capsuling Adriamycin was administered in mice with transplanted human colon cancer cells, the degree of accumulation of Adriamycin in cancer cells was more than 10 times higher than in single agent treatment with Adriamycin owing to the EPR effect, and a high anticancer effect was confirmed. Currently, phase 1 of the clinical study is in progress, and the micelle is highly expected as a targeting DDS to solid cancer. Moreover, the system of polymer micelle is really a general-purposed system that is easily applicable to cisplatin and other anticancer drug hardly soluble in water. The system is being studied to apply to gene therapy in which gene-encoding protein for treatment is enclosed in the micelle and carried effectively into the target cell.

(2) Application to regenerative medicine

Except for blood cells, most cells adhere to the scaffolding material, i.e. extracellular matrix, for proliferation and differentiation in the living body. When the tissue has a large defect, the scaffold is also lost. In this case, even if only cells are supplemented to the defect site, regeneration of the tissue cannot be expected. In order to regenerate the tissue, a tentative scaffold of cells must be supplied to the defect site, and, at the same time, a cell growth factor to proliferate the cells must be used. However, the cell growth factor is protein, and the life span in the living

Figure 6: Macromolecular micelle containing drug



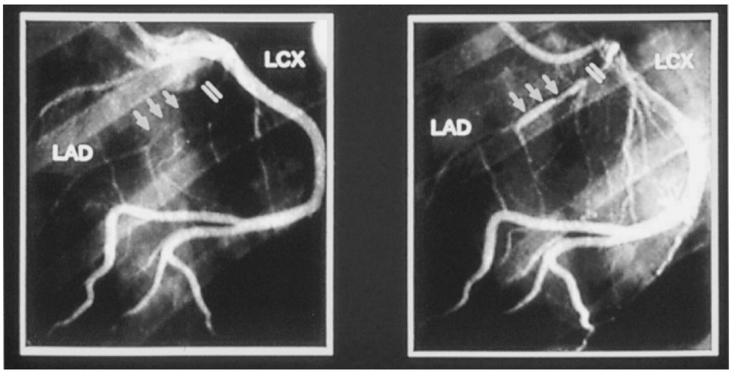
body is short and unstable. To solve these problems, if the cell growth factor or the related gene is capsuled in a bioabsorbent material to sustain the release in the regenerated site, it is considered that regeneration of the tissue will accelerate. Researches of regenerative medicine using DDS are being conducted actively, and here we introduce a part of them.

[1] Sustained release of cell growth factor using bioabsorbent polymer hydrogel

This is a technique to prepare hydrogel by cross-linking gelatin or collagen, or polymer mixtures such as hyaluronic acid and alginic acid, and fix the aqueous solution of cell growth factor within freeze-dried polymer hydrogel. The hydrogel is decomposed over time in the living body, and the decomposition rate can be controlled by the degree of the cross-linking of hydrogel.

Yasuhiko Tabata (Institute for Frontier Medical Sciences, Kyoto University) et al. are conducting a study of sustained release of cell growth factor utilizing the bioabsorbent gelatin hydrogel with less toxicity in the living body. They consider that neovascularization can be induced by sustained release of basic fibroblast growth factor (bFGF), which is one of the angiogenesis factors, from gelatin hydrogel. In order to attempt regeneration of the coronary artery in the heart, at one week after the furcation of the left anterior descending artery was ligated in dogs, bFGF impregnated gelatin hydrogel particles were administered. As

Figure 7: Effect of bFGF impregnated gelatin particles on coronary arteries in the heart

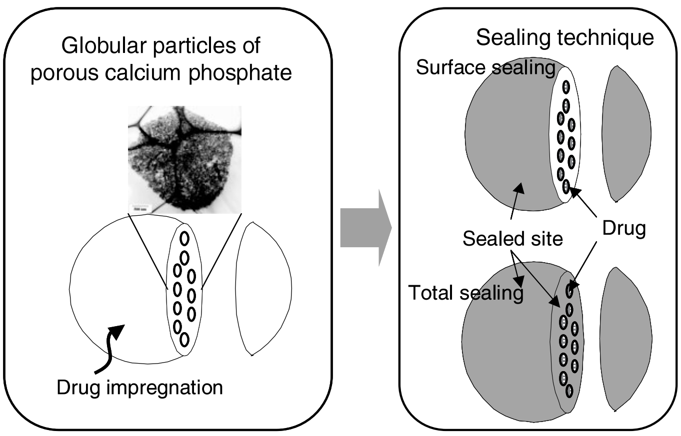


Treatment with bFGF water solution

Treatment with bFGF impregnated gelatin particles

Source: Department of Biomaterials, Department of Molecular Interaction and Tissue Engineering, Institute For Frontier Medical Sciences, Kyoto University; homepage of Tabata Laboratory: http://www.frontier.kyoto-u.ac.jp/te02/studies/research/heart.html

Figure 8: Sustained release system using inorganic materials



shown in Figure 7[8], at one week after treatment, the blood flow resumed within the cardiac muscle and neovascularization was confirmed. This technique is a very useful method to supply oxygen and nutrition to ischemic disease or transplant cells, and to maintain the functions. [9]

[2] Sustained release of cell growth factor using bioabsorbent ceramic material

Yutaka Mizushima, Junzo Tanaka (Biomaterials Center, National Institute for Materials Science, Japan) and others are conducting the development of carrier materials for regenerative medicine using materials existing in hard tissues in the living body such as calcium phosphate and calcium carbonate. These materials are characterized in that the carrier is dissolved in the living body after sustained release of drug and shows no toxicity within the living body after being dissolved. In a product using calcium carbonate, sustained release of steroid hormones and basic protein was successfully achieved.

In recent years, they have developed the drug sustained release technique (plug up the pore of material) for apatite porous particles (pore diameter, 1-10 μm) existing in the hard tissue (particularly, bones) in the living body. As shown in Figure 8, in this system, after a drug is enclosed in the pore of calcium phosphate particles, the surface and inner pores are closed using a material without biotoxicity such as polysaccharides and calcium carbonate to increase the sustained release. This can be applied to regenerative treatment such as subcutaneous and intramuscular sustained release of protein products, local treatment, and local retentive sustained release. Two-week sustained release was successful in erythropoietin to increase red blood corpuscle, and in brain neurotropic factor essential for the survival of neuron of corpus striatum in the brain. These products were produced by focusing on the good adsorption of protein by calcium phosphate. Application to many protein products are expected after this.

(3) Application to gene therapy

In gene therapy, detoxicated viruses are currently used as the transgenic agent (vector) in many cases. However, occasionally it is difficult to completely eliminate the toxicity of the virus, or the virus may mutate later causing to obtain toxicity. Due to such problems, research and development activities on non-virus transgenic agents are conducted.

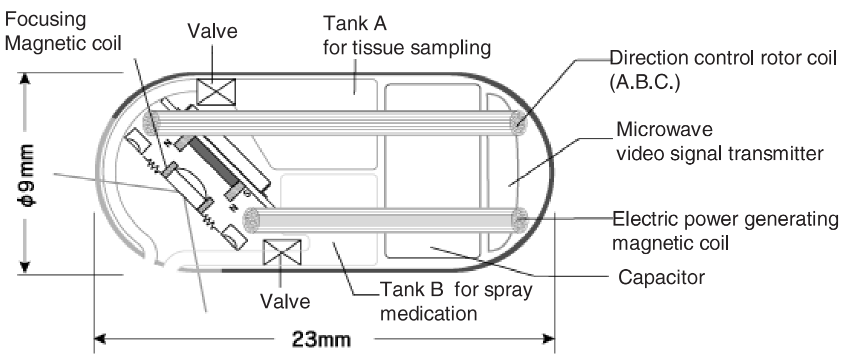
Kazunori Kataoka et al. are conducting the development of a non-virus transgenic agent in which a polymer compound mainly consisting with polyethylene glycol which has biocompatibility, covers around calcium phosphate taking in the gene. If this is mixed with human culture cells, the transgenic agent will be spontaneously taken into the cells. In cells with low calcium concentration, calcium phosphate will dissolve and the gene is expected to be released. In vitro experiments revealed that the transgenic agent could introduce a gene into cells and exhibited no toxicity to the cells. Following this, they plan to start experiments using animals such as mice.

Masahito Nakanishi (Gene Function Research Laboratory, National Institute of Advanced Industrial Science and Technology) et al. are aiming to develop a new transgenic system necessary for human gene therapy by membrane-fusion- liposome utilizing the membrane fusion activity of Sendai virus. The Sendai virus prolongs a very stable infection without killing the host cells. The membrane-fusion-liposome prepared using the Sendai virus has the outer membrane originating from the Sendai virus, so that it is directly fused with cell membrane, and can transport the inner substance to the objective cell.

(4) Drug targeting by MEMS

As for drug targeting using micro-electro-mechanical systems (MEMS), a capsule-type endoscope for the gastrointestinal system without batteries "NORIKA v3" [10], was announced in the autumn of 2002 by RF System Lab. (Japan), a medical camera manufacturer, with a catch phrase "A robot submarine enters the living body to give diagnosis and treatment," as shown in Figure 9. NORIKA v3 has a built-in electric power generating magnetic coil and electriccondensor in a 9ϕ~23mm capsule, and can be driven and controlled from outside of the patient's body using electromagnetic waves. By employing a CCD device for the imaging sensor, and by combining white and infrared lights and additional light with

Figure 9: MEMS for the gastrointestinal system



Source: Homepage of RF-System Lab., http:// WWW.RFNORIKA.comindex1.html

a different wavelength, high-quality moving pictures just like home videos are able to be obtained. The capsule has two tanks sharing 40% of the total volume which is for the administration of drug solution at the desired position by an exclusive valve control, that enables it to function as a DDS in the gastrointestinal system. As for the prices of NORIKA v3, the capsule will be launched at 100 U.S. dollars, with the extracorporeal control device at around 10,000 dollars. In December 2002, samples will be shipped for clinical studies.

On the other hand, for the cardiovascular system, because the size of the MEMS must be several hundred nm, the diameter of the capillary is as small as 5μm. It would be difficult to manufacture MEMS of such size even though current nanotechnology is utilized. Therefore, modification of liposome and polymer micelle with the nanomachine utilizing the morphological change of the nano-structure molecules are conducted to obtain a drug targeting nanomachine. In this case, the valve for control release of drug is intend to open and close utilizing the molecular morphological change.

6.4.2 Status of research and development of DDS in the United States and Europe

Research and development of DDS was also actively conducted in the United States and Europe as well as in Japan, aiming for application in cancer therapy, gene therapy, regenerative medicine, and AIDS therapy. Also in these countries, the employed polymer structures are micelle, dendrimer (dendriform structure), and liposome, etc. These polymer structures are characterized in that they can carry larger amount of drugs than other structures. The combinations of the polymer structure and drug are varied according to the employed methods; targeting to the affected site and sustained release of drug. As an example, the following may be given[11].

(1) Targeting to cancer cells

- R. Duncan (Cardiff Univ.) et al. in U.K. developed an anticancer drug for solid cancer and metastatic cancer tissue. An anticancer drug is bound to polyethylene glycol and N-(2-hydroxypropyl) metacryl (hydrophilic polymer by peptide bond) by peptide bond, which allows this to circulate in the blood for 24 hours.
- James R. Baker Jr. (Univ. of Michigan) and Jean M.J. Frechet (Univ. of California, Berkeley) et al. in the United States have already evaluated the use of an anticancer drug such as cisplatin and methotrexate bound to dendrimer (dendriform structure). The dendrimer is considered to reach the tissue easier owing to its small particle size of several nm.
- Glen S. Kwon (Univ. of Wisconsin) et al. in the United States evaluated an anti-AIDS agent, amphotericin B combining with micelle of polyethylene glycol-poly (L-amide asparate) with 30-50 nm in diameter for the use in AIDS therapy.

(2) Application to regenerative medicine

- Jeffrey A. Hubbell (Swiss Federal Institute of Technology, ETH) et al. evaluated the application of material such as fibrin whose structure turns to gel from liquid in the living body to regenerative treatment such as neovascularization, bone regeneration, and nerve regeneration. Cell growth factors (VEGF, etc.) are taken into the material.

(3) Application to gene medicine

- Alexander T. Florence (Univ. of London) et al. in U.K. developed a dendrimer aggregate (complex) such as dendrisome and dendriplex to bind with DNA, and attempted the application as a transgenic agent.

(4) Drug targeting MEMS

- Given Image Inc. in Israel published the development of a battery-driving capsule camera "M2A" in May 2002. However, several problems were pointed out including picture resolution, battery life span, retention of the capsule in the living body, and the sufferings of the battery's chemical substances, and it was reported that it would take several years to resolve such issues.

As stated above, research and development of DDS were also conducted extensively and actively in the United States and Europe. As a general evaluation of the research and development of DDS in Japan, in the 1950s when the concept of DDS was born, development of new pharmaceutical was highly evaluated but DDS was not appropriately evaluated. Therefore, the level of research and development of DDS was behind the United States and Europe. However, in the 1980s and after, when the new DDS gained general appreciation, the study of DDS significantly increased and achieved the present level in Japan not inferior to that of the United States and Europe but likely equivalent or superior to their level.

6.5 Measures taken by the government

From the 1980s to 1990s, research and development activities of DDS were covered mainly by the Grant-in-Aid for Scientific Research of the Ministry of Education. For 6 years from 1982, research and development activities on materials for DDS were conducted with the grant for special research (Teiji Tsuruta, professor emeritus of the University of Tokyo), etc. In addition, for 3 years from 1999, "Biomolecular design for biotargeting" in "Research of special area (A)" (Takeshi Kobayashi, representative of the Area and belonging to the Graduate School of Engineering, Nagoya University) was conducted and the targeting function was examined from a chemical point of view and the DDS was reconstructed using engineering knowledge.

It was taken up in the research project "Development and the application of the advanced science and technology (Nanomedicine project to apply nanotech to medicine)" of the science and technology policy by the Ministry of Health, Labour and Welfare in 2002. As application of nanotechnology to the medical field, DDS development is advanced by the understanding of diseases such as cardiovascular disease and of the function of cell receptors. As application of nanodevice to the medical field, the research and development of small precision therapeutic instruments are advanced. Those are important from the viewpoint of reinforcement of international competitiveness.

In the Japan Science and Technology Corporation, in the research area "Invention of new materials for chemical and biological systems" of the Core Research for Evaluational Science and Technology (CREST), as part of "Aiming to invent chemical and biological innovative functional materials, molecular machine, biodevice, biosensor technique in the nano scale" (Masuo Aizawa, research supervisor and belonging to the Tokyo Institute of Technology), "Invention of nano-structure device functioning as a gene vector" was proposed and taken up by Kazunori Kataoka et al. in 2001. The purpose is to create a safe and high-function "gene vector" carrying various drugs including gene to targeted tissue in the living body, and conducting treatment and diagnosis. The vector is prepared by the exact self-organization of polymers and lipid molecules.

In addition, in 2002, the proposal of Tokuko Haraguchi (Communications Research Laboratory) et al. concerning the "Invention of artificial cell nucleus as a gene delivery system" was taken up in the "Construction and utilization of advanced function structures of soft nanomachine" (Hirokazu Hotani, research supervisor and belonging to the Graduate School of Science, Nagoya University). The research aims to develop a gene delivery system with a special function useful for gene therapy and drug treatment. Beforehand, understanding of the formation mechanism of the nuclear membrane around the chromosome and development of an artificial cell nucleus with a special function are conducted.

In the National Institute for Materials Science, Biomaterials Center was started in October 2001, aiming to realize a society with advanced medicine. At the center, extensive and comprehensive research and development activities on biomaterials are conducted. Application of polymer micelle to targeting to cancer and to gene therapy and that of ceramic materials to regenerative treatment are conducted for DDS. At present, they collaborate with 20 engineering departments of universities (including 4 foreign universities), 15 medical departments of universities (2 foreign) and 15 companies (2 foreign), aiming to be the main foothold of research and development of biomaterials in Japan[12].

6.6 Picture of DDS in the future

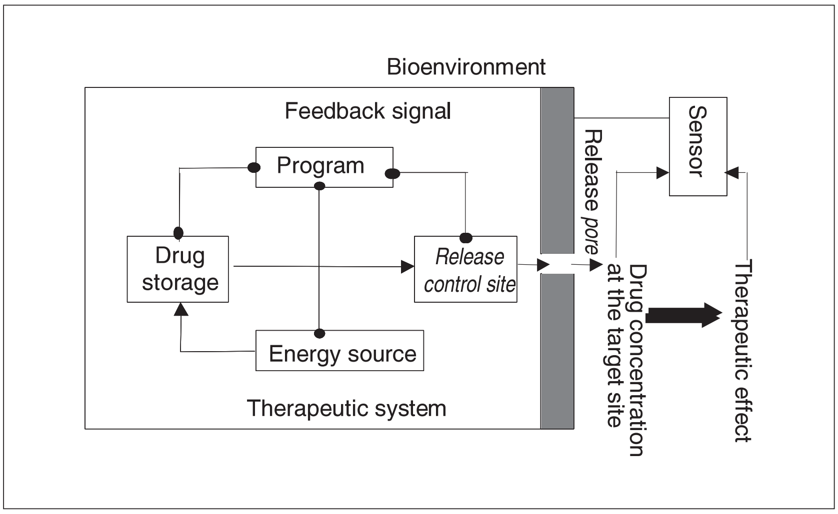
What is desired for the future DDS is to control the drug transfer and reaction within the living body according to a patient's individual differences, i.e., what amount, what speed, and where and how the drug is released. For example, in the treatment of diabetes, as stated above, it is necessary to release insulin according to the glucose concentration in the blood. The system shown in Figure 10 is an ideal drug controlled release system. To realize this system, the system must have the following functions.

(1) Sensing function for the therapeutic effect and drug concentration (Sensor development)
(2) Function for data processing and setting release patterns (Data processing development)
(3) Precision release function based on the above setting (Precision release device development)

It is also required for materials to have reliability and safety to keep functions (1) to (3).

Not only research and development of material sciences such as polymer and ceramic materials to be combined with drug, but also the development of sensing function, microanalysis, and precision machine engineering are important. The following research and development may be suggested.

Figure 10: Ideal drug controlled release system



- Development of nanomachine for targeting DDS, which has a drug-release control valve driven by the morphological change of molecule. It may be enabled by the modification of liposome and polymer micelle with nanomachine utilizing the morphological change of nano-structural molecule, drugs, and proteins having a sensing function.
- Research and development of a drug releasing MEMS associated with the sensing function, data processing, and precision release device.

6.7 Present status of examination of DDS products

The "examination of DDS products" in the Ministry of Health, Labour and Welfare is not considered very much. The present status of the "examination of DDS products" is as the following[13].

- According to the notification from the Director General in April 1999, regulations concerning new active ingredients, new compounding ingredients, new route of administration, new virtues, new dosage form, and new dosage are provided, but there is no peculiar regulations corresponding to DDS products.
- In the regulation for the new dosage form which is considered to be most related to DDS products, toxicity tests, and efficacy pharmacology and general pharmacology tests are not necessary. However, those tests are necessary for DDS products that provide significant efficacy owing to excellent ideas and technology.
- In the case of DDS products secondly put on the market, even if the ingredients are different from the advanced product, it is examined and permitted in the same way of conventional drugs.
- The guidelines for the examination of sustained-release drugs were publicized in 1988, but the revision of the guidelines is not conducted.

Therefore, the Japan Society of Drug Delivery System submitted the "draft guidelines for the examination of DDS products" to the Ministry of Health and Welfare in July 1999. The guidelines suggests that the characteristics of DDS products should be understood well, logically necessary basic and clinical tests should be sufficiently conducted, and unnecessary ones should be omitted to shorten the examination period[13].

An actual problem is that the period of examination of pharmaceutical manufacturer in our country is so long that the drugs are sometimes re-imported after receiving permission in the United States and European countries. The long duration for the examination of new drugs in Japan delays the practical use of drugs, that is likely to be one of the causes for the lower competitiveness of the medical industry of Japan than that of the United States and Europe.

6.8 Conclusion

In the case of sustained-released type DDS, almost all of the products with less difficulties in the development are already introduced and put into practical use. In the case of targeting DDS to cancer cells that was stagnant, its development rapidly progressed and the results came to be applied clinically. In the field of regenerative treatment and gene therapy, not only gene but also cells are recognized as a drug, and a system to carry this to the targeted affected site is demanded. Moreover, MEMS being able to be used as a DDS for the gastrointestinal system was developed. Under these circumstances, projects for DDS were taken up and proceeded in the research project of the science and technology policy (Nanomedicine project to apply nanotech to medicine) of the Ministry of Health, Labour and Welfare, and in the Core Research for Evaluational Science and Technology of the Japan Science and Technology Corporation. In addition, in the "New industry created by nanotech" — n-Plan 2002— published in November 2002, Nippon Keidanren proposed that in order to maintain Japanese technological competitiveness being high in the field of nanomedicine, which is expected to develop in the future, the government should head the frontline of the research and development in the nanomedicine field and tackle the arrangement such as review and rapid operation of the medicine-related system, as well as close cooperation between medical and engineering fields.

The research and development of DDS is an interdisciplinary area, and requires close cooperation among medical science, pharmacy, material science, bioengineering, precision mechanical engineering, electronics, computer and information science and so on. The achievement of cooperation among such wide fields cannot be expected by the effort of only one corporation, one university, or one institute. Therefore, followings are necessary to maintain and raise the level of Japan's high technological competitiveness. Constructing an organization to play a key role in the cooperation under the strong leadership of the government as soon as possible, gathering highly competent researchers, arrangement of an environment and system, and advancing the research and development of DDS by a joint industry-university-government project. Under the circumstance, the "Biotechnology Strategy Meeting" proposal of fundamental principles suggested the increase in funds of bioresearch (double in 5 years) and the relief of regulations including the reduction of the period for the examination of new drugs.This proposal is an important policy to promote the research and development of DDS.

Acknowledgement

We would like to express our heartfelt thanks to Prof. Kazunori Kataoka (Graduate School of Engineering, University of Tokyo and of the Biomaterials Research Center, National Institute for Materials Science, Japan) for his advice and offer of the latest information.

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(Original Japanese version: published in December 2002)

7

Current Status and Foresight of Photocatalysts

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7.1 Introduction

Photocatalysts work by making use of photo energy. When they absorb light, they are excited to a higher energy state, and accelerate chemical reactions by giving this energy to reactants. This action is called "photocatalysis." The term "photocatalysis" was first used back in the 1930s [1] , and the effect of photocatalysis was recognized as the cause of deterioration of pigments contained in coating materials (choking phenomenon) in the 1950s. In those days, therefore, various studies were made for the elimination of photocatalytic reaction that caused detrimental effects such as the deterioration of pigments contained in coating materials. That is, photocatalysis has been regarded with a negative image for a long time[2]. In the 1960s, several groups conducted research on the reactions of organic compounds using the photocatalytic action of zinc oxide powder[3]. However, the research works did not attract much attention because the reaction had a defect that zinc oxide itself dissolves by the effect of light. In the 1970s, Honda, Fujishima, and coworkers discovered that the generation of hydrogen was promoted by irradiating electrodes of titanium oxide with light, which is now called the Honda-Fujishima Effect[4]. With this discovery as a start, technologies in this field have been rapidly developed resulting in a boom in the research on photocatalysts. It was also found in the 1980s that photocatalysis could be applied to the decomposition of harmful materials[5, 6]. Photocatalysts including titanium oxide possess strong oxidative decomposition power, and can completely decompose any compounds. Even organic chlorides are completely decomposed into carbon dioxide and chlorine. There is no possibility of secondary pollution. Thus, photocatalysts are now receiving a great deal of attention as an environmentally friendly material for environmental cleanup that easily detoxificates various difficult-to-decompose chemical substances by just utilizing light.

When photocatalysts such as titanium oxide are irradiated with light, two kinds of reactions take place as shown in Figure 1. One of them is the reaction that completely decomposes substances with strong oxidizing power as has been described above (photocatalytic decomposition reaction), and the other is the reaction in which

Figure 1: Two phenomena occurring on the surface of titanium oxide photocatalyst

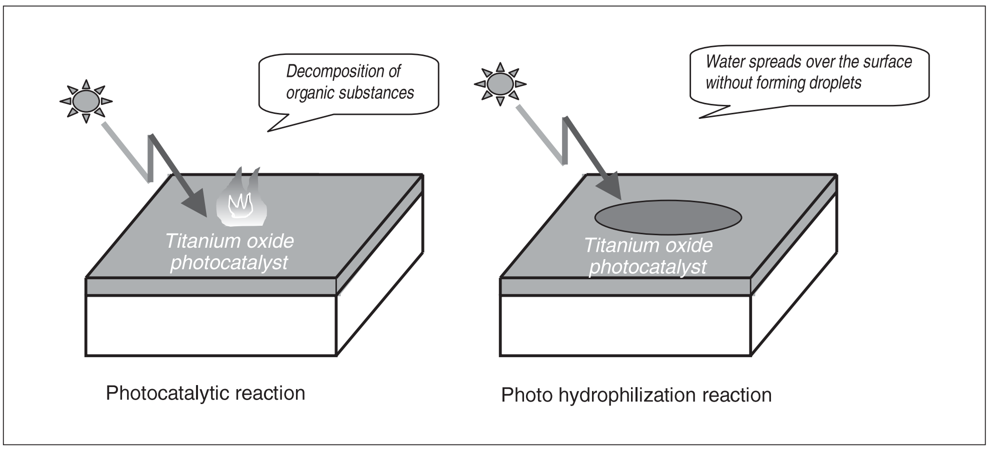
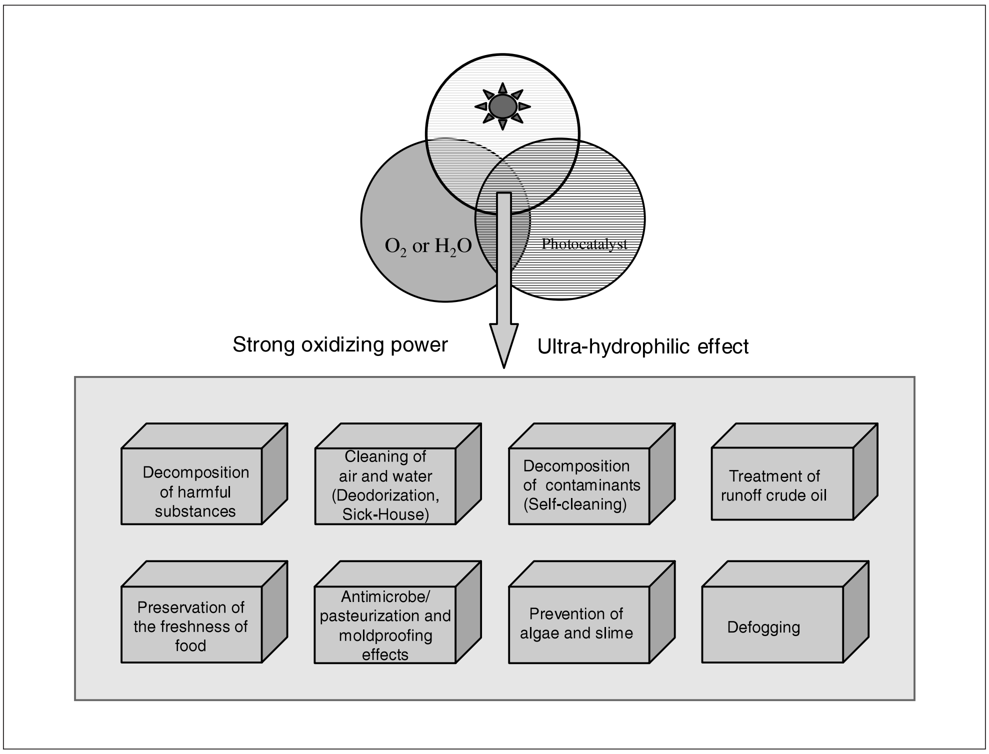


Figure 2: Photocatalyst systems and possible application fields



the surface of catalyst becomes hydrophilic with wettability being increased (photo hydrophilization reaction[7]. Research on the hydrophilicity of photocatalysts has rapidly become very popular recently[8], and practical technologies have been remarkably developed.

