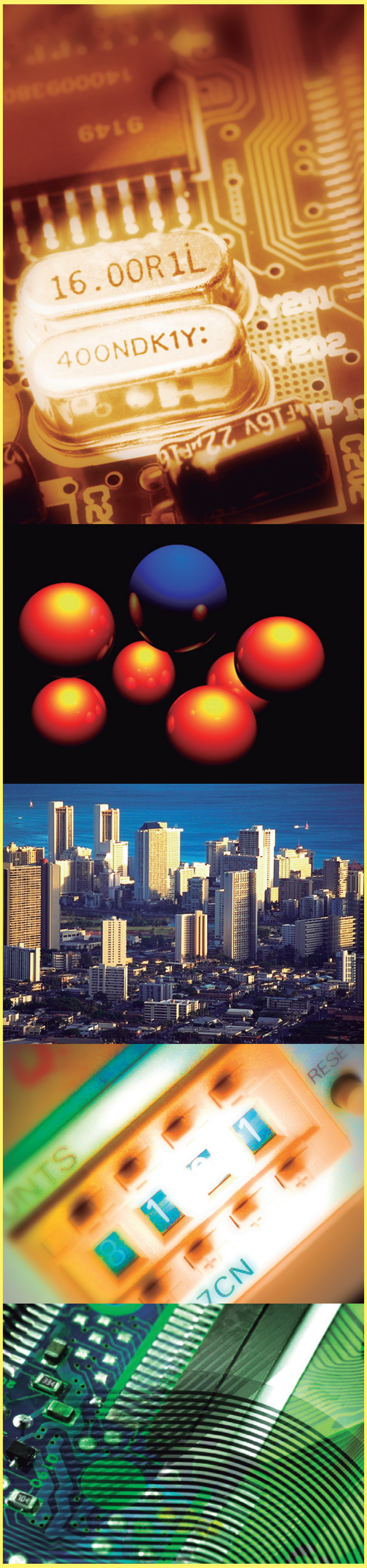
ISSN 1349-3671

Science & Technology Trends

Quarterly Review

Science & Technology Foresight Center, NISTEP

2007 July No. 24



Information and Communication Technologies

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Foreword

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

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

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

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

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

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Executive Summary

Information and Communication Technologies

1 Research and Development Trends in Critical Infrastructure Protection in the U.S.

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In the U.S. Department of Homeland Security alone, the science and technology R&D budget for homeland security stands at around 1.5 billion U.S. dollars a year. Research on how to protect critical infrastructure has a particularly important status within this budget, and such research is currently being carried out widely, mainly from within national laboratories under the control of the Department of Energy.

Critical infrastructures such as water supply, upon which modern societies are built, have a profound interdependent relationship with other infrastructures, such as the communications network. From the perspective of homeland security, “interdependency analysis” is necessary in order to both understand the nature of the interdependent relationship of these infrastructures, and to evaluate risks, based on the nature of these interdependencies.

As an example of some of the research being carried out in the U.S., one project is constructing a computer system that will assist the decision-making by policymakers in relation to risk management. Having envisioned a certain disaster, such as an act of terrorism or a natural disaster, this computer system can carry out various simulations on the damage caused to multiple infrastructures, and on the subsequent recovery of these infrastructures. Based on a unified evaluation model, utility functions are then presented to policymakers; further, information such as the extent of damage, time needed for recovery, the predicted results for alternative policy choices and alternative responses, measures for reducing the level of damage, specifications on the most dangerous areas, investment alternatives, and damage mitigation measures can all be examined by simulating an act of terrorism or a natural disaster.

Within Japan, also, the need for research and development on risk analysis from a public perspective, as well as on preservation and safety, across a wide range of infrastructures is anticipated to increase. We can learn much from the examples of pioneering research and development being carried out in the U.S. For example, there is a need to organize experts from a diverse range of fields, from those specializing in computer-based simulation technology to those involved in the maintenance of specific facilities, within one body. Further, since the results of the research are practically orientated, it is important to examine both the temporal and spatial dimensions of the problem areas, and to then utilize the results of any analysis to aid the decision-making process of policymakers.

(Original Japanese version: published in January 2007)

2 Analog Technology Trends and the Importance of Human Resources Development

— Centered on the New-Era Analog Technology Seen in CMOS High-Frequency LSI —

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The technology that surrounds us is not only digital, analog technology is also in heavy use. Mobile telephones include various analog technologies in antennas, displays, cameras, chargers, telephone functions, and two-way data transmission.

The Third Science and Technology Basic Plan designates and prioritizes 10 strategic sciences and technologies in the field of information and communications. One of these is “Technology for use with ubiquitous networks that supplement people’s abilities and support their lives.” Wireless communication plays an important role in infrastructure for the creation of ubiquitous networks. Wireless communications in mobile telephones, close-range wireless devices, and so on are becoming ever more advanced and diverse. Advanced new-era analog technology is necessary in order to realize them.

Advances in LSI miniaturization have brought about the SoC (system on a chip) era, with a single SoC requiring a mixture of digital and analog circuits. The development of analog circuits has come to have a major impact on the development period of LSI as a whole and on product viability.

With the advance of digitization, corporations have replaced analog circuits with digital technology and shifted engineers and the focus of their training from analog to digital. However, not everything can be replaced with digital circuits. Furthermore, the limits of the pursuit of higher speed in digital circuits have become visible, requiring thinking in terms of analog technology. It is becoming increasingly difficult to secure product superiority or added value solely through digital circuit design using sophisticated design automation. Rethinking of architecture and other changes in vision are necessary. Analog technology in the new senses now plays larger part in enabling product differentiation that is difficult to copy and improving quality.

During this important time, Japan faces the serious problem of a shortage of analog engineers for this new era. Because analog circuit design requires not only basic knowledge of electronic circuits, but also the general knowledge to see the whole picture, rapid human resource development is difficult. The USA, Europe, and other countries in Asia recognize the importance of new-era analog technology and are actively pushing research and development along with human resource development.

Under these circumstances, it is important for human resource development to center on the following measures to improve analog technical ability in order to “improve the quality” of semiconductors: “enhancing education and research,” “transferring expertise into design automation tools,” and “improvement of measurement environments.”

(Original Japanese version: published in January 2007)

Nanotechnology and Materials

3 Development Trend for High Purity Silicon Raw Material Technologies
— Expecting Innovative Silicon Manufacturing Processes for Solar Cell Applications —

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Solar cell materials are broadly classified into the silicon system, compound semiconductor system, and organic system. About 95 percent of current solar cell products are based on the silicon system, in which about 60 percent is polycrystalline. The fact that silicon type solar cells are the mainstream is expected to continue for the next 10 years.

Annual worldwide solar cell system production is growing by 30 to 35 percent, year to year comparisons. At the same time, as a principal raw material high purity silicon demand is rapidly increasing, eliciting a shortage of silicon materials. There is even a concern that a supply shortage of raw materials could become the determining factor for solar cell progress.

In terms of manufacturing technologies for processing silicon raw materials to high purity silicon, chemical and metallurgical methods are available, of which the chemical method is mainstream, utilizing the processing technology of repeated refinement of trichlorosilane. For strategies to deal with the shortage of high purity silicon for solar cell application, there is a proposal, as a long term approach, to reduce silicon consumption by developing cell systems with new types of structures. However, for the foreseeable future, the traditional cell structure will continue to be used as solar cell production grows. Thus, it is necessary to actively make the best efforts toward expanding silicon refinement facilities while developing and introducing new process technologies for manufacturing in order to increase production volume.

Up to now, major application of high purity silicon has been for semiconductors, but from now on, the semiconductor grade silicon will be a specialty product, making solar cell application the volume-wise major. Under such circumstances, the role played by researchers involved in nanotechnology and materials science will be greater than ever in areas, such as high efficiency power generation by solar cells, low cost manufacturing, and innovative refinement technology, among others. In particular, it should be taken into consideration to establish new venture type organizations and to utilize technical seeds provided by university and public research centers, through which promoting to commercialize technologies that are not the extension of traditional ones, that is, innovative process technology development for silicon production completely independent of the traditional raw materials manufacturing processes.

(Original Japanese version: published in January 2007)

4 Current Status of Biomaterial Research Focused on Regenerative Medicine

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Regenerative medicine is a generic term for a variety of therapeutic techniques to restore lost or damaged tissues to their original state taking advantage of the regenerative capacity inherent to many biological entities. Regenerative medicine is considered to become one of the important pillars supporting next generation medical care. This medical technology will contribute immensely to improve the quality of life of patients, especially those who are elderly, as well as to reduce medical and welfare costs for treatment and care. Research in regenerative medicine, in particular tissue engineering, is also important in establishing market position in and outside Japan. Medical devices using regenerative products which consist of a wide variety of valuable products in small quantities are considered suitable for Japan, a country with no natural resources yet replete with state-of-the-art technology.

Almost all living tissues are made of organic compounds such as proteins, lipids and polysaccharides. Since techniques for designing and synthesizing organic macromolecules have been well established, many researchers specialized in organic polymers/materials are taking part in development of new materials. Inorganic material research in Japan has attained one of the most advanced levels in the world, as evidenced by the development of hydroxy apatites for artificial bone substitutes and advances in creating artificial body fluids. Japan has a leading edge in biomaterial research combining these organic and inorganic materials.

Tissue engineering has already attained realization of biomaterials in some areas, such as skin (basically a two-dimensional tissue) and cartilage (cells occurring in a hypoxic and low-nutrient environment). However, there still remain many challenges to be solved; for example, there is a significant difference in three-dimensional structure between regenerated and natural tissues/organs. When considering the current status and problems in regeneration research on tissues currently under development for practical applications, in the order of difficulty, from skin, cartilage, bone and pancreas to liver, the largest problem lies in the fact that we are unable to regenerate large functional tissues consisting of different types of cells that can be used in the clinical setting. To regenerate large functional tissues, it is essential to create and control an appropriate environment that ensures the growth of cells during regeneration and avoids necrosis. Such an environment includes artificial extracellular matrices to support tissue growth: Such matrices should not only have appropriate structures to support the growth of cells, but also be able to control cell environment in a timely fashion by following or even preceding the functional development of the cells. Development of materials that can control the cell culture environment in terms of three dimensional structure and time is thus eagerly awaited. Development of scaffold materials to control the correct proliferation and differentiation of cells is also important.

Before the results of regenerative medicine research come into practical use, techniques must be approved officially on the basis of the results of clinical studies. In Japan, tissue regeneration techniques are considered medical devices that contain medicinal substance. Some of the data required for the official review of cell-material complex seems to lack scientific grounds, delaying the approval process of new regenerative medical products. It is also important to rationalize domestic standards and propose them for international adaptation, which will surely increase the advantage of Japanese regenerative medical products gaining ground in the international market.

(Original Japanese version: published in March 2007)

Frontier

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Exploration Technologies for the Utilization of Ocean Floor Resources
— Contribution to the Investigation for the Delineation of Continental Shelf

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Ocean floors several thousand meters deep in the sea area far away from the seashore are thought to be a huge reservoir of resources, such as petroleum, natural gas, metal minerals, living organisms, and microorganisms. However, to extract such ocean floor resources, it is necessary to investigate the geographical and geological conditions of the ocean floors to obtain detailed information on the offshore resources.

According to the UN Convention on the Law of the Sea, when certain conditions are satisfied, coastal states are entitled to exercise sovereign rights on the continental shelf beyond the exclusive economic zone. The process to define the limits is called “delineation of the continental shelf.” Countries, such as Brazil, Australia, and New Zealand, that possess a vast exclusive economic zone, have already submitted information on the delineation of continental shelf to the Commission on the Limits of the Continental Shelf (CLCS) of the United Nations. In Japan, related government ministries and agencies including the Japan Coast Guard, the Ministry of Education, Culture, Sports, Science and Technology, and the Ministry of Economy, Trade and Industry are carrying out the investigations for the delineation of continental shelf under the coordination of the Coordination Office for Continental Shelf Surveys of the Cabinet Secretariat.

Ocean floor exploration technologies used in such investigations include bathymetry technologieseismic exploration technology, bedrock sampling technology, and geophysical observation technology. The investigations of geographical and geological structure of the sea area to be studied are scheduled to be finished by the end of FY2007. Based on the results of these investigations, the information on the topography and geological conditions of the continental shelf that are considered to expand beyond the limits of 200 nautical miles in the sea area around Japan is to be submitted to the “Commission on the Limits of the Continental Shelf” by May 2009.

For future ocean floor exploration and utilization by Japan, the investigation for the delineation of continental shelf in the southern sea area, which is due in 2009, is nothing but an intermediate target. Japan, a maritime state that owns the sixth largest jurisdictional sea area in the world must develop ocean floor exploration and utilization technologies from the long-term viewpoint, so that the exploration technologies are applied to multilateral purposes, such as scientific research, resource exploration, and safety ensuring of the water channels. The following are proposals for future ocean floor exploration and utilization.

(1) In addition to the present ocean floor exploration technologies, new technologies that will bring about new achievements must be developed and introduced. In the Third Science and Technology Basic Plan, high-accuracy survey of crustal structure and drilling of the bedrock are listed as the major subjects in the frontier fields. Furthermore, it is necessary to nurture human resources and establish comprehensive policies in order to be prepared for the utilization of new equipment that has not been typically used in Japan, such as the three-dimensional seismic reflection survey, riser drilling, and offshore platform.

(2) Because of the high cost, utilization of ocean floor resources is not yet economically practical at this moment. However, since the supply of resources of various metals is becoming tight worldwide due to the rapid economic development of BRICs, technologies for obtaining metal resources from the ocean floors should be strategically developed as a measure to offset the risk of security assurance of the country. The Japanese government should establish policies that lead to an advantageous position in the future utilization of ocean floor resources.

(3) The present target of ocean floor exploration is the southern sea area because the area is directly related to the national objective of the prolongation of continental shelf. However, it is also necessary to promote the investigation of other sea areas such as Japan Sea that are not directly related to continental shelf prolongation. Ocean floor exploration cannot be carried out only by scientists. It requires diversified indirect supports including the navigation of the vessel, development and manufacturing of equipment, establishment and management of training facilities for the human resources of ocean floor exploration. Therefore, comprehensive policies for sea area exploration should be established before taking individual measures.

(Original Japanese version: published in March 2007)

Science & Technology Policy

6 Trends in Policies for Promoting Converging Technologies Expected to Bring Innovation

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Converging technologies (CT(s)) are "technologies converging two or more separate fields of science and technology for achieving specific goals" and are "categorized as 'metatechnologies' that affect other technologies to bring about drastic changes to the entire system." According to the reports on CT promotion published by the U.S. National Science Foundation (NSF) in 2002 and 2005, we are living in the "Age of Transition" and are already experiencing technological innovations brought by computer and information technology, nanotechnology and biotechnology. From now on, CTs, which are based on these technologies and transcend conventional frameworks in the fields of science and technology, are expected to serve as key technologies that will trigger revolutionary technological and social changes. Particularly, interdisciplinary convergence of science and technology based on cutting edge fields of nanotechnology, biotechnology, information technology and cognitive science (abbreviated as "NBIC"), is considered to associate social needs or policy issues with science or technology and is therefore promoted in U.S. and European Science and Technology Policies. The U.S. expects that promoting CTs will result in drastic improvement of human performance, social innovation and the creation of new business. The U.S. report presents expected years of accomplishment and ratings of benefit of the 20 specific CT topics.

The difference between CTs and the so-called integration technologies or fusion technologies is that CTs are mission-oriented and strongly needs-oriented; they are technologically and socially revolutionary; and they are interdisciplinary technologies based on NBIC. Recently, Japan has become aware of the importance of integration and fusion of technologies, but these aspects of CTs have not been sufficiently reflected in CT promotion in this country. Vertical driving powers within individual science and technology fields are strong in Japan, which are said to be hindering the creation of interdisciplinary technologies. This situation can be changed by incorporating the concept of CT promotion that might be effective for creating innovation. The following three measures are considered to be effective in Japan for the future:

(i) Holding of workshops on CTs regarding specific themes by governm ent-industry-academia groups concerned with common missions and topics, where participants can exchange opinions and share knowledge on CTs.
(ii) Reconsideration of the Strategic Prioritized Science and Technology areas of the Third Science and Technology Basic Plan from the viewpoint of CTs, and collective promotion of those expected to be effective in developing innovation through interdisciplinary implementation.
(iii) Government-industry-academia collaboration in the selection of topics that will be important in the future Japanese society and can be accomplished by science and technology, priorities in investigation of their status of progress and the formulation of promotion policies.

(Original Japanese version: published in February 2007)

7 Trends in Electronic Scientific, Technical, and Medical Journals
— The Research Information Gathering Environment and Business Innovation

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The information-gathering environment for researchers changed drastically with the advent of the Internet. Many international scientific, technical, and medical journals have interfaces on their websites for electronic submission of articles, which has led to a sharp reduction in submissions by mail. Furthermore, Internet article information provision services are now fully developed. One advantage of electronic journal services is that there is no need for binding, so individual articles can be released on the Internet as soon as they have been proofread. Electronic journals have already progressed well beyond mere digitization of paper texts and simple viewing services. Functions specific to electronic journals, such as electronic review of submissions over the Internet and citation links, have already been fully established. Concentration on shared platforms utilizing economies of scale, including standardized access counters, is advancing. Furthermore, through the shift to electronic journals, each article receives an accessible URL, enabling direct viewing of relevant articles from databases and integrated search results. The result is not just access from searches of secondary information, but access to the articles that constitute primary information through search engines by a broader range of readers.

Looking at electronic journals as a business worldwide, the open access movement has been an attempt to solve the problems of sharp rises in the price of journals and the pressure on library budgets that arose during the era of paper journals and to provide free access to scientific, technical, and scholarly information. Experiments with providing free-of-charge access to various kinds of electronic journals are currently underway. This is having major impacts not just on the operation of the electronic journal business but also on the question of the proper forms for academic societies, libraries, and research funding organizations.

Japanese electronic journal services are lagging behind those of Europe and the USA. Subsidies from the longstanding Grants in Aid for Scientific Research and the problem of integrating academic societies are having significant impacts on Japanese electronic journals. Because the journal projects of various academic societies are scattered, the economies of scale, which are a major advantage of shifting to electronic journals are not being generated, and the environment makes it difficult to train publishing professionals. Japan must move swiftly to train professionals in scientific, technical, and academic publishing and to create a system that will give them an international voice.

Furthermore, even if the integration of academic societies does not progress, their publishing arms should join together to strengthen the legal, public relations, and other functions that have been the weak points of Japanese publishing. The result would be an internationally recognized Japanese model for a not-for-profit publishing organization.

(Original Japanese version: published in February 2007)

1

Research and Development Trends in Critical Infrastructure Protection in the U.S.

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1 Introduction

Evaluating the risks that face the infrastructures that comprise our modern society has been given greater emphasis in recent years, particularly from the perspective of homeland security.

The networks that support our everyday lives, such as energy supply (oil and gas pipeline etc.), transportation, communications, and water supply, are in a complex interdependent relationship. Within the context of this interdependent relationship, the information network plays an extremely important role in facilitating the operation of many other infrastructures. At the same time, in order for stable operation of the Internet to be achieved, maintenance is needed from a number of aspects, beginning with information security, but also including the securing of the electricity supply and efficient traffic management.

Research into risk evaluation based on 'interdependency analysis' is extremely important in the context of the security of a broad array of critical infrastructures, and is indeed one of the central issues of research and development aimed at the protection of critical infrastructures. For interdependency analysis, system modeling, computer simulations, and the building of knowledge databases must all be carried out through a highly integrated approach.

In the U.S. today, research projects are being implemented in which, having envisioned the occurrence of an act of terrorism or a natural disaster, interdependency analysis is carried out from multiple perspectives to examine economic impact, and the effect that such an incident would have on public health and on the environment. A total of 14 different defined critical infrastructures, including the electricity supply network, the communication network, the water network, the Internet and waterworks facilities are included in the analysis.

In this report, I will introduce some of the projects being carried out in national laboratories affiliated with the U.S. Department of Energy, where the projects are financed by research and development funds from the U.S. Department of Homeland Security. In particular, I shall focus on research projects concerned with the protection of critical infrastructures based on interdependency analysis, and also aim to give a broader overview of these projects.

2 An overview of science and technology research and development at the Department of Homeland Security

Since the simultaneous terrorist attacks that took place in the U.S. on 11th September 2001, interest in safety and security in terms of homeland security has increased throughout the globe. In the U.S., the Department of Homeland Security Act was passed in November 2002, and in January 2003 the Department of Homeland Security (hereinafter referred to as the DHS) began operations. This department has since played a significant role in homeland security in the U.S. The main pillars of DHS policy are: (i) border security and transportation security; (ii) preparation for and response to emergency situations; (iii) science and technology and; (iv) intelligence analysis and the protection

Table 1 : Main research and development projects promoted by the U.S. Department of Homeland Security

Name of project	Contents	Implementing body
DNDO (Domestic Nuclear Detection Office)	Research on the detection of nuclear substances within the U.S.	DHS, DOD, EPA
CIP (Critical Infrastructure Protection)	Research on the protection of critical infrastructure	DHS, DOD, DOE, NRC
CBTR (Chemical & Biological Threat Reduction)	Research on the response to biological and chemical threats	DHS, DOD, EPA

DHS : Department of Homeland Security
DOD : Department of Defense
DOE : Department of Energy
EPA : Environmental Protection Agency
NRC : Nuclear Regulatory Committee

Prepared by the STFC based on relevant documentation

of infrastructure. In order for these to be implemented practically, the functions of other existing government agencies are utilized.

Within the DHS, science and technology research in the area of homeland security is carried out by the Directorate for Science and Technology, the Directorate for Preparedness, the Office of Intelligence and Analysis, and the Domestic Nuclear Detection Office. Science and technology research can be summarized as 'Defense and Homeland Security (D&HS)', and the three projects as outlined in Table 1 represent the main components of this overall project.

The total amount spent by the DHS on science and technology research and development was 1.5 billion U.S. dollars in 2006, and particularly, the budget of the Directorate for Science and Technology was more than 1.0 billion U.S. dollars. Within the same directorate, the Homeland Security Advanced Research Projects Agency (HSARPA) has been set up, modeled on the Defense Advanced Research Projects Agency (DARPA) within the Department of Defense. A huge variety of research projects are being implemented within the HSARPA.

In this report, I will introduce research trends in 'Critical Infrastructure Protection,' or CIP, within the science and technology research and development being carried out in the field of homeland security in the U.S. I will focus particularly on trends in research that examines risk evaluation based on a method known as 'interdependency analysis.'

3 Implementation structure for projects on Critical Infrastructure Protection (CIP)

CIP is a project that is attempting to construct a computer system that will assist decision-making process undertaken by policymakers by presenting utility functions based on a united evaluation model. Having envisioned a certain disaster, such as an act of terrorism or a natural disaster, this computer system can carry out various simulations on the damage caused to multiple infrastructures and on the subsequent recovery of these infrastructures. In the event that such a disaster actually occurred, various specific questions would emerge: What is the extent of the damage? How much time is needed for recovery? What would the predicted results be for alternative policy choices and alternative responses to the incident? What are the most effective choices for minimizing the damage caused? What are the most dangerous areas, considering the extent and vulnerability of the threat? What investment alternatives / damage mitigation measures / research strategies would be most effective in reducing the overall risk? The CIP system supports the discovery of the most accurate answers to these kinds of questions.

3-1 The implementation structure of the CIP project

Figure 1 shows the positioning of the CIP project within the three projects relating to critical infrastructure protection in the U.S. The CIP project extends across a number of research facilities, including the Los Alamos, Sandia and Argonne National Laboratories, affiliated with the Department of Energy (hereinafter referred to as the DOE). Individual research themes are allocated to these laboratories, and members of each facility cooperate throughout the research.

As can be seen in Figure 1, an organization known as the 'Visualization and Modeling Working Group (VMWG)' exists within the Office

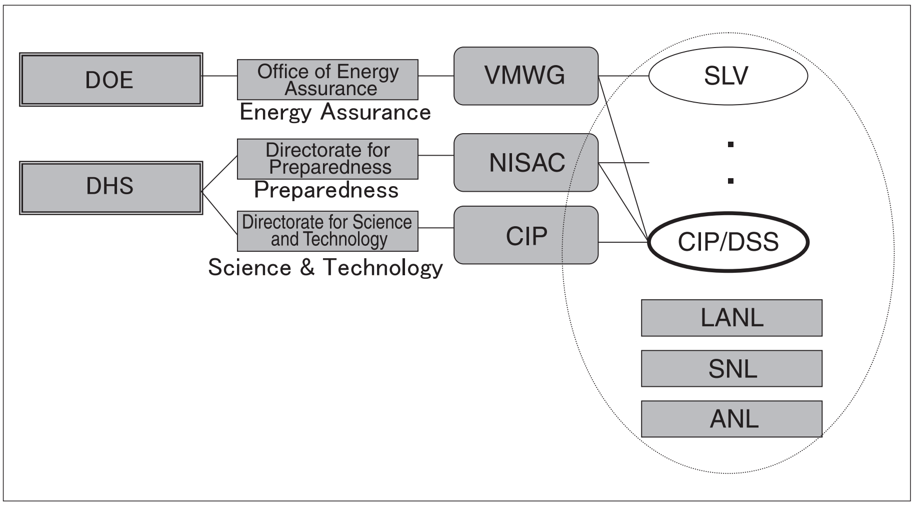


Figure 1 : The three projects on the protection of critical infrastructure in the U.S. and the positioning of the CIP Project within these

VMWG : Visualization & Modeling Working Group
SLV : Scenario Library Visualizer
NISAC : National Infrastructure Simulation & Analysis Center
CIP/DSS : Critical Infrastructure Protection/Decision Support System
LANL : Los Alamos National Lab.
SNL : Sandia National Lab.
ANL : Argonne National Lab.

Prepared by the STFC based on relevant documentation

of Energy Assurance in the DOE, and within this organization research is conducted into the visualization of simulation results, known as Simulation Library Visualizer (SLV). At the 'National Infrastructure Simulation and Analysis Center (NISAC)', which is under the jurisdiction of the Directorate for Preparedness in the DHS, researches envisioning various scenarios of terrorism and natural disasters that could affect critical infrastructure are being carried out. This organization is made up of a number of smaller organizations.

The central project in CIP is the Critical Infrastructure Protection Decision Support System (CIP/DSS), which I will describe after the following section. As previously mentioned, this project is concerned with the construction of a system that will aid the decision-making process with regard to various accidents or natural disasters that have the capacity to damage critical infrastructure. Within the CIP/DSS, disaster response research is being carried out, taking into account the 'interdependency' of risks to various infrastructures.

3-2 An overview of U.S. national laboratories - the main implementing bodies of CIP

Within the research and development currently being carried out in the U.S. in area of homeland security (including CIP), the role of national laboratories under the jurisdiction of the DOE is particularly prominent. The DOE operates many of its research programs, including 'nuclear accident response,' the 'chemical, biological, radiological and nuclear (CBRN) countermeasures program,' 'environmental measurement research,' and the 'energy security program,' through these national laboratories, which are under the control of the National Nuclear Security Administration (NNSA).

The three laboratories which I will now briefly introduce - Los Alamos, Sandia and Argonne - play particularly significant roles within this research.

(1) Los Alamos National Laboratory

The Los Alamos National Laboratory (hereinafter referred to as the LANL) is located in New Mexico. It was established in 1943 as part of the Manhattan Project, with the objective of developing the atomic bomb. The most significant role that the LANL has played up until now in science and technology research in the U.S. has been in the context of the development of nuclear weapons. Now, the laboratory conducts technological development with the objectives of establishing the safety and reliability of nuclear weapons, and promoting global security by working towards reducing the threat posed by weapons of mass destruction.

Like most other national laboratories in the U.S., the LANL is operated under the Government-Owned Contractor-Operated (GOCO) system, whereby the facility is owned by the federal government but operated by a private institution, such as a university. For a long time, the LANL has been operated by the University of California, which played a central role in the Manhattan Project. In 2005, however, an invitation to tender was issued, and since June 2006 the laboratory has been operated by a union made up of several private organizations, including the University of California, the University of New Mexico, and New Mexico State University[4].

(2) Sandia National Laboratories

The Sandia National Laboratories (hereinafter referred to as the SNL) is also located in New Mexico, and was established in 1949. As well as research into 'nuclear weaponry,' the SNL has been engaged in research into 'national defense systems and assessment,' 'energy resources and nuclear nonproliferation,' and 'homeland security and national defense.' In particular, with regard to its work on nuclear nonproliferation, the SNL made important contributions to the safe storage and disposal of nuclear weapons held by the former Soviet Union after the collapse of the communist regime. Amongst these contributions was the creation of employment opportunities for nuclear scientists from that region who could no longer find work at home. The SNL is also operated under the GOCO system. In previous years it was operated by AT&T, but is currently under the operation of Lockheed Martin Corporation.

(3) Argonne National Laboratory

The Argonne National Laboratory is located in Illinois. Like the LANL, it was established in 1946, centered around some researchers who had been involved in the Manhattan Project, which during World War Two had been concerned with promoting the development of the atomic bomb. This laboratory is similarly operated under the GOCO system, and the current operator is the University of Chicago.

4 An overview of CIP projects

4-1 The objectives and research management of the CIP project

The objectives of the CIP project are: (i) calculating the extent of potential damage to those critical infrastructures with certain designated risks; (ii) creating a basic interdependency model for critical infrastructures; (iii) calculating the effect of natural disasters on critical infrastructures; (iv) evaluating the efficacy of damage mitigation measures and; (v) providing practical support measures on region-wide, nation-wide and area-wide scales.

With regard to the research management necessary for the implementation of the CIP project, the following represent the basic thinking behind any such management. First, risks to homeland security must be assessed according to two factors, the 'probability of occurrence,' and 'damage.' It goes without saying that response to those risks which score highly for both factors is important, but in actuality there is a diverse range of issues, with varying levels of risk for both factors.

It is necessary to prescribe each risk clearly from both 'temporal' and 'spatial' aspects. Each phenomenon being examined needs to be classified into either a long-term or short-term risk, and further as either macroscopic or microscopic, and the methods of analysis and response adopted differ according to the nature of these classifications. Within the CIP project, analysis is carried out having selected criteria for the most appropriate perspective, according to the specific nature of the risk.

Further, because this research is concerned with homeland security, attention is also given to the origin of the data or information that will be utilized and to issues of security in terms of the operation of the decision-making support system. The following three standards of judgment are therefore crucial: the 'credibility' of the information upon which analysis will be based, the 'salience' of the information, in other words deciding which information will be given the highest priority, and the 'legitimacy' of the information, in other words consideration as to whether or not the source of the information handled is trustworthy or not.

In the event of infrastructure being threatened by a terrorist attack or a natural disaster, there would very rarely be a situation in which only a single social infrastructure would be affected. For example, in order to repair damage to energy supply equipment, the transportation network must be used to supply replacement parts to areas where the damage has occurred, and to transport these parts fuel supplies are also needed. Further, the communications network must be functioning normally in order to identify the areas where repairs are needed, and for coordinating any necessary cooperation during the actual repair work on multiple parts of the equipment.

Furthermore, when considering risks to homeland security, it is also necessary to give careful consideration to the trade-off between the cost of risk mitigation strategies, and the benefits that these same strategies create. Amongst the analysis functions of risks that need to be considered are the probability of the incident occurring, the gravity of the effects of such an occurrence, and the cost of protection against any such occurrence, as well as the current status of disaster prevention preparations. Creating a support system for policymakers who have to make judgments on disaster prevention measures means enabling those policymakers to understand the potential effects of disasters more clearly, and thus to take more appropriate and effective measures. In addition, it helps policymakers to make informed choices on strategic disaster prevention investment by identifying any issues likely to hinder recovery.

The main objective of CIP research is to carry out a comprehensive evaluation of risks extending across multiple infrastructures, and to ensure that information that can support the decision-making process in times of disaster is provided to policymakers as quickly as possible.

There are 12 critical infrastructures defined within the CIP Project, as outlined in Table 2. Modeling of these 12 infrastructures is carried out from a two-tiered perspective: the 'national perspective', and the 'designated city perspective'.

Table 2 : Critical infrastructures

1	Agriculture
2	Financial institutions
3	Chemical and hazardous substances
4	Industrial infrastructure
5	Emergency response facilities
6	Energy
7	Food
8	Information and communications networks
9	Post and transit
10	Public health
11	Transportation
12	Waterworks

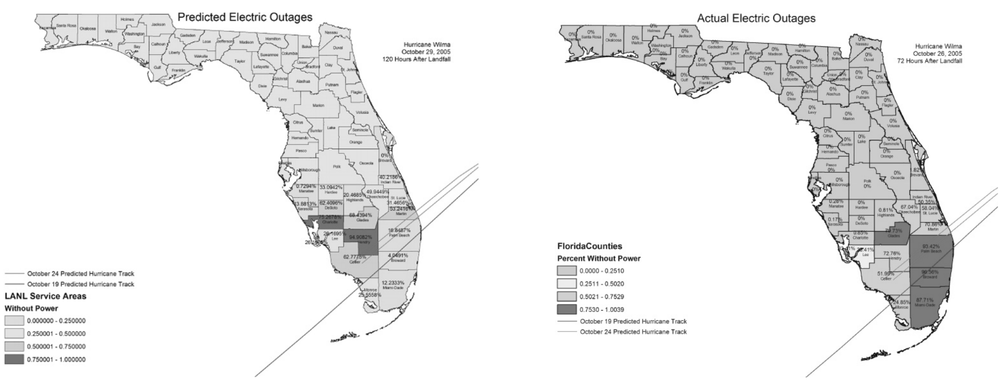
Having set up the model, risk evaluations for individual questions are then analyzed from various perspectives, including 'national defense', 'public health', and 'economic activity'.

4-2 Examples of research results

(1) Real-time damage prediction simulations

Figure 2 shows the results of a recent damage prediction simulation that tracked the path of a moving hurricane, and is an example of the practical application of the results of CIP project research. A simulation of electrical power supply cuts caused by the hurricane was carried out at the Los Alamos National Laboratory, and the results of this have been compared to the actual damage caused. The hurricane in question, Hurricane 'Wilma', was the strongest hurricane ever to be recorded in the U.S., and was first identified on 15th October 2005. It approached Florida from the Atlantic, and dissipated on the 25th. With the hurricane predicted to reach U.S. shores in just a few hours, the LANL received a request for risk analysis, including the likely path of the hurricane. A computer simulation was carried out, and the results of the subsequent risk evaluation were presented to the DHS in real time.

Section (a) in Figure 2 shows the results of the predictive simulation for electrical power cuts on the 19th October, 120 hours after the hurricane was first identified. The probability of electrical power cuts was calculated to be one of four levels for each area: 0-25%, 25-50%, 50-75% and 75-100%. Section (b) in the same



a) Predictive simulation for electric power cuts   b) Actual figures on electric power cuts

Figure 2 : Damage prediction simulation and actual figures for the passage of a hurricane

Prepared by the STFC based on relevant documentation

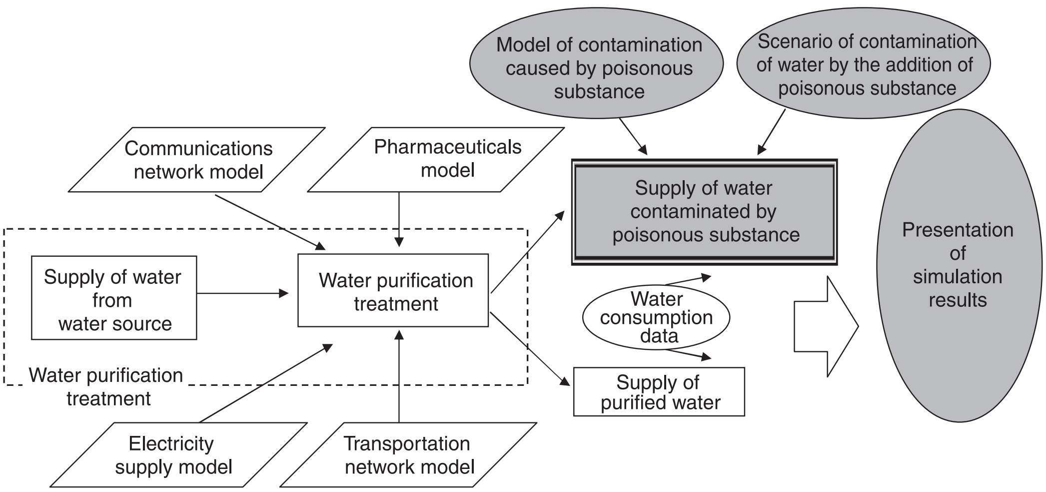


Figure 3 : Analysis case study on the contamination of an urban water system with a poisonous substance

Prepared by the STFC based on relevant documentation

chart shows the actual figures on electrical power cuts for the 26th October for each area. In this example, it can be seen that the results of the advance simulation and the actual damage caused by the subsequent hurricane are in close agreement. As such, this case study clearly demonstrates the high level of the modeling and simulation capabilities of the Los Alamos National Laboratory.

(2) An example of interdependency analysis

Figure 3 shows a flow chart used in predicting damage, based on interdependency analysis, having postulated a scenario in which urban water facilities - a critical infrastructure - have been contaminated by a poisonous substance. Relationships with other infrastructures are outlined, with a focus on water facilities. Actual data on water demand is also referred to, and a number of scenarios are envisioned in terms of the poisonous substance mixing with the water supply. Using the database, which will be referred to in more detail later, a simulation is carried out using a diffusion model, and the level of damage can be calculated using a time series.

In this example, the contamination of water by a poisonous substance has been assumed to have occurred under a number of different scenarios. Here, it is necessary to describe a detailed scenario for multiple potential incidents, and to carry out a quantitative evaluation for each of these incidents. The factors related to each incident need to be analyzed, the causal and interdependent relationships for each of these factors investigated, and the probability of occurrence for each factor calculated based on the historical record for each. At this stage, interviews with specialists are crucial. Once the probability of occurrence for each factor has been established, a quantitative evaluation of the risks associated with the interdependency of each factor can be carried out by applying, for example, 'Bayesian estimation on the basis of probability theory.' Within this research, the probability of occurrence is shown in models, based on the interdependent relationships of each factor within the scenario.

(3) Other case studies

Within CIP there are also many other examples of research successes leading to the practical application of risk evaluation solutions to a number of other issues. In a case study dealing with the evaluation of the threat of terrorism using bioagents to attack agricultural produce, analyses of the potential effects of various incidents, such as exposure to contagious bioagents, are undertaken, and simulations on the appropriate response to such incidents are also carried out, with details on the production areas and distribution of such cereals as corn, and of domestic livestock such as dairy cattle, beef cattle and poultry having being taken into account.

Another study estimates the extent to which traffic paralysis would occur in the event of various incidents, such as a natural disaster or terrorist attack. Detailed information on population distribution, going as far as specifics on the vocational demographics of individuals, within designated cities is compiled into a database, and the results obtained from the database are used to predict patterns of utilization for the various methods of transport.

An interdisciplinary approach is essential in research such as this. The CIP project is run by a team of researchers with diverse backgrounds. At the same time, the tools used for the simulations necessary for research, such as software etc., are generally existing tools that have been developed for use in other areas.

4-3 Creating a database for decision-making support

The manner in which the results of CIP research are used in problem solving, in terms of the utilization of relevant knowledge, will now be introduced.

First, in order to support the decision-making process undertaken by policymakers in the event of a disaster, a database known as the 'Scenario Library' is available. This is a database of documentation detailing information on previous hurricanes, heat waves, cold weather damage etc., using a standard document format.

The results of modeling and simulations carried out by the CIP team are also stored within this database. These data provide information on the circumstances of the damage caused to the critical infrastructure that was the focus of the research, the modeling technique utilized, the various conditions (priority given to detail, to management time, etc.) necessary for the provision of information to help in the specific decision-making process, the method adopted for practical experimentation, the external visualization method, and the assumed damage to facilities based on either the relevant modeling or simulation.

Within this Scenario Library, the results of risk analysis previously undertaken within the CIP are stored in a uniform digital archive form, and these can thus be used as reference material for any similar analysis undertaken in the future. The operation and utilization of this library is aimed at strengthening the level of knowledge and intelligence on information analysis. When simulating an incident involving bioterrorism, for example, it is possible to analyze and describe the various factors which would comprise the circumstances of such a threat. For example, in the case where an extensive bioterrorism incident is postulated, the question of whether or not there is possibility that a certain bioagent will enter into and contaminate water supply facilities would be one factor in the overall evaluation of the incident. It is also possible to carry out numerical evaluations of situational transitions amongst these partial factors within risk evaluation for facilities that have interdependent relationships.

5 Conclusion

It can be said that the sense of threat that exists in the background to the research introduced in this report is not felt by the U.S. alone, but rather is an issue for all developed countries. Within Japan, also, the need for research and development in the area of risk analysis from a public perspective across a wide range of infrastructures is anticipated to increase. For example, there is concern about the occurrence of a large-scale earthquake in Japan, and the damage from abnormal weather conditions has become more evident in recent years. Compared with the measures being taken by the U.S., Japan's approach to these issues has fallen significantly behind.

In October 2006, in Honolulu City, Hawaii, the first workshop on the construction of a safe and stable society, based on the U.S.-Japan Science and Technology Agreement was held; discussions were held on the possibility of joint research between the U.S. and Japan on measures to deal with the risks facing extensive areas and social infrastructures, such as terrorist attacks and natural disasters. It can thus be seen that interest in research and development in this field is growing, particularly in the context of international cooperation. However, in Japan, research themes on 'critical infrastructure protection' and 'interdependency analysis,' which were introduced in this report, do not yet benefit from an organized research body structured around a consensus of objectives. Rather, relevant research is spread across a number of ministries and government offices, and under these circumstances it will prove difficult to create a comprehensive research framework for this field.

This report is based on the observational survey that I carried out in 2006, visiting various national laboratories in the U.S. Throughout this survey, I gained the impression that within the CIP research team research was managed in such a way as to facilitate cooperation amongst researchers working in diverse specialized fields, so that common goals could be achieved. In particular, with regard to modeling and the methods used for analysis, it seemed that these were well discussed at each level throughout the organization, and that a common set of basic principles and rules was shared by the whole team. If this field of research is to be promoted within Japan, then I believe that there is a lot to be learnt from the example set by national laboratories in the U.S., with particular reference to the management of organizations.

Within Japan, also, the need for research and development on risk analysis from a public perspective, as well as on preservation and safety, across a wide range of infrastructures is anticipated to increase. We can learn much from the examples of pioneering research and development being carried out in the U.S. For example, there is a need to organize experts from a diverse range of fields, from those specializing in computer-based simulation technology to those involved in the maintenance of specific facilities, within one body. Further, since the results of the research are practically orientated, it is important to examine both the temporal and spatial dimensions of the problem areas, and to then utilize the results of any analysis to aid the decision-making of policymakers.

Acknowledgements

I would like to express my thanks to all of those persons at the DHS, the DOE, the Los Alamos, Sandia and other National Laboratories who so kindly cooperated with my research.

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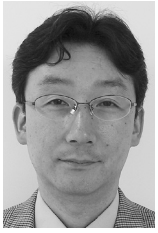

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(Original Japanese version: published in January 2007)

2

Analog Technology Trends and the Importance of Human Resources Development

—Centered on the New-Era Analog Technology Seen in CMOS High-Frequency LSI—

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1 Introduction

The Third Science and Technology Basic Plan designates and prioritizes 10 strategic sciences and technologies in the field of information and communications. They include "Technology for use with ubiquitous networks that supplement people's abilities and support their lives." Wireless communication plays an important role in infrastructure for the creation of ubiquitous networks. Wireless communications in mobile telephones, close-range wireless*1 devices, and so on are becoming ever more advanced and diverse. Advanced new-era analog technology is necessary in order to realize them.

Advances in LSI miniaturization have brought about the SoC (system on a chip) era, with a single SoC requiring a mixture of digital and analog circuits. The development of analog circuits has come to have a major impact on the development period of LSI as a whole and on product viability. Furthermore, using digital alone, it is becoming increasingly difficult to obtain added value from products. Analog technology is becoming radically more important as a source of added value.

Although analog technology is valuable in these ways, there is a worldwide shortage of analog engineers. Many nations recognize the importance of new-era analog technology and are vigorously promoting R&D as well as human resources development.

This article will focus on "CMOS analog RF system LSI*2," an advanced analog technology needed as wireless communication infrastructure, and will discuss what analog technology is, why it is necessary now, trends in its research and development, and issues surrounding it, and will propose necessary policies for improvement.

2 What is analog technology?

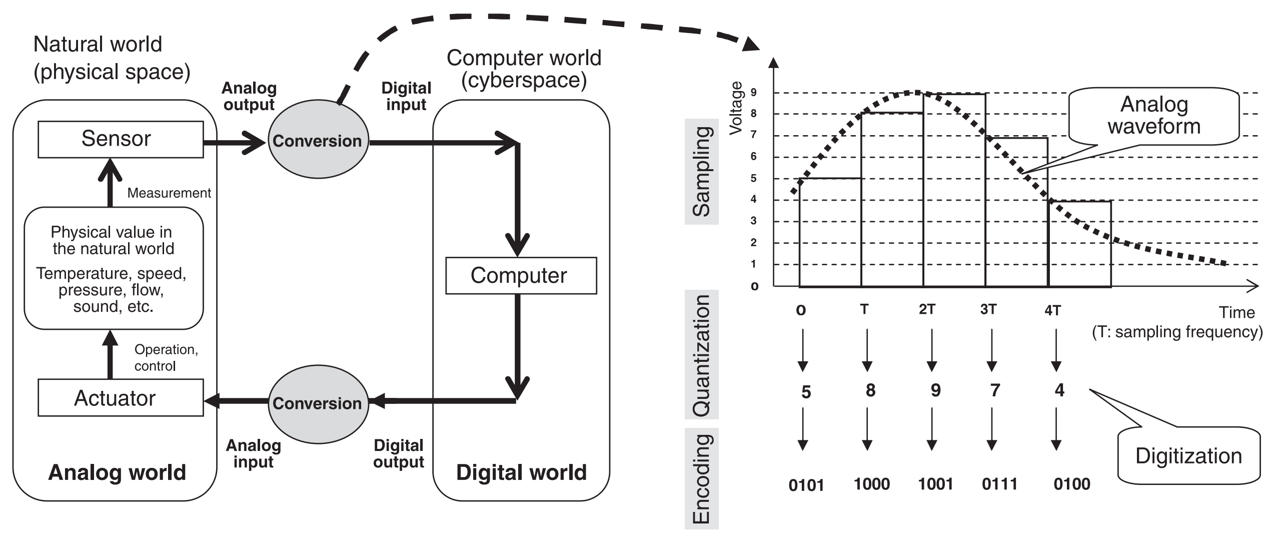
2-1 *Analog and digital[1]*

Analog information expresses the state of substances, systems, and so on through continuously varying physical values. Familiar things such as temperature, speed, pressure, flow, and human voices, are all analog. Analog data converted to continuous electrical values are analog signals.

Digital information, in contrast, is in discretely countable form. Inside computers and other kinds of electronic equipment, the presence or absence of electrical pulses is interpreted as the two digits "0" and "1" of the binary numerical system, and digital signals expressing digital values are used to achieve electronic function.

2-2 *How analog technology is used*

Analog technology is in heavy use all around us. This includes, for example, human interface components of displays, speakers, and microphones; analog circuits in wireless components; conversion components at the interface between digital and analog; cameras; and sensors. The analog circuits of mobile telephones, for example, include antennas,



(a) Interconversion of analog and digital values (b) Analog-to-digital conversion

Figure 1 : Interconversion of analog and digital values

Compiled by the STFC based on Reference[1]

displays, cameras, chargers, telecommunications devices, human interfaces, biometric authentication, telephone functions, and two-way data transmission. On the function side, low-noise and noise-elimination technologies are used because it is easy for noise to mix with the input of fine signals from the outside. For outputs to the outside such as displays and speakers operation, technologies for reproducing true signals without distortion are used[2].

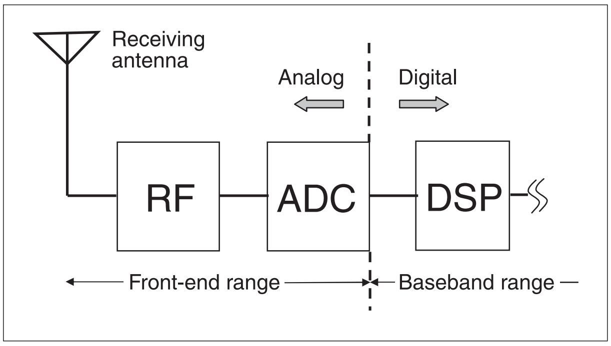


Figure 2 : Receiving circuit structure

Prepared by the STFC based on Reference[5]

2-3 Examples of analog processing

(1) Analog-to-digital / digital-to-analog conversion

This article will describe how information from the outside is processed digitally. Figure 1(a) illustrates the interconversion of analog and digital values. For analog signals to be processed in the computer world (cyberspace), they must be translated into data that computers can read. That is, conversion to digital values (analog-to-digital conversion, ADC) is necessary. Then, for the results processed inside computers to return to the analog world outside, conversion from digital signals to analog signals (digital-to-analog conversion, DAC) is necessary.

Figure 1(b) illustrates ADC function. At each sampling time (T), the value of an analog waveform (in this case, a voltage value) is measured, and then digitization takes place to convert the information to binary notation, which a computer can read. The number of bits that represent a data point is called resolution. For example, digital cameras have a resolution of 10-12 bits, while CDs have 16-bit resolution. DAC is the opposite process.

(2) Analog processing in mobile telephones

Inside mobile telephones, numerous cutting-edge analog technologies are used along with digital technologies. Figure 2 shows the basic receiving circuit structure. The electronic circuit domain can be roughly divided into the front-end range and the baseband range depending on the frequency bands to be handled. RF and ADC to the left of the dotted line belong to the front-end range, while DSP (digital signal processing) to the right of the line belongs to the baseband range (electronic circuit domain where digital processing takes place). In the front-end

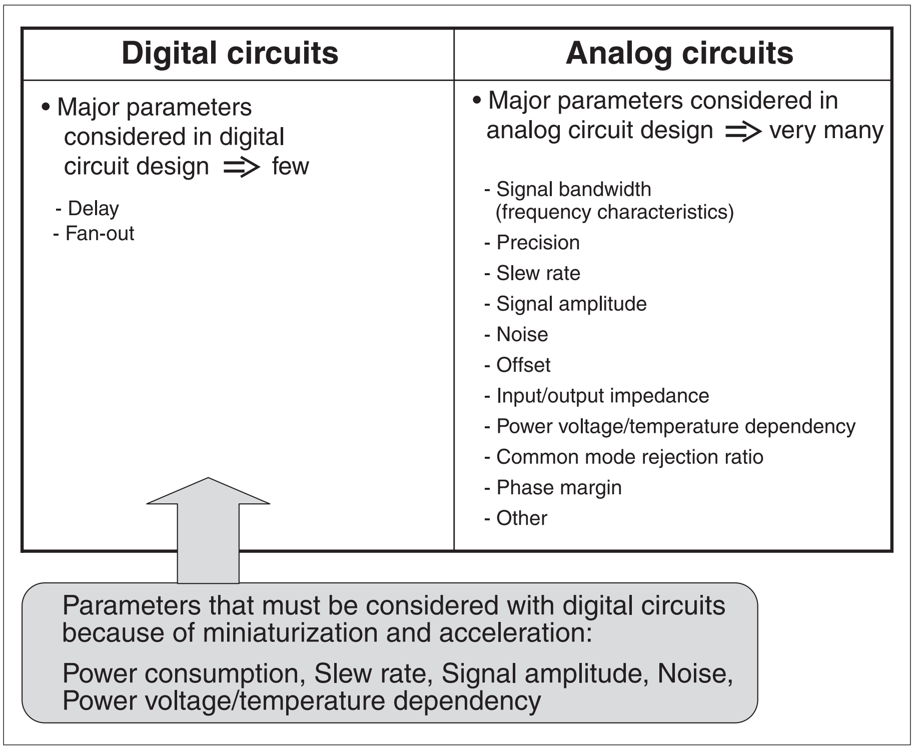


Figure 3 : Complexity in analog circuit design

Compiled by the STFC based on Reference[3]

range, weak radio waves received by receiving antennas are amplified, and analog technology is used to remove carrier waves from received signals. Transmission circuits are the opposite. In the front-end range, signals must be placed on high-frequency carrier waves and transmitted as radio waves. Analog technology achieves efficient transmission of high-frequency electric power.

2-4 Differences in the design of analog and digital circuits

Here the article will contrast analog and digital circuits.

One example of the education of digital circuit designers is a course on simple gate arrays*3. The program begins with Boolean algebra, and over the course of several weeks students acquire the basic ability to assemble logic circuits. With digital circuits, circuits made of transistors and elements are black-boxed, so designers need to think only of logic gates, the macro functions that combine them, and the relationships among their input and output terminals. Understanding of circuit details in gates and macro are therefore not necessarily required. Furthermore, there are not that many different types of gates and flip-flops.

On the other hand, analog circuit design deals with the transistor and element level, so entire circuits must be considered. Moreover, as illustrated in Figure 3, many parameters must be considered in their design. An error in one place will have a major impact on the entire circuit. Designers must consider characteristics such as circuit frequency response*4 that need not be considered with digital circuits. In analog circuit design, the insistence on solving formulas requires massive calculations, so approximations are common. It is thus necessary for designers to polish their sense of how to use frequencies, element values, and so on to simplify circuit models[4]. Therefore, acquiring the expertise to develop sophisticated analog circuits requires years of education.

Furthermore, analog LSI design is not merely the design of circuits. Designers must think at the system and block levels and consider the package layout to meet performance requirements. On the manufacturing side, consideration of device technology and process variation is essential. The final step requires that the specified performance is achieved with the packaging and boards. Some say that a person who merely designs circuits is not really an analog designer.

Figure 3 illustrates the fact that with miniaturization and acceleration, digital design also requires consideration of an increasing number of parameters.

2-5 Analog technology in digitization

Analog technology is thus essential for electronic equipment, but it has not been given sufficiently serious consideration in recent years because efforts have focused on digital technology. Osaka University Professor Taniguchi provides a frank discussion of that history and current conditions, stating, “Digital circuits spread explosively during the second half of the 1980s, and many analog circuit engineers were shifted to digital circuit design. It became clear, however, that knowledge of analog circuit design is necessary in order to draw advanced performance from digital circuits. Young engineers have almost no experience with analog circuit design. Very few universities in Japan provide education in CMOS analog circuit design, so there can be no expectation of newcomers”[5].

While there are currently few Japanese manufacturers who are proficient in analog technology, they do exist. However, many major corporations position digital-type semiconductors as a core business and have shifted design development and production technology to that area. This has been pointed out as related to Japan’s increasing weakness in the area of analog semiconductors[6].

3 Why analog technology now?

3-1 A paradigm shift from PCs to communication: an increase in analog-combination SoC

SoC is used mainly in digital appliances, mobile telephones, automobile electronic equipment, and so on. They are large specialized LSI circuits that concentrate many necessary functions. Their aim is to incorporate complete electronic device systems in silicon LSI. For example, with digital television, semiconductors account for about 50% of the cost structure, about the same as for PCs (personal computers). For electronic equipment as a whole, SoC provides significant benefits in reduced size, advanced performance, and diversified function, as well as lower costs. Furthermore, SoC is being aggressively pursued as a solution to the problem of electromagnetic radiation leakage between chips in the same package, because it reduces several chips to one chip. Against this background, SoC use is continuously expanding. It is no exaggeration to say that electronic equipment development today is synonymous with SoC development[7].

Furthermore, the driving force behind semiconductor development is shifting from the PC sector to communications. For the past 20 years, most of the world’s semiconductors have been intended for use in the PC sector, but looking at sales percentages in the world semiconductor market, in 2000 the communications sector surpassed the PC sector for the first time. During the PC era, the main semiconductor structural elements were microprocessors and memory, but with the advent of the Internet era, the importance of DSP (digital signal processing) and analog functions has increased significantly[8]. Therefore, the inclusion of communications functions in SoC development has naturally become important, and demand for combined analog and digital SoC (mixed signal SoC) is increasing. During the first half of 2006, semiconductor sales grew by 8% compared to the previous year. In contrast to a drop in processors for PC use, semiconductors for mobile telephones grew, underlining the shift towards communications[9].

3-2 The impact of analog circuits on SoC development

When analog circuits are combined with digital circuits in SoC, design of the analog circuit domain has a significant impact on SoC development.

First, it impacts the area of the LSI. Analog circuits cannot be expected to benefit from the CMOS miniaturization effect to the same extent as digital circuits. This is because suitable physical domains are necessary to obtain the needed performance from elements such as inductors and condensers, and it is necessary to secure symmetrical layouts for the differential amps used to amplify weak signals. Layouts that are resistant to noise require a large area.

Second, there is an impact related to the design automation (EDA: electronic design automation) tools that support analog design. Analog design directly lays out transistors and devices for capacity and resistance, estimates their electrical performance, and simulates the circuits. During the design process, the primitive and painstaking method of using specialized tools to bring the design data near completion is prevalent[10]. Analog circuit verification conventionally has taken place with analog circuit simulators such as SPICE. Compared to digital circuit verification, this requires a great deal of processing time and a long period of verification. Furthermore, because the parasitic capacitance of wiring and other variables affect circuit characteristics, circuit design and layout design must be repeated through many iterations. This is also a major contributor to long design periods.

In these ways, analog circuit development periods and performance have a major impact on the whole of LSI development and product viability. Because analog circuitry was used separately from LSI in the past, these problems did not surface. With advances in SoC, however, they have become a major focus.

3-3 Securing future product superiority

Design automation has made great progress in the area of digital circuit development. It has evolved to the point where designers can produce the desired circuits simply by using design description language to specify the LSI functions needed. While some effort is required to verify that an LSI is operating properly, taken to its extreme this means that anyone can create the same product, using digital technology alone, which makes it difficult to establish product superiority. Securing product superiority in the future will require a redirection of conventional vision towards areas such as devising architecture. Analog technology enables greater product differentiation than digital, and is not easy for competitors to imitate. For example, with digital, copying the wiring pattern will obtain roughly similar performance, but with analog, that is not necessarily the case. Analog usually requires other expertise[11]. In SoC today, analog circuits have come to be combined with digital, becoming a major element in product superiority. Accordingly, analog technology is playing an increasingly important role in securing product superiority.

3-4 The analog business is brisk

Figure 4 shows the Semiconductor Industry Forecast Autumn 2006 of World Semiconductor Trade Statistics (WSTS). According to this forecast, the size of the world semiconductor

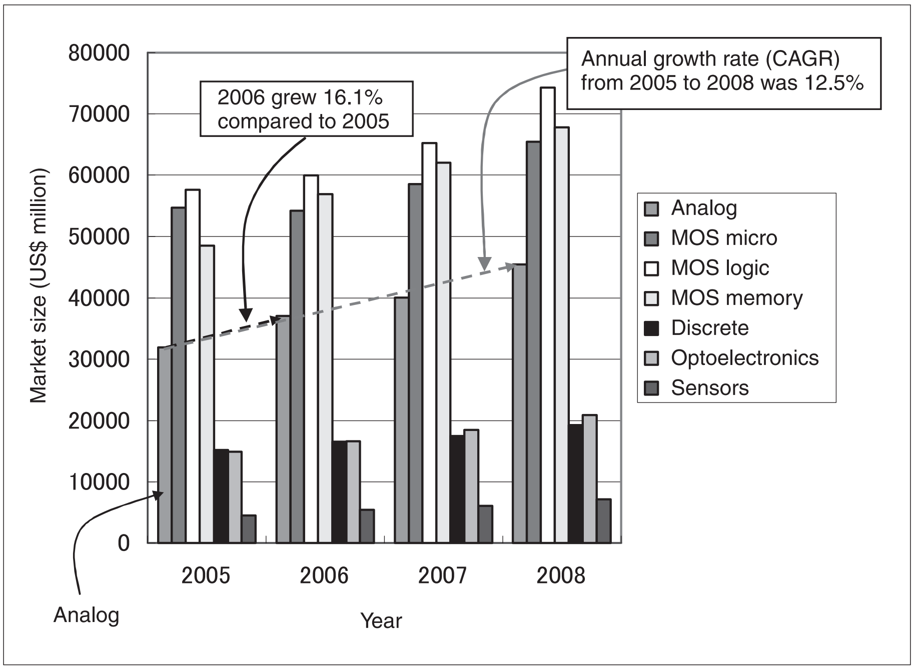


Figure 4 : World Semiconductor Industry Forecast Autumn 2006

Compiled by the STFC based on WSTS October 2006 market in 2006 was expected to grow by 8.5 percent from the previous year, to US $246.8 billion. By product, the market forecast for IC as a whole in 2006 was an 8.0 percent annual increase, to US $208.2 billion.