As a result of the above-mentioned technological progress, photocatalysts are now behind-the-scene key players for the creation of a comfortable life for human beings by contributing to the detoxification treatment of industrial wastes, air cleaning, cleaning of underground water and lake water, decomposition of contaminants, treatment of runoff crude oil, preservation of the freshness of food, antimicrobial and moldproofing effects, prevention of clouding and slime, and so forth (Figure 2). Furthermore, studies are progressing on the decomposition and elimination of harmful substances contained in the atmosphere in minute amounts including endocrine disrupters (such as environmental hormones) and allergic substances.

Since the research and development of photcatalysts is most actively conducted in Japan, we are responsible for playing the role of leader in the research and development of photcatalysts in the world. For this purpose, it is necessary for us to take the initiative in all of the following aspects: basic studies such as the potentiality and limits of photocatalysts, advantages and disadvantages, detailed surface structure observation of each catalyst, close investigation of the selectivity of catalysts at active sites; application technologies that fully utilize the advantages of photocatalysts; and quality assurance and control procedures that provide reliable products for everybody.

From the above-mentioned viewpoint, the current status and future prospect of the research and development of photocatalyst are described briefly in the following sections.

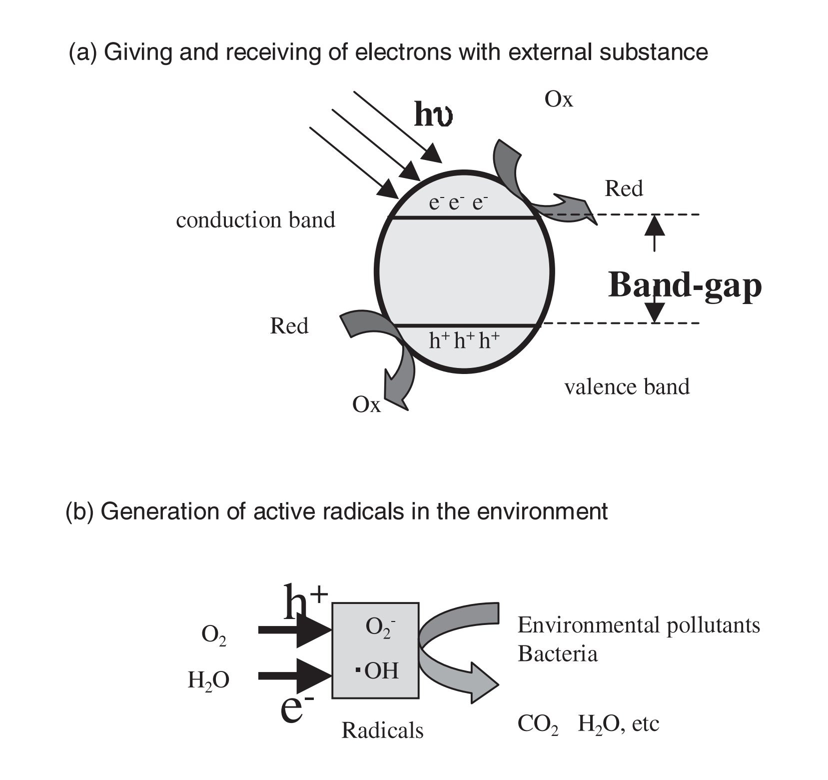
7.2 Mechanism of catalysis

Mechanism of photocatalytic reaction

Semiconductors are used the most as photocatalysts although metal ions and metal-complex compounds are also used. Particularly, oxide semiconductors such as titanium oxide, zinc oxide, tungsten oxide, iron oxide, strontium titanate, and cadmium sulfide are the major materials used for photocatalysts.

Values of the electric conductivity of semiconductors literally lie between those of metals and those of insulators. That is, certain non-conductors that do not pass electricity under normal conditions become able to pass electricity when excited by external stimulus such as light,

Figure 3: Semiconductor photocatalyst under the irradiation with light



heat, or electric fields. In the case where conductivity is obtained by photoexcitation, not all light with any wavelength can excite but only light with a certain wavelength or shorter (i.e., with a photon energy higher than that of a certain wavelength). This energy is called the band gap energy, and is specific to each semiconductor material[9].

Photocatalytic reactions take place when the surfaces of catalysts act on reactants. Figure 3 (a) illustrates, from a chemical point of view, the situation of a semiconductor in touch with the environment when the semiconductor is irradiated with light having an energy equal to or higher than the band gap energy.The electron that is normally in the valence band is raised to the conduction band when excited by the light energy, generating two charge carriers--electron (e-) and positive hole (h+). These carriers diffuse over the surface of the semiconductor and some of them transfer to external substances. When the external substance has received electrons, the substance is said to be reduced. When the external substance reacts with positive holes losing electrons, the substance is said to be oxidized. Therefore, photocatalysts are materials that provoke both oxidation and reduction reactions.

When photocatalysts are used in the natural environment, oxygen and hydrogen existing abundantly in the environment preferentially react with electrons and positive holes and generate superoxide ion ($\bullet O_2^-$) and hydroxyl ($\bullet OH$) radicals. These radicals called reactive oxygen species have oxidizing power stronger than chlorine or ozone, and decompose many substances by oxidation. Most of the diversified functions of photocayalysts derive from the ability to generate the reactive oxygen species.

Characteristics of photocatalytic reactions

Characteristics of photocatalytic reactions from the viewpoint of application are as follows:

(1) Particularly effective for the decomposition of minute amounts of reactants

It has been confirmed that various substances on the surface of photocatalysts from cigarette tar to E. coli decompose. As the name photocatalyst implies, this decomposition reaction takes place using light energy. As a matter of course, this reaction takes place only when the substance to be decomposed is in touch with the surface of catalysts and light exists. This fact is an important point for understanding the photocatalytic reaction and in the consideration of its applications. Due to this characteristic, photocatalysis is not suitable for decomposing a large amount of material within a short time, but is suitable when the substance to be decomposed is in a small amount increasing little by little. Referring to Figure 4, let us compare a case where a tile block coated with photocatalyst is slightly contaminated and a case where the tile block coated with photocatalyst is significantly contaminated. In the former case, the decomposition proceeds effectively, whereas, in the latter case, the surface of the tile block is covered all over by contaminants making it impossible for the light to reach the surfaces of the tile, and decontamination cannot be effected. Since harmful matters in small amounts such as substances with offensive odor and environmental hormones, which are now receiving public attention, present a danger to public health and the environment, they are the most suitable targets for the application of photocatalysis.

(2) Pseudo high temperature effect (producing the effect of burning materials at room temperature)

As has been previously described, when the titanium oxide catalyst absorbs light, two phenomena occur on the surface of catalyst. One is photocatalytic decomposition, in which materials are decomposed and organic materials are decomposed ultimately into carbon dioxide and water. This reaction is the reverse of photocatalytic synthesis and corresponds to a combustion reaction. In order to obtain the same effect by thermal energy as obtained with ultraviolet rays of a wavelength of 380 nm or shorter, a temperature of 30,000 degrees centigrade or higher is required. In the catalytic reaction, however, it is not necessary to raise the temperature and the reaction proceeds at only room temperature. In the combustion reaction, once ignited, the reaction continues until the material burns out. Furthermore, in the photocatalytic reaction, when irradiated with light, the reaction proceeds corresponding to the amount of light absorbed. Thus, it is one of the characteristics of photocatalytic reaction that the reaction can be controlled more easily than combustion reaction.

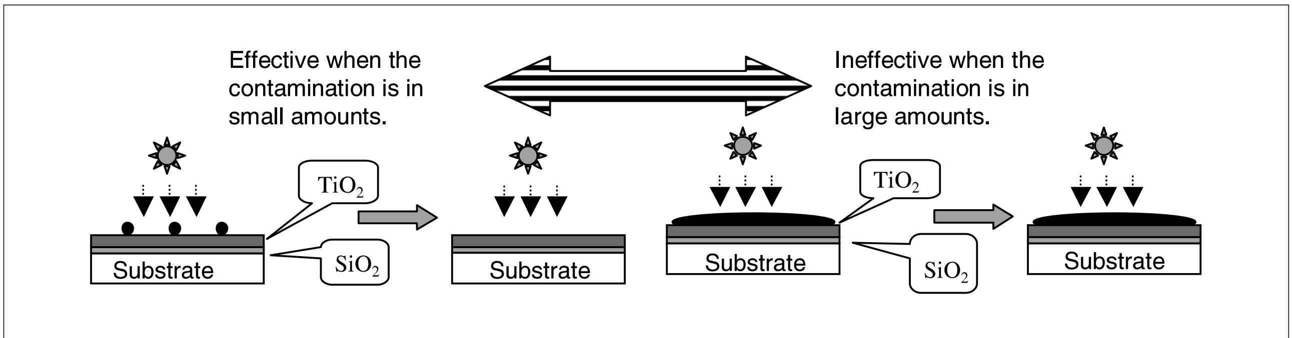
Why is titanium oxide used?

As mentioned above, there are many semiconductor materials that have the photocatalytic function. However, most of the products applying photocatalysis use titanium oxide as the catalyst. Reasons for this are summarized under the following four points:

(1) Extremely stable physically and chemically

Since the main component of sunlight is visible light, it is desirable to use semiconductors with smaller band gaps so that visible light can be used for excitation. However, when materials with smaller band gaps than that of titanium oxide such as cadmium sulfide and cadmium selenide are irradiated with light in water, self-dissolution occurs. This is a phenomenon in which the positive holes generated by the irradiation with light oxidize the semiconductor itself, resulting in the dissolution as metallic ions. Many semiconductors suffer from this phenomenon and are unsuitable as practical materials. Titanium oxide does not exhibit such self-dissolution and is superior to other semiconductors in stability.

Figure 4: Limits of photocatalysis (unsuitable for treating a large amount of material)



(2) High photocatalytic activity

The photocatalytic activity of titanium oxide strongly depends upon its crystal structure. While it is known that titanium oxide has three kinds of crystal structures--anatase, rutile, and brookite--the anatase structure has the highest photocatalytic activity. Therefore, anatase is considered to be most effective for the application of photocatalytic reaction.

(3) Harmless, nontoxic and environmentally friendly

Safety of titanium oxide has been proven as with white pigment and food additives, and there are little adverse effects on the human body and the environment.

(4) Inexpensive raw materials

Titanium itself is a metallic element abundant in natural resources, being the ninth most plentiful element in the earth's crust. Ores used as raw materials to produce titanium oxide are ilmenite which isa compound of oxides of iron and titanium, and rutile. Production processes (chlorination method and sulfuric acid method) are relatively simple and inexpensive.

Judging from the above-mentioned characteristics, titanium oxide has advantages for use in the environment in large amounts. From the viewpoint of stability only, it has been found that strontium titanate and layered potassium niobate have a photocatalytic activity comparable to that of titanium oxide. However, in addition to the problems with complicated production processes and high costs, there is concern that these compounds will have ill effects when released in the environment. Regarding the decomposing ability and costs, zinc oxide has potential as a candidate material but it has the defect of photodissolution, which must be resolved before being put into practical use.

Since the band gap of titanium oxide is 3.2 eV, only ultraviolet radiation is absorbed. In order to improve the effectiveness in utilizing light energy, many research studies are being made to solve this problem.

Light source

As understood from the above-mentioned mechanism of action, "photocatalyst," "water and oxygen," and "light source" are the three major factors required for catalytic reaction. Now let us discuss the third factor, "light source."

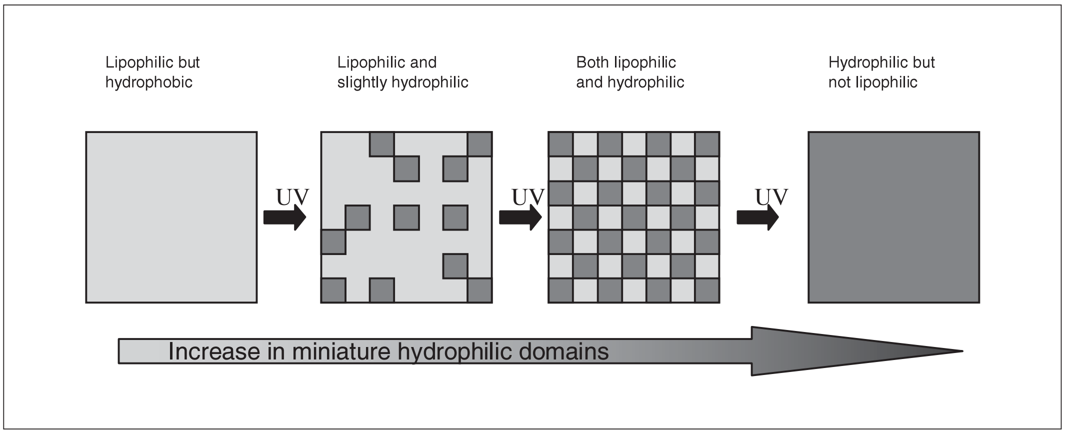
The most readily available light source in nature is sunlight. The light coming from the sun to the earth consists of wavelengths from 290 nm to 4,000 nm. The light with wavelengths up to 400 nm is ultraviolet light; the light with wavelengths from 400 nm to 800 nm is visible light in the order of purple, blue, green, yellow, and red; and the light with wavelengths of 800 nm or longer is infrared light. The spectrum of sunlight exhibits the highest strength around 450 nm in the visible light range. The total amount of light energy that the earth receives every year is 3.0×10^{24} J/year. This energy equals more than 10,000 times the annual consumption by humans using petroleum and coal, and about 4 to 5% is ultraviolet light, about 45% is visible light, and about 50% is infrared light.

Since the photocatalysts in practical use at present are of titanium oxide, the light utilized for the photocatalytic reaction is ultraviolet light. As has been mentioned above, the strength of ultraviolet light in the sunlight is not high, and it is a realistic choice at present to use artificial ultraviolet light sources. Mercury lamps, xenon lamps, black-light lamps, and chemical lamps are commonly used. However, the life of these light sources is several thousand hours and it is

Table 1: List of the selected materials for the research on photocatalysis since 2000 based on a literature search

Materials	Number	%
TiO_2	617	78
ZnO	35	4
WO_3	22	3
Fe_2O_3	14	2
ZrO_2	12	2
$SrTiO_3$	4	1
Nb_2O_5	4	1
V_2O_5	3	0
CeO_2	3	0
Others(including organometallic complex)	76	10
Total	790	100

Figure 5: Structure-change model of the surface of photocatalyst caused by irradiation with light



necessary to replace the lamps about every half a year, restricting the area of application. Furthermore, with normal ultraviolet lamps, the efficiency of conversion from electricity to light is 20% at most and the rest of the energy is wasted as heat. Therefore, it is a serious problem that light sources being used at present cost much more than expected.

As a candidate for alternative light sources that may solve this problem, the light-emitting diode (LED) is being studied. Because the life of a light-emitting diode is as long as about 100,000 hours and power consumption is very low having a high electricity-to-light conversion efficiency of 80% or more, LED is a hopeful light resource that may replace the fluorescent lamp in the future. Recently, short-wavelength LED based on gallium nitride has been developed and air cleaners for vehicles that utilize this LED have been put to practical use in Japan for the first time in the world[10]. It is thought that the development of low-cost, short-wavelength LED is the key to widening the application areas of photocatalysis.

Using visible light for activating photocatalysts

Only ultraviolet light has been used for the photocatalysts that are applied to the production of oxygen and hydrogen with the electrolysis of water or detoxification of environmental pollutants. Since ultraviolet light is harmful to humans in the first place, it causes anxiety to use strong light within a normal environment. Furthermore, in order to improve the efficiency, it is necessary to utilize natural sunlight or room illumination. Therefore, development of photocatalysts that are activated by visible light is now one of the most important targets in this field. Several methods including the following five have been proposed for this purpose: (1) doping of transition metals[11], (2) hydrogen plasma treatment[12], (3) dye sensitization[13], (4) compounded semiconductor that absorbs visible light[14], and (5) replacing oxygen with nitrogen[15, 16]. Method (1) requires expensive equipment for the implantation of metallic ions. In method (2), the ability to absorb visible light is rendered by the oxygen defects generated by the plasma treatment, and the consistency and reproducibility must be fully studied. Method (3), dye sensitization, does not seem to be suitable for photocatalyst application. Because the oxidation ability is rendered to the dye, high oxidizing power cannot be expected. Methods (4), compounded semiconductor, and (5), nitrogen doping, are the most hoped-for methods. Research on the utilization of visible light for photocatalysts is being intensively conducted with focus on these two methods.

Hydrophilicity of photocatalysts

When the photocatalyst of titanium oxide absorbs ultraviolet light, two phenomena occur on its surface (Figure 1). As has been already mentioned, one is the photocatalytic decomposition and the other is photo hydrophilization. Why does the surface of photocatalyst render the photocatalytic characteristic and high wettablity by the irradiation with light? We have reviewed the photocatalytic reaction that utilizes the high oxidizing power of photocatalyst. It has been thought that photo hydrophilization also derives from the high oxidizing power that decomposes organic matters adhering to the surface by oxidation resulting in the their removal. However, the results of recent studies on the surface structure have lead to a new concept that hydrophilizaton by irradiation with light derives from the change in the surface structure of titanium oxide. Figure 5 illustrates a structure-change model of the surface of photocatalyst. Before the irradiation, the surface of titanium oxide is uniformly hydrophobic. With the irradiation, minute hydrophilic domains are formed, and, finally, the hydrophilic domains cover the entire surface. The mechanism of the formation of hydrophilic domains is still under study. But judging from the results of various experiments, the most probable process is that the positive holes generated by irradiation with light are oxidized by the oxygen of titanium oxide resulting in oxygen defects in the lattice, and water is absorbed at these defects forming hydrophilic domains[17].

Affinity of photocatalysts for water is greatly increased when exposed to light due to their hydrophobic property in addition to the various catalytic functions. Discovery of new functions such as photo ultra-hydrophilicity (property or phenomenon in which the contact angle with a liquid is 0 degree) seems to promise the possibility of new products such as defogging mirrors and windows for high-rise buildings that do not require cleaning (self-cleaning effect), and prevention of snow accumulation on power transmission lines in snowy districts and on roofs to reduce the burden of snow removal by combining photocatalysts with alumina that has ultra-water-repellency (property or phenomenon in which the contact angle with a liquid is 150 degrees or more).

Decomposition of water by photocatalysis

As is well known, hydrogen is attracting attention as an energy resource that is environmentally friendly. However, a problem still to be solved is how hydrogen should be produced. One possible method is the decomposition of water using photocatalyst. Initially, this triggered the attention to photocatalyst, and basic research works including the search for adequate materials are being made. However, no material superior to titanium oxide has been found. Titanium oxide photocatalysts have a problem that the quantum efficiency is quite low when used for the decomposition of water. It is said that the efficiency is 1% or less, which is significantly lower than that of solar cells used for converting light energy to electric energy. The immediate target is 10%, and the issue of hydrogen resource will be solved once and for all if the efficiency reaches 30% in the visible light range with the wavelengths of 600 nm or shorter. For the application to the decomposition of water, the problem of the response to visible light still remains as in the case with other photocatalysts.

Evaluation of photocatalytic performance

Many evaluation methods have been proposed by researchers according to the applications including pigmentolysis, fluorescence method, and analysis of reaction products. In the method by the analysis of reaction products, reactants and reaction products are usually analyzed by gas chromatography or high-performance liquid chromatography after the actual photocatalytic reaction. The reaction apparatus is classified as follows according to whether the catalysts are in the form of membrane or plate (fixed type) or powder, and also whether the reaction media are liquid or gas:

(1) Fixed type photocatalyst: gas phase: reactants are introduced into the reaction cell (closed type or flow type) together with a medium gas (usually air) and made to react by irradiation with light. (2) Fixed type photocatalyst: liquid phase: basically the same as the gas phase method. This method is advantageous for the cleaning of water because it is not necessary to remove the photocatalysts. (3) Powder photocatalyst: gas phase and (4) Powder photocatalyst: liquid phase are also used.

The Society of Industrial Technology for Photocatalytic Articles has published methods for the evaluation of photocatalytic performance and performance standards (http://www.photo cataoysis.com). In the published evaluation methods, “ Method for the Evaluation of Photocatalytic PerformanceáT(liquid film close contact method)” relates to the evaluation of plate type photocatalysts, "Method for the Evaluation of Photocatalytic Performance IIa (gas bag A method)" relates to photocatalysts of powders and granules, and "Method for the Evaluation of Photocatalytic Performance IIb (gas bag B method)" relates to the evaluation of the performance of photocatalysts with strong adsorption. However, these methods cannot meet the requirements for the various applications described in this report, and are still insufficient as standard procedures.

7.3 Actual applications of photocatalysis

As previously described, full-scale research on photocatalysis started in the 1970s and various new materials related to photocatalysis have been developed. One of the characteristics of the research on photocatalysis compared to other research areas is that the process from basic research to application is very short and the development of materials are immediately reflected in the development of practical products. Furthermore, when a new material has been developed, new applications are soon developed thereby accelerating the commercialization of products. Products related to photocatalysts are expected to be used in our daily life in simple and safe manners, familiar to everybody from the aged to children and usable anywhere as long as light is available. Particularly, these products are suited for developing countries where energy is insufficient. In order to realize such targets, diversified products utilizing photocatalysis have been created as a result of ingenious efforts of many private companies and research organizations. The following are some examples of these products.

•Example•1

Antimicrobial stain-proofing photocatalytic tile

The photocatalytic tile, which was originally developed for medical application, was the first product using photocatalysis and put into practical use as early as 1994. Since it was found that photocatalytic tiles are effective for MRSA (methicillin-resistant staphylococcus aureus), which causes hospital infection and is resistant to antibiotics, they have become widely used in operation rooms and other places in hospitals. Furthermore, these tiles that exhibit high performance in medical applications are now being used in houses. These tiles are most suitable for damp places such as the bathroom and kitchen where microorganisms and trash accumulate. Figure 6 shows the production process for photocatalytic tiles. It should be noted that copper metal, which has an intrinsic antimicrobial property, is fixed on the surface of titanium oxide aiming for a complex effect in order to promote antimicrobial functions in dark places.

•Example•2

Air cleaning photocatalyticacoustical board

The color of the sound-insulating walls installed on both sides of express highways is now changing from dark gray to white. The reason is because air cleaning photocatalytic acoustical

Figure 6: Production process for photocatalytic tiles

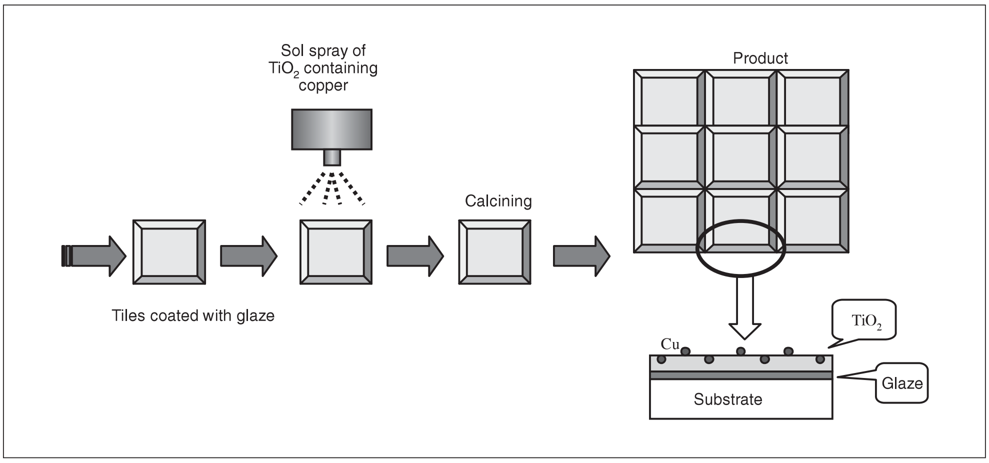
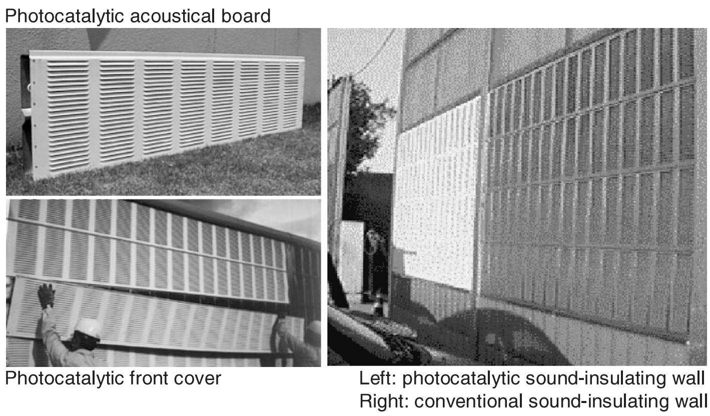


Figure 7: Air cleaning photocatalytic acoustical boards and sound-insulating walls for express highways



Source: two photos on the left,[18] photo on the right [19]

boards are being attached to the surface of conventional acoustical boards.

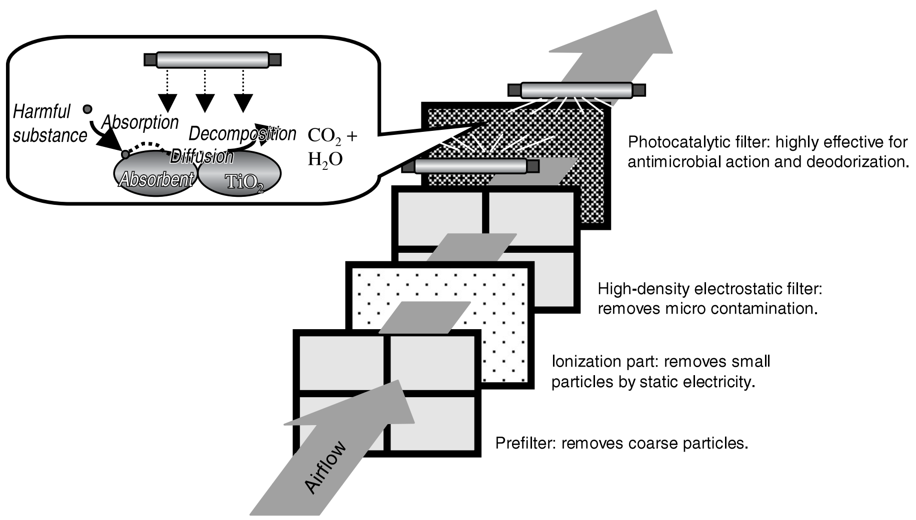
These air cleaning photocatalytic acoustical boards can completely oxidize the NO_X gas emitted from vehicles into harmless nitrate ion without emitting harmful intermediate compounds. These acoustical boards also have a stain-proofing function and maintain their appearance for a long time due to the self-cleaning function. This is a typical example of air cleaning systems that work only with natural energy. Figure 7 shows pictures of highways provided with air cleaning photocatalytic acoustical boards[18, 19]. About 4,000 m^2 of such air cleaning photocatalytic acoustical boards have been installed across the whole country. The success of air cleaning photocatalytic acoustical boards has led to the demonstration test of photocatalytic paving concrete blocks with an air cleaning function. The application of photocatalysis technology in the field of road construction materials has just started, and it is expected that many practical products will be developed in the future.