Within this, MOS memory increased significantly, by 17.3 percent to US $56.9 billion, as did analog, by 16.1 percent to US $37.1 billion. MOS logic, however, increased only slightly, by 3.9 percent to US $59.9 billion, while MOS micro decreased by 0.8 percent to US $54.2 billion. This indicates the overall large growth in analog. Furthermore, sensors, which are heavy users of analog technology, grew by 19.2 percent. Growth rates from 2005 through 2008 were high at 12.5 percent for analog and 16.3 percent for sensors[12].

Because the above forecast should include combined analog-digital in MOS logic and analog functions in discrete, one may conclude that the actual size of the analog market is even larger. In the future, analog technology will also be used in areas related to extended human interfaces, such as flat panels, digital TV, ultrahigh-speed wireless communications, in-vehicle systems, and robots. Analog techonology will be the basis for the creation of new businesses such as sensor networks, services using RFID, context-aware devices, and so on in the coming ubiquitous era.

4 Research and development trends in analog technology centered on analog RF

4-1 Growth of analog research seen in conference presentations

Figure 5 provides an overview of the state of analog-related activity (not limited to analog RF) at the International Solid-State Circuits Conference (ISSCC), where leading-edge semiconductor technology is presented. Whether the proposed circuits have actually been reduced to practice is an important criterion for acceptance of papers at ISSCC, so the conference's presentations provide an insight into trends in working technology. As the chart illustrates, the number of analog-related sessions increased steadily from 1985 to 1995, and again 2005, indicating how much attention analog is receiving. A striking recent trend is the jump in wireless-related applications.

4-2 Research and development trends in various countries

(1) Research and development trends in the USA

The United States of America has many outstanding manufacturers and venture

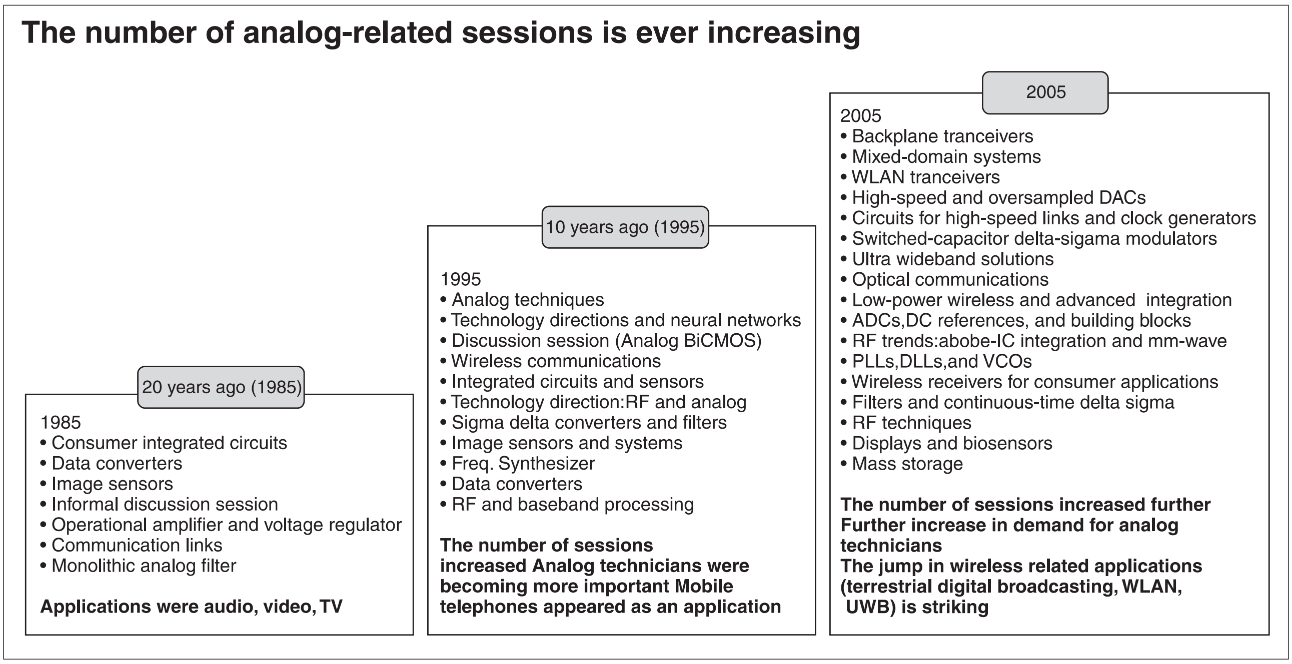


Figure 5 : The number of analog-related sessions at ISSCC

ISSCC: International Solid-State Circuits Conference

Compiled by the STFC based on Reference[24]

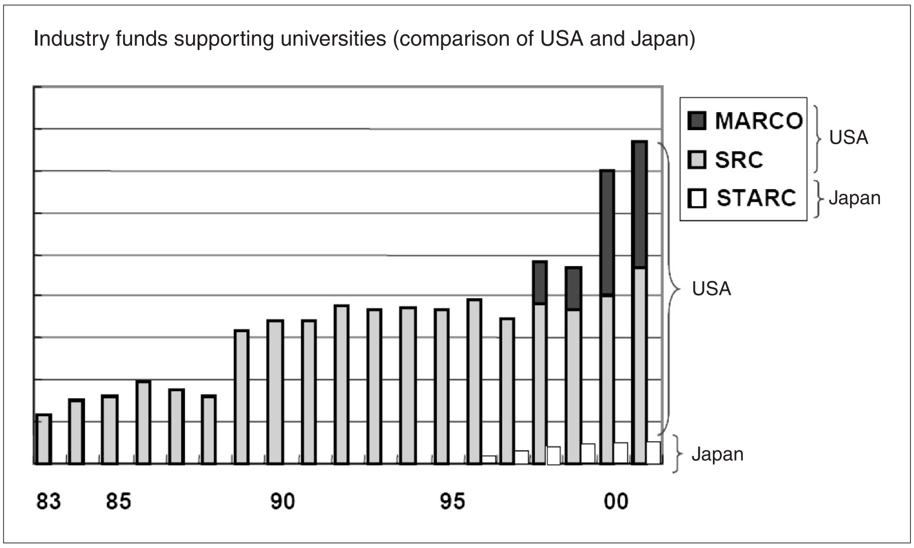


Figure 6 : Industry support for universities

MACRO : Microelectronics Advanced Research Corporation
SRC : semiconductor Research Corporation
STARC : Semiconductor Technology Academic Research Center
Provided by the Semiconductor Technology Academic Research Center

corporations that specialize in analog technology. Analog-related research is flourishing at universities such as UC Berkeley, UCLA, Stanford University, MIT, Oregon State University, the California Institute of Technology, and the University of Florida. UC Berkeley's Wireless Research Center is an example of leading-edge research. Since 2002, it has been carrying out research on 60-GHz CMOS radio systems[13]. Universities have created many ventures, such as Broadcom Corporation started by UCLA and Atheros Communications started by Stanford University.

As for existing corporations, IBM's forte is high frequency. It has a leading-edge foundry that can handle silicon-germanium and can develop and manufacture high-frequency-related circuits. Texas Instruments (TI) is particularly adept in products using digital signal processing (DSP), especially mobile telephone-related LSI products, and is making advances in the field of high-performance analog products for x-ray CT diagnostic equipment. Intel's core business is microprocessors (MPUs), but it is also strong in wireless-related products, drafting standards for wireless protocols such as Bluetooth and WiMax. In 2004, the general-use analog market accounted for about 6 percent of the entire semiconductor market. The top five companies, including TI, Analog Devices, and National Semiconductor, are American. They account for almost 60 percent of world market share[6].

In these ways, both universities and corporations in the USA are very strong in analog research and development. For the past 20 years, industry in the USA has strongly supported universities, in other fields as well as analog. This has become a driving force for university activities. Figure 6 illustrates semiconductor-related support for universities by industry. There is a large gap in Japanese support.

(2) Research and development trends in Europe

Europe also has many corporations with well developed analog technology for communications and industrial uses (e.g., CT scanning). European corporations were at the heart of the creation of standards for communications protocols such as GSM (global system for mobile communications*5) and ADSL (asymmetric digital subscriber line). Major universities or research centers engaged in analog research include the Netherlands' Delft University of Technology, Eindhoven University of Technology, and University of Twente, Belgium's IMEC (Interuniversity Microelectronics Center*6) and KUL (Katholieke Universiteit Leuven), Italy's University of Pavia, Finland's Helsinki University of Technology, and Switzerland's Swiss Federal Institute of Technology (ETH Zurich).

The industry-academia-government project NANOCMOS is one of a number of projects related to the EU's 6th Framework Program, and capital is being invested in MINATEC*7 and IMEC. MINATEC's research on wireless terminals positions CMOS RF and reconfigurable hardware as future key technologies[14]. The research program of France's LETI (Laboratoire d'Electronique de Technologie de l'Information) takes on wireless technology in leading-edge devices, engaging in RF front-end device development[15].

(3) Research and development trends in Asia

(i) Research and development trends in Taiwan

Taiwan positioned semiconductor research and development as primary industrial development (Industrial Evolution) from 1980-2000, but shifted it to secondary industrial development in 2001-2020. Taiwan moved to a design-weighted strategy by initiating the Si-Soft project as a driving force for secondary industrial development in 2001. The motivation for setting up Si-Soft was the idea that in the past Taiwan successfully shifted from a labor-intensive to a capital-intensive economy, but in the future it should shift to a knowledge-intensive one. The project's goal is to convert to a powerful industrial structure based on new design methods, design environments, and manufacturing.

Taiwan promoted the NSoC (National SoC) program as an SoC development strategy to strengthen industrial prowess and thereby generate high added-value products. The NSoC program's first phase (2003-2005) promoted five plans, human resources development, product development, platform maintenance, IP (intellectual property), and new-industry development. The result was that after having no papers accepted at ISSCC in 2002, Taiwan experienced a rapid increase, with 3 accepted in 2003, 6 in 2004, 15 in 2005, and 18 in 2006. Furthermore, the number of papers accepted at the International Symposium on Circuits and Systems (ISCAS) rose from 87 in 2003 to 106 in 2004 and 202 in 2005, second only to the USA. Currently, the NSoC program is in the second phase (2006-2010), promoting three plans: innovative SoC product technology, leading-edge SoC design technology, and leading-edge SoC design environments. Three taskforces have been set up, one of which is RF and Mixed Signal Circuit Design. Research and development of analog RF technology is playing a major role[16].

Taiwan's government is providing abundant funding for the infrastructure needed for education and research related to LSI design. The National Chip Implementation Center (CIC) is an organization under the umbrella of the National Applied Research Laboratories (NARL). It assists Taiwan's universities and research institutions financially. It supports the maintenance of EDA used for design, trial production of designed LSI, and so on. Trial production services for LSI include testing and measurement[17].

(ii) Research and development trends in South Korea

A great deal of research on CMOS analog RF is carried out at South Korean universities. Research on CDMA (code division multiple access) began to flourish in the early 1990s. Many universities began research on wireless in 1995, and the number of papers increased. Recently, there have also been presentations covering systems. Looking at the content of presentations at the RF Integrated Circuit Technology Workshop (an annual event; this year's will be the sixth) held in South Korea in September 2006, sessions on mobile communication, automobiles and milliwaves, WPAN/WLAN, reconfigurable RF, and so on were held. Of the 23 presenters, 10 were from corporations, 9 from universities, and the remainder from other research institutions[18].

4-3 Research and development trends in Japan

Figure 7 shows the number of wireless and analog RF-related papers presented by corporations and universities at the February 2006 ISSCC. Compared to other countries, Japan had very few papers from universities. From 1992 through 2001 as well, the number of papers presented by universities alone or universities in joint research was much lower than for the USA and Europe[20].

However, one cannot simply blame Japan's universities for this problem. Developing leading-edge analog technology is not at all easy

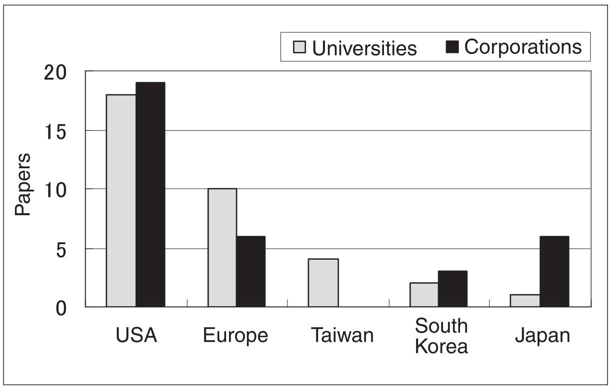


Figure 7 : Number of analog-related papers at ISSCC 2006

Compiled by the STFC based on Reference[19]

for corporations either. As described above, semiconductor corporations and governments in Europe, the USA, Taiwan, South Korea, and elsewhere have supported universities in this research. This has resulted in leading-edge research, as in the case of UC Berkeley.

Below, this article describes analog technology research and development trends occurring in Japan. The results, however, have not yet manifested themselves in numbers such as those in Figure 7.

(1) Technical committees and groups on analog RF technologies (activities of academic and other societies)

The Technical Committee on Silicon Analog RF Technologies was established for the period from February 2004 through March 2007. Its members are experts representing Japanese universities and corporations. Its statement of purpose says, “In silicon LSI, RF technology has become important in both wireless applications and digital LSI applications. Aiming towards the realization of microwave circuit technology centered on compound semiconductors with CMOS, the Society will form technical committees and groups including universities along with related corporations that will provide venues for discussion of technology, contributing to the further vitalization of this field and to the holding of international conferences.” Research fields span a wide range of analog RF-related areas, including circuit technology, wiring technology, measurement technology, modeling technology, and electromagnetic field simulation technology. The technical committee has met 10 times to date.

(2) Development of textbooks on analog RF by STARC (initiatives in industry-academia collaboration)

Eleven Japanese semiconductor companies provided the funds to start STARC in 1996. In April 2006, it began the “Asuka II Project,” a five-year plan. The project’s programs include “development of new textbooks through industry-academia collaboration.” The analog RF textbooks (basic edition and applied edition) are scheduled for completion by the end of March 2008. Through collaboration among Tokyo Institute of Technology (Professor Akira Matsuzawa), the University of Tokyo/VDEC (VLSI Design and Education Center; Professor Asada), the University of Tokyo (Associate Professor Fujishima), and STARC, the aim is to create practical textbooks based on actual data.

(3) Example of education at universities

Research groups and seminars are forming at several universities[21].This article will examine the case of the seminar on high-frequency evaluation technology at Tokyo Institute of Technology as an example. Since August 2006, the institute has offered a class on “Advanced High-frequency Measurement Engineering” in cooperation with an instrumentation company. Its purpose is to teach students basic knowledge in topics related to high frequency. For example, it provides students with an understanding of the characteristics peculiar to microwaves, microwave transmission lines, parameters used with various types of high frequencies, types of devices in high-frequency circuits, noise, and frequency spectrums, teaches them how to use instruments, and provides training on trial production and measurement of high-frequency circuits. Such basic knowledge is essential for students who wish to engage in research on the high-frequency domain, where modulation methods for mobile telephones are diversifying. The course is open, so students from other universities can also attend.

(4) Example of a regional initiative

Regional initiatives are being carried out by Gunma Prefecture, Fukuoka Prefecture (Kitakyushu City), and others. This article will examine the case of Gunma Prefecture, which has a long history of manufacturing and ranks about 10th in Japan. It has many corporations with technological prowess in the fields of analog integrated circuit design (semiconductor manufacturers), and electronic products (electronics manufacturers) that use the circuits. Collaboration in the electronics field is taking place, centering on Gunma University's Faculty of Engineering. It promotes the Analog Integrated Circuit Society (established in October 2003; its main activity is lectures on technology), joint industry-academia analog-related human resources development (lectures and internships), joint industry-academia research (promoted at the national level), and so on. Centering on alumni in corporations, it promotes the practical education of mid-level engineers for the purposes of analog technology education, transmission of know-how, and consulting. In addition, several Gunma-based electronics manufacturers and Gunma University's Faculty of Engineering are cooperating on activities to strengthen industry, research, and education related to analog circuit technology through the "analog technology-oriented Gunma concept."

(5) Government initiatives

In the Ministry of Economy, Trade and Industry's Technology Strategy Map 2006, the technology map for the information and communications field, "Technology Roadmap for Semiconductor Field"[22], indicates (i) conversion of analog technology to intellectual property, high-speed/high-precision simulation, and analog-DFT (2005-2007) and (ii) automated design of analog circuits and design integrated with packaging (2008-2014) as (SoC) design silicon implementation technology.

5 Issues in new-era analog technology

5-1 *Increasingly sophisticated technology acquisition*

In Section 2-4, this article discussed the differences between analog circuit design and digital circuit design and the difficulty of acquiring analog technology. However, with the miniaturization and acceleration of CMOS, even more advanced analog technology will be necessary in the future.

(1) The necessity of broad knowledge acquisition

Figure 8 depicts the areas of technology essential to the construction of wireless systems. As the chart makes clear, the mastery of an extremely broad range of basic knowledge is required. This knowledge includes silicon device physics, electromagnetics, digital signal processing for circuit design, RF/analog/digital circuit technology, the application of silicon wireless engineering for systemization, and

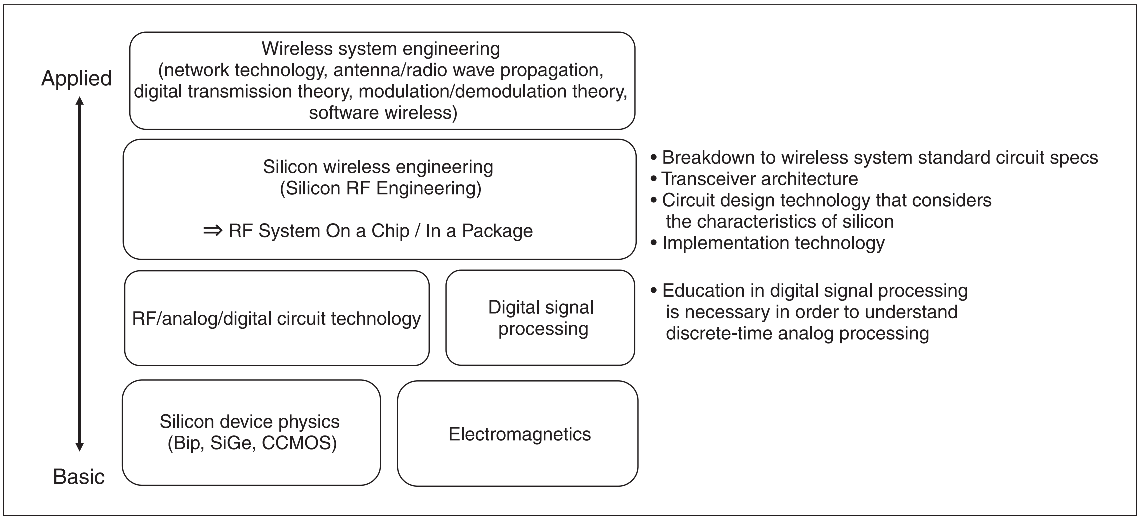


Figure 8 : Essential technology fields for the construction of wireless systems

Compiled by the STFC based on materials provided by Professor Tsuneo Tsukahara of the University of Aizu wireless system engineering.

In addition to that, it has recently become imperative to be able to respond intelligently to the changes in the frequency bands available for various wireless systems such as mobile telephones and close-range wireless. In product development for the world market in particular, one must bear in mind the differing frequency band allocations in different countries, the various modulation methods, differences in wireless protocols, differences in power voltages and standards, and so on[23].

(2) The necessity of systematic thinking

In the past, it was acceptable for analog engineers to specialize in a particular type of block (circuit part), but from now on it is desirable that they have a certain amount of technical prowess spanning multiple blocks so that they will be at a higher level and enable the optimization. They will also be required to raise their sights even farther, and to acquire the technical ability to consider architecture that aims to improve overall characteristics[24]. Regarding the difference between Japan's technical ability and that of other countries, we note the following opinion. "In Japan, when one speaks of being able to design analog circuits, it means the ability to make elemental circuits (parts) such as operational amplifiers. Graduate students in the USA, however, do not just make parts, they can also combine them to make systems. They also have the ability to design from architecture." Training in systematic thinking with awareness of the electronic equipment that will be used in the actual applications is necessary.

(3) Securing venues for experimentation and practice

The analog field requires all-around strength. It is a field where experience is put to use. Practice is important in the acquisition of analog technology, and deep study of the technology involves the integration of practice and theory[25]. In corporations as well, experimentation and hands-on education are vital, not just classroom instruction[26]. It is therefore extremely important to prepare environments where such practical education can take place.

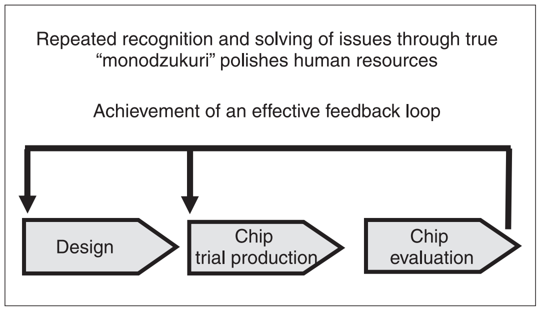


Figure 9 : Flowchart of "monodzukuri" in SoC development

As illustrated in Figure 9, the general flow of "monodzukuri" (skilled hands-on manufacturing) in SoC development proceeds in the order: design, chip trial production, and chip evaluation. In universities, installation of VDEC is steadily improving design automation tools at the design stage and chip trial-production environments. Issues remain, however, at the stage of measuring leading-edge analog LSI prototypes.

In the case of digital circuits, verification results in the design stage are reflected in the quality of the LSI after manufacture. Placing an emphasis on verification during design therefore enables defect-free LSI to be obtained, a major advance in digital LSI technology. With analog circuits, however, judging post-manufacture soundness of LSI requires measurement of waveforms. For wireless-related circuits, even more sophisticated measurement is necessary. To date, however, the provision of measurement environments for analog circuits has been extremely limited. Standards for acceptance of papers at ISSCC and so on emphasize the results of actual circuit operation. VDEC has enabled extensive trial production, but the reason the number of papers accepted by ISSCC has not grown is that there is a bottleneck at the measurement environments. Because leading-edge instruments are expensive, it is difficult for individual universities to obtain them. As measurement technology has become more sophisticated, it has become more difficult to master measurements. Furthermore, universities are unable to retain faculty who will provide human support for measurement and look after it.

(4) The difficulty of reeducation

The analog technology that will be necessary in the future differs from conventional analog technology. For example, old analog technology was for analog products. Intended for televisions, videocassette players, and so on, it was mainly bipolar. New analog technology is mainly intended for digital products. It is realized through CMOS for digital recording, communications, and networks.

A 1997 ISSCC discussion panel had the following theme:

"RF Designers are from Mars, Analog Designers are from Venus"

In other words, by 1997, there was already awareness of a significant difference between RF/microwave designers and analog designers. Conventional RF/microwave circuit designers work with compound semiconductors as a base, while new-era analog circuit designers work with silicon semiconductors as a base. The academic societies they belong to, their vocabularies, and their ways of thinking differ as well[27]. Currently, those two different worlds are integrating on the single platform of CMOS, and it is necessary for designers to master both disciplines.

Even if one attempts to reeducate bipolar technology analog engineers in CMOS analog technology, there are practical difficulties. This is because the differences in the technologies mean that their circuit construction methods are very different. Simply replacing bipolar circuits with CMOS circuits causes problems such as dispersion and noise. Because an understanding of the circuits peculiar to CMOS circuits is necessary, engineers brought up with the old analog technology are often unable to follow the logic of the new analog technology[28].

5-2 Responses to new issues through semiconductor miniaturization

As shown in Figure 2 (receiving circuits), a wave of silicon semiconductorization and CMOS-ization is surging from the baseband side to the front-end side. In the past, analog LSI used compound semiconductors and bipolar technology, while digital LSI was manufactured separately and packaged on printed boards, achieving the desired circuit functions. Regarding silicon semiconductors, there was a time when there was an awareness that from a performance standpoint, analog circuits were realized with bipolar technology, and MOS (metal oxide semiconductor, CMOS is one type) could not be used for this because of inferior performance. Through the miniaturization of silicon semiconductors, however, even if the RF circuit area is formed with CMOS technology, receiver sensitivity could be raised to the level of previous-generation bipolar technology. This level would be adequate for mobile telephones. At the same time, through efforts to bring down the costs of CMOS manufacture, the design and manufacture of mixed signal SoC began to flourish. Already, there are mobile telephones whose modulation methods are constructed entirely with CMOS.

Silicon semiconductor miniaturization is already entering the era of 65-nm technology nodes (node: one-half of the minimum wiring pitch). A problem accompanying miniaturization is increased power consumption. In response, means are being devised to decrease power voltage. Power voltage is now beginning to drop below 1 volt. In mixed signal SoC, however, it is harder to lower the voltage for analog circuits than for digital ones. It therefore is becoming difficult to further the move to SoC. Various possible solutions are being studied, including once again separating analog chips. With the miniaturization of CMOS processing, the degree of difficulty of analog circuit design has increased dramatically, so further research and development are necessary.

5-3 The analog-type thinking needed for acceleration of digital circuits

Currently, radio carrier wave frequencies use a bandwidth of several GHz, and signal transmission speed inside LSI has also reached several GHz. The development of even higher-speed operation is in progress. Connections among elements in circuit diagrams can be taken as wiring with no resistance value in the low-frequency domain, but they contribute significant resistance in the high-frequency domain. Furthermore, in the high-frequency domain, with two parallel conductors, the influence of parasitic elements (resistance of individual conductors, floating capacitance generated among conductors, parasitic inductance, mutual inductance, etc.) not in the circuit diagram cannot be ignored. Here the idea of “distributed constant circuit”*8 is necessary. The following are examples of phenomena that can occur along with higher frequencies[29].

(i) The generation of signal distortion and delays that cause timing errors and malfunctions.
(ii) The quality of the signal waveforms of digital signals is questioned like analog signals, requiring analog-type analysis.
(iii) Electromagnetic waves are easily generated.
(iv) The higher the frequency, the shorter the distance between wires, and the longer that wires run parallel to each other, the greater the crosstalk (signal leakage).
(v) A skin effect, in which current does not flow except on the surface of a conductor, appears. This increases high-frequency resistance by several powers of 10.

In other words, problems that previously only occurred in signal transmission between chips can now occur within a chip. These phenomena must be considered during design. Therefore, even if one calls it digital, there are cases in which design is impossible without analog-type thinking.

Currently in digital LSI design, DFM (design for manufacturability) is a major issue. Various problems occur due to electrical behavior during high-frequency operation, and their solution requires an understanding of analog technology.

5-4 Underdeveloped design automation tools

The functions of typical EDA tools for analog RF design provided by vendors from the USA include system/circuit diagram entry, linear simulator, harmonic balance, HSPICE simulator, EM simulator, interactive layout, placement and routing, interactive DRC (design rule check), and parasitic element extraction. Design automation tools for analog circuit design center on verification and interactive design. This is very different from digital circuit design, where automation is advanced.

Future issues in verification are, first, circuit modeling. With miniaturization, circuit models are unable to accurately express actual characteristics using conventional methods. Furthermore, simulation of high-frequency environments, formerly required at the packaging development stage, is now necessary during LSI design. In response to new changes, the development and enhancement of new tools is necessary.

6 Measures to improve analog technical ability

In the past, when the number and variety of digital products were growing rapidly, industry needed large numbers of digital circuit designers. It trained design engineers for digital LSI, typified by ASIC (application specific integrated circuit). In universities, VDEC (VLSI Design and Education Center) was established, providing full support for digital circuit designers. Today, however, it is difficult to secure product superiority or added value with digital circuits alone. Analog technology will also play an important role in the new sense of realizing high-speed digital circuits. Undoubtedly, analog technology will play a major role in the future in increasing the added value of Japanese semiconductors, i.e., in improving their quality. Below, this article will discuss measures for improving analog technical ability with an eye to enhancing semiconductor quality.

6-1 Enhancing education and research (proposals for industry and academia)

(1) Awareness of new analog technology

Added value in semiconductor design can be divided into the upstream of architecture and intellectual property, and the downstream of solving sophisticated problems at the physical level. Intermediate work that views only time and worker hours as issues is steadily losing added value. In order to thrive in global competition, personnel who can do work with high added value (or who can add value) are necessary. Analog technology is a source of added value. The first step in enhancing it is to recognize that the analog technology required today is not the same analog technology required in the past. Even in industry, there are still few executives who recognize this. There is little awareness of the need for reeducation. Second, it is necessary to establish new programs for personnel development and the reeducation of engineers in line with these concepts. Industry and academia should therefore work together to create educational programs and materials. An example of this is the creation of STARC's analog RF textbooks described above.

(2) Implementation of education tailored to those being educated

Human resources development should proceed on two fronts: broadening the base and training the top ranks.

Education to broaden the base should provide more potential researchers and engineers with opportunities not only to acquire basic knowledge, but to deepen their understanding through experimentation and practical training. A broad education from fundamentals to applications is necessary, but universities should first of all provide a thorough basic education. In addition, universities should set development targets and engage in the necessary research and development on elemental technologies and systemization in order to meet them. Universities and industry must actively collaborate in advancing this type of education. Research with industry will refine leading-edge ideas and implementation methods to deal with issues from the front lines of the latest developments in SoC.

How to foster elite human resources is a more difficult problem. Because they must accumulate the necessary knowledge and experience in several technological fields and in management rather than in just one specialized field, it will be difficult to create generalized education programs. If this is neglected, however, Japan will lose its overall superiority in the future. Industry and academia need to cooperate to deepen the discussion of this challenge.

(3) Analog technology education for digital engineers

As discussed in Section 5-3, analog-type thinking will become increasingly necessary with the higher speeds of digital circuits. Development has already reached a stage where it is difficult to rely on existing design automation tools alone. The usual tools will not by themselves be sufficient to solve the design issues that arise with full automation. There will be many points at which designers conversant with electrical characteristics will be needed. Japan should seek added value and improved quality in semiconductors by training digital engineers in basic analog technology and fostering human resources who understand both analog and digital technology.

(4) Expectations for university research

The field of analog technology is one where victory is determined not by excellence of equipment, but by the abilities of researchers and engineers. European and American universities present many prominent papers at leading international conferences on analog integrated circuits[30]. Venture businesses started by universities are succeeding in many countries. Through the combination of theory and practice, it is necessary not just to acquire technology, but to grasp research style that will develop it and sophisticated methods to deal with the issues. This is an area in which universities can be very active. Today in Japan, corporate engineers with advanced specialized knowledge are transferring to universities, where they are laying the foundations for leading-edge technology research based on actual development experience.

6-2 Transferring expertise into design automation tools (proposals for universities)

Transferring expertise into design automation tools converts research results into concrete assets. These tools should be improved through use at university research and development sites as well as actual industry development sites, and the process should be linked to human resources development. Development of design automation tools does not require expensive manufacturing equipment. It is a field in which ideas compete. Development of leading-edge design automation tools must begin with theory. In this sense as well, it is a research and development area well suited to universities, so their active involvement can be expected. The SPICE simulator is a tool developed by a university in the USA. Expectations are particularly high for the following concrete outputs:

(1) Research and development on simulators of high-frequency environments

Through the pursuit of high-speed operation, LSI has come to demand a design level close to the level of the packaging design of conventional packaging and boards. The development of highly accurate, high-speed simulators is expected to improve technological ability in analog circuit design.

(2) Research and development of leading-edge modeling methods

In circuit simulation in LSI design, the key is how accurately transistor models can express actual electrical characteristics. With conventional modeling, circuit models are increasingly failing to match the results of actual LSI measurement. The limits of response to miniaturized processes below 90 nm are becoming visible. Hiroshima University is researching and developing a next-generation MOSFET model called HiSIM. Recognized worldwide for its excellence, it is a finalist in the Compact Model Council's (CMC) selection of the next-generation MOSFET model standard[31]. Expectations are high that in the future universities will carry out further research and development on this type of model.

(3) Research and development on analog-type design support for digital engineers

Digital circuit design automation tools are becoming more sophisticated, but the state of development for circuit design that requires analog-type thinking is still inadequate. Immediate initiation of research and development to produce better analysis tools and other support tools will enable the securing of LSI product superiority. The number of engineers able to work in the domain of integrated analog and digital will also increase. Expectations for university research in this area are high as well.

6-3 Improvement of measurement environments (proposal for industry, government, and academia)

As a means to improve measurement environments, this paper proposes the establishment of a center that can provide a measurement environment and support ("measurement services") for its joint use by university and corporate engineers. This would solve the problem of the bottleneck in measurement. It should effectively implement feedback utilizing results as depicted in Figure 9. To ensure continued operation, the appropriation of new instruments should be accompanied by support for facilities as well as human support such as maintenance and training. These measurement services must be available to all, without regard to whether the users are universities or corporations. Basic education such as seminars on evaluation technology should also be provided. Universities already supplied with instruments for mixed signal SoC by national or local governments must open them and expand human support. Bases with measurement center functions should be opened in multiple regional universities (or research centers) in order to raise the general standard throughout Japan. They can become sites where analog engineers and other leading-edge LSI development engineers can gather, developing human resources through mutual communication.

7 Conclusion

This article has discussed analog technology trends and the importance of human resources development, focusing on CMOS analog RF SoC, which is wireless communications infrastructure that will play an important role in the coming of ubiquitous network connections and requires new-era analog technology. In order to make improvements for the future, enhanced education, the transfer of expertise into design automation tools and the upgrading of measurement environments as sites for practice are necessary.

For digital circuits as well, the limit of leading-edge, high-speed LSI development for supercomputers, digital appliances, automobile

LSI, and more will inevitably be challenged, so the role of analog technology will become increasingly important. Although this article did not touch on the subject, power circuits are another technologically and industrially important analog technology area requiring future research and development. Analog technology is an area that can be expected to "improve the quality" of Japanese semiconductor products. Its further enhancement is necessary.

Acknowledgments

Professor Akira Matsuzawa of Tokyo Institute of Technology Graduate School of Science and Engineering provided valuable opinions and materials on all aspects of the writing of this article. Professor Haruo Kobayashi of the Department of Electronic Engineering, Faculty of Engineering, Gunma University; Senior Manager Akira Kanuma and Chief Researcher Koichiro Mashiko of the Education Planning Group, Research and Development Department, Semiconductor Technology Academic Research Center; Mr. Hiroshi Nakamura of Jedat Inc.; Mr. Kazuteru Tada of the Electronic Measurement Group, Agilent Technologies; and Dr. Masanori Hirata of the Corporate Planning Division, NEC Electronics Corporation provided valuable advice and materials. President and CEO Katsuhiro Shimohigashi of Semiconductor Technology Academic Research Center; Professor Tsuneo Tsukahara of the University of Aizu; Professor Masao Hotta of the Department of Electronics and Communication Engineering, Faculty of Engineering, Musashi Institute of Technology; and Chief Research Scientist Tetsuro Itakura of the Toshiba Corporate Research and Development Center also provided valuable materials. The author wishes to thank all those involved for their kind assistance.

Glossary

*1 Close-range wireless is telecommunications utilized over relatively short distances. Wireless LAN, Bluetooth, etc., are commonly used.

*2 CMOS analog RF (radio frequency) system LSI refers to LSI in which analog circuits such as high-frequency processing and high-speed ADC/DAC (analog-to-digital/digital-to-analog conversion) that achieve wireless function are components in CMOS technology with mixed analog-digital LSI. This type of system LSI is called SoC (system on a chip).

*3 A gate array is a semi-customized IC with a master wafer with complete front-end processes prepared in advance.

*4 Frequency response describes several types of possible changes in output signal that might result from a frequency change in a circuit's input signal.

*5 GSM is a wireless communications protocol used with digital mobile telephones. It is utilized in many countries especially in Europe and Asia.

*6 IMEC is a European semiconductor-related research and development consortium based in Leuven, Belgium. IMEC actively collaborates with the Indian Institute of Science.

*7 MINATEC (Centre for innovation in micro and nanotechnology) is a project to create an international industry-academia-government research center to carry out research and development in a broad range of fields from microtechnology to nanotechnology. It is led by CNRS (Centre national de la recherche scientifique), CEA-LETI (the French Atomic Energy Commission's Electronics and Information Technology Laboratory), INPG (Grenoble Institute of Technology), and the regional government agency AEPI (Isèe economic development agency).

*8 Distributed constant circuit: Unlike general electrical circuits (called lumped-constant circuits) where circuit design takes place with circuit elements such as resistance, capacitance, and inductance (coil) concentrated at one point, with a distributed constant circuit, circuit elements cannot be spatially separated and circuit constants are distributed over its entirety. In this case, designs must consider the layout of each part, fully grasping the relationship between transmission line length and wavelength and whether there are connections among transmission lines.

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(Original Japanese version: published in January 2007)

3

Development Trend for High Purity Silicon Raw Material Technologies
— Expecting Innovative Silicon Manufacturing Processes for Solar Cell Applications —

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Kumi Okuwada
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1 Introduction

Solar energy is potentially capable of supplying most of the global need for primary energy, and it is expected to become an alternative source for fossil fuels as a clean energy, but the economic aspect of the system is a major hindrance to its growth. Yet, as accessible fossil fuels will run out in time as well as a growing global emphasis for introducing systems to reduce environmental burden[1], solar power generation is gaining importance every year. For the past 10 years, annual worldwide production of solar cell systems has been growing 30 to 35%. In terms of solar power generation, it reached about 1.7GW in 2005[2]. As a result, there is a shortage of high purity silicon raw materials. Future use of solar cell systems is expected to increase at a rate higher than in the past[3].

Presently, solar power energy is many times more expensive than that of fossil fuels. Every year, the cost of the solar cell portion for installation is increasing[4], and hence the reduction of its cost share, more than 50% now, is indispensable for expanding solar energy use. A share of the cost of silicon in the cell is estimated to be about 20%, making it an important factor for minimizing cost increase stemming from a shortage of raw materials.

As indicated in “The Third Science and Technology Basic Plan,” projects for research and development in the field of nanotechnology and materials will develop innovative materials, dramatically improving power conversion efficiency and enabling high efficiency energy utilization. In order to develop commercial processing technologies, it is proposed that the technologies enabling nanoscale control need to be established for material morphology, structures, and grain-boundaries[5]. Also, in the field of nano-electronics, it has been stated that for the next 10 years, silicon-based semiconductor device technologies should realize further high functionalities, a key to fast advancing an information-oriented society .

In this article, we review the background and development trends of solar cell grade silicon, and discuss the current status for high purity silicon supply and its processing technologies. Also, as strategies for coping with the silicon shortage, we review current developments of raw materials processing technologies, and discuss expected emerging materials science analyses or potential innovative process technology developments. In concluding, we would like to propose promotional organizations for addressing the silicon shortage.

2 Reasons for attention given to polycrystalline silicon solar cell

2-1 Rapid expansion of solar power generation

Lead by Europe, with a strong conviction for environmental issues, deployment of solar power generation is fast advancing worldwide[1,6,7]. The United States seems to take an interest in solar power generation more from the standpoint of energy security. The global power generated by solar cell systems reached 1.2GW in 2004 and 1.7GW (forecasted) in 2005. In terms of penetration rate, Germany is at the top in the world. This is because in Germany, the "Renewable Energy Sources Act" and "100,000 Roof Scheme" created the solar power boom prompted by setting up a subsidy program to purchase (solar power) electricity, which is 3 to 4 times higher than that of a traditional one[1,8].

The total world solar cell system production in 2004 was nearly 60% higher than the previous year, a significant growth. In terms of each country's system production, Japan generated 0.6GW, Europe 0.3GW, and the U.S. 0.14GW, demonstrating remarkable growth in Japan and Europe[9]. According to the report "Renewable Energy Scenario to 2040" by the European Renewable Energy Council, the prediction is that solar power's share of total world electric power will be 0.1% in 2010, 1.1% in 2020, and 8.3% in 2030[3].

Figure 1, prepared by the New Energy and Industrial Technology Development Organization (NEDO), shows the world production of solar cell modules, future forecasts, and a road map for solar power generation from the cost point of view[2,10,11]. Assumed here is that the cumulative deployment of solar power until 2030 is 100GW, which is 10% of the total power.

About 95% of the current solar cell module market is based on solar cells using silicon as raw material, of which about 60% is polycrystalline silicon, called bulk crystalline silicon, and 30% is single crystal silicon[9,12]. For the past 3 years, these figures have remained about the same, which is expected to continue for some time.

For further expansion of solar power system, it is necessary to lower the cost of solar cell module, comprising 60% of the system cost. To this end, the challenge is to reduce the cost of silicon raw

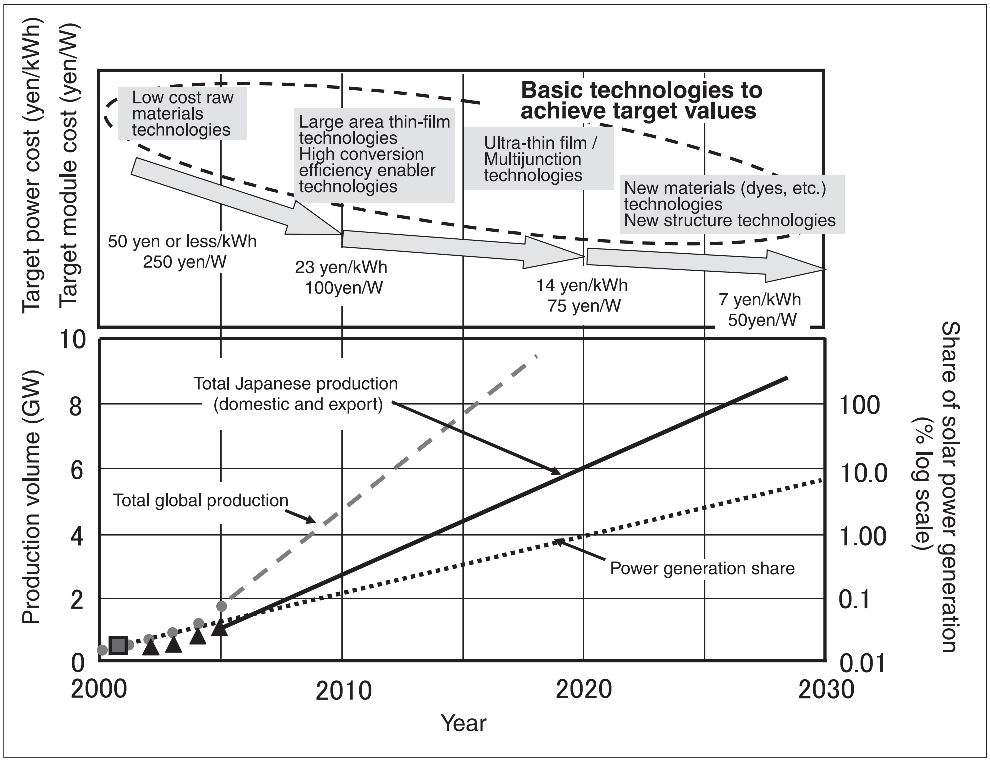


Figure 1 : World production of solar cell modules, future forecasts, and a road map for solar power generation from a cost point of view

Reproduced by the STFC based on References[2,10,11] by New Energy and Industrial Technology Development Organization (NEDO) materials, which comprise 20% of the module cost. Technology development realizing a vast cost reduction of module production is crucial, and equally so is the stable supply of silicon raw materials. However, if the current trend continues, the fear is that the silicon shortage will put a limit on solar power growth — it goes without saying that the cost reduction efforts for silicon raw materials will be overshadowed.

2-2 Issues for each type of solar cell by materials and its power generation efficiency

In terms of materials, solar cells are broadly classified into silicon system, compound semiconductor system, and organic system. Table 1 lists conversion efficiencies of solar cell modules, major features/issues, and summaries of the current status for each technology[9,10,13].

(1) Bulk type silicon system

In terms of crystalline states or device structures, silicon solar cells are classified into four types: bulk, thin film, single crystal, and polycrystalline. Among the types, bulk type silicon solar cell has the major share of current production, and this trend is expected to continue for some time. Power conversion efficiency is 16 to 18% for single crystal and 13 to 17% for polycrystalline.

Solar cell silicon, despite high purity, is orders of magnitude lower in purity than the semiconductor grade silicon, thus traditionally sourcing the off-grade silicon from the semiconductor industry. However, because solar cells require greater volume of silicon when compared with semiconductor chips, more silicon is produced just for the solar cell application in order to meet recent rapid increase in demand. With such high demand, development for low cost raw materials manufacturing is drawing attention. In particular, for bulk type solar cells of high silicon consumption, under development are technologies to reduce the crystal thickness (down to 50μm from 100μm) and cutting waste during the slicing process to lower material consumption, helping save raw materials.

(2) Thin film type silicon system

A thin film type solar cell is the one in which thin film silicon is deposited on a substrate. Since the raw material requirement is small, it is considered as a low cost solar cell for future mass production. However, even if thin film of crystalline silicon is formed, its power conversion efficiency is much lower than that of bulk type silicon. When thin film is amorphous, the power conversion efficiency gets even lower,

Table 1 : Conversion efficiencies of solar cell modules and major features/issues

Representative type			Production volume (2003)	Power conversion efficiency (module, %)		Major features and issues
				Current	Target in 2030 (NEDO)	
Silicon system	Bulk type	Polycrystalline	61	13~17	22	• Established record for mass production
		Single crystal	27	16~18	—	• High conversion efficiency
		Ribbon	1	16	—	• Slicing step not needed
	Thin film type (amorphous, crystalline)		4	7~12	—	• Possibility for low temperature, large area, and multilayer manufacturing • Low cost potential
Compound semi-conductor system	Single crystal type (GaAs system)		—	30~40	—	• High conversion efficiency, but high cost • Containing environmental burden substances
	Polycrystalline type (CIGS, CdTe)		1	13	18	• Necessary to secure In sources, reduce consumption, and explore alternatives to In • Necessary to improve the system reliability
Organic system	Dye-sensitized type		—	6	15	• No need for vacuum and high temperature processing • Low cost potential • R & D stage
	Organic thin film type		—	4	—	

* Ribbon means a thin film product manufactured directly from a silicon melt utilizing its surface tension (string-ribbon method), about 100nm to a few hundred μm in thickness.

Reproduced by the STFC based on References[9,10,13]

7 to 10%, despite the advantage that formation at low temperature enables greater varieties of substrates to choose from. Accordingly, improving power conversion efficiency is a key to reduce the power generation cost with these solar cells. As its power conversion efficiency improves, it is likely to become a mainstream technology because of its merit, that is, low raw material consumption.

(3) Compound semiconductor and organic systems

Compound semiconductor and organic systems are expected to become the next-generation solar cells. Research and development are taking place and the part of them has already been put into practical use. However, it is unlikely that they will replace a silicon system as the major alternative in the near future.

Since the expectation is that the compound semiconductors are theoretically capable of yielding higher efficiency than silicon, research and development are continuing. For instance, a polycrystalline thin film of a compound thin film type solar cell, CIGS (Cu-In-Ga-Se), has achieved power conversion efficiency exceeding 13%, and its band gap can be altered in accordance with its composition, which is considered as a merit. However, since indium(In) is in short supply, the supply and the cost problems are basically irresolvable. GaAs compound thin film type solar cells are also used but there is a concern along with the supply of raw materials that a large consumption of arsenic (As) will have environmental problems in the future. Although these compound semiconductor type solar cells are now increasing in production, eventually they will be targeted only for specialty applications.

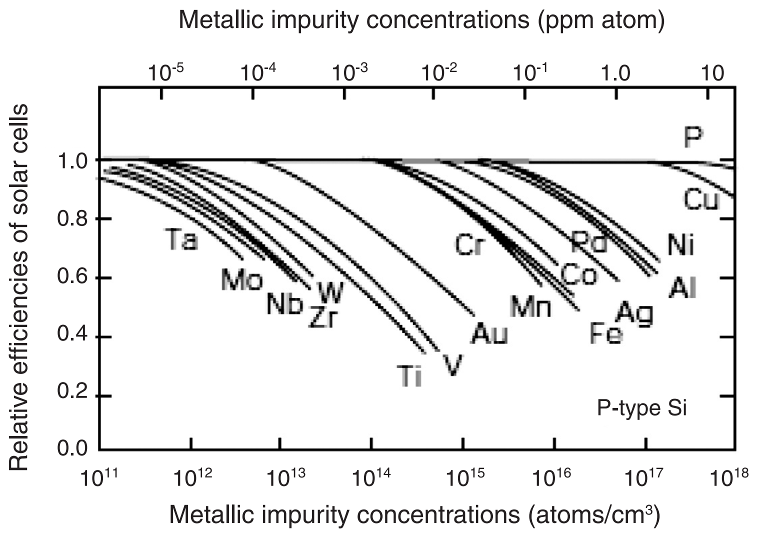
The organic systems, being overwhelmingly low cost in raw materials, may not be applicable for high efficiency power generation, but expected in applications for a low cost and/or a wearable solar cell. Organic dye-sensitized solar cells are reported to demonstrate greater than 10% in power conversion efficiency, providing high hopes for future low cost solar cells. However, up to now, they are not commercialized because of issues such as outdoor module efficiency, stability, life-expectancy, and reliability.

The quantum dot solar cell, not based on single junction, can potentially produce significantly high theoretical efficiency of 60%, drawing much attention from nanotechnology field. However, research in this field has just begun.

2-3 Relationship between power generation and impurity concentration in silicon system solar cells

Silicon for solar cells (99.99999% pure) is low in purity compared with that for semiconductors (99.999999999%), but the power conversion efficiency of solar cells is largely dependent on impurity levels in the silicon raw materials. Therefore, it is necessary to determine what the allowable impurity levels are in regard to both power conversion efficiency and associated costs. Currently, the guidelines for allowable impurity levels in silicon materials vary in accordance with the material suppliers due to existing relationships with the cell and module preparation processes.

Figure 2 shows impurities influencing the single crystal silicon solar cell performance and their concentrations found in various silicon raw materials[14-16]. Since many metallic impurities, present in less than the order of ppm, such as iron, aluminum, titanium, and others affect acutely the power performance, it is necessary to understand their quantity limits. The impurities are thought to delicately interact with grain boundaries and crystal defects, affecting the electric characteristics. However, full elucidation has not been conducted on the effect of impurity behavior in grain boundaries and crystals on cells characteristics[17]. It should be necessary to clarify these issues if low cost and high efficiency silicon system solar cells are to be realized.



(Unit : mass ppm)

	B	P	Fe	Al	Ti	C	O
Industrial metallic Si	5-10	25-30	1000-1500	600-800	150-200	150-200	–
Remelting Si for solar cells	0.1-0.3	<0.1	<0.1	<0.1	<0.1	<5	<6
Substrate Si for solar cells	0.1-0.3	<0.1	<0.007	<0.06	<4×10^{-5}	<3	<4

Figure 2 : Impurities influencing the single crystal silicon solar cell performance and their concentrations found in various silicon raw materials

Copied from References[14-16]

3 Forecasted demand for high purity silicon

With the recent significant growth of solar cell production, the demand for high purity silicon as a principal raw material is rapidly increasing, eliciting a shortage of high purity silicon. This is because many raw materials suppliers are prudent in making capital investment now, due to the fact that when high purity silicon was in short supply for semiconductors, they expanded manufacturing facilities only to find themselves with overcapacity. From a business point of view, the business of silicon system solar cells are comprised of five business sectors: silicon raw materials, ingots, wafers, cells, and modules. The further the downstream in business, the more production capacities are required, creating out of balance situations. Also, compared with downstream operations, upstream requires greater capital investment as well as longer lead times for construction of facilities for the same level of downstream production capacity, all of which are responsible for the current silicon shortage[18].

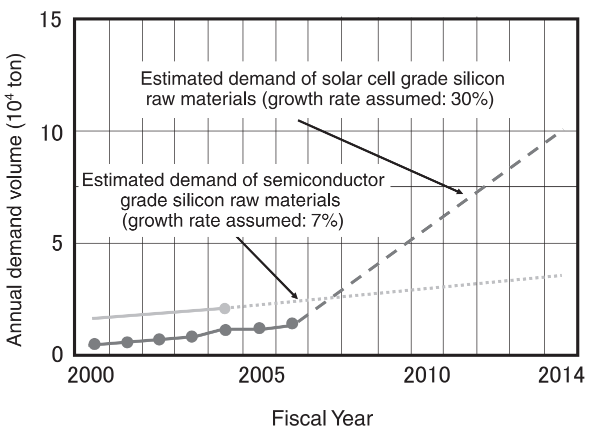


Figure 3 : Predicted total world demand of high purity silicon raw materials

Reproduced by the STFC from References[2,18,19] to calculate annual production volume assuming the growth rates

Figure 3 presents the estimated total worldwide high purity silicon supply[2,18,19]. In this chart, the pre-2005 annual production is based on actual volume (or predicted estimated value), but from 2006 onward, annual production volume is calculated based on the predicted silicon demand growth for solar cells and semiconductors. The average annual growth rate for the near future is predicted at 7% for semiconductor silicon and 30 to 35% for solar cell silicon. According to this chart, in 2007 silicon production for solar cells will exceed that of semiconductors. Currently, there are ten manufacturers of solar grade silicon raw materials in the world (Japan, the United States, and Germany). The top four companies are also wafer suppliers. For the next two or so years, even these ten companies will not be able to meet the raw material supply, thus undoubtedly causing a shortage. Furthermore, for the next several years, total demand for both semiconductor and solar cell applications will probably continue to exceed the total world production capacity of high purity silicon, creating a concern that the silicon shortage will become a stumbling block for solar cell growth.

In several years, the demand and supply balance will probably be stabilized, but the situation of the whole industry may be drastically changed. In the future, while Japan has been a leader in silicon supply for the semiconductor industries, the high purity silicon for semiconductors will be a specialty product in terms of total demand of high purity silicon. In this regard, when solar application becomes a major one, it is uncertain if Japan can continue positioned in a leading role for the silicon industry of solar cell application.

4 Processing technologies of high purity silicon for solar cell application

4-1 Development status of processing technologies for silicon raw materials

Table 2 summarizes the high purity silicon processing technologies for solar cell application, including those under development[19,20]. This chart also shows domestic patent application activities for each processing technology.

Roughly speaking, purification processing technologies are classified into chemical and metallurgical methods. The current mainstream method for raw materials processing is chemical, using repeated refinement of trichlorosilane ($SiCl_3$) (Siemens method). The processing starts with reducing silica sand (silica, SiO_2) making low grade silicon. This silicon reacting to hydrochloric acid yields trichlorosilane, from which impurities are removed via distillation and refinement. Then reacting the refined trichlorosilane with hydrogen at high temperatures yields high purity silicon deposits.

Table 2 : Processing technologies for high purity silicon for solar cell application and the activities in patent application

Basic approach	Features (secondary raw materials)		Production processes	Number of patent applications (1/1996 to 3/2006)	Representative companies	Status of development
Metallurgical approach	• Simple process • Low cost		Molten silicon refinement method	25	JFE Steel Corporation Nippon Steel Corporation Elkem Solar Crystal Systems Dow Corning	• Basic technology established • Large scale technologies under demonstration
Chemical approach	• Complex processes • High purity	$SiHCl_3$	Improved Siemens method	1	Hemlock	
					Wacker	
			VLD method	—	Tokuyama	
			Fluidized bed method	—	Wacker	—
		SiH_4	Fluidized bed method	—	REC	
			Inside silicon tube method		Joint Solar	
		$SiCl_4$	Zinc reduction method	10	Chisso	

* VLD (Vapor to Liquid Deposition) method: Silicon deposition method from silicon solution
The search system of the Japan Patent Office was used to search words, silicon, high purity, and solar cell from 1996 onward, and a total of 65 patent applications were found. Among the metallurgical and chemical approaches, 36 were selected, relating to high purity silicon processing technologies. It should be noted that the names of patent applicants and assignees, i.e., representative companies, do not necessarily agree.
Prepared by the STFC based on References[19,20]

The processes require a significant amount of electricity.

4-2 Trends for measures against silicon raw materials shortage

As illustrated in figure 4, one measure against the shortage of high purity silicon for solar cell application is to make best efforts to increase production capacity by expanding facilities and introducing new manufacturing process technologies because one premise is that the traditional cell technologies will continue to be used for the foreseeable future. At the same time, a long term development project for new cell structures is carried out in order to attain high efficiencies. In terms of policies, two major directions are being pursued: reduction of materials use and increase of raw materials production.

(1) Reduction of silicon use

In the future, more efforts will be focused on lowering as much silicon consumption per unit power as possible, by reassessing materials technologies to improve power conversion efficiency along with using new cell technologies. As mentioned already, in terms of the smaller consumption of silicon, the preference is to use single crystal or thin film silicon, but the cost is high. Still another approach is to make spherical silicon from the molten silicon, which is arranged within the reflector/electrode combination forming new structure cells, enabling significantly reducing silicon[21,22].

Further example showed that power generation was multiplied[23] by developing double-faced solar cells made from single crystals.

In addition, some researchers are attempting to reduce silicon consumption by developing a new machining method achieving lower raw materials waste[18]. More developments to reduce silicon consumption are reported: using fine wires when machining silicon ingot, thinner wafers are made; ribbon type wafers are made directly from molten silicon utilizing its surface tension; and a film-forming method developed for preparing wafers.

(2) Improved raw materials manufacturing processes and new developments, enabling expansion of silicon raw materials production

For improving the Siemens method, a current mainstream production process, the number of refinements is being minimized via increasing trichlorosilane's refinement efficiency, thus increasing the production volume per unit time. Also being pursued is the improvement

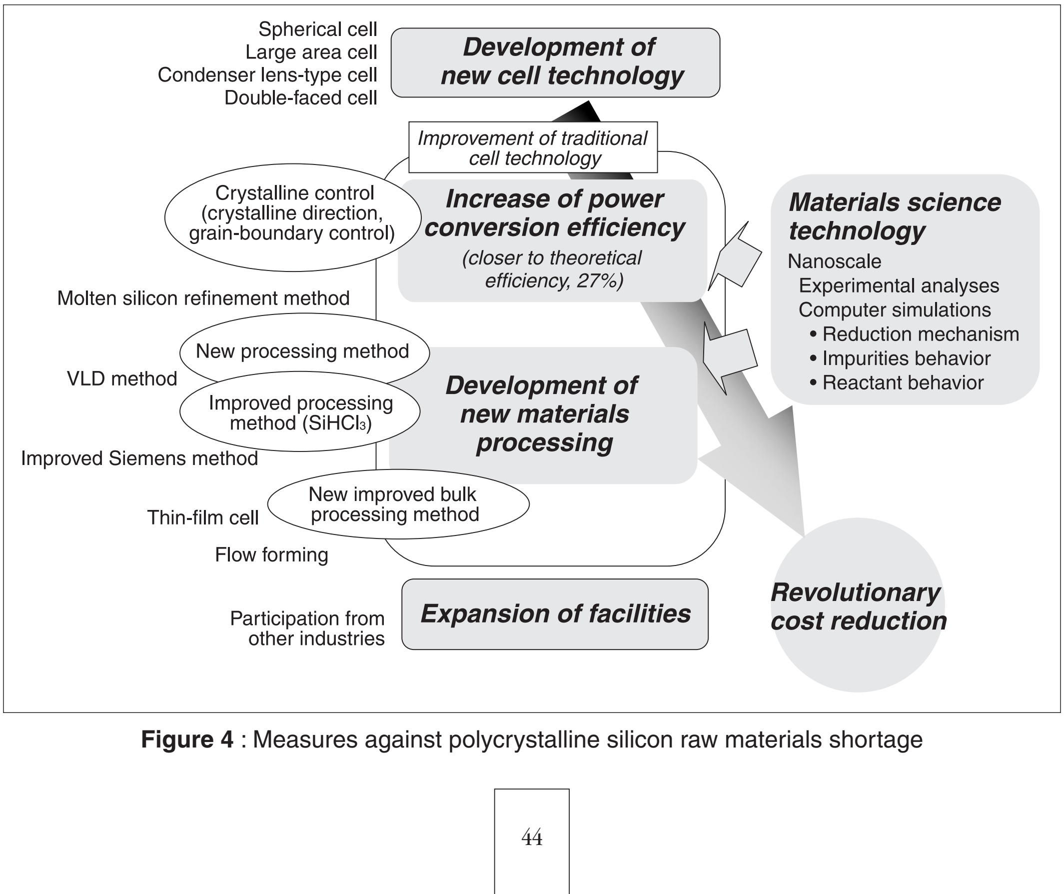


Figure 4 : Measures against polycrystalline silicon raw materials shortage

of ultimate product efficiency for high purity silicon. However, the Siemens method has been used for almost 30 years, during which time the method has undergone many improvements, offering little hope for drastic future improvement of refinement efficiency.