•Example•3

Filters for deodorizing and air cleaning equipment

Recently, airtight and insulated houses are increasing to improve the efficiency of air conditioning and energy saving. This has caused a problem in that the living environment is contaminated with harmful substances and

Figure 8: Structure of an air cleaner equipped with photocatalytic filters



bacteria. Newspapers and TVs are reporting on the sick house syndrome and new house sickness. Volatile organic compounds (such as formaldehyde and toluene) are believed to be causing such sickness. Offensive odors from cooking, garbage, cigarette, and bathrooms not only make people feel sick but also have harmful effects on the human body, staying for a long time in the house. Air cleaners equipped with a photocatalytic function now play important roles in decomposition and removal of these harmful substances in minute amounts. Figure 8 illustrates the structure of filters used for air cleaners using titanium oxide. These filters have the feature that they are combined with absorbents such as activated carbon to improve cleaning efficiency. The combination with absorbents is essential because titanium oxide cannot efficiently absorb molecules of harmful substances by itself. These harmful substances are first captured by the absorbents and then diffuse onto the surface of the titanium oxide for decomposition. Furthermore, antimicrobial and antiviral effects are expected because airborne bacteria and virus cannot live on the surface of photocatalytic filters.

Deodorization is the easiest part of the application of photocatalysts and many practical products have been introduce into the market including deodorizing air cleaners, air conditioners and refrigerators, all of which are equipped with the antimicrobial function.

•Example•4
De-fogging glass

On rainy days, water droplets attached to the windshield and sideview mirrors distract the driver. Particularly at night, droplets on the sideview mirrors reflect the beams of headlights, making the driver's vision blurry. The surface of titanium oxide becomes highly hydrophilic when exposed to only a small amount of ultraviolet light during the day, and the formation of droplets is prevented by this effect. When used for the prevention of water droplets on sideview mirrors, however, the effect is workable in daylight but is difficult to maintain for a long time after sunset or in dark places, thereby making hybridized technology indispensable.

This problem has been solved dramatically by the addition of silica. It is known that silica strongly absorbs water molecules on its surface. It is thought that the surface of silica is cleaned by the photoexcitation reaction of the titanium oxide, so that water molecules are strongly absorbed on the clean silica and the hydrophilicity can be maintained in dark places, and, as such, it has become a real possibility to apply this technology to the sideview mirrors. Figure 9 shows the production process for the sideview mirrors of automobiles. The intermediate silica layer has been introduced to prevent the diffusion of sodium ions contained in the glass into the layer of photocatalytic titanium oxide. Regarding

Figure 9: Production process for sideview mirrors for automobiles

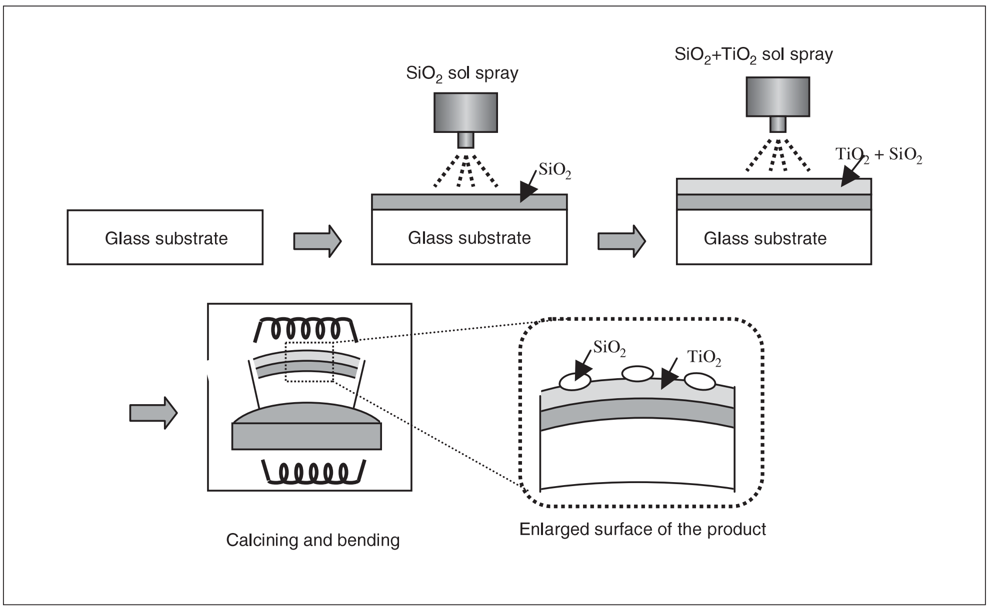
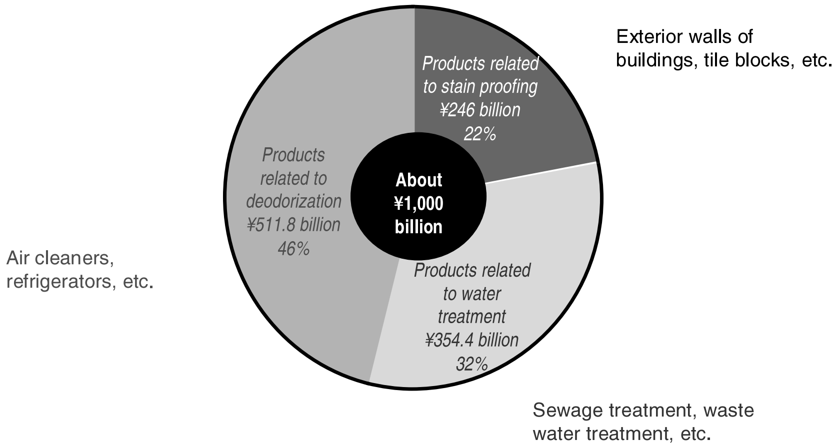


Figure 10: Forecast for photocatalyst market in 2005



Source: Authors' compilation based on a report by Mitsubishi Research Institute

automobile components that apply photocatalysis, not only new sideview mirrors but also photocatalytic films with adhesives for attaching to existing sideview mirrors are available on the market.

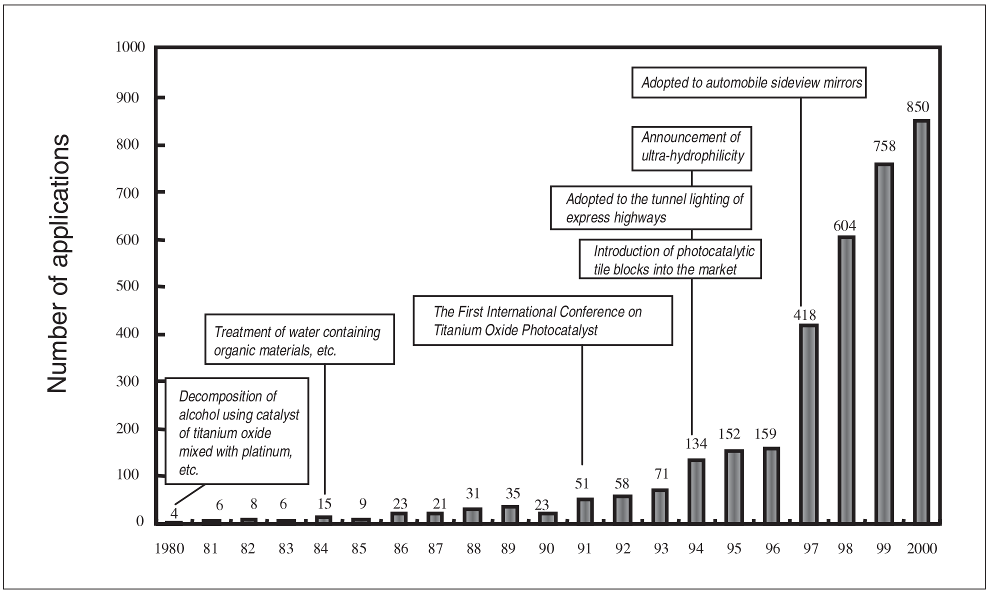
Four application examples and their structures and production processes have been briefly explained. Photocatalysis was at first expected to provide a technology for the production of hydrogen as in the Honda-Fujishima Effect. Then, the technology developed into the field of air cleaning and water treatment, and the applications have been drastically expanded to a wide range of areas including construction materials and automobiles since the thin film coating was devised. In the future, further expansion is expected with the progress of photocatalytic technologies. Now it is not a mere dream that photocatalysts will be incorporated in almost all of our daily commodities, and that we will enjoy the diversified benefits of photocatalysis in the near future.

7.4 Markets created by photocatalysts

In recent years, environmental contamination on a global scale has progressed and the environmental problem has become a very important issue that threatens the existence of human beings. In such a situation, photocatalysis is a hopeful technology for the 21st century that is called "the century of environment," because it is applicable to a relatively wide area of environmental issues including cleaning of air and water, measures for the sick house syndrome, deodorization, stain-proofing, and antimicrobial action. And yet, no harmful substances are emitted after treatment with photocatalysts. Development and practical application of high-performance photocatalysts have rapidly advanced, and it is estimated that about 3,000 companies have already entered this market.

The present market size of photocatalysts is estimated at ¥40 billion, and a research report published by Mitsubishi Research Institute expects that the market will grow to over ¥1,000 billion in 2005 (Figure 10)[20]. In the forecast, products related to deodorization for air cleaner and refrigerator account for ¥511.8 billion, those related to water treatment including sewage water and waste water for ¥354.4 billion, and stain-proofing of outside walls and tile blocks for ¥246 billion, amounting to ¥1,112.2 billion in total. Furthermore, the environmental industry market is expected to grow to ¥37,000 billion in 2010, and the photocatalyst industry is considered to be promising, playing a major role in the market. On the other hand, it is true that the present market size remains below expectations. The reason for this is that the cost of the catalyst is too high and

Figure 11: Number of patent applications related to photocatalyst



Source: Reference [21]

not that there are technical problems (reference[20] :"The World of Photocatalysts," p. 124). While it is not clear how much the cost hinders the growth of the industry, the recent rapid expansion of applications indicates that the cost related problem is being solved.

It is also possible that products not counted in the estimation may enter the market as a result of technical progress. For example, in agriculture, photocatalysts may be used in storage facilities for fruits and vegetables, utilizing their action to decompose and remove ethylene gas that accelerates the putrefaction of such fruits and vegetables. Also in the food manufacturing industry, where the control of bacteria in facilities is always a major issue, application of photocatalysts is expected. Since resistant microbes are generated when a large amount of disinfectants are used, the sterilizing power of photocatalysts that is not affected by the type of bacteria is the focus of attention as a very important function. It is expected that a new field of application will be developed as the research on photocatalysts advances.

Japan, where the world's most extensive research on photocatalysts is being conducted, has taken the leadership in its research and development. According to data from the Japan Patent Office, the number of patent applications in Japan over the past 20 years from 1980 to 2000 totaled 2,860 (Figure 11). This number significantly surpasses the number of registrations in the U.S. (409) and the number of applications in Europe (390) for the same period[21]. This indicates that patent application in Japan is very active compared to other countries and the number of applications accounts for almost 90% of the total of the world. Judging from this number of patent applications, Japanese photocatalyst technology is highly competitive in the world, and may offer a ray of hope to the Japanese long slumping economy.

7.5 Conclusion

Attracting attention as a new environmentally friendly technology, photocatalysts have a rapidly expanding market and are being used in our daily living environment.

In addition to the investigation to maximize the possibilities of individual photocatalyst, it is also expected in the future that completely new systems will be developed based on multi-photocatalyst systems, in which different types of catalyst cover the shortcomings of each other by combining their individual advantages, or transfer engineering, in which the photocatalytic function is combined with technologies of completely different fields.

As an immediate problem, cheap products with insufficient qualities are flowing in from overseas due to the present boom in photocatalyst development. Therefore, it is indispensable to establish standards such as JIS and ISO in the future.

Although the development of industrial applications for photocatalysts using titanium oxide as the major material is intensively advancing, these applications are essentially functioning as complementary roles for other technologies. Since photocatalysis is basically a clean technology, it has limitless possibilities if some kind of technical breakthrough can be achieved. There are two basic subjects in the research and development of photocatalysts.

One is the low quantum efficiency. In order to solve this problem, it is necessary to elucidate the basic mechanism of photocatalysis, and further, to search for materials that have quantum efficiency higher than that of titanium oxide. As has been previously described, one of the problems of titanium oxide is its high cost that prevents the prevalence of photocatalysts. If the problem of photodissolution is solved, for example, zinc oxide that is less expensive than titanium oxide can be used to achieve a breakthrough in the expansion of the market. Such basic research and development cannot be done by the industry, which is trying to develop the technology using titanium oxide as the major material. In a sense, this trend in the industry prevents the prevalence of the photocatalysis technology.

Another basic subject is the development of materials that respond to visible light. In this area, as has been already described, some trial tests have been made by adding nitrogen and transition metal elements. But the search for new materials has just started and satisfactory results have not yet been obtained. The initiative of technology in the post-titania age will be held by those who secure the basic materials. Since such search for materials is accompanied with a great deal of risk, it is difficult for the industry whose top priority is to make profits to undertake this.

Practical application of the photolysis of water is unforeseeable. Since the mechanism has not been elucidated, it is difficult to propose guidelines for the searching of materials. Therefore, it is indispensable to promote basic research as quickly as possible.

As explained above, in order to maintain and further develop the advantage Japan now enjoys in photocatalysis technology, it is insufficient to rely only on the efforts of the industry. It is essential to render political backing for the research and development. Particularly, the clarification of the photocatalysis mechanism provides the basis for the material search, and requires organizing physical and chemical knowledge theoretically. Even though Japanese private companies have intensively achieved their search for materials in the past, it is now economically difficult for them to search for materials even for their main lines of business. Essential materials for the next generation must be searched for from a national point of view. In the application of titanium oxide that is the major material at present, Japan is far ahead of other counties. However, a quarter of a century has past since titanium oxide was first used for photocatalysis. To establish a new phase for the photocatalyst industry, it is essential for Japan to develop materials for the next generation that supersede titanium oxide. It is most efficient if a wide range of public institutions take the charge of elucidating basic catalytic phenomena and searching for new materials, and this should be done urgently.

In order to complete photocatalysis technology that is friendly to all creatures on earth including human beings, we must make all-round efforts including a wide range of research and development from fundamentals to practical applications as well as the establishment of standards for the assurance of product quality.

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8

Non-fossil-resources-based Hydrogen Production Technology
— Key to Sustainable Hydrogen Energy Systems —

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8.1 Introduction

In the face of global energy and environmental concerns, there is a growing need to simultaneously deal with the issues represented by "3E," namely, energy supply, environmental conservation, and economic growth.

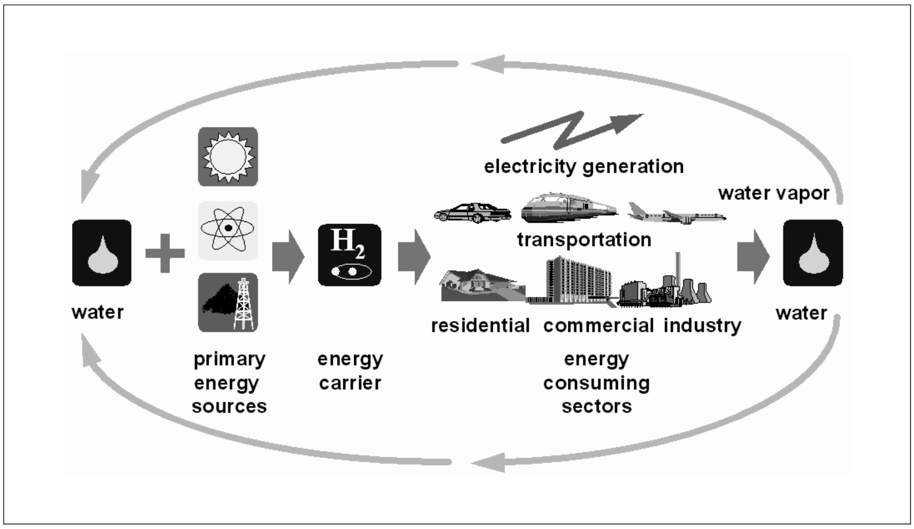
With this situation as a backdrop, hydrogen-energy-based systems such as fuel cells are receiving widespread attention. Hydrogen along with electricity is expected to play a major role as a source of secondary energy in the future.

In promoting hydrogen energy, however, it is indispensable that a variety of element technologies are developed and the infrastructure improved with respect to fuel cells and the production, transportation, storage and utilization of hydrogen. While global competition in this particular area heats up, both industry and academia in Japan have been pouring significant resources into research and development of fuel cells and hydrogen energy systems, the achievements of which are being published in succession through scientific journals and mass media.

The government is also active in developing promotional strategies and budgetary measures. The Council for Science and Technology Policy (CSTP), for instance, set the "2003 Guidelines for the Distribution of Budgets and Human Resources in Science and Technology" [1] in June, specifying fuel cells and the use of hydrogen as "priority areas and issues to be promoted" in the energy field.

Likewise, the Strategic Research Council on the Commercialization of Fuel Cell Technology under the Ministry of Economy, Trade and Industry specified five advantages in introducing fuel cells - i.e., energy saving, reductions in the environmental burden, diversified energy supply and substitution of oil, merits associated with decentralized power sources, and improved industrial competitiveness and development of new industries. The council positioned fuel cells as a key technology in the fields of energy and the environment in the 21st century.[2]

Figure 1: Two phenomena occurring on the surface of titanium oxide photocatalyst



Fuel cells are, so to speak, power generators using hydrogen as fuel; they generate electricity through the chemical reaction between hydrogen and oxygen, which produces water. Fuel cells, themselves, discharge water only. Hydrogen gas, however, does not exist naturally in any significant quantity on Earth, and hence it should be produced from fossil resources, biomass, water, etc.

At the moment, the widely held view is that hydrogen production will be heavily dependent on natural gas and other fossil resources. Underlying this view are scores of problems associated with the non-fossil-resources-based hydrogen production technology, the commercialization and spread of which are likely to take considerable time.

However, in view of conserving fossil resources and reducing greenhouse gas emissions, transition to the non-fossil-resources-based hydrogen production technology is required in the long run. Widespread applications of technology for producing hydrogen from resources such as water and biomass through the use of renewable and nuclear energy will dramatically conserve fossil resources and reduce greenhouse gas emissions (Section 8.3.3 addresses a quantitative study on these issues). Expectations for the commercialization of such sustainable hydrogen energy systems constitute the backbone of today's research on fuel cells and hydrogen energy. Figure 1 shows the hydrogen energy cycle using hydrogen derived from water.

Prospects for when and how these sorts of "ideal system" will be commercialized have a substantial influence on the significance and contents of policies for the introduction, commercialization and R&D strategies concerning fuel cells and hydrogen energy in the future. Determining the potential of the non-fossil-resources-based hydrogen production technology is thus critical for Japan in developing not only long-term but also short-to-medium term energy policies and R&D strategies.

For these reasons, this article will focus on the non-fossil-resources-based hydrogen production technology. Specifically, Chapter 8.2 provides an introduction to hydrogen energy and fuel cells; Chapter 8.3 reviews in a quantitative manner its significance in solving the 3E problem, based on the achievements of previous studies; Chapter 8.4 outlines trends in the research and development of mainstay technologies; and Chapter 8.5 rounds up findings and provides suggestions.

8.2 Hydrogen energy and fuel cells

Hydrogen along with electricity is expected to play a major role as a source of secondary energy in the energy system of the 21st century. Electricity can be converted into hydrogen, and vice versa; they are complementary to each other as follows:[4]

- Hydrogen can be stored in bulk, which is not the case with electricity;
- Electricity can transmit energy without moving substances, which is not the case with hydrogen;
- Hydrogen can be used as chemical fuel and industrial materials, which is not the case with electricity;
- Electricity can be used for processing and storing information, which is not the case with hydrogen; and
- Hydrogen is suitable for long-distance transportation, while electricity is an ideal medium for short-distance transportation.

Fuel cells are the most promising system for making use of hydrogen energy. The principle of fuel cells is the opposite of water electrolysis; they produce electricity through the chemical reaction between hydrogen and oxygen, which produces water. As shown in Table 1, fuel cells can be categorized into four types in terms of the electrolytes they use — i.e., the solid oxide type (SOFC), the molten carbonate type (MCFC), the phosphoric acid type (PAFC), and the polymer electrolyte type (PEFC). Fuel cells are used primarily for fuel cell vehicles (FCV), stationary power sources for domestic and business use (including cogeneration systems) and power sources for portable equipment.

Table 2 shows the "prospective targets for introduction" specified in the Strategic Research Council Report on the Commercialization of Fuel

Table 1: Four types of fuel cells [5], [6]

	Solid Oxide Type (SOFC)	Molten Carbonate Type (MCFC)	Phosphoric Acid Type (PAFC)	Polymer Electrolyte Type (PEFC)
Electrolyte	Stabilized zirconia	Carbonate	Phosphate	Ion exchange membrane
Fuel (Reactant)	Hydrogen, carbon monoxide	Hydrogen, carbon monoxide	Hydrogen	Hydrogen
Operational Temp.	900-1,000℃	650-700℃	200℃	70-90℃
Power Generation Efficiency (HHV)	45-55%	45-50%	40-45%	35-40%
Characteristics	High power generation efficiency Accommodates internal reforming	High power generation efficiency Accommodates internal reforming	Soon to be commercialized Difficult to start and stop operations	Can be operated at low temperatures High energy density Relatively easy to start and stop operations
Development Status	Demonstration stage	Demonstration stage	Commercialization stage	Soon to be put into practical use
Applications	Centralized large-scale power generation, decentralized power sources, cogeneration systems	Centralized large-scale power generation, decentralized power sources, cogeneration systems	Decentralized power sources, cogeneration systems	Vehicles, domestic cogeneration systems, portable power sources

Table 2: Prospective targets for the introduction of fuel cells commercialization conference (cumulative amount) [3]

Period	Description of the Period	Targets for Introduction by the End of the Period	
		Fuel Cell Vehicles	Stationary Fuel Cell
2002 - 2004	Period for improving infrastructure and demonstrating technology	-	-
2005 - 2010	Period for introduction	50,000 units	2.1 million kW
2010 - 2020	Period for applications	5 million units	10 million kW

Cell Technology (for the polymer electrolyte fuel cells).[2]

8.3 The significance of the non-fossil-resources-based hydrogen production technology — from the viewpoint of solving the “3E” problem

As mentioned earlier, molecular hydrogen does not exist naturally in any significant quantity on Earth, and, hence, hydrogen for fuel cells should be produced on- or off-site. In the case of fuel cell vehicles, hydrogen can be produced off-site and transported for use for fuel cell vehicles (pure hydrogen fuel cell vehicles), or it can be produced from methanol or gasoline by in-vehicle reformers (reformer fuel cell vehicles) (see Footnote 1). The advantage in introducing fuel cells (e.g., substitution of oil, energy saving and reductions in the environmental burden) depends largely on fuel types and their production methods.

This chapter outlines supply and demand trends of hydrogen and its production methods, provides the results of existing analyses regarding the effects of saving energy and reducing greenhouse gas emissions by fuel and production method, and sheds light on the significance of the non-fossil-

Footnote 1:

Fuel cells based on molten carbonates or solid oxides accommodate internal reforming, and can use natural gas and coal gas as fuel. However, their applications for vehicles and small-scale stationary power sources have yet to be examined.

resources-based hydrogen production technology.

8.3.1 Supply and demand trends of hydrogen

The world's hydrogen production currently stands at some 500 billion Nm^3 a year (Nm^3: volume at 0°C and 1 atm), most of which is produced by steam reforming of fossil fuel such as natural gas; about 40% of which is consumed by ammonium synthesis, and some 20% by oil refining. The world's largest steam-reforming plant can produce 100,000Nm^3 of hydrogen per hour.[7]

Domestic demand for hydrogen is estimated at 15-20 billion Nm^3 a year, about half of which is consumed by oil refining. As for applications for energy, 3-5 million Nm^3 of liquid hydrogen is used annually for launching space rockets.[5] On the other hand, more than 10 billion Nm^3 of hydrogen is produced annually as the by-product of steel-making, oil refining and ethylene production, most of which is consumed by the producers themselves as energy sources or materials for chemicals (a mere one percent, more or less, is sold on the market).

As shown in Table 2, the Strategic Research Council on the Commercialization of Fuel Cell Technology set the target for introducing fuel cell vehicles at 5 million units by 2020 (cumulative amount). About 5 million fuel cell vehicles on the road require some 14 billion m^3 of hydrogen per year.[8] If fuel cell vehicles become widespread in the future, commanding a 50% share of the total number of passenger vehicles (which currently stands at 53 million units[9]), five times this volume will be required to meet the expected demand. Taking into account hydrogen to be consumed by stationary fuel cells, much more hydrogen will be needed.

The widespread use of hydrogen energy systems will inevitably boost demand for hydrogen. How to produce hydrogen is thus a major challenge to be addressed, which in turn determines the entire framework of the systems.

8.3.2 Hydrogen production methods

Table 3 shows typical methods for producing hydrogen, which are broadly categorized into those using fossil resources and those using non-fossil resources, as materials or energy sources. The methods using fossil resources have been industrialized, but they emit large amounts of CO_2 (see Footnote 2). Take the steam-reforming process for instance: this mainstay method for producing hydrogen emits 0.9kg of CO_2 in producing 1m^3 of hydrogen even when using natural gas — a material that involves the least amount of CO_2 emissions.[7]

The methods using non-fossil resources can be categorized into; (1) water electrolysis using electricity derived from non-fossil fuel, (2) thermochemical water splitting, (3) biomass

Table 3: Hydrogen production methods

	Method	Material	Energy	Status of Technological Development
Fossil-resources-based	Steam reforming	Natural Gas, LPG, Naphtha	Heat	Commercialization
	Partial oxidation	LPG, Naphtha, Crude Oil, Coal	Heat	Commercialization
	Catalytic reforming	LPG, Naphtha	Heat	Commercialization
	Coke furnace gas	Coal	Heat	Commercialization
	Electrolysis	Water	Electricity (derived from fossil resources)	Commercialization
Non-fossil-resources-based	Electrolysis	Water	Electricity (derived from non-fossil resources)	Commercialization
	Thermochemical splitting	Water	Nuclear, Solar Heat	Demonstration stage
	Biomass conversion	Biomass	Heat, Bacteria, etc.	Demonstration stage
	Photolysis	Water	Sunlight	Basic study stage

Footnote 2:

Even when reforming fossil resources, zero emissions can be achieved at large-scale hydrogen production facilities through the applications of CO_2 recovery and sequestration technologies. There has been a growing interest in CO_2 underground storage; for details, refer to "Trends in the Development of Measures Against Global Warming Centered on CO_2 Underground Storage" (Kazuaki Miyamoto, the Jan. 2003 issue of Science & Technology Trends – Quarterly Review).

conversion, and (4) water photolysis, all of which virtually eliminate CO_2 emissions and the consumption of fossil resources. Of these, however, only the method based on "(1) water electrolysis" has been established so far.

8.3.3 Life cycle assessment of fuel-cell-based systems

Section 8.3.1 demonstrated that hydrogen production should be expanded dramatically in response to the widespread applications of hydrogen energy systems. Even if fossil resources are used for hydrogen production in this scenario, fossil resources can still be conserved and global warming gas emissions can be reduced on the condition that the energy efficiencies of fuel-cell-based systems (vehicles, stationary power sources, etc.) are higher than those of their conventional counterparts. Then, to what extent are they effective in these respects?