There are some candidates for new processing: VLD (Vapor to Liquid Deposition) and Molten Silicon Refinement methods. In the VLD method, trichlorosilane together with hydrogen is injected into graphite tubing heated at 1,500°C, producing a silicon melt deposit. The deposition rate is faster than that of the traditional Siemens method, enabling high efficiency silicon raw material production[17,19].

In contrast, the molten silicon refinement method uses a metal refining technology, reducing silicon's impurity concentration via metallurgical approach. Although it cannot be used for semiconductor application, solar cell grade is a good option. This has advantages in that different industries may be able to participate and also initial production facilities can be small compared with the chemical approach (approximately 100 tons). With a technology developed by the NEDO project, a metallurgical production processing, the metallic silicon of 99% purity is used as a starting raw material, from which impurity elements are removed to make high purity solar grade silicon. In this method, solidification refinement is performed twice. For the first step, after removing phosphorus with a graphite container under high vacuum, iron, aluminum and titanium are removed in the first solidification refinement. A zone concentrated with impurities in this ingot is cut out; then the remainder is crushed and washed. For the second step, after removing boron and phosphorus by water vapor oxidation in a plasma melting furnace, iron, aluminum, and titanium are again removed by a second solidification refinement[17,20,21].

5 Materials science technologies expected to contribute to making high purity silicon raw materials

Figure 5 presents various nanoscale approaches to elucidate impurity behaviors in silicon, showing potential capabilities. They are illustrated according to intermediate processing products staring from raw materials silica to solar grade silicon (99.99999% purity). As can be seen below, focused efforts of nanoscale experimental analyses and computer simulations are necessary in order to analyze impurity behaviors in crystals and grain boundaries. However, historically in

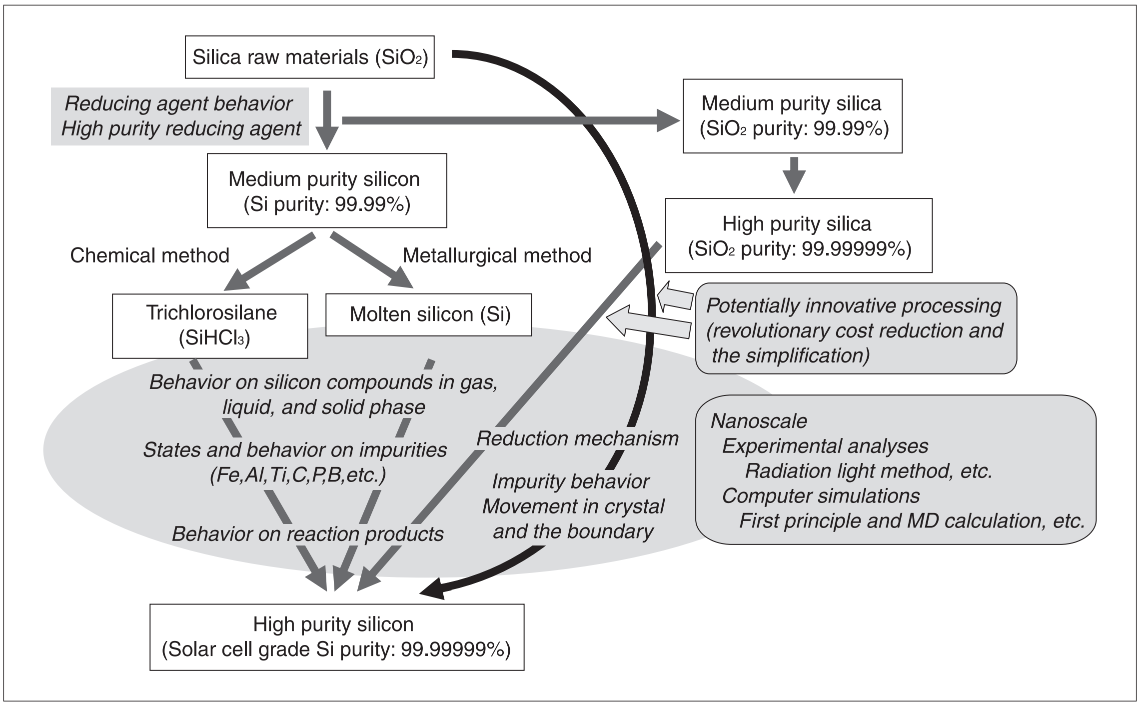


Figure 5 : Nanoscale approaches to analyze behaviors on impurities included in silicon

Japan, the traditional research and development of solar cells is centered around device development and the materials research mostly relies on the semiconductor silicon industries, generating fewer numbers of materials scientists in this field at universities and public institutions.

5-1 Need for analyzing impurity behaviors for high purity production processing

Aiming at the ultimate objective of cost reduction, that is, making the energy cost of solar power nearly equivalent to that of fossil fuel, one must dramatically reduce the cost of raw materials and establish their stable supply. To this end, clarifying the allowable level of each impurity element, as described in Section 2-3, is indispensable, while sustaining the performance of solar cell power generation. However, an allowable level of impurities is inconsistent depending on ingot, wafer, cell, or module step, failing to elucidate the effects of each impurity on cells characteristics until now. In terms of solar grade high purity silicon production processes, it is important to clarify each nanoscale impurity behavior. Such research activities are expected to occur jointly at industry-government-university centers. In particular, universities with technology basis of materials science and government research institutions can play a big role. As an overseas example of industry-government-university institutions, Crystal Clear in the European Commission can be cited. With emphasis on silicon raw materials technologies, Crystal Clear is developing processing technologies of raw materials which are low cost and capable of generating sufficient electric power[24,25].

(1) Clarification of impurity behavior in grains and the boundary layers of silicon

In traditional manufacturing processes, wood chips and/or cokes are used to reduce silica in the first processing step, that is, silicon (Si) is produced from silica raw materials (SiO_2). Since wood chips and coke as a reducing agent contain impurities, such silicon is lower in purity than that of original silica raw material. Furthermore, carbon, a reducing agent, must be investigated as to how it remains in the grains and the boundary layers of silicon.

Research is being carried out in the removal of metallic impurities in the above mentioned metallurgical processing, using the principle that the metallic elements of smaller segregation factors at the silicon solid/liquid phase boundary (that is, iron, aluminum, titanium) are discharged into the liquid phase via the one-directional solidification method. These elements of smaller segregation factors are, as mentioned in Section 2-3, elements of particular interest for removal. For removing phosphorus, the electron beam vacuum melting method is used to drive off phosphorus preferentially through evaporation when silicon melt surface is locally heated. Boron and carbon are removed subject to oxidation by oxygen from water vapor, which is added to a plasma melting scheme.

In particular for polycrystalline silicon, the presence of grain boundaries (boundaries between crystals) creates crystal defects and/or complicates microstructures at grain boundaries due to impurities, making simple determination of impurity limit affecting the performance very difficult. Also, even for the single crystal case, it is necessary to find distribution and chemical states of impurities. Future research to achieve high purity will require understanding of composite defect structures and their formation mechanisms stemmed from grain boundaries, defects, and impurities, and above all how to inhibit them[25].

(2) Clarification of impurity behavior using nanoscale experimental analyses and computer simulations

For instance, according to the SPring-8 radiation light study, investigating iron distribution and its electronic state in the silicon crystal, the iron is found to situate in specific locations[17]. Hopefully, the nanoscale mechanisms may be elucidated through research regarding how impurities during production diffuse through silicon to form silicide (compounds formed by silicon and metals) deposits or what structural morphologies are formed with polycrystalline defects.

Conducting such research, computer aided materials design or simulation could become a revolutionary tool for developing high purification process technologies as referred to in the "Chemical Element Strategy to be adopted by Ministry of Education, Culture, Sports, Science and Technology"[26] which is described as an R&D subject in the Nanotechnology and Materials field in the "Third Science and Technology Basic Plan". With the first principle calculation and the molecular dynamics calculation, one can analyze impurity behavior in grains and the boundaries using the materials database that has accumulated through past materials research[27], making it possible to explore new simple and low cost processing technologies for high purification.

5-2 Need for innovative process technology development for high purity production

In order to lower power generation costs in accordance with the roadmap in Figure 1, significant cost reduction as well as a stable volume supply of silicon are required. As both electric power and module costs continue to decrease, so do raw materials costs. Under the premise that the silicon base solar cell maintains the mainstream, it will be difficult to achieve the power generation costs as targeted in the roadmap even though materials cost increase may possibly be mitigated or at least remain about the same.

In order to reach the goal, innovative production processing technologies aimed at dramatic cost reduction, as shown in Figure 5, must be also explored. To this end, it will be even more necessary to clarify the reduction mechanism of silica and the mechanisms for expression of characteristic features. For example, based on the concept that cheap solar grade silica is prepared first and then reduced to silicon while maintaining the same purity level, research was conducted focusing on electrochemical reduction. Since silica is by nature an insulator the electrochemical approach is difficult, but by feeding electrons externally, researchers found a way to electrochemically reduce silica into silicon[28-30].

5-3 Promoting production processing technologies with venture type organizations

Traditionally, silicon industries, including silicon manufacturing, require large scale facilities - only the affiliates of major semiconductor companies can participate due to large initial capital requirement. However, recent surveying of solar cell related companies show that more are distinctively based on venture type organizations. One of the reasons is because of great worldwide attention drawn to the solar cell industries, investment is made heavily even for venture type organizations. Another reason, however, is that throughout the solar cell industry including silicon, divisionalization is proceeding at each level. As a result, more than a few hundred companies have evolved, many of which are venture organizations and international cooperative companies. The situation resembles the era of warlords. This situation will last for a while, but eventually new multinational type companies will emerge from among the companies. For example, in China, there is a case in which a solar cell venture start-up from a university has succeeded big and is now listed on the overseas stock market.

Regrettably, however, there are very few newcomers in Japan — primarily traditional silicon industries. In commercializing frontier technologies, such as a nanotechnology, even if each company can make full use of operating resources such as their own technology and manpower and possibly benefits from the industry and academia consortium, each company may not find a good fit with its business strategy, and consequently, usually fails to create a new business. For introducing such technological accomplishments to the world, a venture type start-up should be created, while employing manpower, technologies, and aggressively promoting its market value[31].

Only new venture organizations should be involved in developing innovative silicon production process technologies if we consider requirements, such as new ideas not limited by the traditional raw materials processing technologies; a good match between seeds from raw materials suppliers and the needs of post-processing user sides; and minimal risks of small scale technologies. At the same time, such organizations require backing with technology seeds provided by universities or other public research centers. For instance, among a small number of such examples found in our country, a venture company, using R&D results from the Institute of Industrial Science, University of Tokyo, takes solar silicon waste from a semiconductor production plant, which is then melted in melting equipment under low pressure and hit with electron beam to vaporize impurities, making solar grade silicon[32].

It is difficult to see the market potential at the technology stage when commercializing new silicon raw materials technology that is created via nanoscale level research dealing with atoms or molecules and not an extension of any traditional technology. Accordingly, this is too great a risk for large companies. Especially, the downstream processing industries are too cautious, despite the market need, for investing the basic raw materials technology area due to lack of technical experience. Because of the complex nature of manufacturing processing steps up to product shipping, large companies tend to be less involved in the basic raw materials technologies, that is, those requiring substantial technical seeds. It is hard for a traditional company to single-handedly acquire or train the personnel necessary for researching such basic technologies. As a result, there is a great expectation for technical seeds provided by university and public research centers from Japan's solar cell industries including silicon materials technologies.

6 Conclusion

The expectation is that the market for solar cell power generation will continue to rapidly grow led by Europe and the U.S. as the world pays more attention to global conservation. The dissemination and expansion of solar power generation systems are heavily dependent on how much one can reduce power generation costs, and hence key technologies should be developed toward reducing the cost of solar power generation systems. In regard to solar cell materials, since solar power generation using silicon systems continue to be mainstream, the fear is that a supply shortage of raw materials could become a determining factor for future growth. In terms of measures against the shortage of high purity silicon, one long-term project is to deploy new structure cells consuming less silicon. However, since the traditional cell system will continue to be chosen in the near future while solar cell production increases, it is necessary to aggressively expand silicon production, reinforcing more refinement facilities as well as developing and/or introducing new process technologies. From a materials point of view, the highest priorities should be given to issues of securing a stable silicon supply and lowering silicon raw materials costs.

Up to now, major application of high purity silicon has been for semiconductors, but from now on, the semiconductor grade silicon will be a specialty product, making solar cell application the volume-wise major part. Under such circumstances, the role played by researchers involved in nanotechnology and materials science will be greater than ever in such areas as high efficiency power generation by solar cells, low cost manufacturing, and innovative refinement technology, among others. In particular, it should be taken into consideration to establish new venture type organizations and to utilize technical seeds provided by university and public research centers, through which promoting to commercialize technologies that are not the extension of traditional ones, that is, innovative process technology development for silicon production completely independent of the traditional raw materials manufacturing processes.

Acknowledgements

In writing this article, we would like to thank Professor Masafumi Maeda, Director of the Institute of Industrial Science, University of Tokyo, for his valuable knowledge of metallurgical approach for high purity silicon processing and Dr. Teruyasu Mizoguchi, Research Associate at the Institute of Engineering Innovation, School of Engineering, University of Tokyo for his in-depth information in computer simulation of silicon impurities. We would also like to extend our thanks to Mr. Tatsumi Maeda, Managing Director of KYOCERA Corporation for his useful current and future information on silicon raw materials technologies as well as cell and module technologies; Mr. Koichi Ozawa, Project Manger of Advance Materials and Metals Products Business Unit and Mr. Daisuke Kamo, in the Non-Ferrous Metals Division, both with Mitsubishi Company, for valuable comments on silicon raw materials supply conditions; and Mr. Susumu Abe, Managing Director of ADMATECHS Co., LTD for his leading-edge information and knowledge of silica reduction technologies.

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(Original Japanese version: published in January 2007)

4

Current Status of Biomaterial Research Focused on Regenerative Medicine

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1 Introduction

Rapid advances in medical technology have made it possible to save the lives of patients who have lost one or more vital organs due to severe disease, such as cancer, or from serious traffic accidents. Many of these patients can even be rehabilitated back into society. Future medical technology strives to restore lost tissue to its original state. Inspired by the famous experiment by Vacanti et al. in the United States, in which auricular cartilage was regenerated using cell-incorporated biomaterials[1], the medical community is experiencing a worldwide boom in "regenerative medicine" research.

Regenerative medicine is a generic term for a variety of therapeutic techniques to restore lost or damaged organs and tissues due to accidents or diseases to their original state, taking advantage of the regenerative capacity inherent in biological entities. Biomaterial research has two lines of investigation: one is to aim at cell/tissue regeneration by means of tissue replenishment, such as bone marrow transplant, and the other is to regenerate tissues using "tissue engineering" techniques. Regenerative medicine is advancing internationally along these two lines[2]. In this context, tissue engineering refers to techniques to restore tissues using cells, scaffolds required to settle in the body, and cell growth factors. Some tissue engineering products have already been brought into practical use in the fields of skin, cartilage and bone regeneration, and their worldwide market size is estimated to be around 17.1 billion yen. If we include regeneration and transplantation of bone, cardiovascular system, teeth and organs, the total worldwide market size is estimated to reach 250 billion yen by 2015[3]. In a separate approach to treat diseases and physical damage with minimal invasion, research on drug delivery system (DDS) and minimum invasive surgery have also shown remarkable progress. These next-generation medical technologies will contribute immensely to improve the quality of life (QOL) of patients, especially those who are elderly. These technologies also contribute to reduce medical costs associated with prolonged admission and visits to hospitals and welfare costs associated with nursing care.

Research in tissue engineering has a worldwide demand, as does Japan, which has a rapidly aging population. In Japan, deployment of medical and welfare measures are highly sought after. Almost every country is engaged in fierce competition for better regenerative medicine. However, the fruits of this research are limited to such areas as skin (basically a two-dimensional tissue) and cartilage (cells occurring in a hypoxic and low-nutrient environment). There still remain many challenges to be solved, such as a significant difference in three-dimensional structure between regenerated and natural tissues/organs.

This article provides an overview of the current status of biomaterial research from the nano level and discusses challenges and solutions for industrialization of biomaterials in Japan.

2 What are Biomaterials?

Biomaterial is a generic term for a variety of materials used for manufacturing artificial organs that have direct contact with cells and tissues for a relatively long period of time, or those used in regenerative medical techniques, which will be discussed in later sections of this paper. These materials include those applying surfaces of the body or connecting the body via tubes, such as contact lenses and artificial dialysis membranes, as well as implantable devices, such as artificial hearts and artificial joints. Figure 1 shows the types of artificial tissues and organs currently used in the clinical setting[4].

An essential requirement for materials that remain in contact with living tissues for a medium to long period of time is that they are not harmful to tissues and biological activities, which is a challenging objective. The toxicity of substances implanted in the body must be considered differently from those taken orally. For example, cooked rice taken by mouth will become nutrients for the human body, but implanting the same cooked rice inside the body (for example, under the skin) will give rise to inflammation. Thus bioaffinity, or biocompatibility of the material, is the essential element for the development of biomaterials.

It is thus particularly important to "use materials with molecular structures that are similar to those found in the body". However, making a clear demarcation is difficult regarding to what extent the pursuit of similarity is effective and beyond which it is dangerous. In organic chemistry, clever combination of partial spatial configuration and functional groups can induce reaction with biomolecules, having inspired a variety of efforts to develop new drugs for alleviating disease symptoms. These drugs, however, may have serious side effects.

Considerable effort has been made to compensate or regenerate lost functionality of living tissues by producing materials and developing novel devices thereof using a selected range of inorganic, organic, and metal materials, giving rise typically in the 1990s to the evolution of the concept of regeneration medicine and tissue engineering. More recently, there is also an effort afoot to produce artificial extracellular substrate that is actually required by cells and

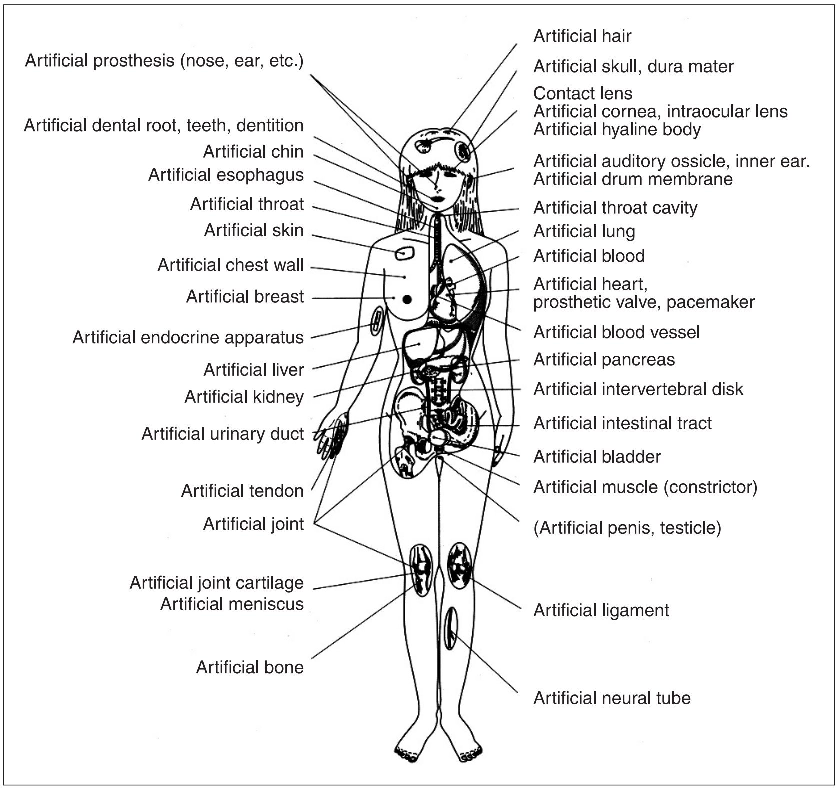

Figure 1 : Prosthetic devices

Quoted from Reference[4], p.15

tissues utilizing nanoscale control in response to needs in the clinical setting. Along this trend, "soft nanotechnology" that does not require extreme conditions (high temperature/pressure, vacuum, etc.) has come into practical use in such areas as artificial bones[5] and drug delivery systems[6]. Application of biodegradable metal materials has also entered into consideration in these areas.

3 Current status of regenerative medicine of body part/organ and biomaterial research

Table 1 summarizes, from the perspective of relatively advanced regenerative medicine research, the challenge level of regeneration and biomaterials used for body parts and organs.

Almost all living tissues are made of organic materials such as proteins, lipids and polysaccharides. Because the method of chemically modifying organic polymers (for example, by introducing functional groups) has been established in many cases, molecular structure design of organic materials is more feasible for organic biomaterials than for other materials, generating a proliferation of organic material research. In the area of inorganic biomaterials, Japan has attained one of the most advanced levels of research in the world. For example, artificial bone using hydroxy apatites*1 was developed in Japan, and artificial body fluids*2 was also first postulated in Japan. In the development of organic-inorganic compound

Table 1 : Challenge level of regeneration of and biomaterials used for tissues/organs

Tissue / Organ	Challenge level of regeneration	Organic material	Inorganic material	Organic-inorganic polymer
Skin	Basically two-dimensional tissue. Culture is relatively straightforward.	Collagen, synthetic biodegradable polymers (polylactic acid, etc.)	—	—
Cartilage	Extracellular matrices have 3-dimensional structures, but there are no blood vessels in cartilage tissues. Cartilage cells are tolerant to low-oxygen, low-nutrient environment, making it relatively easy to perform 3-dementional culture.	Polysaccharides (collagen, chondroitin sulfate), synthetic biodegradable polymers (polylactic acid, etc.)	—	Collagen / polysaccharide, collagen / polysaccharide / hydroxyl apatite
Bone	Extracellular matrices have 3-dimensional structures containing blood vessels. Difficulty in sustaining cellular activity and function in the central porous core.	Collagen, synthetic biodegradable polymers (polylactic acid, etc.)	Calcium phosphate (hydroxyl apatite, _-tricalcium phosphate, _-tricalcium phosphate)	Biodegradable polymers/calcium phosphate, collagen/calcium phosphate
Pancreas	Almost no extracellular matrices exist. The organ has two parts: the exocrine system secreting proteases for digestion and the endocrine system (pancreatic islets) secreting insulin and other hormones. Current research focuses on regeneration of pancreatic islets that produce insulin used for diabetic treatment.	Hydrophilic polymers (polyethylene glycol, etc.) and hydrophobic polymers (coating) for culture plates. Agarose as immunoisolation membrane.	Silica gel hollow beads used as immunoisolation membrane	Agarose / polystylene sulfonate as immunoisolation membrane
Liver	Almost no extracellular matrices exist. Regeneration is difficult because of the extensive vascular networks and large blood flow..	Hydrophilic polymer (polyethylene glycol, etc.) and hydrophobic polymers (coating) for culture plates. Temperature-responsive culture plate for regeneration of 2-dimensional liver cell sheet.	Apatite porous media used for liver cell culture	—
Capillary blood vessel	Regeneration of capillaries is difficult to regenerate because of the small tubular structure consisting of 3 different layers, but capillaries are necessary for survival of regenerated organs. Vascular endothelial cells are the most common target of tissue engineering.	Patterned culture plates capable of regulating cell adhesion. Hydrogel-cell compositions. Synthetic biodegradable polymer nanofibers used as scaffolds for cell culture.	—	—

materials, Japan also occupies a top level in the world.

The following summarizes the current status of research and challenges in roughly the order of attainability.

3-1 Skin

The skin system is comprised of two components: epidermis and dermis, as shown in the accompanying Figure 2[7]. Epidermis, or scarfskin, has a thickness of 0.1-0.2 mm (palms and soles have thicker scarfskin, from 0.8 to 1.5 mm), in which cells originated by cell division in the innermost part move toward the surface, gradually cornifying, and finally fall off from the skin surface. Dermis or inner skin, in contrast, consists of meticulously woven collagen fibers and elastic fibers protecting blood and lymph vessels as well as providing a tough and elastic texture.

Skin can lose its elements due to burn injury and decubitus (bedsores). Skin loss is classified into epidermis loss and full-thickness skin loss, depending on the depth of the layers lost. The former can be effectively cured by grafting cultured skin containing only epidermis cells. Skin generally has the resilient capacity of regeneration and, because of the thin tissue layer, skin rarely has difficulties in culturing such as necrosis of the core due to insufficient exchange of nutrients and gases. Cultured skin has practical worldwide applications, including in Japan. Although artificial skin has not been approved in Japan, we have many cases where patients' own skin is cultured and grafted onto themselves. In emergency cases such as extensive burn, a common practice is to temporarily graft cultured skin from another person and later replace it with the patient's own cultured skin tissues.

For decubitus treatment, a porus collagen sponge layer coated with polymers such as silicon on one side to reinforce the membrane is used to regenerate an artificial epidermis, in which cells and tissues attach on the surface and migrate into internal pores of the collagen sponge layer to produce an epidermis-like layer. For enhancing the efficacy of this treatment, some specialists immerse the collagen layer in bone marrow fluid taken from the patient to induce active tissue regeneration. These methods using collagen sponges can be useful in emergency cases, but subsequent partial skin grafting from other parts of the body or cultured skin grafting is required after the artificial dermis layer has grown.

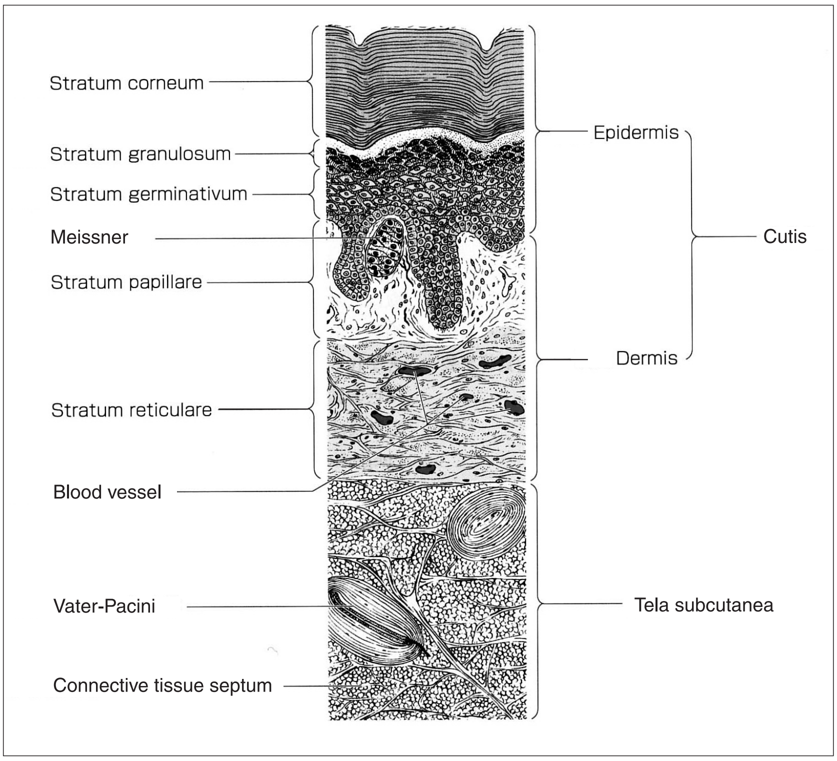

Figure 2 : Cross-sectional view of human skin

Quoted from Reference[7], p.254

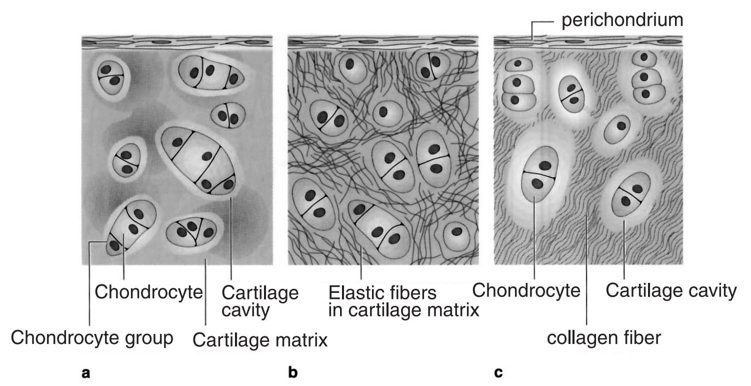

Figure 3 : Schematic view of cartilage tissue

a: hyaline cartilage b: elastic cartilage c: fibrocartilage

Quoted from Reference[7], p.20

Although skin treatment is a relatively advanced area among regenerative medical techniques, it still has many challenges, such as a prolonged treatment period required due to repeated operations.

To shorten the period required for a complete cure, new types of cultured dermis and cultured skin consisting of dermis and epidermis have been developed using collagen as a scaffold material*3. These cultured skin substitutes have shown good results experimentally, and considerable effort is being invested towards commercialization. In Japan, Japan Tissue Engineering Co., Ltd. (J-TEC) and BCS, Inc. are aiming at bringing the technique into clinical application, and the regenerated skin from J-TEC is expected to obtain official approval by the end of 2007. Skin regeneration is in a relatively advanced stage both in technique and materials, but currently available artificial skins does not include skin appendages, such as sweat glands, sebaceous glands and hair follicles. Research and development for regenerating skin containing these appendages and developing suitable scaffold materials is needed. The aesthetic aspect should also be an important consideration for new generation regenerative skins.

The number of patients requiring skin transplantation because of scars or ulcerations in Japan is estimated to be around 35,000, and the forecast is that the number will remain at the same level until 2020. Another forecast indicates that about 30% of these patients will use cultured skin in 2020, and the market size of cases is expected to grow to the level of 5.4 billion yen. Extending cultured skin applications to patients with burn and traumatic skin damage will result in a market size several times larger than this, and further extending applications to severe burns cases will create an estimated 28.5 billion yen market in 2020[8].

3-2 Cartilage

Cartilage consists of cells and substrate, with the cells distributed among the substrate without touching other cells (Figure 3). The cartilage of human adults contains 80% of water and does not have vascular tissues. The cells take in nutrients and oxygen from synovial fluid through the perichondrium, and dispose of wastes and carbon dioxide in reverse direction. Because the amount of nutrients transported using this pathway is much smaller than through blood vessels, chondrocytes generally have greater tolerance against nutrient/oxygen-depleted environment. Organization of cartilage is different for each part of the body: hyaline cartilage (Figure 3-a) is found in joints, fiber-rich elastic cartilage (Figure 3-b) is found in the earlobe, and fibrocartilage (Figure 3-c), which contains type-I collagen and shows strong tolerance against pressure, is found in tendons in meniscuses and interspinal disks and ligament tissues.

Hyaline cartilage tissues mainly consist of polysaccharides such as hyaluronic acid, chondroitin sulfate and keratan sulfate, and collagen. Polysaccharides account for 10% of total dry weight, and collagen 60%. Collagen that holds the shape of hyaline cartilage is type-II, whose ability to form fibers is lower than type-I found in skin, bone, and fibrocartilage.

Fibrocartilage, if damaged, can be gradually restored, except for the fibrocartilage in blood-depleted area such as meniscuses and interspinal disks. Other cartilages do not have the capacity of spontaneous recovery; surgical procedures must be taken to restore this tissue. Damaged joint cartilages especially need early restoration procedures because they are necessary to absorb shocks and allow the smooth movement of joints, which directly affect the daily activities of the patient[*4].

One of the traditional methods for restoration is to drill a hole through the subchondral bone underlying the damaged joint cartilage into the bone marrow, and introduce precursor cells, nutrients and growth factors to regenerate fibrocartilage. Although this method can restore only the fibrocartilage, it has been widely used because it can provide short-term recovery. However, since the long-term prevalence of arthrosis deformans is high in patients receiving such treatment. the mainstream has shifted to mosaicplasty, a technique of creating an osteochondral autograft by harvesting small cylindrical osteochondral plugs from areas of normal cartilage on less weight-bearing surfaces and inserting them into the defective section of cartilage. This method has the advantage of enabling restoration of hyaline cartilage, but the portion of cartilage from which the autografts are obtained will not restore its original shape and the amount of grafts available is limited.

In order to overcome these problems, a method to restore cartilage using cultured cells, has been commercialized for the first time in the field of orthopedics. A small amount of tissue is obtained from the patient's cartilage in a less weight-bearing region, and the chondrocytes isolated from the tissue are cultured to increase cell numbers, and the suspended chondrocytes are injected into the cartilage defects covered by the patient's own periostea. Remaining problems with this method can be the lowering of activity in cultured cells as chondrocytes and the fact that this method also produces, although small, a defect in the patient's cartilage. One method that has the potential for resolving these problems is to use the patient's own bone marrow mesenchymal cells and make them differentiate to chondrocytes after obtaining a sufficient number of mesenchymal cells through cultivation.

Chondrocytes, being by their nature tolerant to oxygen-, nutrient-deficient environment, are capable of growing well in three-dimensional scaffold materials and producing extracellular substrates. Difficulties in joint cartilage regeneration are focused on the adhesion of cartilage tissues to subchondral bones, and do not include such problems as blood vessel introduction and generation of co-operative environment for different types of cell species (mutual interaction and spatial configuration) as in visceral organs. This makes in vitro cartilage tissue regeneration relatively easy. This is well evidenced in that the experiment by Vacanti et al. that produced a "mouse with a human earlobe on its back" was a straightforward success. Selection of cartilage for the tissue regeneration target was the key to the success of this experiment, and this success opened the door to development of tissue engineering.

In cartilage tissue engineering, chondrocytes or bone marrow mesenchymal cells are multiplied in the scaffold materials suited for this purpose to regenerate, by adding growth factors and mechanical stimuli, cartilage tissue containing appropriate cartilage substrate. Joint cartilage is a supporting organ that always receives mechanical stimuli to support the body. Attempts are also being made to regenerate bone tissue beneath the cartilage tissue to ensure tight adhesion to the subchondral bone.

In most cases, synthetic biodegradable polymers (e.g., polylactic acid and polylactic-glycolic acid copolymer) and collagen sponges have been utilized for scaffold materials; more contributions from biomaterials to cartilage tissue engineering are desired. Gels with similar chemical composition to cartilage substrate (for example, mixtures of type II collagen and hyaluronic acid)[9] have been developed for use as scaffolds for cartilage tissue engineering. However, to cope with a wider range of cartilage defects, the mechanical environment similar to actual cartilage is also important as well as the chemical environment. Composition and structural characteristics of the scaffold material affects the responses of scaffold and artificial extracellular substrates against mechanical stress, and may result in transmission of inappropriate mechanical stimuli to the cells. Further study of appropriate scaffold materials is needed.

Regeneration of elastic cartilage, such as earlobes, garners attention from its aesthetic aspects, but we have had no elastic cartilage substitutes to date. The most difficult challenge in development of cartilage substitutes could be interspinal disk regeneration. Among cartilage tissues, the interspinal disk has the most complex structure consisting of a central pulpy nucleus and surrounding rings of fibrous cartilage (fibrous rings), with a set of hyaline cartilages sandwiching them from above and below providing connection with bones. Achieving regeneration and functioning of such a complex structure in a relatively short period of time will require the development of suitable scaffold materials and tissues that have been sufficiently matured in an in vitro environment. Joint cartilage has a four-layer structure with each layer having a different cell distribution and microstructure: surface layer, intermediate layer, deep layer (zona radiata), and calcified layer (a layer connecting the cartilage and the underlying subchondral bone). Observation at the nanoscale level shows that the layers have a network of type-II collagen for maintaining its structural integrity and nanoscopic structure for incorporating polysaccharides that help retain water. Development of materials with structural characteristics similar to natural joint cartilages will be required to ensure the development of cartilage function immediately after graft implantation as well as the maintenance of functions of cultured chondrocytes.

We have 500 to 600 thousand patients with degenerative arthritis in Japan and approximately 10% of them are considered treatable by implanting relatively small regenerated cartilage grafts that current technology can provide. This market size is estimated to be approximately 60 billion yen. There is room for extending patient coverage by improving current technology, but the room for the increase of curable patients is estimated to be 20% at most (approximately 100 billion yen market)[8]. If bone regeneration technology is developed for practical use, combination of bone and cartilage therapy embraces nearly all patients, including those who suffer from rheumatoid arthritis (approximately 280 thousand patients), and the market size is likely to reach 1,000 billion yen.

3-3 Bone

Bones carry important mechanical functions of supporting the body and protecting vital organs, such as the brain, heart, lungs and central nervous system. Another important function is to provide storage of calcium and phosphorus. Homeostasis of calcium depends heavily on the bones. Extracellular matrix of the bone consists mainly on inorganic non-stoichiometric carbonate-containing hydroxyapatites and type-I collagen. As shown in Figure 4, the nano-structure of bone consists of apatite nano-crystals arranged on collagen fiber in roughly the same orientation. These nano-scale composite fibers are arranged in a random fashion in spongy bones. In cortical bones, they are bundled together in the shape of a sheet with all the fibers aligned in the same direction, and the sheets are stacked in mutually different orientations to form a cylinder-like structure of several centimeters in length. Blood vessels run in the center of the cylinder, and spaces between the fiber sheets are filled with osteoclasts. This unit is called an osteon. Osteons are renewed continuously; this process is called bone remodeling. Bone remodeling begins with dissolution of apatite crystals in an old or a broken bone by osteoclasts and subsequent decomposition and absorption of collagen fibers. Then, osteoblasts form new bone and fill the eroded cavities, and as the new bone ripens and osteoblastic cell changes to bone cell with time, the cylinder-like layer structure develops finally forming a new osteon. Bone remodeling also takes place in spongy bones, although osteons are not formed in this location.

Guided bone regeneration (GBR) is one of the preferred methods in dental and oral surgery, and good experimental results have been reported using polymers, metals, and their composite materials. However, owing to

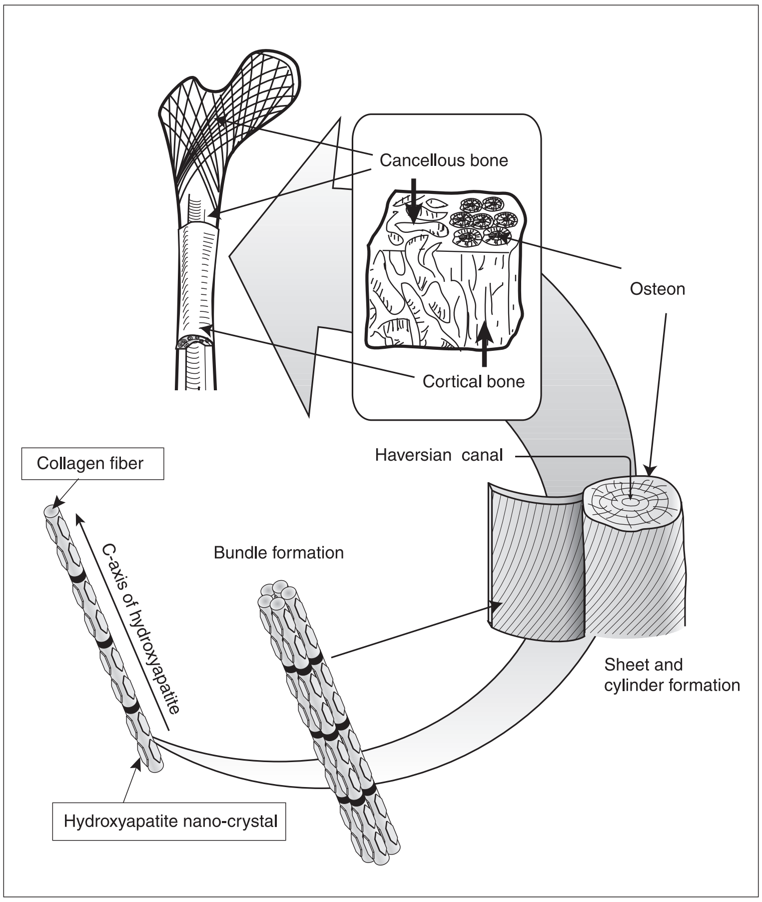

Figure 4 : Schematic view of bone structure hierarchy

the fact that non-biodegradable materials in many cases remain in the regenerated tissue, this method poses long-term uncertainties. Biodegradable materials are much more eligible for this purpose. The method that has stood in the spotlight in the last decade is composition of calcium phosphate that shows good affinity to biotissues with synthetic biodegradable polymers. The use of these composite materials in GBR was proposed around the same time in Italy, Germany, and Japan. This method has already been clinically applied in Italy, where doctors are allowed to exercise a high degree of discretion. In Japan, this is still in a research phase. Membrane materials used for GBR still have much room for improvement. Further upgrades are desired by, for example, adding growth factors and cell-stimulating factors and improving osteoconductive properties.

In a separate development, the tissue engineering method for strengthening the connection between an artificial joint and the adjacent bone has already been put to practical use in Japan. This method harvests stem cells from the patient's bone marrow mesenchymal cells that have the potential of differentiating into osteoblast cells. After separation and multiplying processes, the cultured cells are differentiated by adding cell stimulating factors and subsequently seeded onto the interface of the artificial joint (made of materials, such as alumina, that do not directly integrate with the bone) and the bone for better connection[10]. Regeneration of a finger bone using tissue engineering technique has also been reported. However none of these has succeeded in regenerating blood vessels in bone using tissue engineering methods. In the case of the regeneration of a finger bone, the regenerated bone does not function as an actual bone. Tissue engineering methods capable of restoring major bone defects are still in the research phase. To some extent for bone defects, a good cure can be obtained by autogenous bone graft, or grafting the patient's bones mixed with filling materials. Tissue engineering of the bone has two main objectives: one is to restore bone defects (complete bone defects up to the size of 3-5cm) in a relatively short period of time irrespective of patient age; the other is in vitro regeneration of the whole bone system including cartilage and blood vessels. The former objective has an aspect of time-game with the development of better filling materials. For example, a bone-like hydroxyapatite/collagen nanocomposite, with nano-structure and chemical composition similar to the bone and with a self-organization mechanism, has an experimental achievement of near-perfect restoration of a 2 cm tibial bone defect created in a Beagle dog in three months[11]. However, unless the cell seeding technique can clearly show the promise of more than halving restoration period, bone filler technique will be used at least for younger generations*5.

In order to make the treatment period shorter than that of filler method, development of better scaffold materials is essential. These scaffolds should also be such materials that can be transformed to bone through the function of cells in the adjacent bone, because bone is rich in extracellular matrix and has to respond to mechanical stimuli just as in cartilage, and has a high turnover rate,. Organization of bone tissue starts with the primary structure at a level of nanometer and sequentially develops into higher-order structures that can reach the size of centimeters. In fact, a complex fiber structure of the size up to 75 mm has been successfully produced using soft-nanotechnology starting from a hydroxyapatite/collagen nanocomposite[12]. However, bone substitutes that mimic bones from micro- to macro-scale that contain oriented sheets of fibers and the mechanical properties of natural bones have not yet been produced. There is a hypothesis that substances such as cell stimulation factors incorporated in extracellular matrix of bone may enhance the function of osteoblasts during bone remodeling. At present, such biochemical function can be realized only by immobilizing molecules on the surface of bulk material. More sophisticated function will be needed in the future for delivery of an appropriate amount of biochemical factors at the correct timing. Regeneration of large bone tissues will require techniques to regenerate complete bone tissues including blood vessels. To solve this challenge, development of techniques to construct higher-order structure in step-wise fashion from nano to macro levels, as well as the nano structure construction method that mimics biological processes (soft nanotechnology). Techniques developed for solving these challenges are likely to have applications in the regeneration of other organs that have scarcely any extracellular matrix.

Artificial bone grafts are used in only about 20% of cases that require bone transplantation. The current market size is approximately 7 billion yen, and is forecasted to saturate roughly at the level of 10 billion yen. However, when the next generation artificial bones and tissue engineering come of age for practical applications, the expectation is that autogenous bone grafting that is highly invasive will go out of use, in which case the market size (domestic market only) will grow to the level of 50 billion yen or more. In the United States, the artificial bone market has been relatively small because the use of autogenous and heterogenous (cadaver) bone transplantation has been the dominant method (even heat-treated bovine bones are used in some cases). However, due to concerns about infectious diseases, the demand for artificial ceramic bones has increased in the last decade. All these aspects inclusive, the size of bone related tissue engineering market is likely to reach 300 billion yen. Furthermore, regenerated bones using tissue engineering are, unlike conventional artificial bones, considered applicable for a wider range of patients including infants, elderly people and even people with bone metabolism disorder, making it possible to boost the market size to the level of 600 billion yen.

3-4 Pancreas and Liver

Cells in visceral organs such as the pancreas and liver, have very little extracellular matrix: interaction between the cells plays a more important role in expressing the function of cells as a component of an organ than in skin, cartilage and bones, thus making regeneration through tissue engineering techniques more difficult. As shown in Figure 5 above, the pancreas is located beside the duodenum and its function has two aspects: as a part of the digestive system secreting pancreatic juice that contains digestive enzymes, and as a part of the endocrine system secreting insulin and other hormones. The endocrine function resides in the pancreatic islets, which are located in the pancreas and consist of one to two million cells (See Figure 5 below).

The liver, shown in Figure 6 above, is involved in energy metabolism and detoxication and other functions that are essential to life. These functions are implemented by the cells and vascular system depicted in Figure 6 below[7].

Because regeneration of the liver and pancreas as a whole using the currently available technologies is next to impossible, the mainstream view to solve this problem is to regenerate selected minimal functional units and implant them en masse to effectively substitute the organ. For the pancreas, transplantation of the pancreatic islets has already begun for patients with insulin-dependent diabetes mellitus or patients who cannot produce insulin due to removal of pancreas because of cancer or other reasons.

Among the many attempts to regenerate functional units of these visceral organs, formation of spheroids is attracting attention and most actively under development. A spheroid is a mass of cells that are produced using non-adherent round-bottom culture plates. A variety of techniques is currently under consideration to produce high-density spheroids with controlled cell behavior. In terms of cell culture using nonadhesive plates, use of rotating wall vessel and clinostats*6 are considered promising, and many attempts are being made to produce various types of spheroids while controlling their sizes and maintaining cell functions. One notable experiment using a rotating wall vessel is reported to have succeeded in producing hepatocyte spheroids that contain blood vessels and biliary tracts starting from hepatocytes harvested from a mouse fetus[13]. Further development of this experiment is being watched closely with expectations. Many attempts have been made to produce a large amount of spheroids in non-adherent culture plates by controlling cell's adhesive properties[14]. This approach is attracting attention because it does not require special culture techniques or devices.

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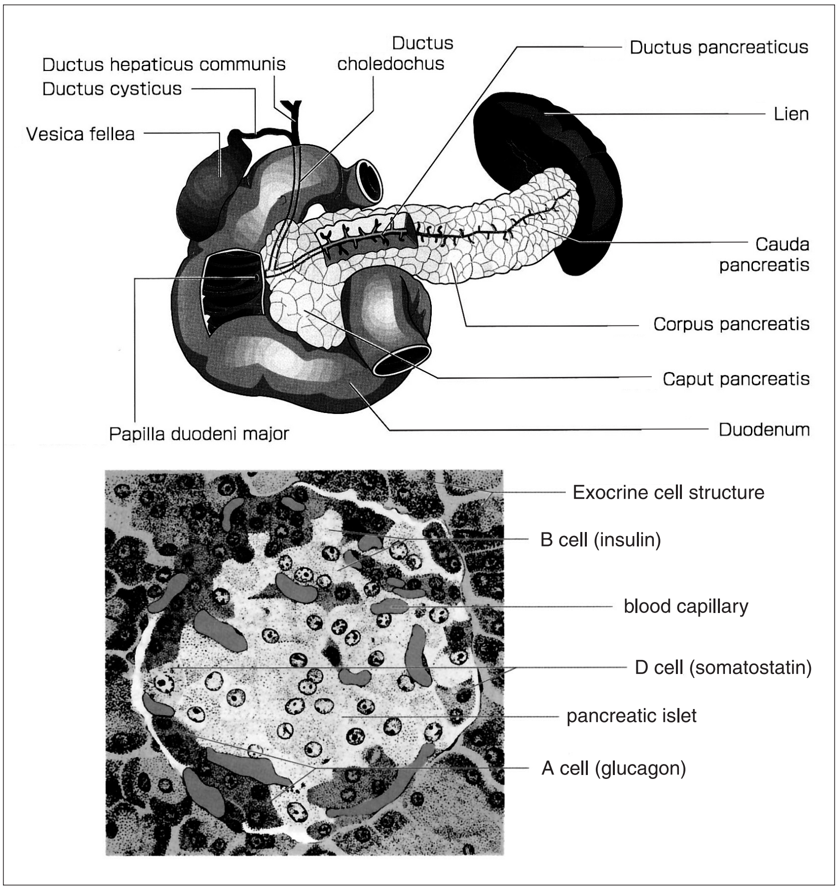

Figure 5 : Pancreas and surrounding organs

Above: Overview Below: Schematic view of pancreatic islet for insulin production
Quoted from Reference[7], p.155 (above), p.114 (below)

of cells is also an important matter to consider. In many cases, organs become necessary after the patient's own organs fail, making it necessary to either differentiate cells from the patient's own stem cells, or to culture another person's cells. In the latter case, the cells and secretion from the cells can cause immunological reactions, entailing the development of the immunoisolation method. These isolation materials have to allow necessary components to pass through while blocking immune reaction causing substances, which is quite a difficult task. For example, immunoisolation materials used for the pancreas must permeate insulin, nutrient components, and waste.

Naturally, regeneration of organs with all the original functions and adequate size is the final target. For this purpose, the highly desirable aim is the development of an auxiliary biomaterials that provide a 3-dimensional framework for initial organ development and maintains its structural integrity until the organ can hold its own shape using only the cells and extracellular substrates secreted from them.

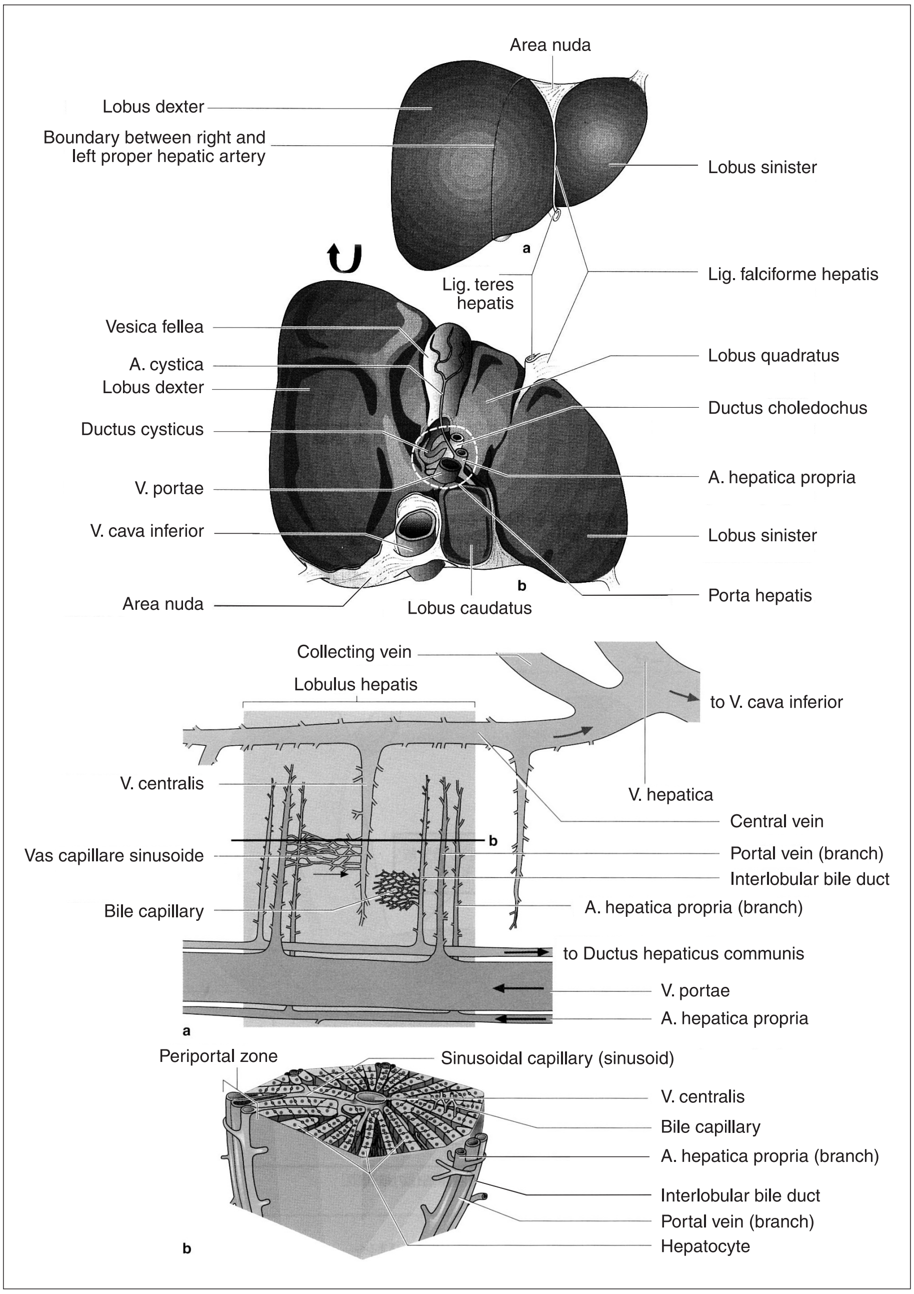

Figure 6 : Liver organization

Above : Whole image (a: front view, b: bottom view)
Below : Liver lobule (a: vertical section, b: horizontal section)
Quoted from Reference[7], p.156 (above), p.157 (below)

Let us estimate the size of the pancreas related regenerative medicine market from the number of diabetic patients. Currently, the estimated number of patients is 2.469 million in Japan, and 0.246 billion worldwide, and will reach 0.38 billion in 20 years[15]. Assuming that 10% of patients are indicated for artificial pancreas, and the cost per patient is around 3 million yen, market size would be 84.5 billion yen in Japan[8] and 850 billion yen worldwide.

Commercialization of artificial hybrid liver (combination of liver cells and biomaterials) is underway with a unit price of around 5 million yen. These units are estimated to create a 48.8 billion yen market by 2020[8]. Regenerated liver will not only supplant these artificial units, but will also increase the percentage of patients viable to liver transplantation (including the use of regenerated liver) up to 20%. There are some 40 thousand patients who need liver transplantation in Japan; thus the market size is expected to grow up to around 40 billion yen.

3-5 Challenges of tissue engineering

As described above, culture and multiplication of cells as two-dimensional structures is relatively straightforward, but to develop tissues in three-dimensional shapes retaining cell functions is extremely difficult. Okano et al. of Tokyo Women's Medical University, who are advocating cell sheet engineering, are conducting studies on the clinical application of corneal epithelial cells that can be brought into practical use with two dimensional culture[16]. However, in other applications, for example myocardial sheets, three-dimensional grafts are quite difficult unless lamination process is carried out by repeated surgeries. Cells need provision of oxygen and nutrient, and they have to dispose of waste matter. In the environment without vascular system, provision and disposal must depend on liquid phase dispersion, causing cell necrosis in the core of thick cell mass. Similar problem can occur in preparation of large spheroids and culture of osteoblasts in three-dimensional porous media. Regeneration of clean organs requires scaffolds where cells can multiply, culture media can be easily exchanged even in the core of tissue, and the vascular system can develop inside (cartilage excluded). Hitherto, efforts have been made, and to some success, to provide surface preparation on mono-functional scaffold materials for better adhesion properties, or simply adding cell stimulus factors to provide above-mentioned functionality to the scaffold. To date, no attempt to reproduce an organ fragment even of the size of 1cm has succeeded.

Taking the above into consideration, to overcome this one-centimeter barrier, it could be useful to produce tissues that perform multiple functions containing different types of cells as found in the living bodies to provide appropriate cell environment over time just as in the natural developmental process. Thus, an important agenda for material development is to produce scaffolds that allow four-dimensional control, i.e, three-dimensional control over time. Such scaffolds should provide a cell environment that can change its state synchronized to, or in advance to, the development, differentiation, and induction processes of the cells, similar to that of actual biological body.

Biodegradable metallic implant materials using magnesium alloy are regaining attention. Many attempts were made in the 1930s and 1940s to apply these alloys to orthopedic materials because they have similar Young's modulus as bones. However, these attempts subsided gradually for two main reasons: magnesium alloys can produce hydrogen that forms air bubbles around the implant and the use of stainless steel with superior mechanical properties became common in starting in the 1940s. In regenerative medicine where biodegradability is an important factor, magnesium alloys with good mechanical strength are an attractive option. In contrast, ceramics are also promising in terms of biological affinity. The expectation is that combinations of ceramics, organic polymers and magnesium alloys will help the development of better scaffold materials.

4 Points for improvement of biomaterial research and practical application

4-1 Official licensing procedures

There is fierce R&D competition taking place among nations in the field of biomaterial and tissue engineering. Developed nations are aiming at rapid introduction of these results to the medical and welfare market to cope with their aging populations. Regenerative products consist of a wide variety of valuable products in small quantities.

Our first requirement towards practical application of this research is to develop an efficient and speedy licensing system for biomaterials or medical devices, and to participate in efforts to establish international standards controlling the biomaterials and medical devices.

A long process is required before biomaterials and tissue engineering techniques can be used clinically: After confirmation of the safety and efficacy of the investigational material/technique in cell culture assays and animal studies, an application for clinical studies of the material/technique should be submitted, and then an application for approval of the material/technique containing data in human should be approved before marketing the material/technique. In Japan, cell-material composites for use in regenerative medicine are regarded as a “medical device” that contains medicinal substances, while materials used for drug delivery systems are regarded as a “drugs” (both are regarded as medical devices in the U.S.). The licensing process for medical devices in Japan is similar to those applied to drugs: a rigorous and lengthy review process is required.

Although vigilant and discreet evaluation is quite justifiable because these products involve human lives, however, applying the same review process as for the drugs includes apparently superfluous steps. Taking implantation of autologous cells for an example, physicians are allowed to harvest, multiply and transplant the cells at their own discretion on the condition that the procedures take place in the hospital to which they belongs. However, if the multiplication process of the same autologous cells takes place in a commercial facility outside the hospital, a separate official approval is required entailing tracking back to the origin of the cells. Careful pedigree evaluation of the cells is important for non-autologous cells because of infectious concerns, but it is highly questionable if these verification steps are still needed when it is apparent that the cells are autologous.

In the U.S., a straightforward supplemental application is available as a method of partial modification of the approved items of a medical device. With this method, modification of an approved medical device can be approved promptly. The same situation in Japan requires going through the whole application process again. Because of this, a case has been reported where an imported product cannot be sold in Japan due to minor modification: the distributor has to stock older parts and assemble or repair the device using the older parts to sell the device in the Japanese market[17]. These rigorous procedures are applied even to regenerative medicine and DDS materials. Efforts should be made to minimize the burden for approval for any combination of those materials, cells, and medical agents that have already been approved, unless there could be a possibility of evolving chemical reactions among them.

4-2 Conflict of views: industry and public administration

Measures towards expediting the examination period have been discussed in the Council for Science and Technology Policy, and a plan to double the number of examiners in three years has been announced, but distribution of area of expertise of these examiners has not been clarified. Joint effort between private sectors and the Ministry of Health, Labour and Welfare (MHLW) towards speed-up of examination is in progress through the activities of the Medical Engineering Technology Industrial Strategy Consortium and Regular Meeting on Pharmaceutical Regulations of Medical Equipment. Unfortunately, it seems that communication among these efforts is insufficient and we will have to wait for some time before these efforts will deliver concrete results.