To answer this question, there is a need to assess the life cycle of fuel-cell-based systems — i.e., energy required for the extraction of raw materials, transportation, fuel production and the actual fuel consumption. This kind of assessment with respect to vehicles is called a "well-to-wheel" analysis.

Take CO_2 emissions for instance: in the case of conventional gasoline-powered vehicles, a large part of their lifecycle CO_2 emissions is attributable to their operations, while the extraction of crude oil and the production/transportation of gasoline involve less CO_2 emissions. By contrast, fuel cell vehicles loaded with hydrogen derived from fossil resources emit no CO_2 when they are being driven, while hydrogen production itself is a major source of their lifecycle CO_2 emissions.

Referring to the results of the life cycle assessment conducted by Thomas et al.,[11] and Wang,[12] the third IPCC report[10] addresses the effects of fuel cell vehicles in conserving energy and reducing greenhouse gas emissions. The New Energy and Industrial Technology Development Organization (NEDO) of Japan conducted a similar analysis through the project for developing hydrogen energy use technology (WE-NET) (see Footnote 3).[13] Based on these findings, this Chapter examines the effects of fuel cell systems in conserving fossil resources and reducing greenhouse gas emissions.

With regard to the effects of conserving fossil resources, the fuel economy figures of pure-

Figure 2: Assessment of the life cycle of greenhouse gas emissions [12]

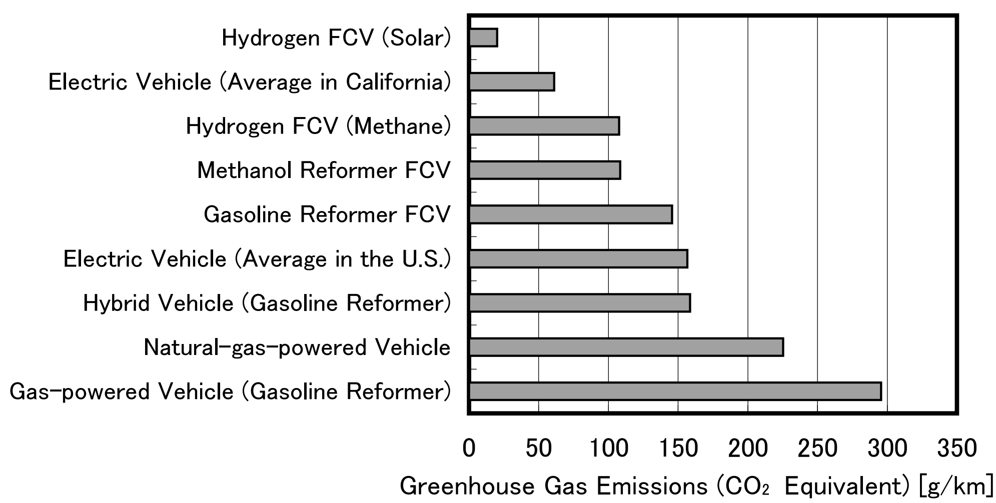
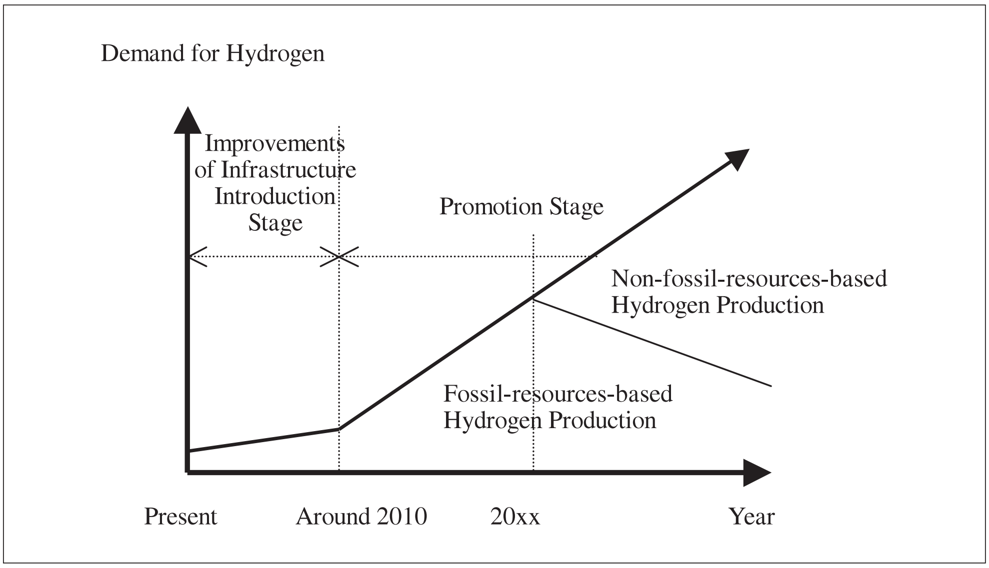


Figure 3: Transition to Non-fossil-resources-based hydrogen production technology



hydrogen fuel cell vehicles and methanol reformer fuel cell vehicles (see Footnote 4) improve by 75-250% and 25-125%, respectively, compared with those of conventional gasoline-powered vehicles, according to Thomas et al. Likewise, Wang's results show 180-215% and 110-150% improvements in fuel consumption, respectively. WE-NET concludes that the fuel consumption of gasoline reformer fuel cell vehicles is about three times lower than those of conventional gasoline-powered vehicles. Moreover, 40-60% improvement in energy consumption can be expected in using by-product hydrogen from coke furnaces, and for fuel cell vehicles using liquid fuel derived from natural gas. It is also noted here that gasoline hybrid vehicles and electric vehicles are likewise effective in conserving energy.

On the other hand, the total energy consumption of fuel cell vehicles using hydrogen derived from non-fossil resources depends largely on the energy sources to be used for hydrogen production, the place of its production and the transportation methods. Meanwhile, there have been discussions as to whether renewable energy should be included when calculating energy consumption. Whatever the case may be, the consumption of fossil resources will be reduced dramatically.

Figure 2 shows part of the results of Wang's life cycle assessment regarding the effects in reducing greenhouse gas emissions in the case of passenger vehicles in the U.S. In general, the amount of greenhouse gas emissions shows a trend similar to that of the results of fuel consumption. The amount of greenhouse gases emitted by gasoline or methanol reformer fuel cell vehicles and fuel cell vehicles using hydrogen derived from natural gas is lower than that emitted by conventional gasoline-powered vehicles by 50% and 60%, respectively. Likewise, electric vehicles reduce emissions by 50%, though depending on the makeup of power sources. Gasoline hybrid vehicles are similarly effective. Emissions can be reduced dramatically in the case of producing

Footnote 3:

The project was launched in fiscal 1993 with an eye toward the global use of renewable energy derived from hydrogen. Phase 1 of the R&D program (a six-year program, budgeted at ¥10 billion) of the project was completed in fiscal 1998, and Phase 2 of the R&D program was subsequently launched in fiscal 1999. Phase 2 will be completed in fiscal 2002, a year ahead of schedule, which will be consolidated into the "project for developing basic technology for the safe use of hydrogen" to be launched in fiscal 2003.

Footnote 4:

Fuel consumption, in this chapter, refers to the total amount of energy consumed by the whole process ranging from the extraction of materials to the driving of vehicles.

hydrogen from solar energy.

Up to this point, we have considered the assessment of fuel cell vehicles. According to the assessment conducted by WE-NET for decentralized stationary fuel cell power sources,[13] their energy efficiency and the amount of CO_2 emissions are almost the same as those of existing large-scale power generation systems, while lagging behind those of highly efficient LNG combined cycle power generation systems, as far as the "power generation" part is concerned. The performance of fuel cells as a cogeneration system is similar to or lower than that of cogeneration systems directly using city gas or light oil.

To sum up, even when using fossil resources to produce hydrogen, fuel cell vehicles are quite effective in conserving fossil resources and reducing greenhouse gas emissions. Fuel cell vehicles, however, compete directly with gasoline or natural gas powered hybrid vehicles and electric vehicles, and so do stationary fuel cells with cogeneration systems directly using city gas or light oil. Fuel-cell-based systems do not necessarily outperform these competing technologies.

Meanwhile, fossil-resources consumption and CO_2 emissions can be virtually eliminated if hydrogen is produced from such resources as water and biomass through the use of renewable or nuclear energy. From the viewpoint of solving the "3E" problem, therefore, it is preferable that the non-fossil-resources-based hydrogen production technology becomes widespread in the near future. Figure 3 shows a scenario for the transition to the non-fossil-resources-based hydrogen production technology.

8.4 Trends in the R&D of the non-fossil-resources-based hydrogen production technology

This chapter addresses hydrogen production methods that use no fossil resources as materials and energy sources, and divides these methods into four categories — (1) water electrolysis, (2) thermochemical water splitting, (3) biomass conversion, and (4) water photolysis - for outlining trends in the R&D of each method.

8.4.1 Water electrolysis

Water electrolysis is the simplest method for producing hydrogen. However, it involves a large amount of CO_2 emissions in the case of using electricity generated by such facilities as thermal power plants burning fossil resources. On the other hand, fossil-resources consumption and CO_2 emissions can be virtually eliminated if water is electrolyzed by the electricity derived from nuclear or renewable energy (including hydropower).

Since electricity is a valuable form of energy, there is a need to consider a balance with other electrical needs and minimize the total cost of energy supply when using electricity for large-scale hydrogen production. Primarily, this hydrogen production method should be promoted in relation to the utilization of nighttime electricity for improving plant availabilities and to output-leveling measures for connecting wind-power plants to the grid.

The electrolytic process of water can be broadly categorized into electrolysis using alkaline water and that using polymer electrolyte. The alkaline

Figure 4: Principle of water electrolysis based on the polymer electrolyte method [5]

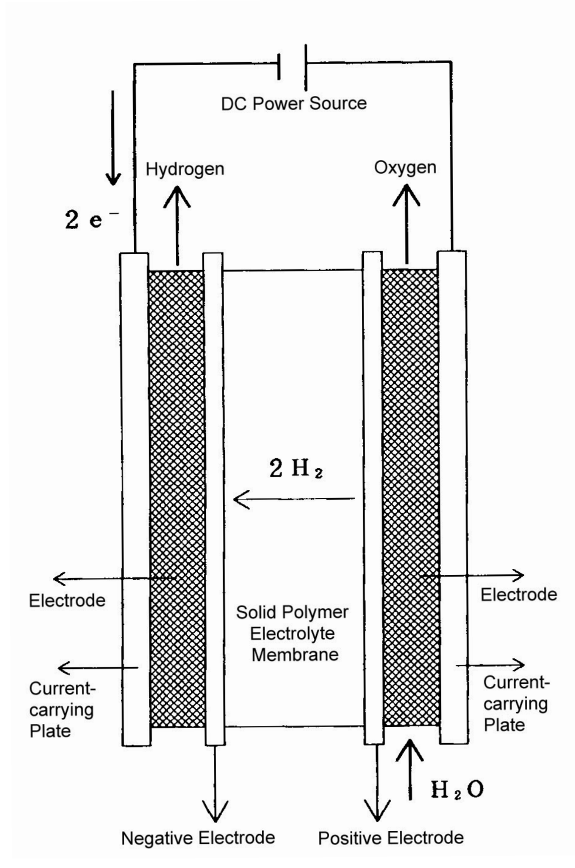


Figure 5: Hydrogen supply station (on-site hydrogen production type) based on the water electrolysis method [14]

water electrolysis method is already in commercial use; it is a simple method but low in energy conversion efficiency and susceptible to corrosion. Figure 4 shows the principle of the polymer electrolyte method:[5] a polymer electrolyte membrane (made of fluoropolymers) is sandwiched by platinum catalytic electrodes, porous electrodes and current-carrying plates. The porous electrodes function as a medium that conveys both electricity and gas/liquid — water is supplied to the positive electrode and hydrogen is generated by the negative electrode. This particular method, which has yet to be commercialized, is high in energy conversion efficiency, free from corrosion because of the absence of alkaline solution, and contributes to making equipment compact.

WE-NET has been conducting a project since 1993 for the technological development of water electrolysis based on the polymer electrolyte method. As part of this project, a hydrogen supply station (on-site hydrogen production type) was set up in February 2002 in the precinct of Shikoku Research Institute in Takamatsu. The station is one-tenth the size of commercial facilities and can produce 30Nm^3 of hydrogen per hour (see Figure 5).

8.4.2. Thermochemical water splitting

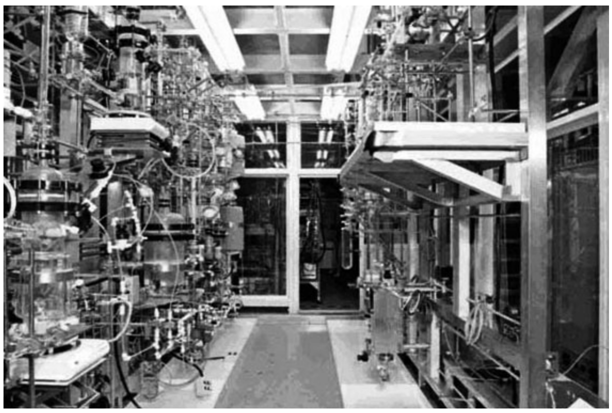
In theory, direct splitting of water requires a large amount of heat with temperatures exceeding 2,500ºC. A number of thermochemical processes have been proposed, each of which incorporates thermochemical reactions to split water at temperatures lower than 1,000ºC. In relation to this, nuclear energy and solar energy are considered their possible heat sources that emit no CO_2. In particular, the use of nuclear reactors is receiving attention as promising heat sources that can accommodate large-scale hydrogen production.[15]

Of the variety of thermochemical water splitting cycles, the “IS Process” is the most promising technique, which is being studied by the group led by the Japan Atomic Energy Research Institute.[16] This particular process, originally invented by General Atomics (U.S.), is designed to recycle iodine (which reacts with material water) and compounds derived from sulfur within the process in order to eliminate the release of hazardous substances. It involves the following three chemical reactions:

At the moment, high temperature gas reactors (HTGRs) are assumed to be the prospective heat sources for the IS Process. High temperature gas reactors can provide a large amount of heat with temperatures exceeding 900ºC and are relatively safe in the first place. Light water reactors, meanwhile, cannot accommodate the process because of their limited capacity for heat supply (300ºC or below).

The Japan Atomic Energy Research Institute developed continuous hydrogen production equipment (capacity: 50 liters per hour) in 2001 based on the IS Process, and subsequently launched relevant research programs. The equipment will be connected to a high-temperature engineering test reactor (HTTR) that

Figure 6: Continuous hydrogen production equipment based on the thermochemical water splitting method (IS process) (The Japan Atomic Energy Research Institute) [16]



(Left front: equipment for the Bunsen reaction process; left back: equipment for the sulfuric-acid decomposition process; and right back: equipment for the distillation of hydrogen iodide.)

Bunsen Reaction	$2H_2O + xI_2 + SO_2 = 2HIx + H_2SO_4$	Ambient Temp. to 100ºC
Decomposition of Hydrogen Iodide	$2HI = H_2 + I_2$	400ºC
+ Decomposition of Sulfuric Acid	$H_2SO_4 = H_2O + SO_2 + 1/2O_2$	800ºC
	$H_2O = H_2 + 1/2O_2$	

is being tested by the Institute. Figure 6 shows the external view of the equipment.

A one-million-kWe high temperature gas reactor that operates 7,000 hours a year can produce 3.4 billion Nm^3 of hydrogen per year (the heat efficiency of hydrogen production = 50%). A light water reactor with the same capacity can produce 1.7 billion Nm^3 of hydrogen per year through water electrolysis.[4] The thermochemical method, which needs no conversion of heat into electricity, outperforms the electrolysis method in total energy efficiency. Incidentally, it is estimated that the combination of a high temperature gas reactor and the IS Process produces hydrogen at a cost 1.5 times higher than that of the commercial steam reforming method using fossil resources.

Because of their large energy output with high density, nuclear power plants can accommodate large-scale hydrogen production; they are expected to be an option that can meet the expanding demand for hydrogen in the future, respond to environmental constraints and conserve fossil resources. However, thermochemical cycles that can make use of the heat generated by today's dominant light water reactors have yet to be developed.

8.4.3. Biomass conversion

Biomass refers to organic resources of plant origin such as agricultural waste, forestry waste, fishery waste, garbage and energy crops. Energy derived from these resources is called bioenergy, which is inexhaustible in its nature and thus receiving attention as a promising option for curbing global warming since, as a whole, it emits no CO_2. Hydrogen production processes using bioenergy, such as combustion heat, electricity, liquid fuel, etc., or biomass as materials generate CO_2, but the amount is equal to that produced by the original plants in the course of their growth. In a total sense, therefore, the use of biomass does not increase the CO_2 concentration in the atmosphere (carbon neutral).

Biomass takes a variety of forms, and so does hydrogen production using biomass. With the use of dry biomass, hydrogen can be produced primarily through the thermochemical gasification process. In this case, the combustion heat of biomass itself is generally used for increasing reaction temperatures. However, there is a need to reform or eliminate by-products such as carbon monoxide and hydrocarbon gases.

With respect to wet biomass, the methane fermentation process is already operational; hydrogen can be produced from methane, but the whole process takes several weeks. Other processes such as catalytic aqueous-phase reforming,[17] supercritical water gasification[18] and bacteria-based hydrogen fermentation[19] have been invented.

One of the advantages of biomass is that it can be readily converted into liquid fuel (ethanol, methanol, biodiesel, etc.). Methanol and hydrogen derived from biomass can be used for fuel cell vehicles, or they can be used directly as internal combustion fuel (see Footnote 5).

8.4.4. Water photolysis

Water photolysis is the technology where hydrogen is produced by splitting water through the use of solar light energy. This chapter addresses the direct photolysis of water using photocatalysts and the like — the area in which Japan has been taking the lead ever since the "Honda-Fujishima Effect",[20] water photolysis by an electrochemical cell made up of a titanium-dioxide electrode and a platinum electrode, was reported in 1972.

Scores of photocatalytic materials responding to

Footnote 5:

Comparison between these options goes beyond the scope of this article. In some states in Brazil and the U.S., ethanol produced from sugarcane and corn or a mixture of ethanol and gasoline are becoming popular as automotive fuel.

ultraviolet rays have been discovered so far, but the energy of these rays represents a mere 4% of solar light energy. In order to produce hydrogen efficiently, therefore, there is a need to develop photocatalysts that respond to a broad range of visible light (wavelength: 400-700nm), the energy of which represents some 43% of solar light energy.

Such photocatalysts with satisfactory stability and function have been considered difficult to develop. However, as some new findings have been reported recently, research in this particular area is gaining momentum.

The group led by Hironori Arakawa, director of the Photoreaction Control Research Center under the National Institute of Advanced Industrial Science and Technology, came up with a breakthrough: using a metal-oxide semiconductor ($In_{1-X}Ni_XTaO_4$, X=0-0.2), doping indium/tantalum oxides with nickel, for the first time in the world the group succeeded in fully photolyzing water (hydrogen:oxygen = 2:1) through the single-step photoexcitation of visible light, the results of which were published in Nature last year.[21] By doping nickel, the activity of photocatalysts for short-wavelength visible light improves dramatically, while it disappears for visible light with a wavelength longer than 550nm. The quantum efficiency stands at 0.66% for light with a wavelength of 402nm (see Footnote 6). The group also succeeded in fully photolyzing water with the use of visible light, imitating a two-step photoexcitation reaction, namely the photosynthesis mechanisms of plants.[22]

Even though under UV irradiation, Associate Professor Akihiko Kudo at the Science University of Tokyo succeeded in fully photolyzing water using $NiO/NaTaO_3$ doped with lanthanum, and produced hydrogen from a reaction tube (with a capacity of about 400ml) at a high rate of 20mmol/h (500ml/h).[23] Compared to water electrolysis, this performance corresponds to an electrolytic current of 1A or more, with its quantum efficiency reaching 50% at a wavelength of 270nm. As for photocatalysts responding to visible light, $SrTiO_3$ doped with Cr^{3+} and Ta^{5+} or Sb^{5+}, $NaInS_2$ and $AgInZn_7S_9$ are reported to exhibit high activity in hydrogen production, though under the existence of sacrificial agents (see Footnote 7).[24]

Footnote 6:

Quantum efficiency refers to the ratio between the number of incident photons and the number of electrons involved in the reaction.

Footnote 7:

Sacrificial agents refer to additives (methanol, etc.) to be added in order to prevent generated hydrogen from being re-oxidized - a reverse reaction that produces water.

The group led by Professor Kazunari Domen at the Tokyo Institute of Technology is conducting another research in this area: aiming at developing photocatalysts capable of splitting water, the group focused on oxynitride/oxisulfide-based photocatalytic materials, and has been testing their response to visible light. The results show that $LaTiO_2N$, Ta_3N_5, TaON and $Sm_2Ti_2S_2O_5$ sufficiently absorb visible light with a wavelength up to 600nm.[25, 26]

The research on photocatalysts responding to visible light is becoming active not only for producing hydrogen but also for developing antifoulants, disinfectants and deodorants for building exteriors, car interiors, etc. This particular area is attractive to researchers in terms of the basic study relevant to materials science and catalyst science.

As far as hydrogen production is concerned, however, water photolysis is low in energy efficiency, and, hence, it is a long way from being commercialized. In fact, the energy efficiency of the process is lower than those of other hydrogen production systems using solar light systems combining photovoltaic generation and water electrolysis, systems converting biomass into hydrogen, etc., by a factor of ten to several hundred. With this situation as a backdrop, there is a need to develop innovative photocatalysts that respond to long-wavelength visible light with sufficiently high quantum efficiency.

In addition to the above processes using semiconductor-type photocatalysts, the feasibility of photobiological hydrogen production — a system where hydrogen is produced by photosynthesis bacteria - is being examined,[19] with genetic engineering techniques being applied in developing photosynthesis bacteria. This hydrogen production system, however, requires a large amount of energy input — a factor that reduces the possibility of commercialization. The hydrogen production capacity of bacteria must be enhanced dramatically.

8.5 Conclusion

In this report, we have focused on the non-fossil-resources-based hydrogen production technology as the key to creating sustainable hydrogen energy systems, and discussed its significance from the viewpoint of future demand for hydrogen and its effects in conserving fossil resources and reducing greenhouse gas emissions. Moreover, we have divided the technology into the four categories of (1) water electrolysis, (2) thermochemical water splitting, (3) biomass conversion, and (4) water photolysis, analyzing trends in technological developments and issues to be addressed for each of these categories.

Fuel cells are energy-efficient in their nature. Take fuel cell vehicles for instance: they both significantly conserve fossil resources and reduce greenhouse gas emissions, even if they use hydrogen derived from fossil resources. As far as the results of our analysis are concerned, however, fuel cells do not outperform other competing technologies, such as hybrid vehicles, electric vehicles, combined cycle power generation, city gas cogeneration systems, etc.

When using hydrogen derived from non-fossil resources, meanwhile, fuel cells virtually eliminate fossil-resource consumption and greenhouse gas emissions. In this context, the non-fossil-resources-based hydrogen production technology is the key to creating sustainable hydrogen energy systems; it is particularly significant for Japan, whose self-sufficiency rates in energy remain at low levels.

Thus, Japan needs to pursue this technology on a long-term basis, placing emphasis on its research and development. Determining the potential of such ideal technology for producing hydrogen will provide fundamental information in developing not only long-term but also short-to-medium term energy policies and R&D strategies.

As we have discussed, all the methods excluding water electrolysis are still in their basic-study or demonstration stages; it is important that potential methods be explored widely and the feasibility of each method be assessed.

It is also important to grasp the role of hydrogen in the whole energy system, keeping track of advances in relevant technologies and changes in the global energy map. For instance, role sharing between electricity and hydrogen has yet to be determined.

Hydrogen is secondary energy along with electricity, functioning as a common currency among various energy systems. In this context, it involves all the aspects of energy such as its production, conversion, transportation and consumption. In designing energy systems including hydrogen energy, it is indispensable to bring up specialists well versed in energy-related technologies and policies. Moreover, exchanges of human resources in the energy field and cooperation among academia should be promoted.

It seems that hydrogen production using renewable energy holds great potential especially for developing countries where available land and renewable energy sources are abundant and many areas have no access to the electricity grid. It requires neither a large amount of initial investment nor advanced technology in plant maintenance.

From the viewpoint of technological development and international cooperation, therefore, it should be of benefit to Japan to actively develop technologies to be transferred to developing countries, while promoting local joint projects.

As is the case with technologies related to hydrogen production, each of which has been discussed in this article, there are also many challenges posed to the technologies related to the storage, transportation and utilization of hydrogen. For this reason, the hydrogen production technology of the future should be developed based on a broad perspective that includes advances in related technologies, improvements in related infrastructures and the usage of hydrogen energy.

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9

Trends in Research toward Integrated Water Management Based on the Water Cycle

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9.1 Introduction

Japanese cities have developed in river basins and the water cycle of nature has been the center of people's lives. However, growing social and economic activities have imposed a heavy burden on the environment, damaging it in many ways.

This is in fact a global issue occurring not only in Japan. Interaction between the water cycle and human activities such as modification of landscapes results in world water problems from both quantitative and qualitative aspects.

The water problem is attracting people's attention today. The current status and prospects of world water supply and demand were presented in the World Summit on Sustainable Development (Johannesburg Summit 2002) held in August 2002. Also, reports on water problem research will be set forth, and debate based on studies will be conducted in the Third World Water Forum, which will be held in Japan in March 2003.

Effective use of water resources and establishment and maintenance of a sound water cycle, in which pure and abundant water circulates continuously, are crucial in solving the water problem.

Research and development for creating a sound

Table 1: Principal goals in the field of the environment

Principal goals	Initiative	Outline
Research on technology for restoring cities in river basins in terms of coexistence with nature	Program for monitoring the urban and river basin environment	Technological development for observing and evaluating the current status of ecosystems and cities from the viewpoint of both the natural environment, such as the water cycle, matter flow and biodiversity, and the social environment, such as urban rivers and coasts.
	Program for developing urban and watershed management models	Improvement of element models, such as water cycle models and ecosystem models, and integration and management models
	Program for improving technology encouraging coexistence with nature	Development of technology for revitalizing ecosystems and our living space focusing on the water cycle
	Creation of scenarios toward coexistence with nature	Creation of scenarios for comprehensively encouraging coexistence with nature and development of practical technologies based on them
Research on global water cycle dynamics	Program for monitoring the global water cycle	Improvement of monitoring systems and management of databases
	Program for developing models of water cycle dynamics	Clarification of mechanisms of energy transportation and natural dynamics of the water cycle, and development of models for estimating fluctuation in the water cycle and the environment caused by human activities
	Program for estimating the effects of fluctuation in the water cycle on human society	Assessment of effects of fluctuation in the water cycle on food production, society, and the economy
	Program for comprehensive evaluation of scenarios and technological development for tackling the water problem	Provision of the optimum scenario for tackling the water problem

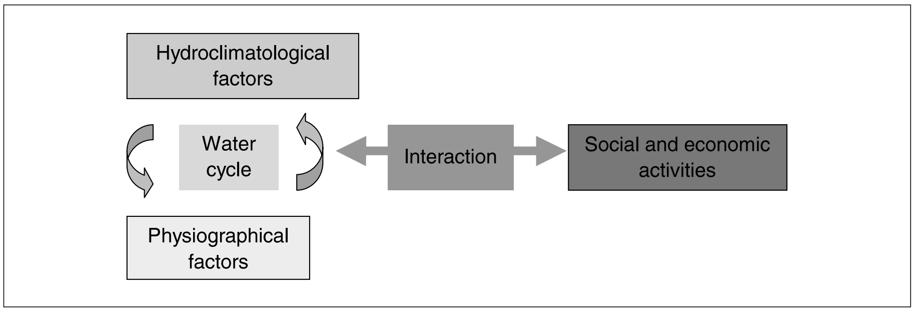
Sources: Promotion Strategy of Prioritized Areas of the Science and Technology Basic Plan

Table 2: Keynotes in the field of urban infrastructure

Keynotes	Research themes	Goals in research and development
Restoration of beautiful Japan and establishment of a high-quality infrastructure	Establishment of a sound water cycle in river basins and realization of integrated water management	Research and development for establishing sound water cycles in important water systems, rivers in major small- and middle-sized cities, areas specified by the government in the Land Subsidence Prevention Rules, i.e., the northern part of the Kanto plains, the Nobi plains and the Chikugo and Saga plains, and major river basins of the world

sources: the same reference as in Table 1

Figure 1: Concept of the water cycle and water resoureces system



Source: Lecture No.93 of the National Institute of Science and Technology policy: Water Cycle and Water Resources–From Local to Global Views

water cycle in river basins and conducting integrated water management have been promoted vigorously in the field of the environment and urban infrastructure under the Promotion Strategy of Prioritized Areas of the Second Science and Technology Basic Plan adopted at the Council for Science and Technology Policy of Japan's Cabinet Office.