Table 2 provides a summary of opinions from industries and administrations put forward at the 5th Regular Meeting on Pharmaceutical Regulations of Medical Equipment. The industry sector hopes to carry forward clinical trials by collecting necessary information and data required for application protocol as quickly as possible. Consultation meetings can be a good tool for accelerating this process. The industry sector is generally dissatisfied with the response from the administrative side because of the lack of rational viewpoint and other reasons and feels this can be the major cause of delay in approval process. Lack of a rational viewpoint causes confusion such as hiatus of important data, delay of data processing, and other such problems, resulting in the whole process. The administrative side, in contrast, has an understanding that it has delivered a sufficient amount of explanation and advice. On the whole, opinions from both sides do not seem to mesh well including the interpretation of terminology, and might well be resulting on the administrative side stipulating more than necessary data to be on the safe side.

4-3 Participation in international standardization

Japan has traditionally paid insufficient effort for proactive international standardization. There is no denying that a passive “just follow what others decide” attitude still prevails. The U.S., for example, has a standardization organization, the American Society for Testing and Materials (ASTM) that strongly reflects U.S. industry’s interests. ASTM is quite proactive in establishing international de-facto standards and actively lobbying to incorporate their interests into the International Organization for Standardization (ISO) standards.

A welcome sign is that some authorities and experts from industry and academia in Japan have started to participate in regenerative medicine related technical committees, such as on orthopedics materials and biological materials. Also, the drive for the standardization effort can be seen among Japanese researchers as evidenced by participation in the pre-standardization organization of advanced materials, Versailles Project on Advanced Materials and Standards (VAMAS), from its initial stage. Continued effort for this line of activities is strongly desired. The Ministry of Health, Labour and Welfare should introduce international standards for evaluation of medical devices. It is also important to rationalize domestic standards and propose them for international adaptation, which will surely effect to the advantage of Japanese medical devices gaining ground in the international market.

5 Conclusion

We have discussed the current status and future problems in biomaterial research focused on regenerative medicine. Outstanding points among the status and problems are as follows.

Table 2 : Difference of view between industry and administration
(at the Regular Meeting on Pharmaceutical Regulations of Medical Equipment)

Views from industry	Views from administration
• Delay of examination due to insufficient number of examiners • Irrational examination process • Disparity between regulation and development promotion • Provisions for devices approved in other countries • Relaxation of regulation on Good Clinical Practice (GCP) • Difficulty in using preapplication consultation	• Insufficient quality of application dossier • Slow flow of information from manufacturer • Insufficient compliance to what was decided
Common views	
• Drug specialists are supported by academia and industry, but there are no academic units to foster medical device specialists. • Fundamental difference of drugs and medical devices. (Takashi Wachi: Chairman, the Japan Federation of Medical Devices Associations,, Tatsuo Kurokawa: Councilor (Pharmaceuticals), Minister’s Secretariat, MHLW)	

Compiled by Mr. T. Tateishi (National Institute for Materials Science) based on Reference[18]

5-1 Control over time of cell environment and development of scaffold materials to support cell environment

To reproduce large functional tissues, it is essential to create and control an appropriate environment that ensures the growth of cells during regeneration and avoids necrosis. Especially, the development of such materials (or artificial extracellular matrix) that can be controlled in terms of three-dimensional structure and time so that the cell environment can be adapted synchronized to or preceding the changes in cell's functional expression is required. Regeneration of organs requires an environment in which different types of cells can function in cooperative fashion. For this purpose, appropriate space must be prepared in the tissue environment for the cells to multiply, differentiate, and develop functions. Physicochemical or biochemical conditions around the organ change constantly. Future scaffold materials that should be developed must be able to control the cell environment in terms of time and should finally disappear.

5-2 Infrastructure for accelerating regenerative medicine research

Timely approval of study products is essential to promote practical application of regenerative medicine research. One of the bottlenecks toward this goal is the fact that some of the data required for examination seems to lack rational grounds, delaying the approval process of new regenerative medical products. Another deplorable problem is the conflict of views that are still persisting between industries and administrative communities. An effective measure against the delay of approval processes and for the establishment of an effective system will be to foster experts with ample knowledge in medicine and pharmaceutical science, and allocate them to authorization organizations or medical facilities. Establishing a new national qualification, corresponding for example to a pharmacist, may be a good idea. Distribution of such expert personnel is also important from the perspective of maintaining medical equipment that becomes increasingly specialized and complex and preventing medical malpractice due to erroneous instrument use. An equally important factor is the effort to establish international standards for medical and technological evaluation that is acceptable or favorable to Japan. This will have a tremendous effect on both acceleration of clinical trials and dissemination of products in the world market, thus stimulating the medical industry in charge of practical realization of research results.

Acknowledgement

The authors express their gratitude to many colleagues and fellow researchers for helpful advice and useful discussions. Among them, special thanks are due to the following researchers: Mr. Yoshihiko Washimi (Senior Manager, Research & Development Department, TEIJIN Limited), Mr. Tetsuro Ogawa (General Manager, R& D Department 1, New Ceramics Division, Life Care Business Division, PENTAX Corporation), Mr. Takafumi Sumino (DES Project Manager, TERUMO Corporation), Mr. Masataka Toyoda (Staff Director, ACCJ Medical Devices and Diagnostics Subcommittee), Mr. Tetsuya Tateishi (Director-General, Biomaterials Center, National Institute for Materials Science), and Mr. Hisatoshi Kobayashi (Biopolymer Group Leader, Biomaterials Center, National Institute for Materials Science).

Glossary

*1 Hydroxyapatite is a main inorganic constituent of vertebrate bones and tooth. Hydroxyapatite may found as calcium-deficient hydroxyapatite, sodium hydroxyapatite, magnesium hydroxyapatite, hydroxyapatite of which carbonate group is replaced with phosphate group or hydroxyl group; and those of which hydroxyl group is replaced with fluorine.

*2 Buffer solution that has nearly equal inorganic components as human plasma. When bioactive ceramics (capable of direct connection with bones inside the body) is immersed in this fluid, fine crystals of carbonic acid containing hydroxyapatite is deposited on its surface.

*3 Most cells except blood cells and other cell types in suspension need to be fixed on matrix for multiplication and differentiation.

Cells in the body are adhered to extracellular matrix such as basal membrane. For effective in vitro multiplication and functional expression of cells, alternative extracellular matrix is required. Such matrix is called a scaffold. Currently, porous materials made of collagen, polylactic acid, and hydroxyapatite are used.

*4 Since regeneration of cartilage and surrounding bone tissues is impossible in patients with degenerative arthritis, their diseased joints are often replaced with artificial joints made of metal and ceramics. This is a viable method because the main function of cartilage is mechanical. However, prolonged use of artificial joints can cause problems in joining area with bone and sliding surfaces; hence an alternative regenerative method is highly desirable.

*5 Elderly people generally retain a considerable degree of bone formation capacity, but many of them have osteoporosis. For safety reasons, many physicians prefer materials containing osteoblasts.

*6 Rotating wall vessels are uniaxial rotating culture apparatuses used to produce a pseudo microgravity environment, which are derived from technology developed by NASA. Klinostats are also rotating culture apparatuses capable of producing even better a pseudo microgravity environment by rotating 3-dimensionally.

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(Original Japanese version: published in March 2007)

5

Exploration Technologies for the Utilization of Ocean Floor Resources
— Contribution to the Investigation for the Delineation of Continental Shelf —

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1 Introduction

Ocean floors several thousand meters deep in the sea area far away from the seashore are thought to be a huge reservoir of resources. However, it is difficult at present to economically extract natural resources, such as petroleum, natural gas, metal minerals, living organisms, and microorganisms, from the seabed. Taking into consideration the situation that onshore resources are expected to run out in the future, the requirement is to develop technologies that enable commercial extraction of resources from the ocean floors. In order to realize economical extraction of resources, it is necessary to investigate the geographical and geological conditions of the ocean floors to obtain detailed information on offshore resources.

The present area of Japan's territory, an area that ranks the 60th in the world, is about 380 thousand square kilometers. However, the total marine area including territorial sea and exclusive economic zone (EEZ), over which Japan has jurisdiction is about 4.47 million square kilometers, which ranks the 6th in the world[1]. Countries that rank higher than Japan are the U.S., Australia, and Canada - which are continental countries with long costal lines, and the two countries - Indonesia and New Zealand - which are island countries with the territories sprawling in wide sea areas.

Ocean floors to be investigated are classified into internal waters, territorial sea, continental shelf (including ocean floors in EEZ), and deep sea floors. When certain conditions are satisfied, the UN Convention on the Law of the Sea permits sovereign rights for ocean floors under the high seas as the continental shelf of the coastal countries in accordance with EEZ. In order to investigate which sea areas of Japan satisfy the above-mentioned conditions, investigations of the delineation of continental shelf are being made by combining various kinds of seafloor exploration technologies. The investigation of geographical and geological structure is scheduled to be finished by the end of FY2007. And based on the results of these investigations, the information on the geographical and geological conditions of the continental shelf that are considered to expand beyond the limits of 200 nautical miles in the sea area around Japan is to be submitted to the "Commission on the Limits of the Continental Shelf (CLCS)" by May 2009 that was established based on the UN Convention on the Law of the Sea. Because of the time requirements, Japan is now accelerating the investigation for collecting necessary information for preparation of the report. The limits of continental shelf established based on the recommendations of CLCS are the final decision in accordance with the UN Convention on the Law of the Sea and have binding authority. The limits have significant meaning in that they define the boundaries of continental shelf under the water to which sovereign rights of the coastal countries extends. Some of the countries, like Japan, that have been conducting ocean floor investigation relating to the delineation of the limits of continental shelf have already submitted information to CLCS, and how CLCS will make recommendations is drawing the world attention.

Among the ocean floor exploration technologies are bathymetry technology (measurement of seabed geography), seismic exploration technology (geological survey of seabed), bedrock sampling technology (seabed drilling), geophysical observation technology (measurement of gravitational force and earth magnetism). Furthermore, in the Promotion Strategies for the Frontier Field of the Third Science and Technology Basic Plan[2], targets for research and development making use of diversified exploration technologies are shown relating to major subjects of ocean development, such as “elucidation of the inner structure of the earth” and “ocean utilization technology.”

This article focuses on ocean floor exploration technologies and describes the objectives and present status of the investigations using these technologies. Legal framework of the delineation of the continental shelf and the organization of the investigation are also overviewed. Finally, I will propose issues on future ocean floor exploration technologies, utilization of ocean floor resources, and long-term ocean floor exploration, which are related to the present investigation on the delineation of the continental shelf.

2 Ocean floor resources that are expected to be utilized

2-1 Ocean floor mineral resources

Mineral resources, such as manganese and copper, exist in high concentrations in the surface layers of sediments covering the seabed and seamounts. Japan Oil, Gas and Metals National Corporation (JOGMEC) has surveyed Japan’s mining concession of manganese nodules in the high seas to the south of Hawaii (obtained from International Seabed Authority (ISBA))[3], and also carried out ocean floor investigation for cobalt-rich crust in the sea area more than 200 nautical miles south of Japan, which is out of EEZ, using “Daini-Hakurei Maru,” a specialized vessel for the exploration of deep sea mineral resources.

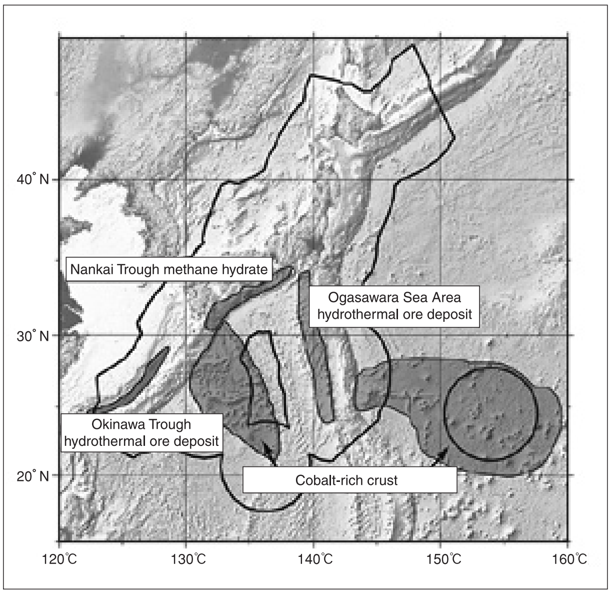

Figure 1 : Ocean floor resources in the adjacent waters of Japan (estimated)

The heavy line indicates the limits of EEZ.

Source: JOGMEC

While the major components of cobalt-rich crust are manganese and iron, the contents of cobalt and nickel are also high and platinum is contained in addition, which makes economical values of cobalt-rich crust very high. In the adjacent waters within 200 nautical miles, manganese crust and hydrothermal ore deposits exist in a large quantity, but these deposits contain less cobalt and platinum. The area where such marine resources exist sprawls beyond limits of Japan’s EEZ as shown in Figure 1.

2-2 Marine organism and microorganism resources

Organisms and microorganisms (including bacteria) living on the bottom of the sea as deep as 6,000 m, where the water pressure reaches 600 atmospheres, are quite different from those seen on the ground, and attracting attention as new marine resources. These organisms and microorganisms living in the deep sea have possibilities to be used for the development of useful materials and new medicines. For this reason, organisms and microorganisms living in the deep sea are noticed as the marine resources that come after petroleum and metal minerals. The role of microorganisms living in the deep sea in the formation of methane hydrate, which is expected to be utilized as energy resources in the future, is also being studied. The National

Committee for Oceanic Research of the Science Council of Japan proposed[4] that technologies which enable long-term utilization of such resources without affecting the environment and ecosystem of the ocean should be developed. The Ministry of Education, Culture, Sports, Science and Technology is promoting frontier research on extreme-environment organisms as well as on crustal microorganisms as the subjects of technical development for utilizing living marine resources[5].

3 Legal framework concerning the utilization of the ocean floors

3-1 Definition of continental shelf according to the UN Convention on the Law of the Sea, 1982

The UN Convention on the Law of the Sea of 1982 defines the "continental shelf" as the area that conforms to the geographical and geological conditions as shown in Figure 2. The "continental shelf" that is referred to here is a legal concept quite different from the geographical "continental shelf," which refers to the area whose water depth is up to about 200m.

Paragraph 8, Article 76 of the UN Convention on the Law of the Sea[6] stipulates, "Information on the limits of the continental shelf beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured shall be submitted by the coastal State to the Commission on the Limits of the Continental Shelf set up under Annex II on the basis of equitable geographical representation. The Commission shall make recommendations to coastal States on matters related to the establishment of the outer limits of their continental shelf. The limits of the shelf established by a coastal State on the basis of these recommendations shall be final and binding." "Commission on the Limits of the Continental Shelf" is hereafter referred to as CLCS.

Article 76 of the UN Convention on the Law of the Sea stipulates basic conditions and restrictive conditions as follows:

(1) Two basic conditions (either one is adopted according to the position) are as follows:
- a. the thickness of sedimentary rocks is at least 1 percent of the distance from such point to the foot of the continental slope,
- b. not more than 60 nautical miles from the foot of the continental slope.

In the absence of evidence to the contrary, the

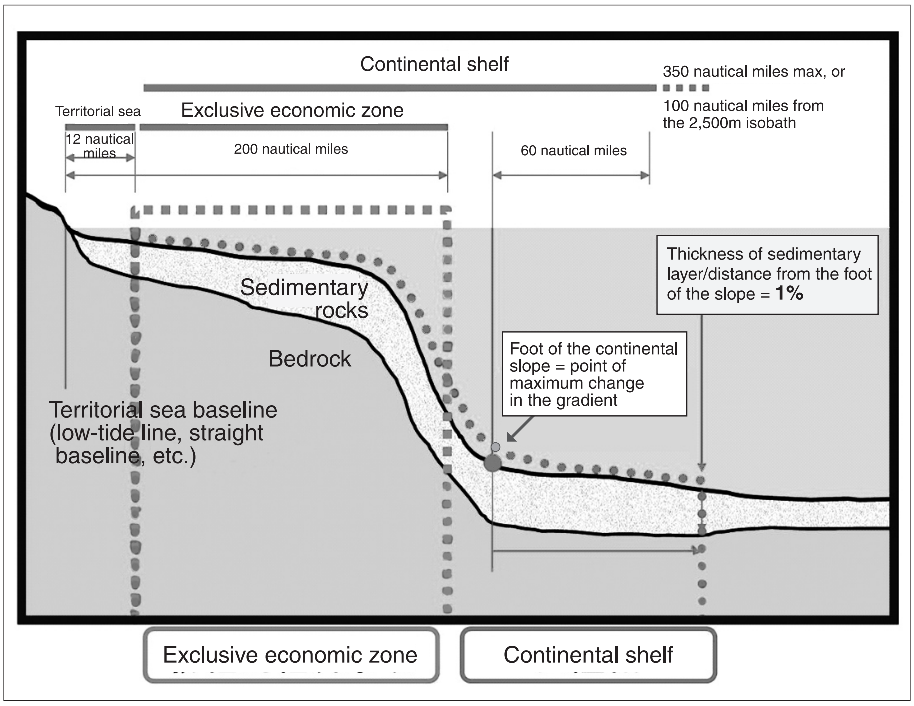

Figure 2 : Definition of continental shelf by the UN Convention on the Law of the Sea

Source: Japan Coast Guard Annual Report 2005 foot of the continental slope is determined as the point of maximum change in the gradient at its base.

(2) Two restrictive conditions (either one is adopted according to the position) are as follows:

c. not exceeding 100 nautical miles from the 2,500 meter isobath,

d. not exceeding 350 nautical miles from the baselines from which the breadth of the territorial sea is measured.

In 1999, "Scientific and Technical Guidelines of the CLCS"[7] was established by the Commission on the Limits of the Continental Shelf as a guideline for its examination.

> **Contiguous zone**
>
> Beyond the 12 nautical mile limit (within EEZ) there is a zone 24 nautical miles from the territorial sea baseline called contiguous zone, in which area the coastal state can exercise the control to prevent and punish infringement of its laws regarding customs clearing, financial administration, immigration control, and hygiene control within its territorial land and sea.

3-2 *Classification of sea areas and significance of the delineation of the continental shelf*

The ocean, which occupies about 70% of the earth's surface, is divided into internal waters, territorial sea, contiguous zone, exclusive economic zone (EEZ), and high seas in accordance with the distance from the territorial sea baseline and other conditions. Table 1 shows the rights and duties of the coastal states and the rights of countries other than the coastal states in each segment. Ocean floors farther than 200 nautical miles from the territorial sea baseline (the shaded portion in Table 1) belong to high seas, and the development of natural resources by individual countries in this area can be carried out by obtaining mining license from International Seabed Authority (ISBA). However, it became possible by the UN Convention on the Law of the Sea of 1982 that coastal states can establish prolongation of the continental shelf by submitting information on the fact that the seabed is a natural prolongation of their territories to the Commission on the Limits of the Continental Shelf (CLCS) and obtaining the recommendations of CLCS. Then,

Table 1 : Possibility of the expansion of sovereign right based on the UN Convention on the Law of the Sea

Distance from the baseline

	Continental area	Baseline ~	12 nautical miles ~	24 nautical miles ~	200 nautical miles
	Internal waters	Territorial sea	Contiguous zone* Exclusive economic zone (EEZ)	High seas	
Sea level	Sovereignty of the coastal state	Right of innocent passage (right of countries other than the coastal state)			
Undersea		Sovereignty of the coastal state	Development of natural resources, establishment of artificial islands and installations		
			Sovereign right for scientific research		
Seabed			Protection of marine environment		
Continental shelf			Development of natural resources	Development of natural resources	
			Sovereign right for scientific research	Scientific research	Deep sea floor
			Protection of marine environment	Protection of marine environment	

Shaded portion is the result of the prolongation of the continental shelf the prolonged seabed of the continental shelf becomes a continental shelf whose sovereign right is owned by the coastal states just as the right for continental shelf of EEZ. However, since the sovereign right in the sea water as in the case of EEZ is not included, there are no changes in economic activities such as fishing.

3-3 Procedure for the delineation of continental shelf

Coastal states must submit the information on the limits that exceed the 200 nautical mile limits of continental shelf to CLCS within 10 years from the effectuation of the UN Convention on the Law of the Sea (according to the resolution of the Conference of the Contracting Parties to the UN Convention on the Law of the Sea, countries in which the law was put into effect by May 1999 are obliged to submit by May 2009, which is 10 years from May 1999), and CLCS provides recommendations. Since Japan put the treaty into effect in 1996, the aim is to submit the information by May 2009 as in the case of many other countries. Although the U.S. has not yet ratified the UN Convention on the Law of the Sea, actual investigation has already been started.

4 Ocean floor exploration technologies

4-1 Bathymetry technology (measurement of seabed geography)

A bathymetry technology using sonic wave is used for accurate measurement of seabed geography. Sonic waves transmitted in the water are reflected by objects in the water or seabed and return to the point of transmission. Using

Velocity of sound waves in the water

The velocity of sound waves in the water is about 1,500 m/s, which is four times faster than that in the air. Suppose the reflection of sound waves that have been transmitted right below the ship is received after six seconds, the water depth is about 4,500 m.

this principle, the distance to an object in the sea or seabed can be estimated. A device used for this measurement is called "sonar." Sonar is used for such purposes as safe navigation of ships (to prevent stranding) and fish detection in fishery. For the accurate geographical measurement of the seabed, such devices as the "multibeam depth sounder," which makes use of multiple highly-directive sound beams and "side scan sonar," are used. The multibeam depth sounder equipped on the survey vessel of Japan Coast Guard is a "phased array" type, in which multiple sound beams are transmitted from the ship bottom and the wave front of the sound beams can be transmitted to the seabed in an arbitrary direction within 75 to left and right by shifting the phase of each sound beam. As shown in Figure 3, the seabed geography within a certain range can be measured at a sweep along the ship track.

4-2 Seismic exploration technology (geological survey of seabed)

When seismic waves produced by artificial forces, such as shock or explosion, are propagated in the water, reflected waves according to the geological conditions under seabed are observed at the sea bottom or on the seawater surface.

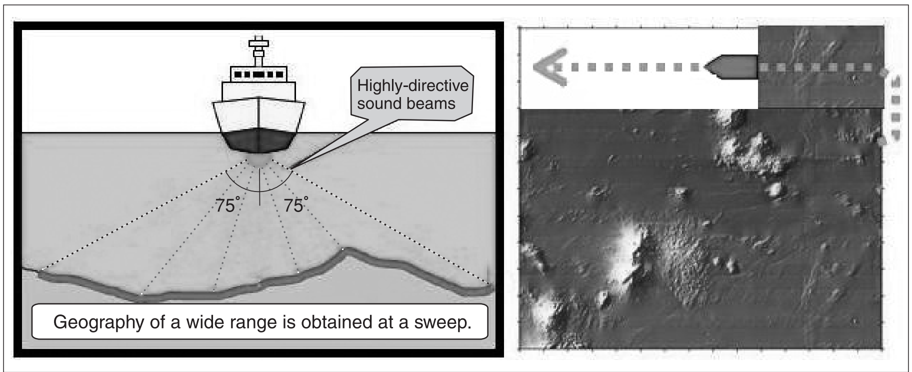

Figure 3 : Accurate measurement of seabed topography using sound waves

Source: Japan Coast Guard[10]

(1) Seismic refraction survey

"Seismic refraction survey" is an exploration method to estimate the crustal structure under seabed in which receivers such as ocean bottom seismometers are placed at appropriate intervals along the traverse line, and seismic waves are transmitted to the ocean crust from an artificial earthquake generator, such as an air gun towed by the survey vessel, and the crustal structures are estimated from the time intervals for the seismic waves to reach the receivers. Sometimes in the survey of continental shelf, the traverse line exceeds 500 km, and more than 100 ocean bottom seismometers are used for the survey. Figure 4 shows a schematic diagram of such an exploration. This method is effective for the exploration of the base structure of thick crust. After the survey is finished, the ocean bottom seismometers are efficiently recovered by a function such as automatic surfacing mechanism activated by sound signals from the survey vessel.

(2) Seismic reflection survey

In the "seismic reflection survey," the survey vessel tows an air gun and streamer cable (length: several hundred meters to several kilometers), and the geological conditions of sedimentary layers and bedrocks of relatively shallow seabed are estimated from the seismic waves received by the channels of receivers that are installed at constant intervals onto the streamer cable.

4-3 Bedrock sampling technology (seabed drilling)

An effective method is to obtain actual samples of bedrock and analyze them to check whether the geological conditions of the seabed structure are continuous from the sea coast. In the survey for the delineation of continental shelf, drilling of the bedrock in the region to be surveyed is implemented by vessels for deep sea drilling to obtain rod samples of bedrock from the ocean floor. The bedrock samples obtained are as shown in Figure 5. Such samples are useful to improve the accuracy of the measurement and estimation together with other geological data obtained by other methods.

4-4 Geophysical observation technology (measurement of gravitational force and earth magnetism)

Geophysical observation technology is a method to estimate the internal structure and composition of seabed by measuring physical

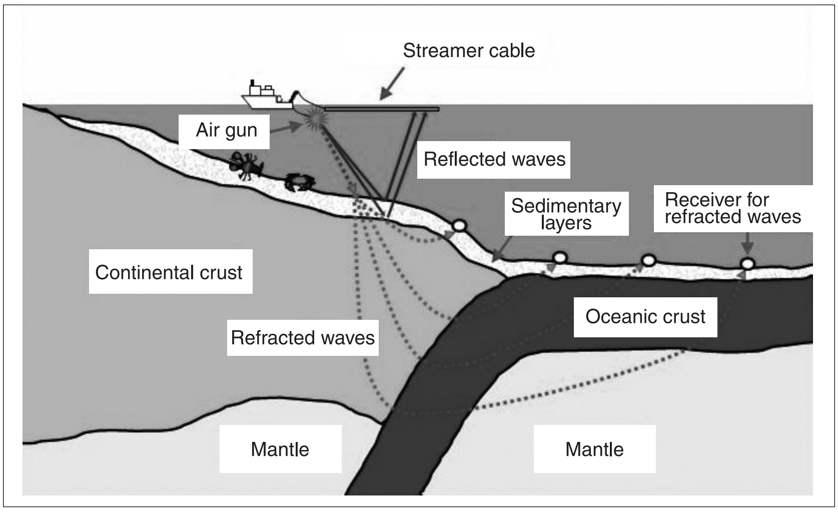

Figure 4 : Schematic diagram for the exploration of seabed structure using seismic refraction method

Source: Japan Coast Guard[10]

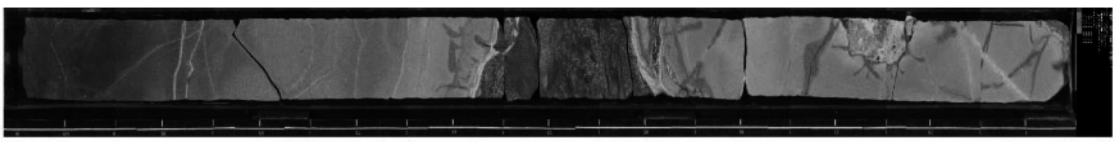

Figure 5 : Example of a rod sample obtained from the seabed rock (cross-section)

Source: From the website of IODP

values, such as gravitational force and earth magnetism. On the ocean floor, there are continental crust and oceanic crust as well as transition zones that cannot be clearly classified. Accuracy of estimation can be improved by measuring various kinds of physical values in the surveying region.

(1) Gravimetrical survey

In the gravimetrical survey, measurement of gravitational force is carried out along the ship track using a gravity meter, as shown in Figure 6, installed on the vessel. Gravimetrical survey is used as one of the means to obtain information on the structure under the ocean floor. Generally speaking, Bouguer gravity anomaly is small on the thick continental crust and large on the thin oceanic crust.

(2) Geomagnetic exploration

When undersea volcanoes erupt and magma spewed out of underground to the seabed solidifies, the status of the geomagnetic field at the time of eruption is recorded by the magnetic substances contained in the magma. Since the information on the seabed at the time when it was formed by measuring the earth magnetism of the seabed, the results of geomagnetic exploration are used as one of the means to study the continuity or uniformity of geological conditions. In geomagnetic exploration using a vessel, earth magnetism is measured along the ship track, as in the case of gravimetrical measurement, using a proton magnetometer or the like.

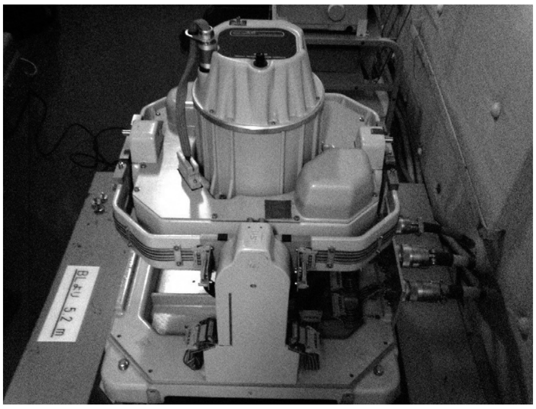

Figure 6 : Shipboard gravity meter of "Shoyo," a survey vessel of Japan Coast Guard

Bouguer gravity anomaly

Generally, the result of gravity measurement is affected by the elevation and geography of the measuring point. Bouguer gravity anomaly refers to the difference between the value corrected so that the conditions of elevation and geography are equalized and the standard value of the gravity at the measuring point.

4-5 Subjects related to ocean floor exploration in the Third Science and Technology Basic Plan

In the Promotion Strategies for Frontier Fields of the Third Science and Technology Basic Plan[2], (i) research on the dynamic behavior of earth's interior using the deep sea drilling vessel, "Chikyu" and (ii) high-accuracy survey of crustal structure effective for the delineation of the continental shelf are listed as the major subjects of the "elucidation of earth's interior structure", and (i) drilling of the bedrock for the delineation of the continental shelf, (ii) exploration and development of petroleum and natural gas resources, (iii) exploration and development of deep sea mineral resources, (iv) research on the utilization of methane hydrate, and (v) development of elemental technologies for ocean platforms are listed as the major subjects of "ocean development technologies."

Among these subjects, the time limit to complete the investigation by the end of FY2007 is set for the crustal structure survey and the bedrock drilling for the delineation of the continental shelf.

5 Trends in the investigation of the delineation of continental shelf in foreign countries

5-1 Status of investigation of foreign countries

Russia submitted information based on the results of investigation in 2001 to CLCS. However, the CLCS recommendations issued the following year did not approve the prolongation of Russia' s continental shelf and advised a resubmission of information. Russia has not submitted new information.