In an effort to reveal the entire mechanism of the water cycle, basic models of urban river basins and analysis models of global demand and supply of water have been improved, and quantitative estimation of the water cycle is becoming possible. It is hoped that highly accurate models in which sediment movement and complex landscapes can be taken into consideration will be developed. Such development will help to establish models of water cycle dynamics and contribute greatly to the estimation of water resources and fluctuation in the water cycle in Asia including Japan.

Meanwhile, integrated water management has been advanced based on case studies of urban river basins. Yet, environmental indicators and estimation methods, which are deeply related to water management, have not been fully researched compared to flood control and water utilization.

In this report, I will introduce to you trends in research toward integrated water management in respect to the water cycle, such as improvement of analysis models of global demand and supply of water, focusing on the field of study dealing with the water cycle, which is prioritized in the Second Science and Technology Basic Plan.

9.2 Research goals in the promotion strategy of prioritized areas

The promotion strategies of the Second Science and Technology Basic Plan set principal goals in water cycle research in the field of the environment and social infrastructure as shown in Table 1 and 2, respectively.

9.3 The water cycle and water resources system

The water cycle and water resources system comprises water, land and people. This is a dynamic system determined by hydroclimatological factors, such as rainfall, evapotranspiration, temperature and irradiation, physiographical factors, such as landscapes, geological features and soil, and artificial factors, such as social and economic activities. Hydroclimatological and physiographical factors fluctuate through interaction with artificial factors, and these three factors characterize the water problem.

9.4 Trends in research for revitalizing the watershed water cycle and achieving integrated water management

9.4.1 Technology helping to revitalize the water cycle

Storage and infiltration are basic technologies for establishing and maintaining the sound water cycle.

Forests and farmland can be deemed as water storage and infiltration facilities with large capacities. Meanwhile, in river basins in highly urbanized areas, how to store and infiltrate water in the ground and return it to rivers through groundwater flow are essential in maintaining the cycle of clean and abundant water. Infiltration facilities such as a seepage pit and a seepage trench serve as infrastructures for realizing this favorable water cycle. Topographical and geological conditions are crucial in building infiltration facilities with sufficient infiltration capacities. Generally, tablelands, alluvial fans, hilly terrains and sands are suitable, while solid ground with low air porosity, viscous soil and places with high groundwater elevation are unfavorable. The infiltration facility is built into each house and rainwater is guided into the ground. This equipment is also connected to rainwater main pipes of the sewer system, so that excessive water may escape to these pipes upon downpours.

In the meantime, in the construction of sidewalks, permeable pavement is spreading instead of conventional pavement especially in urban areas. This provides surface asphalt with adequate porosity and makes water infiltrate into and under the ground through the roadbed.

9.4.2 Environmental estimation methods in river basin water management

A sound water cycle is defined as the sustainable, effective and balanced functioning of water in the water cycle with river basins as its center from the viewpoint of flood control, water utilization and environmental conservation, and this is becoming a worldwide concept. The relationship between the water cycle and people concerns flood control, water utilization and environmental conservation, which have different values and interests, and how to assess the balance with the environment is crucial. The environment is sometimes an abstract concept and is often estimated subjectively. Thus, it is hard to build a consensus among people in this field of study.

A primary goal for the improvement of water management in river basins is to establish a good relationship between the water cycle and people by harmonizing differences in requirements among various entities and easing conflicts of interests through adopting new technologies and altering political systems properly.

Currently, the Ministry of the Environment and the Ministry of Land, Infrastructure and Transport conduct surveys on ecosystems, water analysis and census in river basins every year, accumulate basic data and analyze data properties and distribution. Also, they estimate the recharge and heat-shielding ability of forests, farmland and wooded areas.

By determining environmental indicators based on these basic data, they try to establish an estimation method for comprehensively evaluating the characteristics of species living in river basins and their habitats in terms of the relationship with flood control and water utilization. Such a method will help to boost environmentally friendly projects and nature-restoration programs.

9.4.3 Water cycle models

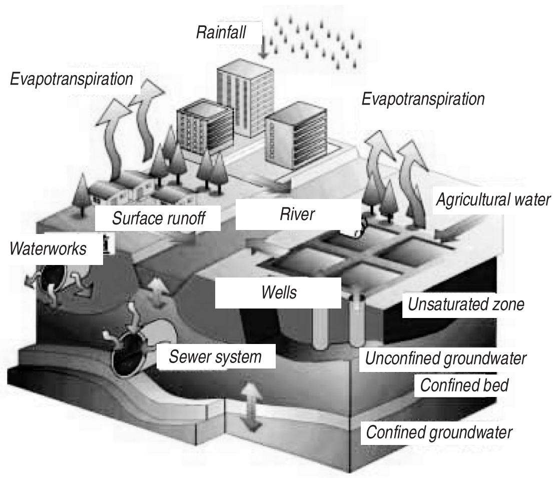
In improving river basin water management based on the sound water cycle, we need to develop analysis models in which related observation data are accumulated and the effects of water management projects are grasped and evaluated quantitatively based on these data.

In this section, I introduce to you water cycle modeling, which helps in the understanding and estimation of water dynamics in river basins from data on land usage and hydrological, geological and topographical properties.

The distributed physically based model is one of the most precise methods for analyzing the water cycle.

In this model, the water cycle in a river basin is

Figure 2: A conceptual model of the water cycle



Source: Material from the Tsurumi watershed committee

Table 3: Data to be inputted in water cycle modeling

Elements comprising the water cycle	Natural system	Precipitation, evapotranspiration
	Artificial system	Waste water, leakage from waterworks and sewer systems, agricultural water, pumped groundwater, runoff-controlling facilities
Information on the river basin	Land surface	Altitude, gradient of elevation, drainage direction, distribution of impermeable layers, mulch, storing capacity of depressions
	Surface soil	Surface soil properties
	Aquifer	Hydrogeological structures, boundary conditions
	Natural system	Various elements in river channels

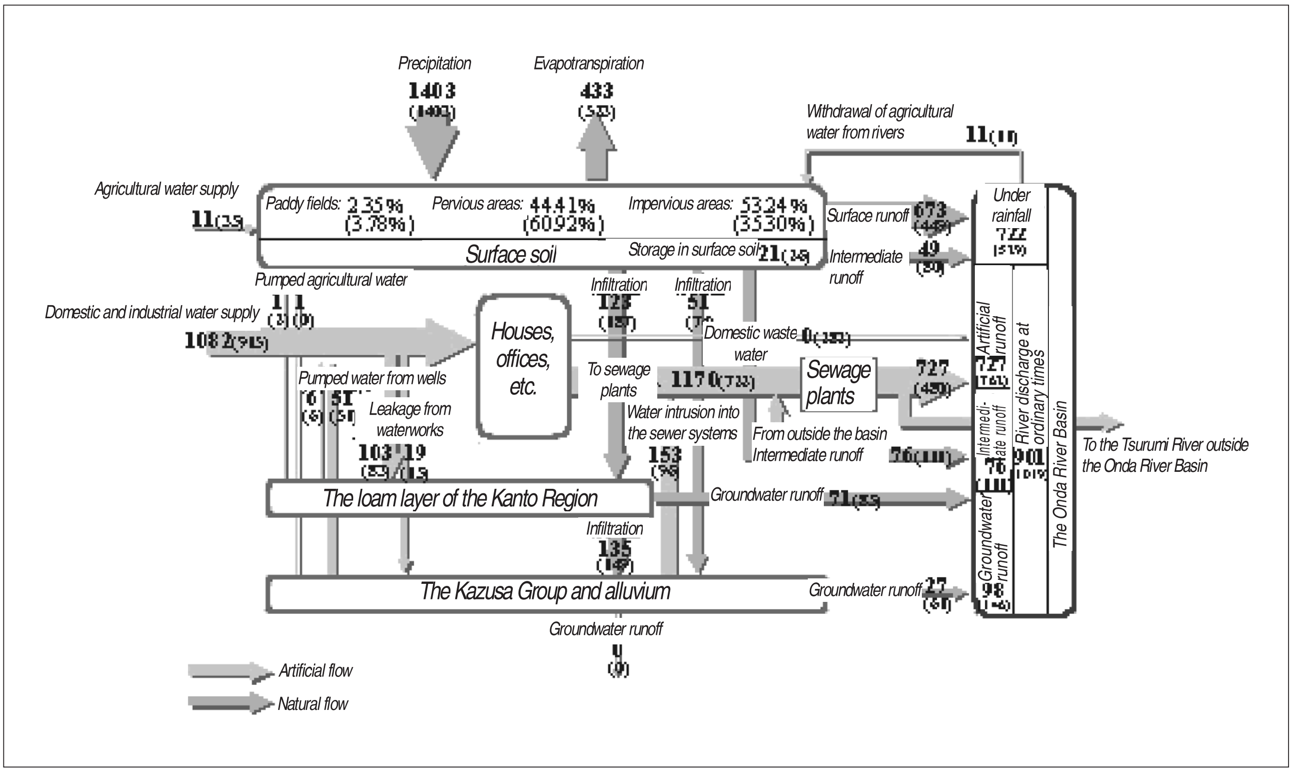
Source: the same reference as in Figure 2

Table 4: Watershed conditions to be set

	Present (1994)	Future (with an urbanization rate of 95%)
Impervious area ratio	Refer to detailed digital information	Presume that all land other than legally guaranteed natural land is developed
Population in the basin	Refer to the resident register	Estimate the population of new urban areas from the population densities of current urban areas
Consumption of supplied water	Multiply the water consumption per capita by population	Multiply current water consumption per capita by presumed population
Waste water volume	Calculate from the diffusion rates of sewer systems and flush toilets	Presume the diffusion rate of sewer systems as 100% and the waste water volume as 0
Leakage of supplied water	Estimate from non-effective supply	Presume that the current non-effective supply is maintained
Volume of pumped groundwater	Refer to the municipality's data	Presume that the current volume is maintained
Agricultural water withdrawal	Multiply paddy field area by water requirement depth*	Calculate in the same way as in "present"
Volume of pumped agricultural water	Refer to the municipality's data	Presume that the current volume is maintained
Volume of water intruding into the sewer system	Calculate from unaccounted water volume	Presume that the current unaccounted water volume is maintained
Outflow rate from sewage plants	Refer to the municipality's data	Presume from water consumption

*The water required depth indicates the decrease of stored water. Water requirement depth per day is generally used.
Source: the same reference as in figure 2

Figure 3: An example of an estimation deduced by water cycle modeling.(Values in parentheses indicate future estimations.)



(Value: mm/y)
Source: the same reference as in Figure 2

explained by representing the basin as a uniform grid of cells and surveying water movement in each cell. Figure 2 shows a conceptual model of the mechanism of the water cycle.

We can analyze water movement on the land surface including river channels, in the ground such as surface soil, and in the groundwater zone using a conventional flood analysis method, a saturated-unsaturated flow model, and a quasi-three-dimensional groundwater model, respectively.

Table 3 shows major data to be inputted.

Table 4 shows an example of an analysis at the Tsurumi River. In this table, "present" indicates the basin status in 1994, while "future" indicates when massive exploitation is conducted in the basin and its urbanization rate becomes 95%.

Figure 3 shows the results of a prospective analysis conducted based on the above conditions.

This estimation of water budget in a small basin of the Onda River, a tributary stream of the Tsurumi River, indicates that; (1) infiltration of precipitation will drop, while surface runoff will jump, (2) groundwater runoff into the river will plunge, and (3) the ratio of treated sewage water to river discharge will surge. In this way, we can quantify the change in the water cycle. Moreover, we can quantitatively estimate how projects on river basins may affect the water cycle. Thus, water cycle modeling helps us to prepare effective projects. Furthermore, qualitative estimation of the water cycle is becoming possible, as the distributed pollutant flow model for water quality estimation has been developed.

9.5 Trends in research on global water cycle dynamics

9.5.1 Social background

World Water Vision 2000, a report of the Second World Forum held in The Hague, the Netherlands, anticipates that world water withdrawal will surge from 3,800km^3 in 1995 to 4,300-5,200km^3 in 2025, because of the increase in demand for irrigation water. Moreover, it warns that economic growth will cause excessive water consumption, heavily damage the ecosystem, and further, may trigger international conflicts and tensions as well as the water problem.

While global water resources have been evaluated based on the amount of water roughly calculated for each country, researchers have recently launched the establishment of models for estimating water resources in each river basin, in which regional properties can be taken into consideration.

9.5.2 Water supply model

In evaluating water supply, water outflow and water resource availability are calculated. By using the Land Surface Model (LSM) in 0.5 degree by 0.5 degree longitude/latitude resolution, outflow from each unit is estimated with the presumption that the water volume calculated by taking evapotranspiration from precipitation equals to the amount of water reaching rivers through surface runoff and underground infiltration. Then, the water resource availability (See Footnote 1) is estimated by assessing discharge in each river based on the world landscape distribution. Annual river discharge is regarded as the maximum volume of water resources available.

Basically, tropical regions, east coasts of continents and Asian monsoonal areas, which have high precipitation, have rivers with high discharge. Also, the Nile Basin in Egypt and other countries contains a large amount of water available because of the flow from its upper stream.

9.5.3 Water demand model

In estimating water demand, consumption rate of domestic and industrial water per unit population is calculated for each nation, and its total water withdrawal is assessed in accordance with the population distribution. Also, consumption rate of agricultural water per unit irrigated area is evaluated for each nation, and its total water withdrawal is estimated in accordance with the distribution of irrigated farmland. Farmland distribution is assessed based on statistical data of not countries but states or counties for India, China and the U.S., which account for 47% of the world irrigated area.

According to this calculation, large amount of water is withdrawn in the West Coast of the U.S., Europe including Eastern Europe, West Asia, the northern part of India, China and Japan.

9.5.4 Current status of supply-and-demand distribution of water resources

Water scarcity index (R_{WS}) is used as an indicator of the current supply and demand of water resources. R_{WS} is defined as $R_{WS} = (W - S) / Q$ where W is annual water withdrawal, S is annual water resource supplied by desalination of seawater, and Q is annual water resource availability. The extent of water scarcity is evaluated from R_{WS}. $R_{WS} < 0.1$ indicates no water stress, $0.1 < R_{WS} < 0.2$ indicates low water stress, $0.2 < R_{WS} < 0.4$ indicates moderate water stress, and $0.4 < R_{WS}$ indicates high water stress, or water shortage.

Figure 4 explains the distribution of R_{WS} calculated from the above method. This figure implies that actual water demand exceeds water resource availability in the Western U.S., the Middle East, the border between India and Pakistan, the region in the northern part of India and the southern part of Tibet, and the region from the Huanghe River Basin to the North China Plain. These areas are probably undergoing water stresses, having little resistance to fluctuation in the water cycle.

Another indicator of supply and demand of water resources is annual water demand per capita which is defined as $(W - S) / C$ where C is population. As shown in Figure 5, water demand in the Western U.S. is significant, because much water is consumed in the production of crops to be exported to other regions.

Water consumed in agricultural production is called virtual water. Japan is deemed as importing large amounts of water along with the import of crops, that is, relying on imported virtual water. Therefore, we must think of returning this benefit to the world.

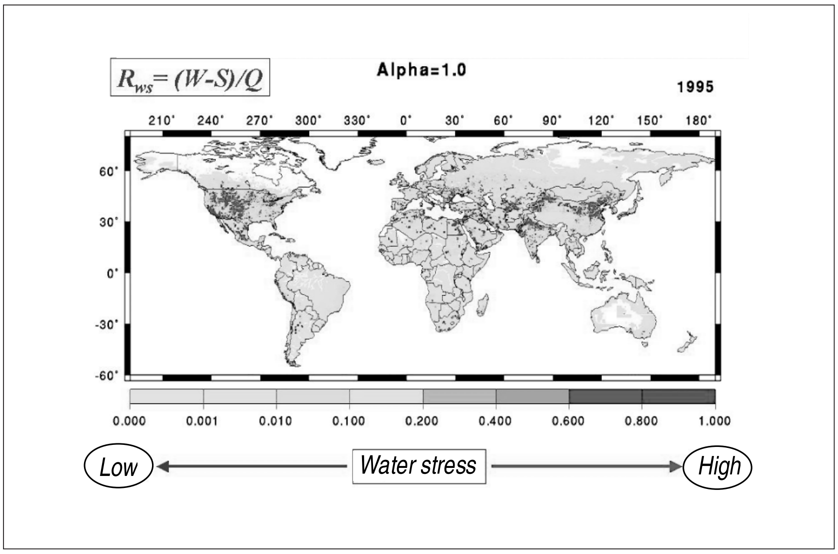
9.5.5 Prospect of supply and demand of water resources

We consider the balance between water resources and demand in the estimation of future

Footnote 1:

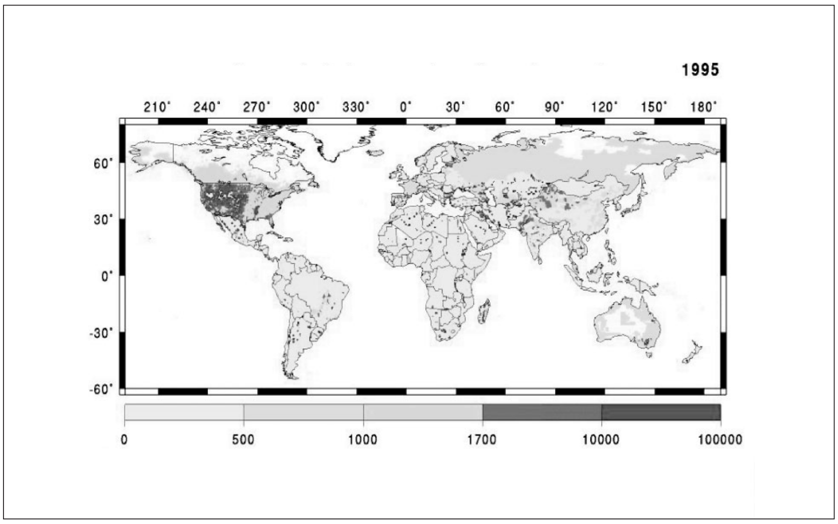
Water resource availability is evaluated by multiplying the water volume (calculated by taking evapotranspiration from precipitation) by the area. This indicates the maximum water volume available for people.

Figure 4: Water stress indicator (annual withdrawal to availability ratio)



Source: the same reference as in Figure 1

Figure 5: Annual water demand per capita (m^3/year/person)



Source: the same reference as in Figure 1

supply and demand of water resources, as in the evaluation of the current water status.

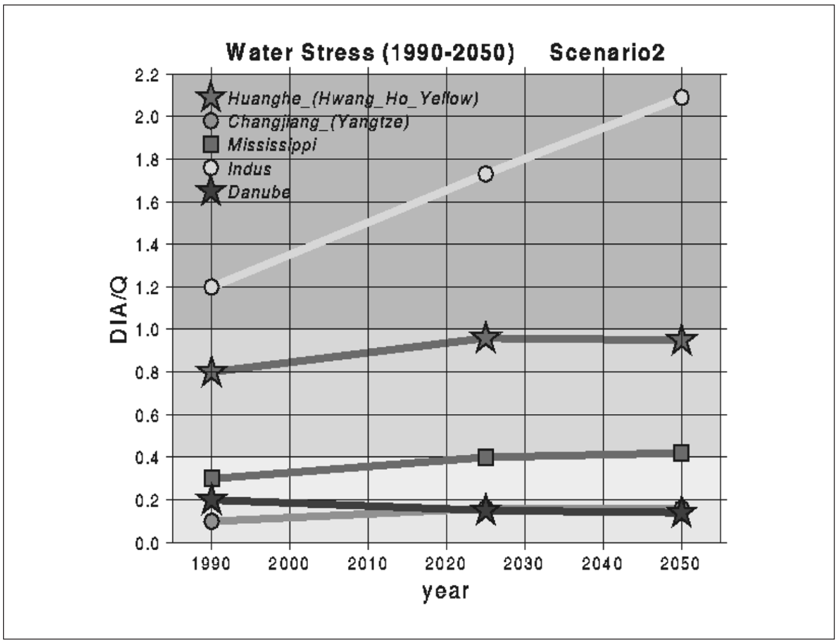
In this analysis, future water resources in volume is estimated with the General Circulation Model (GCM), which was jointly developed by the Center for Climate System Research of the University of Tokyo and the National Institute of Environmental Studies, with the presumption that the CO_2 concentration will be doubled in around 2050. Runoff rate to rivers is calculated from prospected precipitation, and future river discharge is assessed as in the water supply model. The estimation result indicates that river discharge will increase in the northern part of China, India, and the region from the border between India and Pakistan to the Aral Sea, and it is expected that the water problem from the viewpoint of supply of water resources will be alleviated.

Meanwhile, in evaluating water demand, it is postulated that the population will increase in accordance with the medium variant of the United Nation's world population prospects, while agricultural water withdrawal will rise proportionately to population growth. Whereas, increase in demand of domestic and industrial water per capita is presumed based on Raskin et al.

Figure 6 explains year-to-year changes in relative water demand, i.e., demand per discharge, by 2050 in several river basins deduced from the above hypothesis.

- Though discharge will probably rise in the

Figure 6: Year-to-year changesin relative water demande in several river basins



Source: the same reference as in Figure 1

Indus River as a result of global warming, relative water demand is estimated to surge linearly from 1990 to 2025 and 2050 because of continuous population growth. This implies that the impact of population growth surpasses that of climate change.

- Relative water demand will be stabilized from 2025 to 2050 in the Huanghe River Basin, because the population growth rate will decline in this area.

Meanwhile, there are similar reports that population growth affects relative water demand more than climate change does.

9.6 Essential themes of research on the water cycle and integrated water management in Asia including Japan

Understanding of water dynamics at the macro level by the establishment of models for estimating the global water cycle greatly helps to devise effective measures for tackling the impacts of global warming and so forth. Conventional analysis methods have been developed based on data in western countries, because water cycle research has been mainly conducted there. Yet, analysis of the water cycle and water resources system is essential in Asia, where many cities are located in alluvial plains and are exposed to the direct effects of orogeny. Such research is also highly crucial in supporting sustainable development in developing countries. In order to fulfill this necessity, activities to set up the Asia Pacific Association of Hydrology and Water Resources have been launched with the leadership of researchers in Japan. The main themes of this field of study are as follows.

(1) The distributed hydrological model, which was jointly developed in Europe for quantitative analysis of water infiltration, runoff, evapotranspiration and so forth, is for plain terrains, covering vertical infiltration only. Therefore, this model cannot be well applied to analysis of mountains and hills. We need to develop new models that include downhill flow parameters and thus can be applied to Asian mountains.

(2) While karst hydrology for karsts with a peculiar water cycle has been established in western countries, volcanic hydrology needs to be systematized for Asian volcanic regions whose water cycle and processes of sediment production and transport are peculiar.

(3) Sediment production in western countries has been formulated as being determined by sediment delivery by raindrops and erosion

by overland flow. In the meantime, discontinuous sediment production not only by erosion but also by mountain collapse, landslides, volcanic eruptions and mud flows has significant effects in Asia, thus analysis methods reflecting these parameters are necessary.

(4) Other research themes typical of Asian monsoonal areas are as follows.
- The precipitation mechanism, fluctuation of water resources and effects of the El Nino in Asian monsoonal areas.
- Irrigation and drainage technologies and water management in rice-growing areas.
- Flood control, water utilization and environmental issues in cities in alluvial lowlands.
- Water shortage and pollution in major cities resulting from the unbalance between water supply and demand in spite of large water supplies.
- Steps against mass production and runoff of sediment (e.g., soil erosion control and stabilization of alluvial channels).
- Selection of specific themes different from stable zones in western countries and their research and development in meteorology, agricultural engineering, river engineering, forestry, and groundwater hydrology among others.

9.7 Conclusion

In this report, I have introduced to you basic technology and water cycle models that contribute to integrated water management in respect to river basins in Japan and trends in research toward establishment of a sound water cycle, as well as studies at the global level. They will surely and significantly advance water management. While various efforts toward integrated water management can be deemed as groundbreaking experiments, we are facing many hurdles to overcome as shown below.

- It is essential to improve modeling methods like water cycle models for visually understanding various phenomena, so that these techniques may obtain high accuracy and be used in various areas. In addition, we need to promote research and development of environmental evaluation because this is a key field of study in forming a consensus.
- It is preferable to introduce the viewpoint on water cycle into land use. If necessary, we need to consider taking social scientific steps such as enforcement of legal restrictions.
- As a matter of course, citizens, companies, municipalities and the national government must play their own roles and cooperate with each other in order to establish a sound water cycle. Especially, efforts by municipalities, which are in charge of various policies and public projects related to the development of cities in river basins, flood control, disaster prevention and so forth, will be critical. Moreover, the government needs to encourage decentralization and technical cooperation.
- Research in Japan has been carried out based on models developed in western countries, so characteristics that Japan has in common with other Asian countries have not been emphasized very much. We need to present other countries with various measures and technologies that Japanese researchers have fostered in studies of the water cycle and water resources system, and scrutinize their availability especially in Asian countries. Furthermore, we need to introduce to the world our findings on the water cycle and water resources system influenced by landscapes and social and economic activities particular to Asia, and invigorate the necessary research.
- The water problem is now a global issue. It is high time for Japan to pave the way for smoothly and appropriately transmitting to Asian countries social and technological systems that contribute to the establishment of a sound water cycle. We also need to respect the customs and climates in the countries we help in order to provide our technologies effectively and to advance overseas aid such as the Official Development Assistance.

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I have compiled this report based on the lecture “Water Cycle and Water Resources-From Local to

Global Views" by Professor Katsumi Mushiake of the Institute of Industrial Science, University of Tokyo, held at the National Institute of Science and Technology Policy on August 7, 2002, along with the addition of my findings.

My sincere thanks to Professor Mushiake, who contributed highly valuable information and advice

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10

The Need for Competitive Research Grants to Promote The Vitalization of Young Research Scientists

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10.1 Introduction

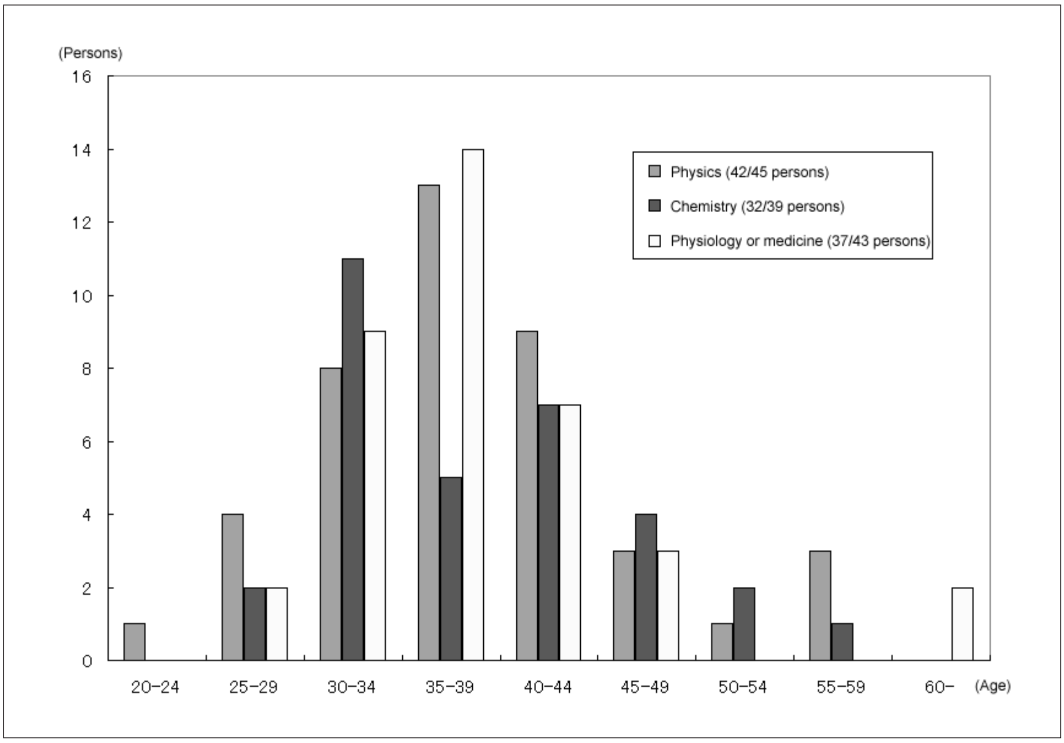
The Second Science and Technology Basic Plan (FY 2001-2005) suggested the prioritized expansion of research funding for young research scientists as a means to increase their independence. In response, the Ministry of Education, Culture, Sports, Science and Technology added the large Encouragement of Young Scientists A grant to its Grants-in-Aid for Scientific Research program. Applications for the new grants, which target young research scientists age 37 or younger who are affiliated with universities or other institutions, became available in FY 2000, with grants to be disbursed beginning in FY 2002. In addition, government bodies outside the Ministry of Education, Culture, Sports, Science and Technology also began offering competitive research grants for young research scientists.

Research grants for young research scientists in the equivalent of U.S. full-time, tenure track assistant professor positions have just begun in Japan. It is vital that we understand the conditions faced by young research scientists in Japan as we consider the necessity of upgrading research grants in this country.

10.1.1 The necessity of support for young research scientists

If young research scientists are to be autonomous and independently follow their own

Figure 1: Distribution of ages at which Nobel Prize winning reseach was published(1981-2000)



Source: 2001 White Paper on Science and Technology ideas in research, they cannot be dependent on receiving funding from full professors and other senior researchers. They must therefore receive a certain amount of support. The 10 to 15 years following receipt of a doctorate are a particularly important period for scientists to develop independent research agendas and to begin research into their own ambitious ideas. As is shown in Figure 1, the peak age for Nobel laureates to have published the research that led to their awards in physiology or medicine and in physics is 35 to 39.[1] As scientists typically receive their doctorates in the second half of their 20s, this represents a period of about 10 years after receiving the degree. For the chemistry prize, the first peak is for ages 30 to 34, and the second is for ages 40 to 44. This phenomenon suggests that we should consider differences in the ways researchers are trained in these fields.

Moreover, the percentages of Nobel laureates who published their award winning work between the ages of 30 and 44 are 81 percent for physiology or medicine, 72 percent for chemistry, and 71 percent for physics. This suggests the possibility that in the fields of physiology and medicine in particular, those 15 years are a period when creative buds reach full flower.

In this report, we will consider the proper form for research grants that can help young research scientists at the university assistant professor level and similar positions to build their creativity and produce research that contributes to the

Table 1: Overviews of K Awards

Grant name	Target	Period	Amount/year
K01 Mentored Research Scientist Development Award	Research scientists acquiring experience under a mentor, with the intention of pursuing independent research	3–5 years	$125,900 (approx. ¥15 million)
K02 Independent Scientist Award	Newly independent scientists	5 years	$125,900 (approx. ¥15 million)
K05 Senior Scientist Award	Independent scientists	5 years	$125,900 (approx. ¥15 million)
K07 Academic Career Award	Scientists aspiring to pursue independent clinical medical research	2–5 years	$128,000 (approx. ¥15.3 million)
K08 Mentored Clinical Scientist Development Award	Scientists who have research experience under a mentor, and who aspire to pursue independent clinical medical research	3–5 years	$120,000 (approx. ¥14.4 million)
K12 Mentored Clinical Scientist Development Program Award	Scientists who have research experience under a mentor, and who aspire to pursue independent clinical medical research	5 years	$400,000 (approx. ¥48 million)
K18 Career Enhancement Award for Stem Cell Research	Scientists who require training in order to pursue research involving stem cells	6 months to 2 years	$166,700 (approx. ¥20 million)
K22 Career Transition Award	Scientists with two or more years postdoctoral experience and less than two years as an independent investigator	Up to 3 years	$125,900 (approx. ¥15 million)
K23 Mentored Patient-Oriented Research Career Development Award	Scientists who have research experience under a mentor, and who aspire to pursue independent clinical medical research	3–5 years	$140,000 (approx. ¥16.8 million)
K24 Midcareer Investigator Award In Patient-Oriented Research	Clinical medical research scientists wit less than 15 years experience in clinical medical research	3–5 years	$100,000 (approx. ¥12 million)
K25 Mentored Quantitative Research Career Development Award	Scientists with engineering experience who aspire to pursue research in basic or clinical medical research	3–5 years	$140,000 (approx. ¥16.8 million)
K26 Midcareer Investigator Award In Mouse Pathobiology Research	Scientists with less than 15 years experience in mouse pathobiology research	3–5 years	$125,900 (approx. ¥15 million)
K30 Clinical Research Curriculum Development	Scientists who are developing new training programs in the field of clinical medical research	5 years	$200,000 (approx. ¥24 million)

Source: Author's compilation from information on the NIH website worldwide progress of science. In particular, we will compare Japanese grants with the research grants available to young research scientists in the United States, and examine elements that should be incorporated into Japanese research grants for young scientists.

10.2 U.S. research grants for young research scientists (biology/medicine)

We will now examine the career development grants of the U.S. Department of Health and Human Services' National Institutes of Health (NIH), the world's largest biological and medical research institution as well as a major grant maker.

K Awards are developmental research grants (training grants), but they are clearly separated from the F and T Awards intended for graduate and post-doctoral students. These research grants are designed to support young research scientists in full-time positions who are at the stage of building careers and becoming independent researchers[2].

10.2.1 Types of K awards

The K Awards currently offered by NIH are shown in Table 1. NIH is a government institution focusing mainly on medical research. It supports young research scientists at various stages of their careers with research grants. K Awards covering basic medical research are K01, K02, K05, K07, K18, K22, K25, and K26, while those for clinical medical research are K08, K12, K23, K24, and K30[2].

10.2.2 K Awards are developmental grants

The concept of "career developing" young research scientists is deeply imbedded in the K Awards. As can be seen in Figure 2-1 and 2-2, the various grants are designated with the clear differences in the career paths of basic and clinical researchers in mind.

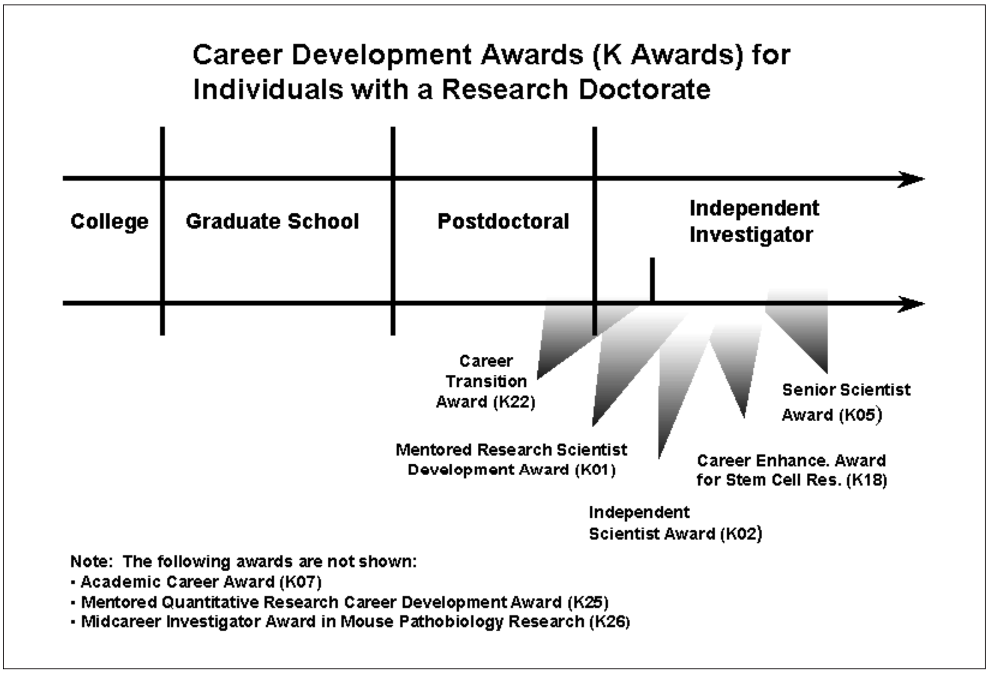
10.2.3 Changes in total K Awards funding

As can be seen in Figure 3, K Awards funding increased rapidly beginning in 1999, with $400 million available in 2001, almost double the 1998 amount. This is approximately 2 percent of the entire NIH 2001 budget of about $20.5 billion. In 2001, 3,135 K Awards were granted[2].

10.2.4 Summary

In the past, NIH offered a grant called R29 for newly hired, full-time research scientists. That grant, however, was eliminated in June 1998. Since then, NIH has actively sought applicants for R01 grants, which have no restrictions on employment history and were promoted in the 19 December

Figure 2-1: The concept behind K Awards for scientists in basic medical research



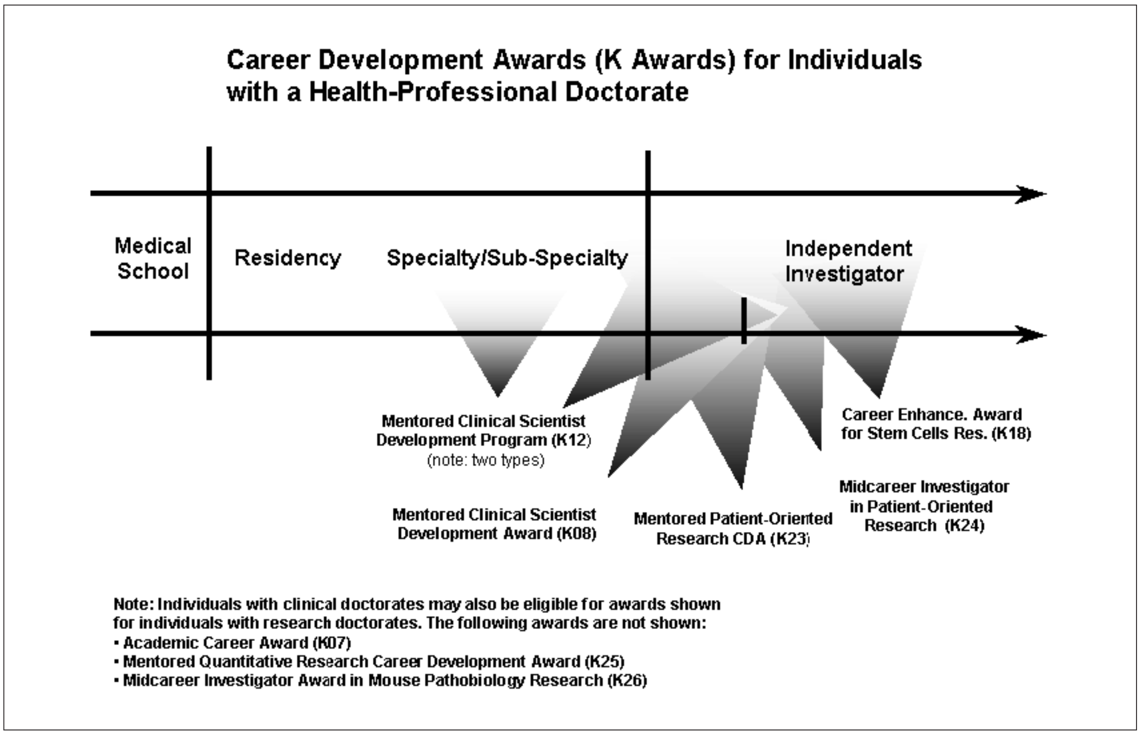
Source: NIH website

1997 NIH Guide (Volume 26, Number 40). R01 application forms include a line to indicate whether the applicant is a newly hired full-time researcher.

It appears that the rapid increase in K Awards funding described in Section 10.2.2. above can be attributed to NIH deciding to position those awards as the research grants for young scientists in place of R29 grants.

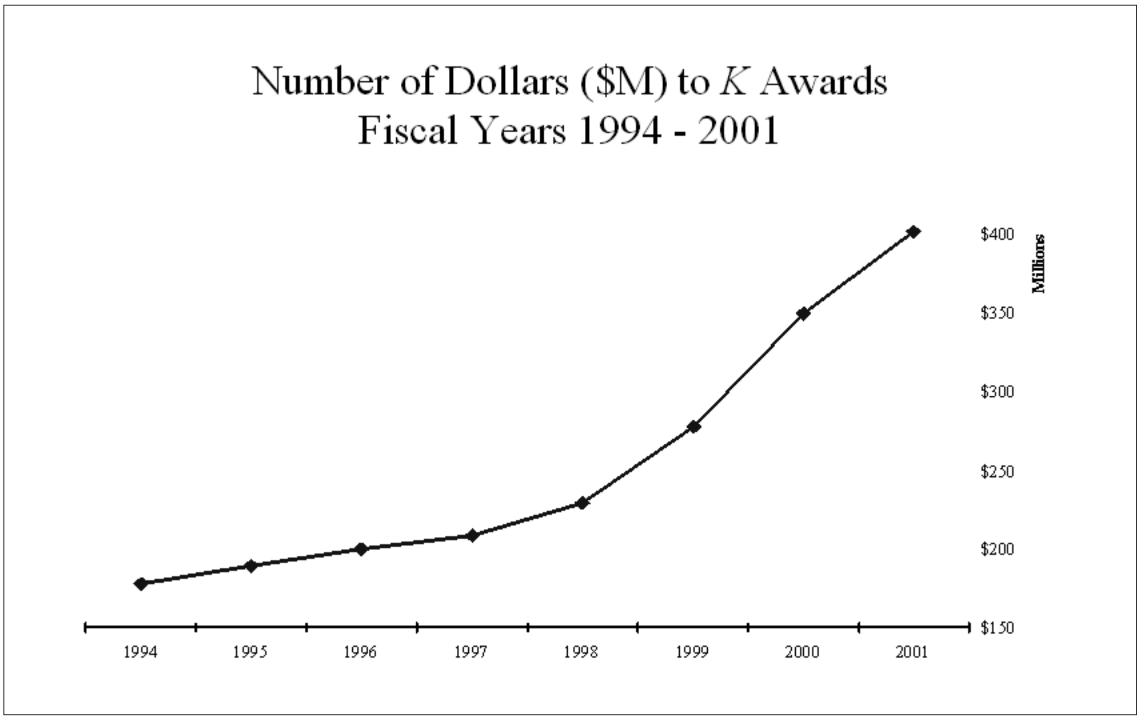
In addition to K Awards, R03 grants function as grants for young research scientists. At about $50,000 per year, R03 grants are smaller than R01

Figure 2-2: The concept behind K Awards for scientists in clinical medical research



Source: NIH website

Figure 3: Changes in total monetary value of K Awards



Source: NIH website

grants, which begin at $50,000, and so are considered small grants. In most cases, R03 applications do not require preliminary research results. R03 grants are for challenging research that may not show results during the grant period and for the testing of new experimental methods.

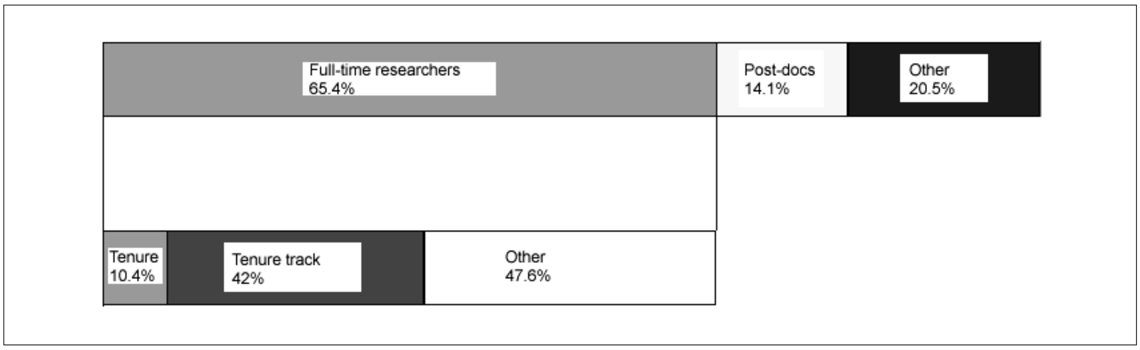
10.3 Conditions for young research scientists in the U.S.

Comparing the number of doctorates awarded in the natural sciences (including engineering) in 1998 in Japan and the U.S., we find that almost three times as many were awarded in the U.S. as in Japan—19,566 to 6,576[3]. The number of universities in the U.S., 1,478, is roughly double the 649 national, public, and private colleges in Japan (not including two-year colleges)[4]. Looking only at the numbers, there appears to be little difference in the opportunities for full-time research employment at universities in the two countries. Compared with Japan, however, the career paths of scientists in the U.S. can be much more difficult.

10.3.1 Research scientist career paths in the U.S.

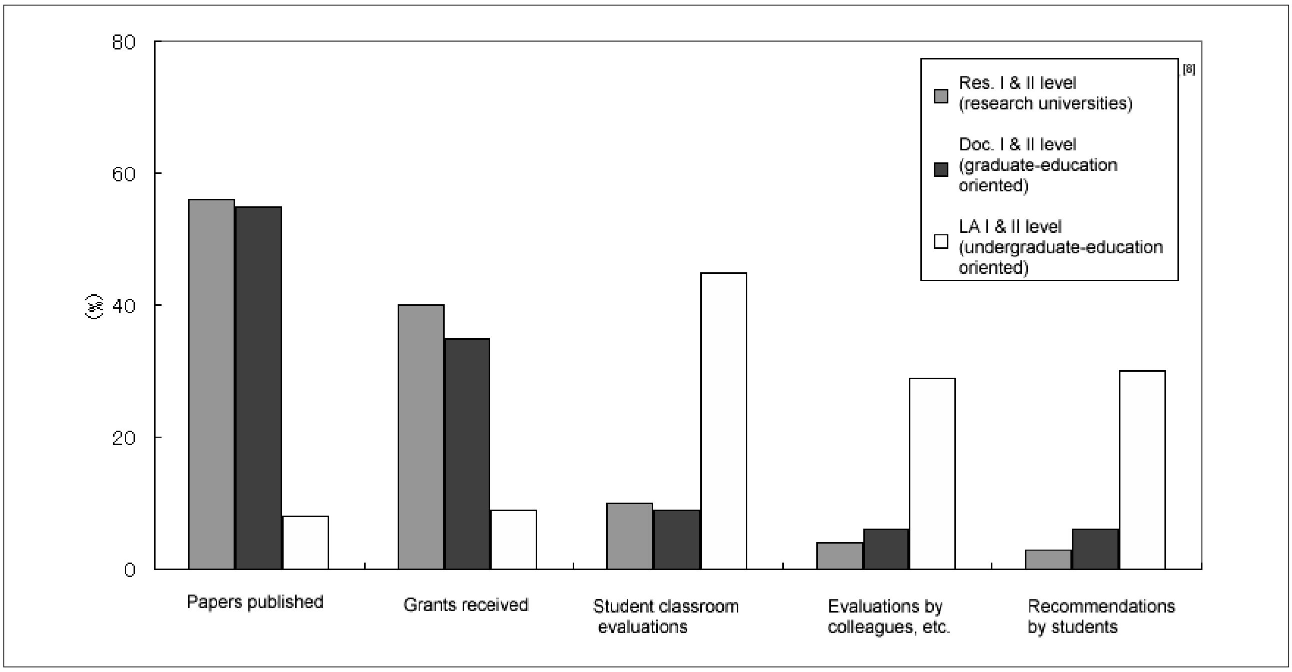
A major difference between young research scientists in Japan and the U.S. is their postdoctoral career paths. Many scientists in the U.S. follow the path of PhD to postdoc to tenure

Figure 4: Employment status of researchers at U.S.universities (4-7 year after acquisition of doctorate)



Source: Author's compilation based on Science and Engineering Indicators 2002, National Science Foundation(1999 statistics).

Figure 5: Factors "most important" in obtaining tenure according to U.S. academics



Source: Author's compilation based on reference[7] track to tenure. Tenure refers to the position held by scientists who have received the right to career-long employment, while tenure track refers to the position held by those eligible to possibly obtain tenure in the future. While regular full-time employment and fixed-term contract employment might be considered the equivalents of tenure and tenure track in Japanese universities, in 2001 only 2,884 university faculty, a mere 2 percent[5] of all university faculty in Japan, were employed under fixed-term contracts. It is not the ordinary career path for scientists in Japan. However, over the three years from 1998 to 2001, the number of such faculty increased by more than 29 times, so it bears watching whether a U.S.-style career path will develop in the future.

10.3.2 Ratio of tenure track personnel to all full-time academic employees

According to statistics in the U.S. National Science Foundation's *Science and Engineering Indicators 2002*,[6] 65 percent of young research scientists (including faculty) employed by universities four to seven years after receiving doctorates were full-time employees. Of these, 10 percent had tenure, while 42 percent were tenure track (see Fiugre 4). The remainder, almost half of those full-time employees, were researchers (and instructors) who were neither tenured nor tenure track. Those in such circumstances must first obtain research results and then try to utilize those results to help secure a tenured or tenure track position. This shows the harshness of the career path for many young research scientists in the U.S.

10.3.3 Requirements for advancing from tenure track to tenure

At research universities (324 institutions), 96 percent of faculty members consider the number of publications and the number of research grants received to be the most important factor in advancing to tenured status (see Figure 5)[7]. Compared to tenure track, tenure guarantees stable employment and freedom to pursue research. To obtain tenure, young research scientists must necessarily work to increase the number of grants they receive. It is believed that this fierce competition helps to raise the overall quality of scientific research in the U.S.

10.3.4 Obtaining research grants contributes to the recipient's organization

To research institutions, research grants are not only proof that a researcher's work has been accepted by outsiders, they are also direct economic contributions. Called "overhead," this is the requirement that the researcher give his or her institution a certain percentage of the grant to cover operating expenses. The percentage varies by university or institution. In the case of an institution requiring 100 percent of overhead, for example, if a researcher receiving a budget of $30,000 from his or her institution receives a grant, that institution would receive a separate $30,000 from the grant maker.

Certain private-sector research grants, however, specify that no overhead will be paid. In such cases, if a researcher at an institution requiring 50 percent overhead were to receive a grant of $30,000, for example, he or she would have to pay $15,000 overhead out of that grant.

Thus, researchers who obtain numerous large research grants are considered to be making an important contribution to their research institutions.

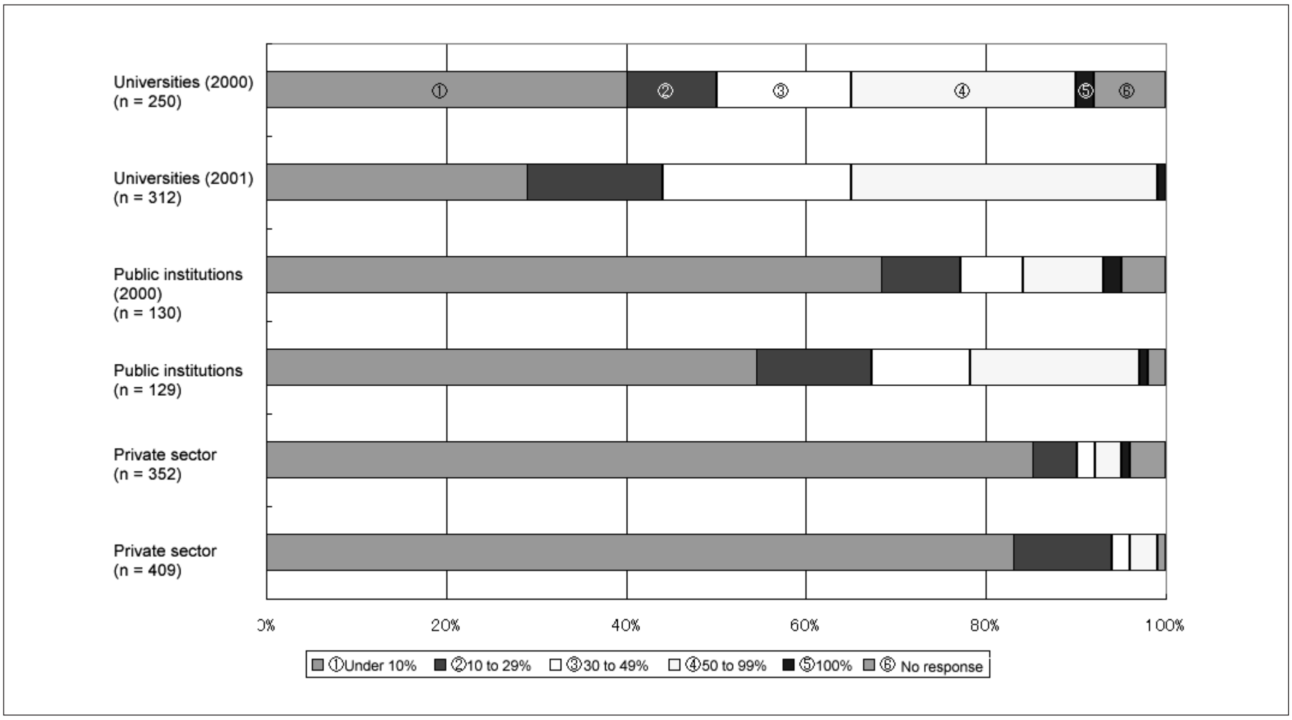
10.3.5 Summary and problem areas

The stability and career advancement of young research scientists in the U.S. depend on their ability to obtain research grants. A research career without grants is inconceivable. Obviously, their attitude towards research grants will be different than that of young research scientists in Japan, who can expect lifelong employment. Young research scientists in the U.S. constantly face enormous stress, and career paths and survival strategies are widely discussed on the Internet[9].

10.4 Awareness of research grants among young Japanese research scientists

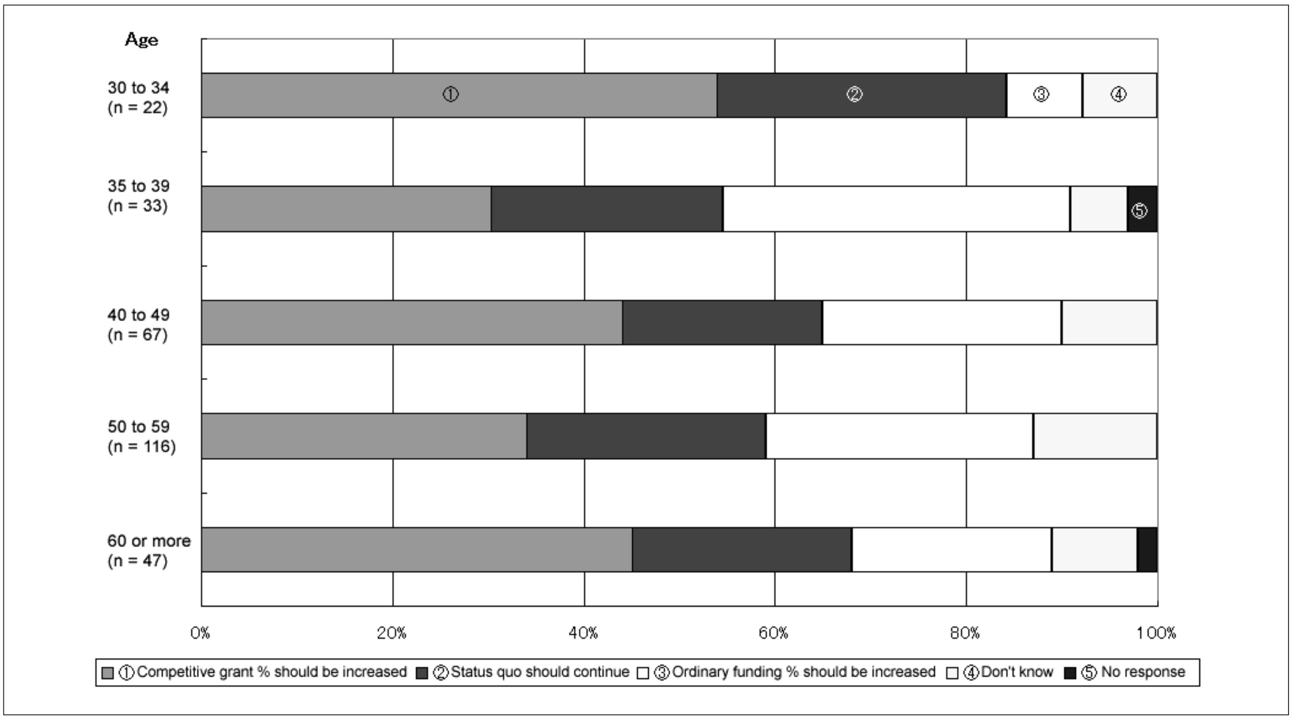
As described above, obtaining research grants is important to the careers of young research scientists in the US. Now we will look at how young research scientists in Japan view research grants.

Figure 6: The percentage of research budgets covered by competitive funding



Source: Author's compilation based on FY 2001 Survey of the Actual State of Research Activities in Japan

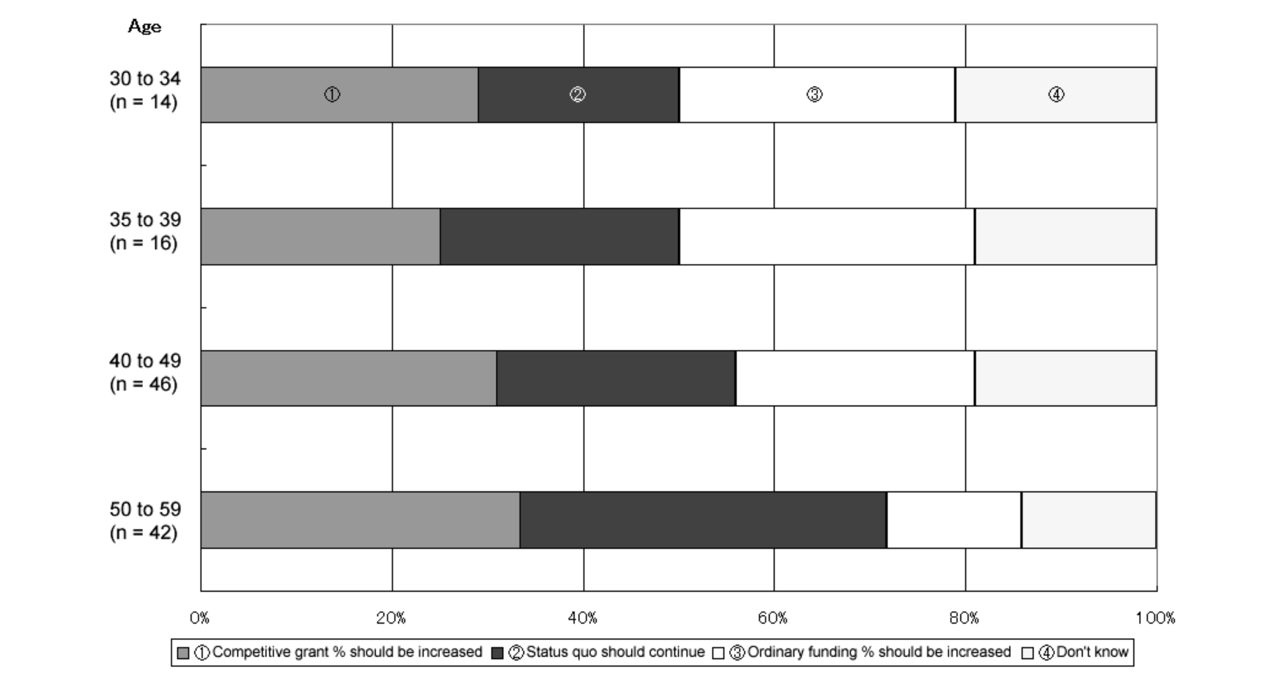
Figure 7-1: Attitudes of Japanese scientists towards the percentage of research costs funded through competitive grants (universities)



Source: Author's compilation based on FY 2001 Survey of the Actual State of Research Activities in Japan

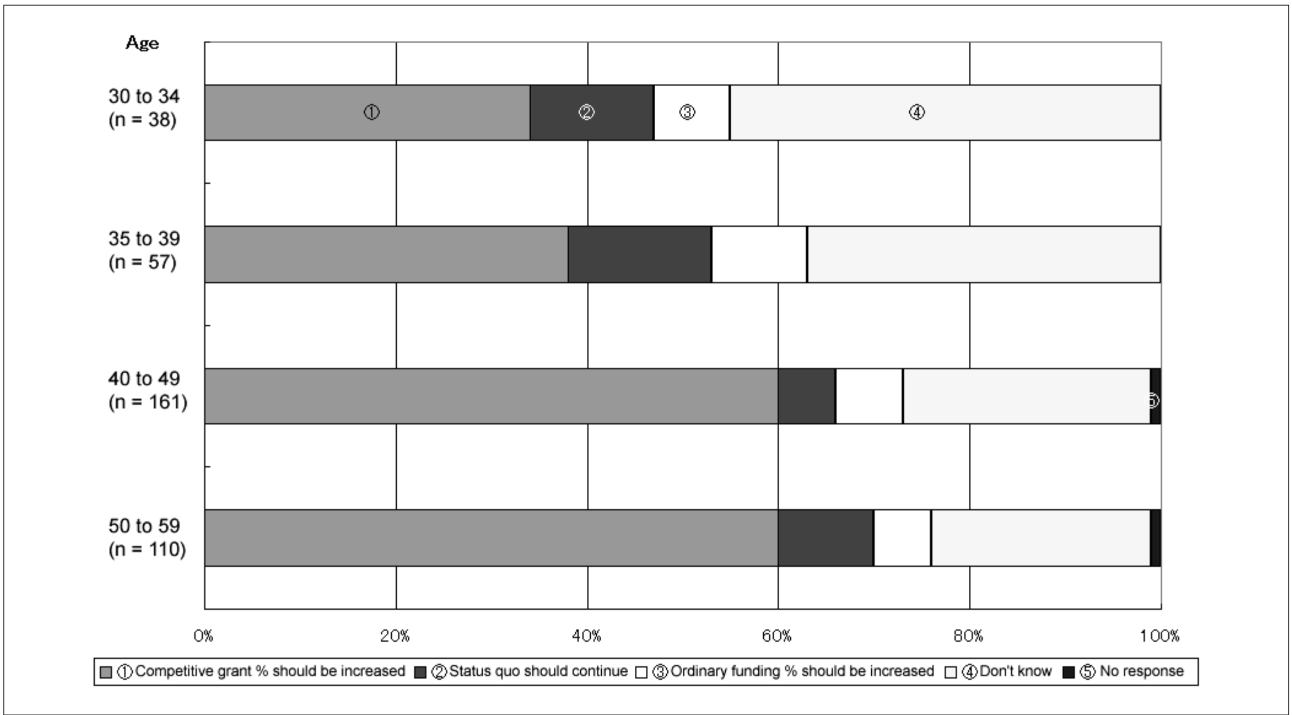
The *FY 2001 Survey of the Actual State of Research Activities in Japan*, a survey performed by the Research Division, Science and Technology Policy Bureau, of the Ministry of Education, Culture, Sports, Science and Technology and announced in September 2002 made clear the attitudes of young Japanese research scientists towards research grants[10]. The survey targeted industry, academic, and government researchers who were listed as first or second authors of papers registered in the Japan Science and Technology Corporation's 2000 bibliographical

Chart 7-2: Attitudes of Japanese scientists towards the percentage of research costs funded through competitive grants (public institution)



Source: Author's compilation based on FY 2001 Survey of the Actual State of Research Activities in Japan

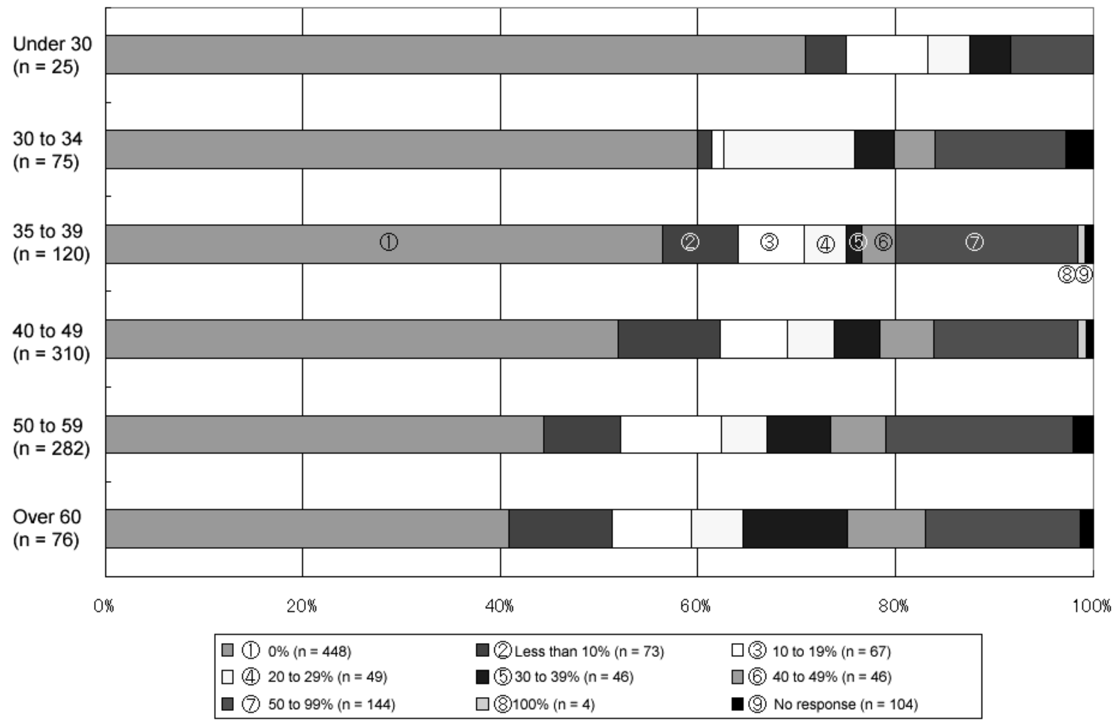
Figure 7-3: Attitudes of Japanese scientists towards the percentage of research costs funded through competitive grants(private sector)



Source: Author's compilation based on FY 2001 Survey of the Actual State of Research Activities in Japan

database. A random sample of 1,200 was selected and questionnaires were mailed to them. Of the 889 valid responses received, 35 percent came from universities, 15 percent from public institutions, and 46 percent from the private sector. In each group, research scientists under the age of 35 comprised about 10 percent of the whole. Those responding worked in diverse fields, including life sciences (22 percent), information and communications (18 percent), materials and nanotechnology (18 percent), environment (9 percent), and energy (8 percent).

Figure 8: Percentage of research funding covered by competitive grants in Japan (by age)



Source: FY 2001 Survey of the Actual State of Reaserch Activities in Japan

10.4.1 The percentage of research costs covered by grants is increasing

The percentage of science and technology-related costs covered by competitive funding (research grants) is increasing each year, as is the amount (2.4-fold from 1995 to 2000)[1]. Next we will look at the percentage of the research costs of those targeted by the survey that is covered by competitive research funding (research grants).

The same question was asked in the 2000 survey. Figure 6 compares the results from 2000 and 2001. The responses are the percentage of laboratory and group research budgets covered by competitive funding rather than of individual budgets.

In universities, public institutions, and the private sector, the percentage of those responding that they receive less than 10 percent of their funding through competitive grants all declined from 2000 to 2001. In universities and public institutions, the percentage responding that they receive 50 to 100 percent of funding through competitive grants increased from 2000 to 2001, as did the percentage of private sector institutions receiving between 10 and 30 percent of their funding through competitive grants.

10.4.2 Young research scientists who welcome the introduction of research grants, and young research scientists who do not

What do scientists, and young scientists in particular, think of the fact that competitive funding (research grants) is increasing every year?

The responses of scientists to the question "What do you think of increasing the percentage of science and technology research costs funded through competitive grants?" are broken down by type of institution and age in Figures 7-1, 7-2, and 7-3.

Over 50 percent of scientists aged 30 to 34 and affiliated with universities responded that the percentage funded through competitive grants should be increased. That was a higher percentage than any other group. They also had the lowest percentage responding that the percentage covered by ordinary funding should be increased. Those aged 35 to 39 had the highest percentage responding that the ordinary funding percentage should be increased.

In all age groups, researchers at public institutions (Figure 7-2) had lower percentages responding that the percentage funded through competitive grants should be increased than did the same age groups in universities or private sector institutions. In the 30 to 34 age group, identical percentages responded that the competitive funding percentage should be increased and that the ordinary funding percentage should be increased. The older the age group, the larger the percentage responding that the status quo should be maintained, and the fewer responding that the ordinary funding percentage should be increased.

Among private sector research scientists (Figure 7-3), the 30 to 34 age group had the lowest percentage responding that the competitive funding percentage should be raised. The older the age group, the higher the percentage saying it should be increased. The 30 to 34 age group had the highest percentage responding "Don't know," and the older the age group the fewer offering that response.

Research scientists in the 30 to 34 age group showed a high awareness of the concept of introducing competitive funding, yet the 35 to 39 group displayed a passive attitude. This difference is believed to stem from differences in job status. Seventy percent of the 30 to 34 group said that they were in the "assistant professor/lecturer class," while the 35 to 39 group said they were in the "associate professor class." We must examine why the attitude of research scientists towards competitive grants becomes passive as their job status improves and they begin operating their own labs.

Among research scientists in public institutions and in the private sector, the 30 to 34 group showed a passive attitude towards competitive grants, while each older age group showed an increasingly high awareness of them.

What is the origin of these different attitudes towards competitive funding?

10.4.3 The research budgets of young scientists come primarily from ordinary funding

As we discussed in Section 10.4.2 above, with the exception of the 30 to 34 age group at universities, older groups tend to have more positive attitudes towards competitive funding. In order to better understand why younger research scientists are more passive towards the idea of competitive grants, we compiled a table (Figure 8) showing funding percentages by age group. Among those under 35, 60 percent responded that they receive 0 percent of their funding through competitive grants.

It is believed that young research scientists who receive funding primarily through ordinary funding fear that such funding will be cut and their research hindered if competitive funding is increased.

10.4.4 Struggling research scientists at universities

In order to understand the attitudes of university research scientists towards research funding to a greater degree than was possible with those statistics, those who responded that competitive or ordinary funding percentage should be increased in Section 10.4.2 above were asked follow-up questions. We will now discuss those results.

Among those in the 30 to 34 group who responded that the competitive funding percentage should be increased, the reason most often given was "Research fund amounts difficult to obtain through ordinary budgeting could be received." In the 35 to 39 group, the most common answers were "It would promote scrapping and rebuilding in research" and "It would help loosen stagnant research budgets." The most common responses of the 50 to 59 group were "Funding would go only to research that is acceptable" and "Research would improve as researchers competed for funding."

Among those responding that the ordinary funding percentage should be increased, the most common reasons given by those in the 30 to 34 and 50 to 59 groups were "Competitive funding might cause research to be influenced by fads, and funds might flow only to certain fields." Among those aged 35 to 39, the most common answer was "Those who don't obtain competitive grants might not be able to continue their research."

Perhaps it is only natural that research scientists in age groups that would struggle to steadily secure competitive grants should take a passive attitude towards their introduction.

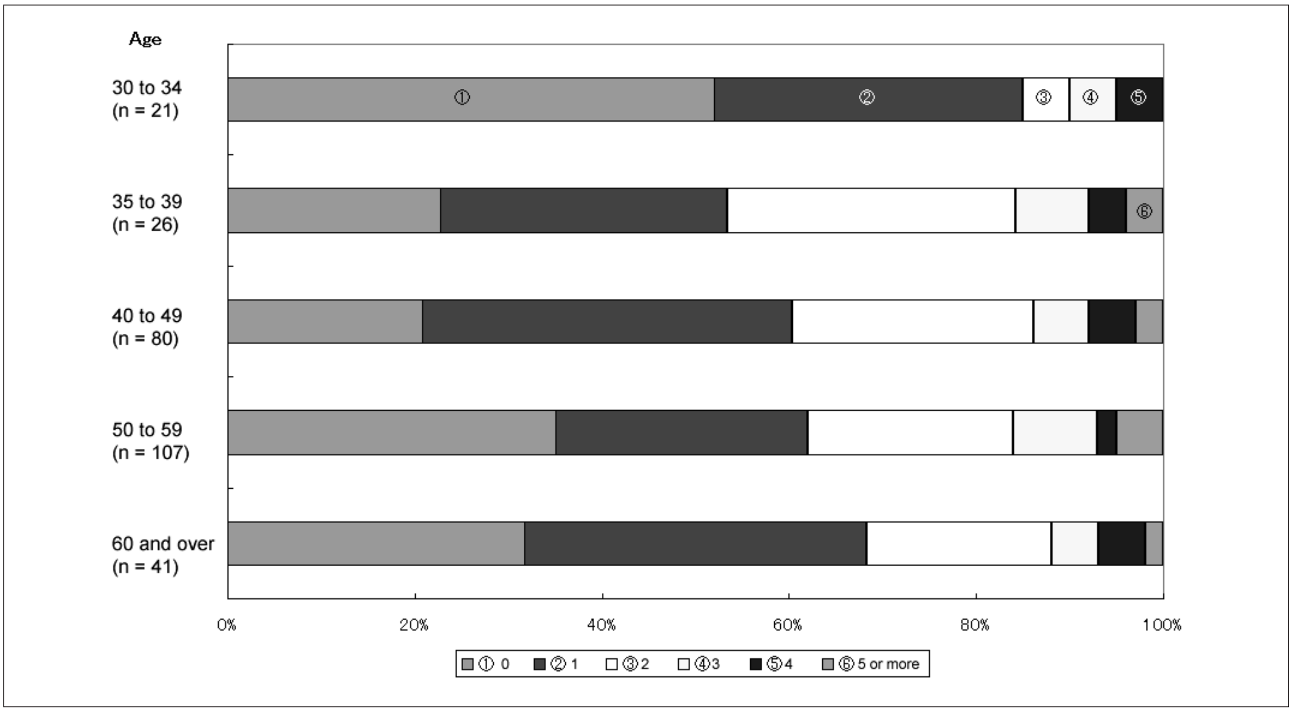
10.4.5 Young research scientists worry about obtaining research grants

How many competitive grants do young research scientists in Japan obtain?

Responses to the question "How many competitive grants have you personally applied for and obtained?" as of the time of the survey (December 2001) are shown in Figures 9-1, 9-2, and 9-3[10].

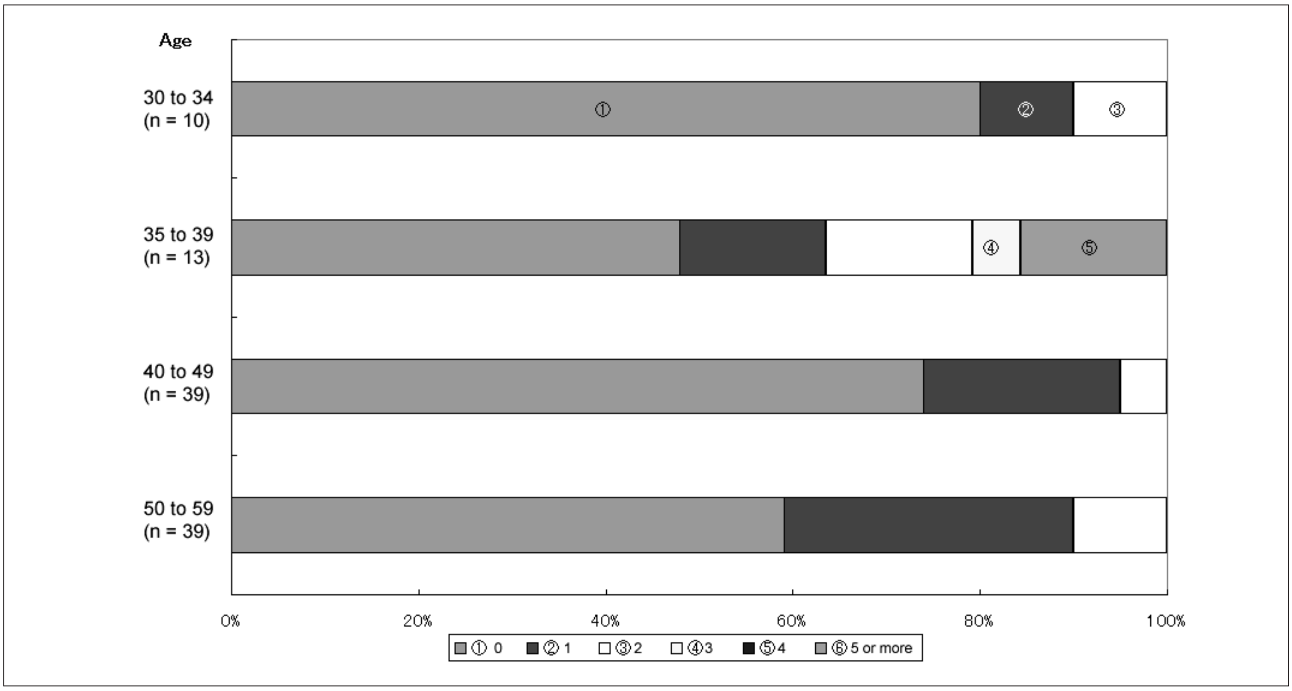
Among university research scientists (Fiugre 9-1), over 50 percent of those aged 30 to 34 said they had obtained no grants at all. Almost 80 percent of those aged 35 to 39 had received at least one.

Figure 9-1: Grants personally obtained (universities)



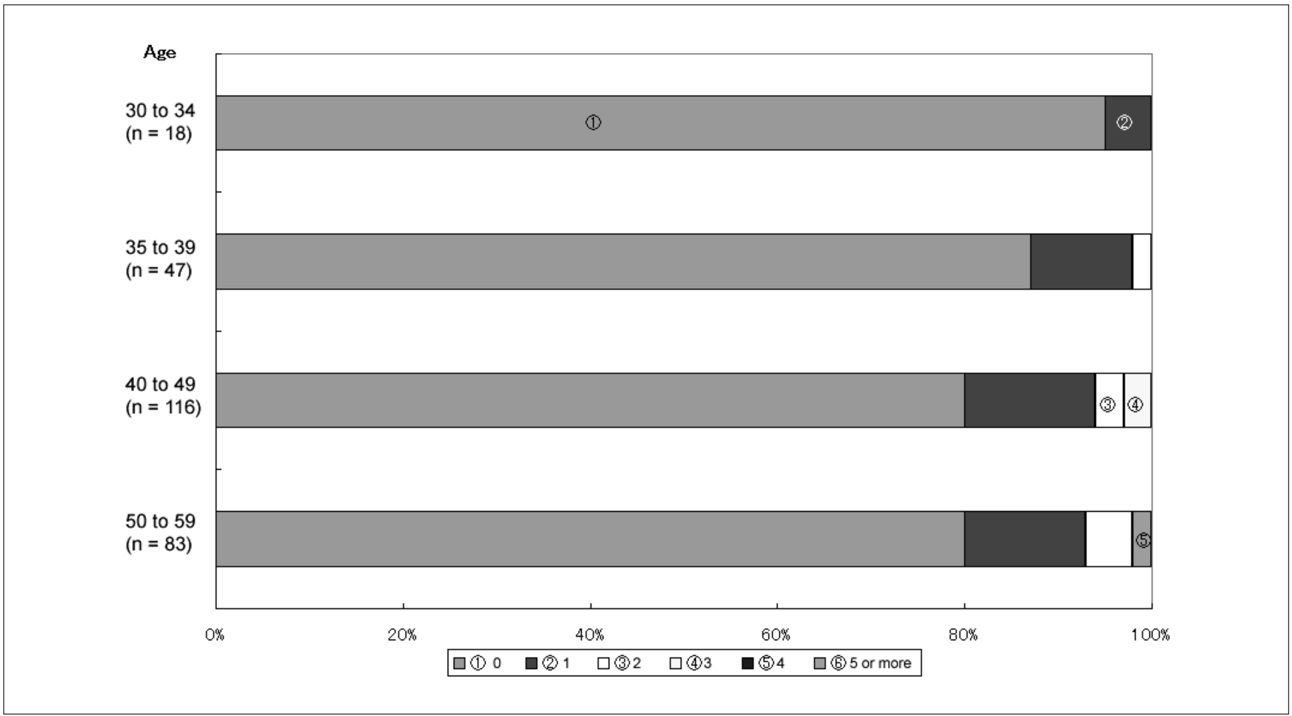
Source: Author's compilation based on FY 2001 Survey of the Actual State of Research Activities in Japan

Figure 9-2: Grants personally obtained (public institution)



Source: Author's compilation based on FY 2001 Survey of the Actual State of Research Activities in Japan

Figure 9-3: Grants personally obtained (private sector)



Source: Author's compilation based on FY 2001 Survey of the Actual State of Research Activities in Japan

Among research scientists at public institutions (Figure 9-2), 80 percent of those aged 30 to 34 said they had obtained no competitive grants. Over 50 percent of those in the 35 to 39 group, however, said they had obtained at least one grant.

In the private sector (Figure 9-3), over 90 percent of research scientists aged 30 to 34 said they had received no competitive grants. Although the number of those saying they had received at least one grant increased with each higher age group, at only about 20 percent the figure was very low compared with the university and public institution researchers.

In each type of institution, the percentage of research scientists aged 30 to 34 obtaining research grants is low compared to older age groups.

10.4.6. Are young research scientists competing for research grants?

To address the question of whether young research scientists are aspiring to obtain competitive grants but failing because of the high degree of competition, we compiled Figures 10-1, 10-2, and 10-3, "Number of competitive grants applied for during the past 5 years (by age) [10]."

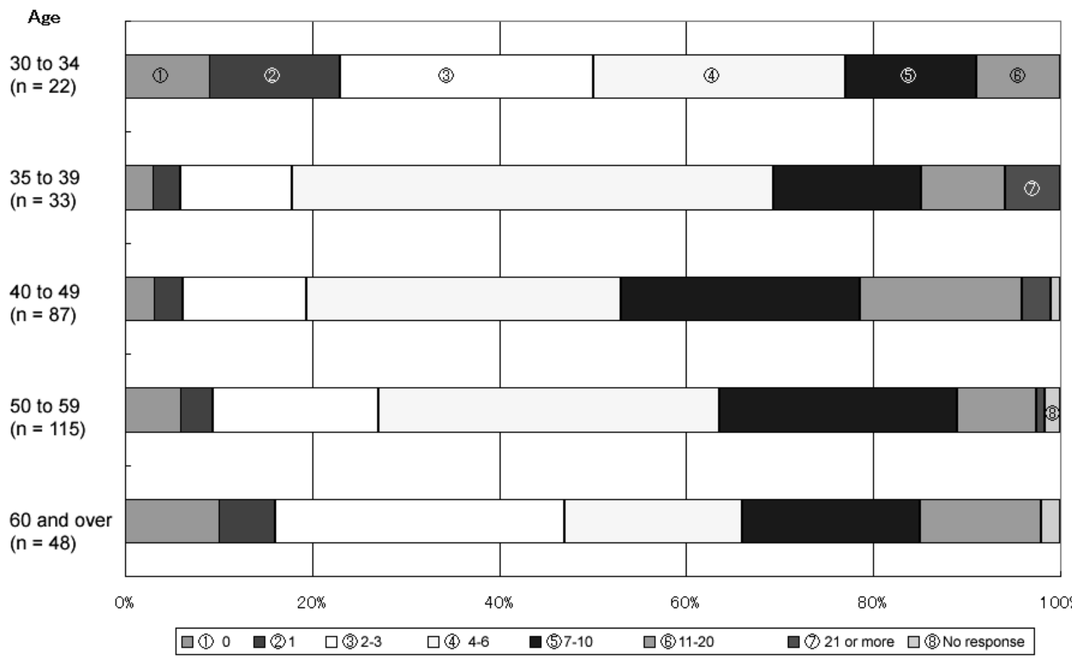
Among university research scientists (Figure 10-1), over 90 percent in each age group said they have applied for at least one competitive grant in the last five years. Compared with other age groups, the large number of those aged 30 to 34 who had applied for no more than a single grant stands out. Fifty percent of university research scientists had applied for four or more grants over the previous five years.

At public research institutions (Figure 10-2), close to 60 percent of research scientists aged 30 to 34 had applied for no competitive grants in the past five years. Among those aged 35 to 39, however, over 75 percent had applied for at least one grant.

In the private sector (Figure 10-3), 80 percent of research scientists aged 30 to 34 had applied for no competitive grants during the previous five years. The percentage of those applying for at least one grant increased in each higher age group, with 45 percent of those in the 50 to 59 group having applied for at least one.

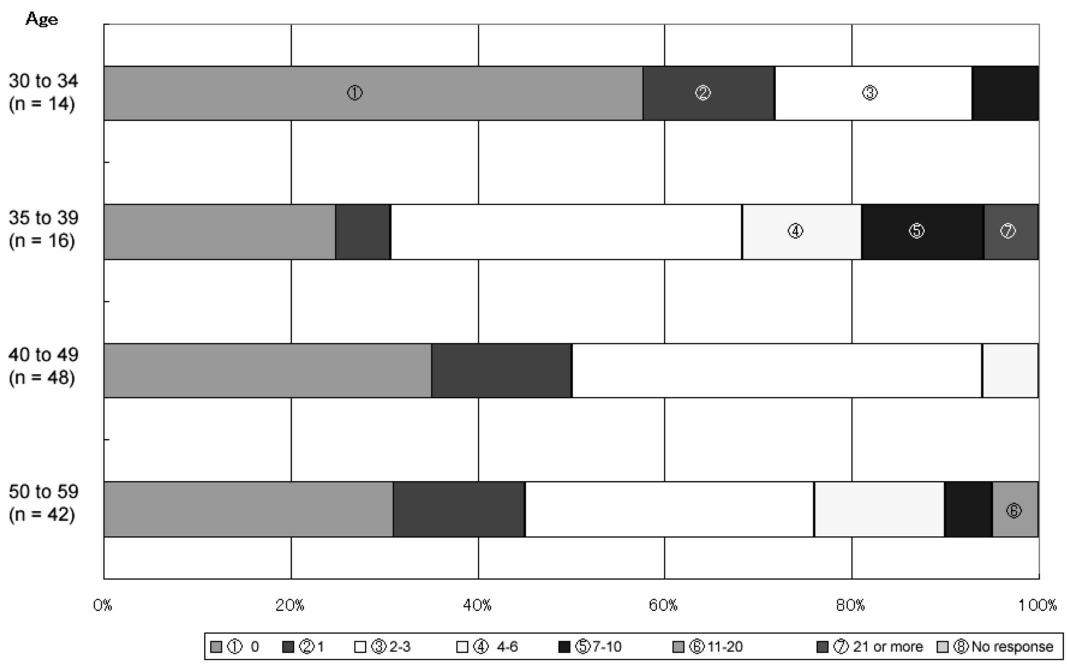
Young research scientists at universities are applying for grants, but are failing to obtain them. On the other hand, young research scientists at public institutions and in the private sector apply for few grants, and from the beginning of their careers generally do not participate in the quest for competitive funding.

Chart 10-1: Grants applied for during previous 5 year (universities)



Source: Author's compilation based on FY 2001 Survey of the Actual State of Research Activities in Japan

Figure 10-2: Grants applied for during previous 5 year (public institution)

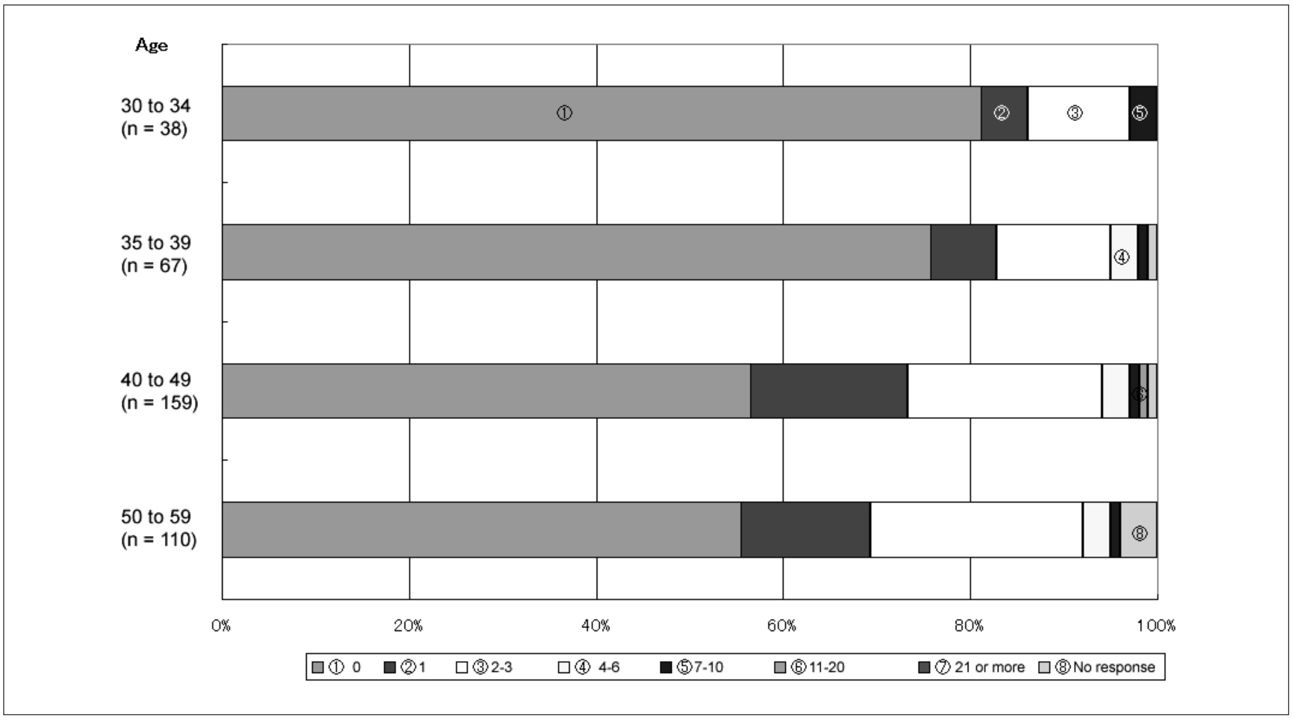


Source: Author's compilation based on FY 2001 Survey of the Actual State of Research Activities in Japan

10.4.7 Summary

The differences in the issues facing young research scientists at universities, at public institutions, and in the private sector are clear. Young research scientists at universities are actively applying for competitive grants, but are obtaining few. At public institutions, young research scientists show less interest in competitive grants than their university peers and want ordinary funding to be increased. They apply for few grants, so a high percentage of them have never obtained one. Interest in competitive funding among young research scientists in the private sector is similarly low, and they rarely

Chart 10-3: Grants applied for during previous 5 year (private sector)



Source: Author's compilation based on FY 2001 Survey of the Actual State of Research Activities in Japan

apply for grants. The percentage of young scientists in the private sector who have obtained at least one grant is thus extremely low.

To develop policies to vitalize young research scientists, it is therefore necessary to consider strategies appropriate to each type of institution.

Young research scientists at universities need to be able to increase the number of grants they receive through the expansion of "young scientist research grants" that are not dependent on a long record of successful research. If the status quo continues, it will tend to discourage the ambition of these young researchers.

Young research scientists at public institutions need to change their attitude towards research grants, and the relevant government agencies need to support them with early career grants.

Young research scientists in the private sector need the support of research grants. Under the Basic Technical Research Promotion Program (Private Sector Basic Research Support System), the Ministry of Economy, Trade and Industry provides research support to private sector enterprises. We would like to see early career research grants included among such research grants. The fact that the winner of the latest (2002) Nobel Prize in chemistry works in the private sector and received the award for work begun in his 20s shows how important research support for young research scientists in Japan can be to the development of this country's scientific research.

10.5 Comparison of research grants for young scientists in Japan and the U.S.

We will now examine major early career research grants from government funds in Japan and the U.S., and consider issues facing such grants in Japan.

10.5.1 Targets of young scientist research grants

Tables 2-1 and 2-2 show major early career research grants (provided from government funds) in Japan and the U.S. The biggest difference between them is in the "Target" category. While in the U.S. they are limited by "years as an independent investigator," in Japan restrictions are currently based simply on age. Using age restrictions excludes many people, such as those who have worked before returning to graduate school or who previously pursued another field.

10.5.2 Grant amounts

A major grant in the U.S. when converted to yen

Table 2-1: Major research grants for young scientists in Japan (government funded)

Grant name	Organization	Target	Period	Amount/year	Funding (2002)
Grants-in-Aid for Scientific Research	Ministry of Education, Culture, Sports, Science and Technology	37 and under	2–3 years	¥5 million to less than ¥30 million	¥1.9 billion
Encouragement of Young Scientists A					
Encouragement of Young Scientists B		37 and under	2–3 years	¥5 million and under	¥10 billion
Science and technology promotion and adjustment funds Young contract scientist support	Ministry of Education, Culture, Sports, Science and Technology	35 and under, contracted	Contract term, up to 5 years	About ¥5 million to ¥15 million	¥1.5 billion
Industrial technology research support program	New Energy and Industrial Technology Development Organization (Ministry of Economy, Trade and Industry)	35 and under, lecturer, assistant professor	3 years or less	About ¥15 million	¥5.28 billion
Basic research promotion for the creation and development of new technologies and fields, young scientist support type	Bio-oriented Technology Research Advancement Organization (Ministry of Agriculture, Forests and Fisheries)	39 and under	5 years	About ¥20 million	¥850 million
Global environment research general promotion funds Issue study survey research Young scientist development type	Ministry of the Environment	35 and under	1–2 years	A few million to ¥10 million	¥20 million
Strategic information/communications R&D promotion Research organ development type R&D	Ministry of Public Management, Home Affairs, Posts and Telecommunications	35 and under (information/communications field)	3 years or less	¥10 million	¥450 million or less

Source: Author's compilation from information on relevant government websites and direct contact with relevant personnel

is typically around ¥12 million. This includes part or all of the scientist's salary. In the case of a research scientist one to four years beyond his or her doctorate, the average salary is about $50,000 (¥6 million),[11] so if that entire amount were taken from the grant it would leave about ¥6 million for research.

In Japan, on the other hand, grants can generally be divided into those of ¥5 million or less and those of ¥10 million or more. Because Japanese research scientists do not need to draw their salaries from grants they receive, they can apply almost all of the money to research. Thus it is possible for young Japanese research scientists receiving ¥10 million grants to have more funds to apply to their research than their U.S. counterparts who receive nominally larger grant amounts.

However, for reasons explained in Chapter 10-3 above, a majority of U.S. research scientists have more than one grant at a time, so the amount of money available to them to spend on research is, in fact, often greater.

10.5.3 Comparing early career research grants in Japan and the U.S. based on the number of young research scientists

Grants-in-Aid for Scientific Research is Japan's largest research grant program, and it covers a wide array of fields, from the humanities and social sciences to the natural sciences. In the U.S.,

Table 2-2: Major research grants for young scientists in U.S. (government funded)

Grant name	Organization	Target	Period	Amount/year	Funding (2002)
CAREER Program	NSF	Tenure track	5 years	Approx. $100,000 (approx. ¥12 million)	$60 million (2002) (approx. ¥7.2 billion)
K Award	NIH (DHHS)	Tenure track	Renewable up to 5 years	$100,000–$400,000 (approx. ¥10–40 million)	$400 million (2001) (approx. ¥48 billion)
Young Investigator Program	DOD-U.S. Navy (ONR)	Tenure track (Less than 5 years from doctorate)	3 years	Approx. $100,000 (approx. ¥12 million)	$8.4 million (2002) (approx. ¥1 billion)
Outstanding Junior Investigator Program	DOE	Independent researchers (Less than 5 years research)	Several years	$60,000 (approx. ¥7.2 million)	$500,000 (2003) (approx. ¥60 million)
New Investigator Awards	USDA	Independent researchers (Less than 5 years research)	Several years	Around $100,000 (around ¥12 million)	$9.8 million (2002) (approx. ¥1.2 billion)
New Investigator Program	NASA	Tenure track (Less than 5 years from doctorate)	3 years	$80,000–$100,000 (approx. ¥10 million)	$2 million (2002) (approx. ¥200 million)

$1=¥120
(Japanese translations of names of U.S. government bodies are from the FY 2001 Indicators of Science and Technology.) Source: Author's compilation from information on relevant U.S. government websites

Table 3: Comparison of young scientist grants in Japan and the U.S.

	Applicants	Selected (% selected)	Average award	No. eligible to apply
Grants-in-Aid for Scientific Research Encouragement of Young Scientists A (FY 2002)	1,999	206 (10.3%)	¥9.22 million	University faculty age 37 or younger (as of 1 October 2001) 40,660
Encouragement of Young Scientists B	13,721	4,155 (30.3%)	¥1.65 million	
NSF CAREER Program (2002)	—	394	$60,000–$80,000 (approx. ¥7.2–9.8 million)	Junior faculty with doctorates (1999) 47,368
NIH K Awards (2001) Encouragement of Young Scientists B	—	3,135 (40-60%)	$128,000 (approx. ¥15 million)	

$1=¥120 Source: Author's compilation from information on various websites, etc.

National Science Foundation (NSF) research grants support a similar wide variety of fields. According to statistics in the NSF's *Science and Engineering Indicators 2002*,[6] however, NIH supplies 60 percent of U.S. government research grants, while the NSF provides only 15 percent. Therefore the Grants-in-Aid for Scientific Research's young scientist program combines the NSF's CAREER Program and NIH's K Awards. In Table 3, we estimate the number of those eligible for the grants and the actual percentages obtaining them.

People affiliated with national, public, or private universities comprise 91.5 percent of all applicants for Grants-in-Aid for Scientific Research[12]. If this percentage holds true for "young" applicants, of the 15,720 applicants for Encouragement of Young Scientists A and B grants (young scientists may apply for only one of either at a time), approximately 14,400 were affiliated with national, public, or private universities. As of 1 October 2001, there were 40,660 university faculty members (not including those at two-year colleges) in Japan who met the Encouragement of Young Scientists criterion of being age 37 or under[13]. Thus, an estimated 35 percent of them applied for a Grant-in-Aid for Scientific Research. The number of those selected for Encouragement of Young Scientist A and B grants was 4,361, so apparently about 11 percent of those eligible received a grant. Grants-in-Aid for Scientific Research are paid over a two to three year period, and only one new or continuing Encouragement of Young Scientists A or B grant at a time may be applied for, so the actual percentage obtaining grants may actually be 22 to 33 percent.

The number of full-time junior faculty with doctorates (a criterion for research grants) in the U.S. is 47,368[14]. As described in Chapter 10-3 above, 42 percent of them are tenure track (another criterion), so an estimated 19,900 are eligible for research grants. The number of Career Program grants and K Awards actually given was 3,529, so an apparent 18 percent of those eligible receive them. However, since Career Program grants and K Awards are disbursed over five years and only one can be applied for at a time, the actual percentage of those obtaining such a grant may actually be close 90 percent.

10.5.4 Summary

Although Table2-1 and 2-2 show little difference between young scientist research grants in Japan and the U.S., differences are seen in the "Average disbursement per grant" and "selection percentage" columns in Table 3. Furthermore, the most common grant in Japan, the Encouragement of Young Scientists B grant, is a small grant averaging ¥1.65 million. The most common grants in the U.S., the K Awards, average ¥15 million, almost 10 times as much.

10.6 Finally

Young research scientists face different situations and hold different attitudes. Young research scientists in Japan are very fortunate in terms of employment stability. Although many Japanese scientists believe their counterparts in the U.S. are free to pursue research without interference, they are in fact bound to the research grant system. Their time is taken up with applying for various grants with different deadlines and with writing interim and final reports. These reports must be both longer and more detailed than ordinary technical papers. An unacceptable interim report can lead to a merciless reduction of the coming year's funding. Changes in government policy can cause decreased (or increased) funding without notice. Research grants must often be used to pay the salaries of postdocs and other research assistants and partners. In some cases postdocs must be laid off because of sudden funding cuts, and it is not unusual for scientists to shut down their labs and move into the private sector.

In contrast, young research scientists in Japan can expect career-long employment, and do not need to obtain grants to ensure career stability. This makes it easier for them to pursue long-term research that may not offer immediate results.

10.7 Conclusion

As we have described, the environments for research scientists in Japan and the U.S. are quite different. For that reason, the introduction of a U.S. style competitive system would not serve to vitalize young research scientists in Japan. Instead, we must consider effective ways to support research in Japan based on an understanding of the harshness of the science career path in the U.S. and the positive aspects of that career path in Japan.

10.7.1 Issues and policies

We believe the following are the major problem areas with Japanese early career research grants in comparison with U.S. grants.

(1) The perspective of researcher development is absent.
(2) The concept that obtaining research grants is proof of the independence and autonomy of a researcher is absent.

Simply increasing the budget for research grants is not sufficient to address these issues. Regarding (2) in particular, a change in the attitudes not only of the young research scientists themselves, but also of professors and other senior personnel at their affiliated laboratories is required. However, (1) could be addressed by incorporating the concept of diversity into early career research grants.

10.7.2 Proposals

We propose that the following be incorporated into research grants for young research scientists.

(1) Incorporate the perspective of researcher development

(A) Applications based on research history rather than age

Do not exclude scientists who differ from the norm, such as those who have worked full-time before entering graduate school or who previously pursued another field.

(B) Create grants for researchers at early career stages

Provide support for scientists at stages such as “newly hired as a full-time research scientist” or “less than five years as a full-time research scientist.” Provide support also for research scientists pursuing high-risk, challenging research or who have recently changed fields.

(C) Increase individual grant amounts and the number of grants

Research grant applications provide a perfect opportunity for scientists to objectively evaluate their own research projects. It is important that many research scientists take advantage of these opportunities at an early stage in their careers.This is another good reason to invest large amounts of funding into research grants targeting young research scientists.

(2) Foster the concept that obtaining research grants is proof of the independence and autonomy of a researcher.

(D) Clarify the role of senior researchers

Applicants for research grants should not only be persons carrying out the research and representatives of the laboratory, but also senior researchers.

The evaluation system for all research grants, not just those for young scientists, should be reformed. Rigorous interim evaluations are more important than rigorous final evaluations. Evaluations should be made not based on how many papers are published, but on whether the research carried out conforms to the grant application. The reporting of any changes should be made mandatory. Evaluations should be used to advise that grants in the next year be increased or decreased, or that the researcher should be advised to seek a higher-level grant, and so on.

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[2] From NIH web pages (http://www.nih.gov, http://grants.nih.gov/training/kawardresearch .htm).

[3] U.S. natural science doctorates are 1998 figures taken from *Science and Engineering Indicators 2002*, National Science Foundation. The total includes doctorates in natural sciences (physics, chemistry, astronomy, earth, atmospheric sciences, ocean sciences, biological sciences, agricultural sciences), mathematics and computer sciences, and engineering. Japanese natural science doctorates are FY 1998 figures taken from the 2002 Educational and Scientific Statistical Summary, Ministry of Education, Culture, Sports, Science and Technology. The total includes doctorates in the physical sciences, engineering, and agricultural science.

[4] Japanese figures are from the 2001 Educational Statistical Summary. The total is for national, public, and private colleges, not including two-year colleges. The number is from 2000 statistics. U.S. totals are from the Carnegie Foundation’s 2000 *Carnegie Classification of Institutions of Higher Education*. The total was reached by adding

the Carnegie Foundation's count of doctoral/research universities, master's colleges and universities, and baccalaureate colleges. Two-year colleges are not included. The number is from 2000 statistics.

[5] Number of contract faculty is from *Daigaku niokeru Curriculum touno Kaikaku Joukyou nitsuite*, 19 December 2001, University Division, Higher Education Bureau, Ministry of Education, Culture, Sports, Science and Technology. University faculty figures for 2001 are from the 2002 Educational Statistical Summary.

[6] *Science and Engineering Indicators 2002*, National Science Foundation.

[7] Richard M. Reis, 1997, Tomorrow's Professor: Preparing for Academic Careers in Science and Engineering, IEEE Press.

[8] Carnegie Foundation categories. RES. I & RES. II are Research University I & II. DOC. I & II are Doctoral University I & II. Those four classes of university carry out high-level research and grant doctoral degrees. LA I & II are Liberal Arts Colleges I & II. Now categorized as Baccalaureate (Liberal Arts) Colleges I & II, their focus is on undergraduate education.

[9] *The Chronicle of Higher Education* (http://chronicle.com/), Tomorrow's Professor Listserv (http://sll.stanford.edu/projects/tomprof/newtomprof/postings.html)

[10] *FY 2001 Survey of the Actual State of Research Activities in Japan*, September 2002, Research Division, Science and Technology Policy Bureau, Ministry of Education, Culture, Sports, Science and Technology.

[11] Average salary for doctorate holders in scientific fields is taken from *Science and Engineering Indicators 2002*, National Science Foundation.

[12] Information on Grants-in-Aid for Scientific Research is from the Japan Society for the Promotion of Science website (http://www.jsps.go.jp/j-grantsinaid/).

[13] The number of university faculty is from *Heisei Juusannen Gakkou Kyouin Toukei Chousa Chuukan Houkoku*, September 2002, a survey by the Lifelong Learning Policy Bureau of the Ministry of Education, Culture, Sports, Science and Technology. Numbers are as of 1 October 2001.

[14] The number of full-time junior faculty with doctorates is from *Science and Engineering Indicators 2002*, National Science Foundation. Doctorates are in mathematics; computer sciences; earth, atmospheric, and ocean sciences; life sciences; psychology; social sciences; and engineering.

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About SCIENCE AND TECHNOLOGY FORESIGHT CENTER

It is essential to enhance survey functions that underpin policy formulation in order for the science and technology administrative 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.

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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

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— 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.

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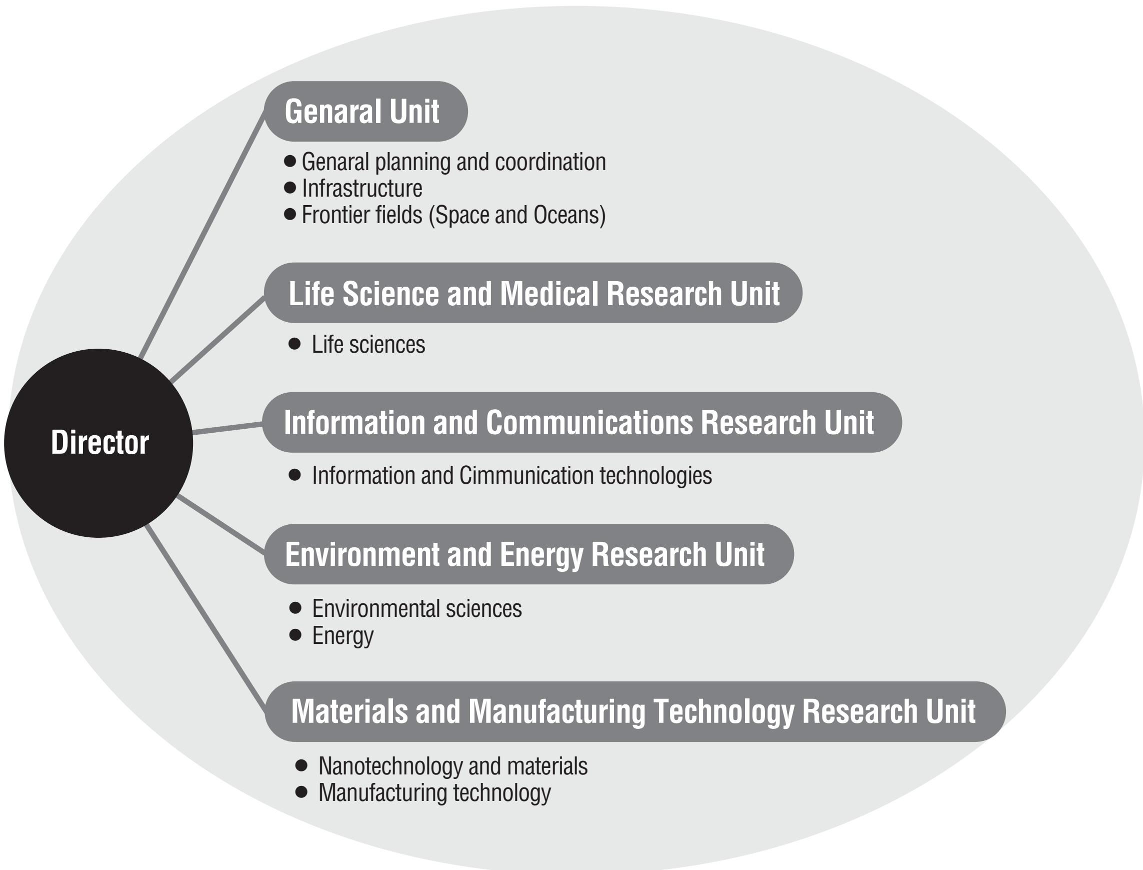

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