Subsequently, Brazil and Australia submitted information in 2004, Ireland in 2005, and New Zealand, four European countries (France, Spain, United Kingdom, and Ireland on a conjoint basis), and Norway in 2006. CLCS reviews the submitted information at meetings that are held two to three times a year. The review of information submitted by Brazil, Australia, and Ireland has almost been finished and recommendations are scheduled to be issued at the 19th meeting of the Commission on the Limits of the Continental Shelf to be held in March 2007[8].

5-2 Information disclosure strategy of New Zealand

New Zealand is an island country just as Japan, and submitted the information on the continental shelf delineation to CLCS in April 2006 after implementing investigations over ten years to verify that the surrounding sea areas are continental shelf extended from its own landmass. To prepare the report, geoscientists who had learned provisions of the UN Law of the Sea analyzed the investigation data and wrote papers, some of which have been published in internationally known journals. In addition, the fact that much information is disclosed on the website and through other media indicates the country is adopting an active information disclosure strategy. Figure 7 shows the information of prolonged sea area that New Zealand submitted to CLCS. Since ocean floor geographical and geological conditions around New Zealand are quite complicated just as in the case of Japan, we should pay attention to the judgment that will be made by CLCS.

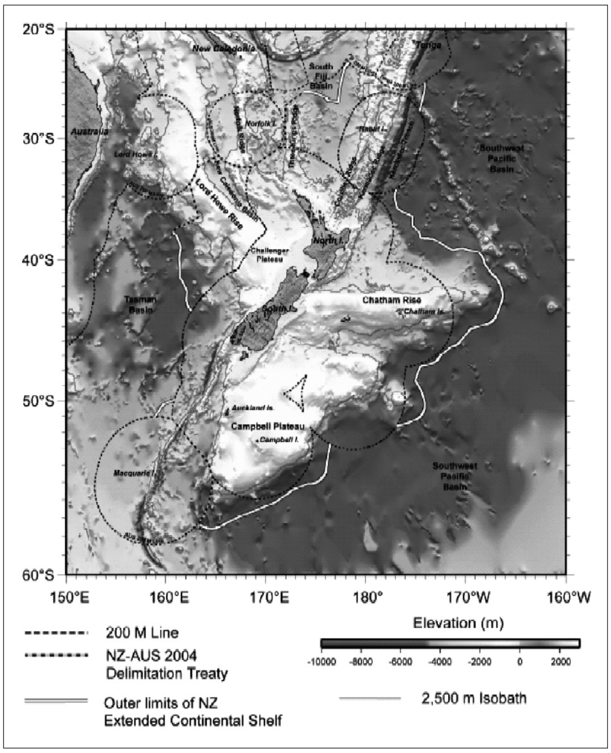

Figure 7 : Prolongation information of continental shelf that New Zealand submitted to CLCS in 2006

Source: Government of New Zealand[9]

The political process that the government of New Zealand took that sympathy to its viewpoint is sought for by disclosing information to the world seems to be an effective measure not only for the prolongation of continental shelf but also for other issues on the global scale.

In March 2006, Japan held a conference for discussion of the scientific and technical aspects of the prolongation of continental shelf, and invited domestic and foreign experts including many CLCS members. The Japanese government should continue such positive activities.

5-3 Trends in the investigation of the delineation of continental shelf in Japan

(1) Japan's organizations for the investigation of the delineation of continental shelf

For the investigation of the delineation of continental shelf of Japan, the Japan Coast Guard takes charge of measuring the ocean floor geography; Japan Coast Guard and the Ministry of Education, Culture, Sports, Science and Technology (implementing agency: Japan Agency for Marine-Earth Science and Technology) take the charge of exploring the ocean floor crustal structure, and the Ministry of Economy, Trade and Industry (implementing agencies: Japan Oil, Gas and Metals National Corporation and National Institute of Advanced Industrial Science and Technology) takes the charge of bedrock drilling (boring). Coordination of the investigation work and comprehensive preparation of documents are carried out by the Coordination Office for Continental Shelf Surveys of the Cabinet Secretariat. Since the data on ocean floor geography obtained by the depth measurement is not sufficient for the preparation of information to be submitted to CLCS, estimated data on geological conditions of seabed obtained by seismic exploration and geophysical observation and the data on marine rock samples obtained by

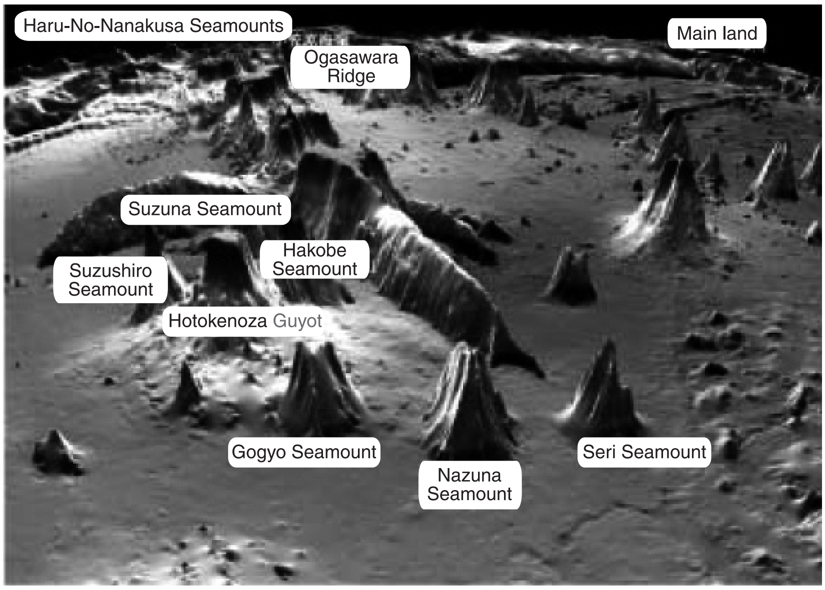

Figure 8 : Example of undersea geography discovered by the ocean floor investigation (Haur-No-Nanakusa Seamounts)

Source: Japan Coast Guard

drilling the bedrock are being comprehensively studied and analyzed by employing all the resources of relevant organizations including seabed exploration technologies, man power, and materials and equipment.

(2) Outline of ocean floor investigations implemented by related organizations

The organizations that take part in the investigation of the delineation of continental shelf are implementing measurement of depth and ocean floor geography, and investigation of geological conditions making use of seismic exploration and drilling of the bed rock using survey vessels of their own.

(i) Japan Coast Guard

Japan Coast Guard (JCG) is carrying out the investigation of seabed geographical and geological structure as part of daily operations, such as the assurance of security of water channels using the survey vessels “Takuyo” and “Shoyo”[10]. Investigations of seabed geography have been carried out for about a million km of traverse lines between the start of measurement in 1983 and 2006 using multibeam echo sounding equipment, and detailed geography of sea areas including Kyushu-Palau Ridge, and Ogasawara Plateau that are considered to be important for the prolongation of continental shelf has been clarified. At the same time, gravitational force and earth magnetism have been measured. During these investigations, more than 200 seamounts have been discovered. For example, the large number of seamounts in the sea area to the east of Ogasawara, shown in Figure 8, were named “Haru-No-Nanakusa Seamounts.”

In 2004, seabed geological survey was started using the nongovernmental geophysical survey vessel, “Tairikudana.” This vessel carries out seismic refraction survey using the multichannel reflection method using tuned air gun array and ocean bottom seismometer (OBS). The tuned air gun array provides accurate means for the crustal survey because the patterns of seismic waves can be arbitrarily adjusted.

(ii) Japan Agency for Marine-Earth Science and Technology

Japan Agency for Marine-Earth Science and Technology (JAMSTEC) owns the ocean research vessel “Kaiyo” and deep sea research vessel “Kairei” and is exploring the crustal structure of seabed as part of geoscience research[11]. In February 2005, for example, Japan Agency for Marine-Earth Science and Technology carried out exploration of the structure of the southern Izu-Ogasawara island arc using 110 ocean bottom seismometers and an air gun of large capacity. “Kaiyo” mainly conducted seismic refraction survey and “Kairei” mainly carried out seismic reflection survey using a streamer cable with a total length of 5 km. Since the seismometers are placed in the sea checking the seabed geography in both of the exploration methods, the GPS equipment that helps grasp the dropping position and multibeam echo sounding equipment played important roles. Figure 9 shows the appearance of "Kairei."

(iii) Japan Oil, Gas and Metals National Corporation and National Institute of Advanced Industrial Science and Technology

Japan Oil, Gas and Metals National Corporation (JOGMEC) and National Institute of Advanced Industrial Science and Technology (AIST) are implementing the seabed drilling to collect seabed rocks that may enable the prolongation of continental shelf using a boring machine system (BMS) installed on "Daini-Hakurei Maru," a specialized vessel for resource exploration for deep sea mineral resources. Japan Oil, Gas and Metals National Corporation makes survey voyages about six times a year, and the National Institute of Advanced Industrial Science and Technology makes survey voyages about once a year. The number of operating days of "Daini-Hakurei Maru" reaches as many as 290 days per year.

Figure 10 shows the outline of equipment installed on "Daini-Hakurei Maru."

Figure 9 : Appearance of the deep sea research vessel "Kairei" of JAMSTEC

Source: website of JAMSTEC

(3) Preparation of documents to be submitted to CLCS

The survey of the sea area was more than half completed by the end of 2006, and the committee of the government which was established in December 2004 to draft the information to be submitted to the United Nations, is now preparing the report to CLCS by January 2009. The data on seabed geographical and geological structure of Japan that have been obtained by the investigations conducted by various organizations are being comprehensively analyzed, and the schedule is to submit information that proves the prolongation of Japan's continental shelf exceeding 200 nautical miles.

At the moment, efforts are concentrated on the data processing and scenario preparation for the prolongation of the continental shelf.

Since the information submitted to CLCS by

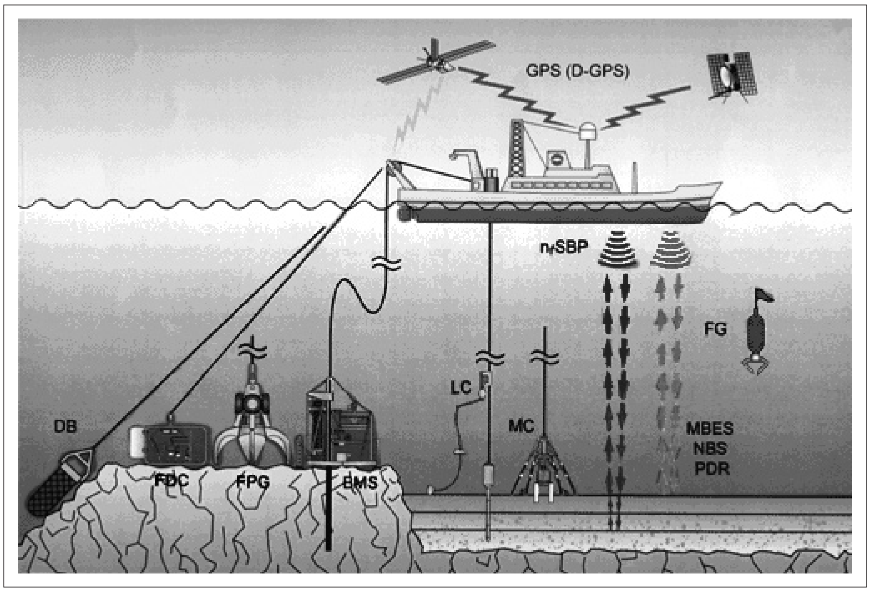

Figure 10 : Equipment installed on the specialized vessel for the exploration of deep sea mineral resources, "Daini-Hakurei Maru"

Source: JOGMEC

May 2009 is reviewed by the members of the Commission consisting of world leading experts in geology, geophysics, or hydrography, this is the first academic ordeal of the whole nation whether Japan can gain the understanding of the Commission and provide clear answers to questions from the Commission members. Prior to the submission of the information, the desire is to nurture international understanding regarding the results of investigation on the delineation of the continental shelf of Japan. In this sense, the New Zealand information disclosure strategy is an encouraging precedent for Japan.

6 Proposals for the future ocean floor exploration and utilization

For future ocean floor exploration and utilization by Japan, the investigation for the delineation of continental shelf in the southern sea area, which is due in 2009, is nothing but an intermediate target. Japan, a maritime state that owns the sixth largest jurisdictional sea area in the world, must develop ocean floor exploration and utilization technologies from the long-term viewpoint, so that exploration technologies are applied to multilateral purposes, such as scientific research, resource exploration, and safety ensuring of the water channels.

6-1 Subjects for the development of ocean floor exploration technologies

In the field of ocean floor exploration, the advancement and sophistication of individual technologies, such as bathymetry, seismic exploration, bedrock drilling, and geophysical observation, have been promoted combined with the development of manufacturing technologies as well as information and communication technology that have been utilized for diversified fields of technology other than ocean floor investigation.

In addition to the present ocean floor exploration technologies, new technologies that will bring about new achievements must be developed and introduced. This includes the introduction of advanced technologies that have been put to practical use overseas, which Japan does not possess. In the field of seismic survey, for example, three-dimensional seismic reflection survey will be applied to the exploration of seabed petroleum resources. For the development of seabed drilling technology, the research vessel for the implementation of earth’s deep interior, “Chikyu,” has been built. The riser drilling equipment installed on “Chikyu” that was originally developed for the offshore oil drilling will provide a means to establish economical resources development technology combined with the offshore platform. In order to be prepared for the utilization of new equipment that has not been typically used in Japan, such as the three-dimensional seismic reflection survey, riser drilling, and offshore platform, it is necessary to nurture human resources and establish comprehensive policies.

6-2 Objectives of utilizing ocean floor resources

Because of the high cost, utilization of ocean floor resources is not yet economically practical at this moment. However, since the supply of resources of various metals is becoming tight worldwide due to the rapid economic development of BRICs, technologies for obtaining metal resources from the ocean floor should be strategically developed as a measure to offset the risk of security assurance of the country.

The Basic Maritime Law has been being drafted since December 2006 aiming to submit the law to the Diet. The fundamental principles of the law are conservation of maritime environment, development and utilization of ocean floor resources, safety assurance, sustainable development and utilization, international collaboration and other related issues, and the intension is for Japan to play a leading role in the formation of international order of the maritime affairs. The Japanese government should establish policies that lead to an advantageous position in the future utilization of ocean floor resources.

6-3 Themes in the continuation of sea area exploration

The present target of ocean floor exploration is the southern sea area because the area is directly related to the national objective of the prolongation of continental shelf. However, it is also necessary to promote the investigation of other sea areas such as Japan Sea that are not directly related to continental shelf prolongation. From the viewpoints of fostering and utilization of human resources in ocean floor exploration, the desire is to steadily continue the exploration activities on a long-term perspective. Ocean floor exploration cannot be carried out only by scientists. It requires diversified indirect supports including the navigation of the vessel, development and manufacturing of equipment, supply of commodities, such as drilling tools, establishment and management of training facilities for the human resources of ocean floor exploration. Therefore, comprehensive policies for sea area exploration should be established before taking individual measures.

Acknowledgments

The author would like to express sincere thanks to the following people for their cooperation in the preparation of this report: Shin Tani, Counsellor and Shinichi Toyama, Assistant Director to the Counsellor, Coordination Office for Continental Shelf Surveys of Cabinet Secretariat; You Iwabuchi, Director, Continental Shelf Surveys Office, Hydrographic and Oceanographic Department, Japan Coast Guard; Narumi Takahashi, Sub-leader, Center for Deep Earth Exploration, Japan Agency for Marine-Earth Science and Technology; Hajime Hishida, Team Leader, Metals Mining Technology Group, Japan Oil, Gas and Metals National Corporation; Akira Nishimura, Deputy Director, Institute for Geology and Geoinformation, National Institute of Advanced Industrial Science and Technology; Manabu Tanahashi, Deputy Director, Institute for Geo-Resources and Environment, National Institute of Advanced Industrial Science and Technology; Junzo Kasahara, Professor Emeritus at the University of Tokyo; Yuzuru Ashida, Professor and Hitoshi Mikada, Associate Professor, Graduate School of Engineering, Kyoto University; Katsutoki Matsumoto, General Manager of Exploration, Deep Ocean Resources Development Co., Ltd.

Abbreviation

AIST: National Institute of Advanced Industrial Science and Technology
BMS: Boring Machine System
CLCS: Commission on the Limits of the Continental Shelf
EEZ: Exclusive Economic Zone
GPS: Global Positioning System
ISBA: International Seabed Authority
JAMSTEC: Japan Agency for Marine-Earth Science and Technology
JCG: Japan Coast Guard
JOGMEC: Japan Oil, Gas and Metals National Corporation
SONAR: SOund Navigation And Ranging

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(Original Japanese version: published in March 2007)

6

Trends in Policies for Promoting Converging Technologies Expected to Bring Innovation

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1 Introduction

In 2002, the U.S. National Science Foundation (NSF) and the Department of Commerce published the first proposal for the promotion of converging technologies (hereinafter abbreviated as CT(s)) titled “Converging Technologies for Improving Human Performance[2].” Following publication, three annual conferences have been held since 2003, which were summarized by the NSF in a report titled “Managing Nano-Bio-Info-Cogno Innovations: Converging Technology Society” published in 2005[1].

Although they were not clearly defined in the report, CTs are acknowledged as “technologies converging two or more fields of science and technology for achieving specific goals“ and “are categorized as ‘metatechnologies’ that affect other technologies to bring about drastic changes to the entire system.”

According to the 2002 report, we are living in the “Age of Transition” and are already experiencing technological innovations brought by computer and information technologies, nanotechnology and biotechnology. From now on, CTs, which are based on these technologies and transcend conventional frameworks in the fields of science and technology, are expected to serve as key technologies that will trigger revolutionary technological and social changes[2].

Regarding NBIC (pronounced enbick or nibick), which stands for the four fields of nanotechnology, biotechnology, information technology and cognitive science, rapid and expansive integration of technologies is observed, and new technologies are continuously being created.

Consequently, the CTs attracting most attention today are “technologies developing from the ‘convergence of NBIC’” and “technologies assisting or enhancing the convergence of NBIC” (Figure 1). Such technologies are believed to create sciences and technologies producing paradigm shift or innovation, and the U.S. promotes further convergence of NBIC-based technologies in the Science and Technology Policy[3].

The mission-oriented aspect and the strong need-oriented aspect of CTs enable them to associate social needs or policy issues with specific science or technology. The U.S. expects that promoting CTs will result in drastic improvement of human performance, social innovation and the creation of new business.

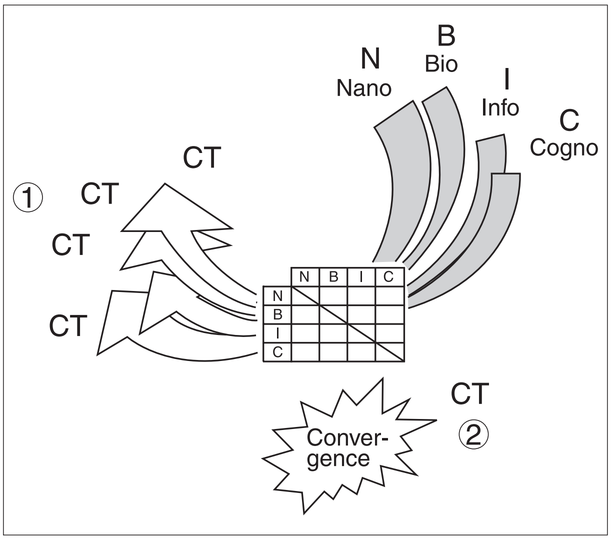

Figure 1 : NBIC and CTs (converging technologies)

(i) Technologies developing from the convergence of NBIC in various combinations
(ii) Technologies assisting or enhancing the convergence of NBIC

Prepared by the STFC

Inspired by the U.S. trend, the European Commission (EC) established an expert group in 2003 to start discussing the European approaches regarding CTs. In 2004, the Commission released a report titled "Converging Technologies - Shaping the Future of European Societies"[4].

Unlike the U.S., the EC has not included "improvement of human performance" in the goals of CTs. Moreover, EC's standpoint slightly differs from that of the U.S., i.e., in addition to the bright future brought by the introduction of CTs, technical limitations or concerns as well as social influences, such as predictable risks, have been brought up for discussion. Nevertheless, the report concluded that "the European societies will be newly shaped by CTs." CTs are expected to contribute to the implementation of the "Lisbon Strategy," which aims at enhancing economic growth and employment by increasing the competitiveness of European economy. The Commission has set the agenda "CTs for the European Knowledge Society (CTEKS)" and proposed to initiate CT research programs. The KNOWLEDGE NBIC Project (2006-2009), funded by the Sixth Framework Programme for Research and Technological Development (FP6) and the following FP7 (2007-2013) by the European Commission, has been implemented to advance research and investigation on the promotion and social application of CTs.

Meanwhile in Japan, no particular discussion on CTs has occurred.

Chapter 2 of the present report introduces the CTs reviewed in the U.S. and their positioning in U.S. Science and Technology Policy. Chapter 3 attempts to evaluate the international status of progress in CT research through bibliometric analysis. Chapter 4 discusses the incorporation of CTs into Japanese Science and Technology Policy, and Chapter 5 proposes measures to be taken in Japan.

2 Twenty topics for CTs discussed in the U.S.

CTs are potentially involved in critical areas having great impact on human activities. Such areas are (i) revolutionary tools or products, (ii) daily human performance, such as work efficiency, accelerated learning (i.e., learning of new knowledge at a high speed), and increased group performance, (iii) changes in organizations, business models and policies for reestablishing infrastructure and setting priorities for R&D planning and (iv) trends toward a "global information exchange" regarding ideas, models and cultures.

The 2002 report[2] listed 20 specific examples (topics) of CTs with potential contributions to the improvement of human performance, etc. within the next one or two decades. Moreover, the 2005 report presented the results of a survey in which experts from industry, government and academia who participated in the preparation of the report were asked to estimate when each of these 20 CT topics might be accomplished. As described below, the content and results of this survey closely resembled those of the Science and Technology Foresight Survey (Delphi Analysis) performed every five years by the National Institute of Science and Technology Policy in Japan.

2-1 Expected years of accomplishment and ratings of benefit of the 20 CT topics

For the 20 CT topics, 26 experts from industry, government and academia were asked to estimate when each of these 20 CT topics might be accomplished and their ratings of benefit. The expected year of accomplishment is defined as "the breakthrough year" in which each of these technologies will be at least partially accomplished. Medians are presented instead of averages for the expected years of accomplishment and ratings of benefit. The ratings of benefit are expressed on a 1 to 10 scale, in which 10 is the maximum.

As shown in Table 1, the 20 CT topics cover a wide range of areas, including health, information, communication and engineering. The CT topics with the earliest expected year of accomplishment were "(3) comfortable, wearable sensors and computer," "(9) instantaneous access to information from anywhere in the world" and "(13) new organizational structures and management principles," whose expected years of accomplishment were 2015, while the topic with the latest expected year of accomplishment

Table 1 : Expected years of accomplishment and ratings of benefit of 20 representative CT topics

CT topics	Expected years of accomplishment	Ratings of benefit of technologies (from 0 to 10, 10 is the maximum)
(1) All kinds of machines and structures, from homes to aircraft, will be constructed of materials having desired properties, including adaptability to changing situations, high energy efficiency and environmental friendliness.	2030	8.9
(2) Individuals or groups of individuals will be able to communicate and cooperate across traditional barriers of culture, language, distance and professional specialization.	2020	8.8
(3) Comfortable, wearable sensors and computers will enhance each individual's access to information of interest, such as his or her health condition, environmental pollution, etc.	2015	8.7
(4) Agriculture and the food industry will increase yields and reduce spoilage through inexpensive networks and smart sensors that constantly monitor the conditions and needs of plants, animals and farm products.	2020	8.7
(5) A combination of technologies and treatments will compensate for many physical and mental disabilities.	2025	8.6
(6) The human body will be more durable, healthier, more energetic, easier to recover and more resistant to various kinds of stress, biological threats and aging.	2025	8.5
(7) The work of scientists will be revolutionized by importing approaches pioneered in other sciences (for example, genetic researchers employ tools or knowledge from natural language processing, and cultural researchers employ tools, etc. from genetics).	2020	8.5
(8) People from all backgrounds and at all levels of ability will gain valuable new knowledge and skills more quickly and reliably at school, job or home.	2020	8.4
(9) Anywhere in the world, an individual will have instantaneous access to information of interest.	2015	8.3
(10) Engineers, artists, architects and designers will experience a dramatic expansion of creative abilities, both with a variety of new tools and through increased understanding of the wellspring of human creativity.	2020	8.3
(11) Average individuals, as well as policymakers, will have an improved awareness of the cognitive, social and biological forces affecting their lives, enabling more adaptive and creative decision making in their daily lives.	2020	8.3
(12) Transportation will be safe, cheap and fast, due to ubiquitous realtime information systems, extremely high-efficiency vehicle designs and the use of synthetic materials and machines fabricated from the nanoscale to achieve optimum performance.	2030	8.3
(13) New organizational structures and management principles based on fast and reliable communication of needed information will drastically increase efficiency for administrators of business, education, and politics.	2015	8.0
(14) Factories in the future will serve as "intelligent environments" that achieve the maximum benefits of both mass production and custom design through systematization of converging technologies and improvement of human-machine capabilities.	2020	7.8
(15) Education will be transformed into a unified but diverse curriculum based on a comprehensive, hierarchical intellectual paradigm for understanding the structure of the physical world from the nanoscale through the cosmic scale.	2030	7.5
(16) Robots and software agents* will be more useful for human beings (* software capable of autonomously adjusting its own action in accordance with change in execution environment or user instructions).	2025	7.2
(17) The potential of the vast universe will be appreciated by means of exploitation of celestial resources such as the moon and Mars, which are near to the earth, efficient landing vehicles and robotic construction of extraterrestrial bases.	2050	6.7
(18) Direct broadband interfaces between the human brain and machines will be introduced into factory work, automobile control, military activities, etc.	2030	6.4
(19) Genetic control of humans, animals and agricultural plants will greatly benefit human welfare (a widespread consensus about ethical, legal and moral issues will be built in the process).	2030	6.2
(20) National security will be reinforced by lightweight, information-rich combat systems e.g., unmanned combat vehicles, smart materials, invulnerable data networks, superior intelligence-gathering systems, effective technologies for detecting and measuring biological, chemical and nuclear attacks.	2020	5.5

Prepared by the STFC referring to Reference[1]

Table 2 : Additional CT topics with high ratings of benefit (8.5 or larger)

CT topics	Expected years of accomplishment	Ratings of benefit of technologies (from 0 to 10, 10 is the maximum)
We will have the technical means to ensure an adequate food supply, clean air and clean water.	2030	9.2
Assistive technologies will overcome disabilities such as blindness, deafness and immobility.	2035	8.8
Computer interface architectures will be changed so that disabled people can access the Internet and other information sources as quickly as other people.	2015	8.8
Free availability of information to disadvantaged people around the world will improve their agricultural production, health, nutrition and economic status.	2015	8.6
A deep understanding of the visual language – communication by pictures, icons and diagrams – will realize more effective interdisciplinary communication, more complex thinking and breakthroughs in education.	2025	8.5

Prepared by the STFC referring to Reference[1]

was "(17) exploitation of celestial resources such as the moon and Mars," which was expected to be accomplished in 2050. The topic with the highest and the lowest ratings of benefit were "(1) machines and structures constructed of new materials" and "(20) reinforcement of combat systems," respectively.

The 2005 report added 56 topics to the above 20 CT topics and discussed 76 topics in total. Among the 56 additional topics, those with ratings of benefit of 8.5 or larger were extracted in Table 2. Among these five highly beneficial CT topics, four aimed directly at human performance improvement. The additional topics included five topics involving performance improvement of soldiers, etc. all of which were given low ratings of benefit. (For reference, see "new realistic training environments revolutionizing training of military personnel, such as virtual-reality battlefields and war-gaming simulations, 2010, rating of benefit 6.2," "soldiers having the ability to control vehicles, weapons and other combat systems instantly, merely by thinking the commands, 2045, rating of benefit 4.5").

2-2 CTs in U.S. Science and Technology Policy

According to the 2005 report, NSF, NASA (National Aeronautics and Space Administration), EPA (Environmental Protection Agency), DOD (Department of Defense) and DOE (Department of Energy) are engaged in research and development projects involving more than one NBIC field. This implies that the U.S. is already implementing national projects related to CTs.

Examples of national initiatives (U.S. systems for setting national strategic agendas and implementing them in an integrated manner) related to NBIC are the Information Technology Research (ITR) Initiative announced in 1999, which aims at the promotion of basic and long-term IT research, and the National Nanotechnology Initiative (NNI) announced in 2000, which aims at promoting nanotechnology. The budgets in fiscal year 2005 for these two ongoing initiatives were $2,000 million and $1,200 million, respectively.

The concept of CTs, i.e., the convergence of different fields, originated from NNI that covers the promotion of integration of sciences and technologies at the nanoscale. However, the 2005 report proposes that NNI support the implementation of CTs through cooperation with ITR, as well as with long-term strategic projects related to NBIC other than national initiatives, i.e., projects implemented by individual agencies or national organizations, such as the NIH's Roadmaps implemented by NIH for promoting biomedical research.

2-3 U.S. industries and CTs

To some extent, U.S. industry is already involved in the U.S. Science and Technology Policy regarding CTs. The 2002 report includes a list of participants in the CT expert meeting that served as the source of this report and contributors to the preparation of the report. The list includes 32 members from the government or national research institutes, namely, NSF, DOE, DOC (Department of Commerce), NASA, NIST (National Institute of Standards and Technology), NIH, EPA, Office of Naval Research, U.S. Air Force Research Laboratory, NOAA (National Oceanic and Atmospheric Administration), etc. Twenty eight members were from the academia, namely, Stanford University, Carnegie Mellon University, Massachusetts Institute of Technology, University of California (Berkeley, Los Angeles, San Diego, etc.), and University of Texas, etc. Eighteen members participated from various fields of industry, including companies such as Boeing, HP (Hewlett-Packard) Labs, IBM, Lucent Technologies (business field: network and communication system), TissueInformatics (biomedical tissue screening system), Klein Associates (undersea exploration and security), Institute for Global Futures (think tank) and New England Complex Systems Institute (complex systems).

The promotion of CTs can be categorized as a science and technology policy of a top-down style, but the U.S. government seems to be successfully involving industry. Consequently, future promotion of CTs may realize convergence of NBIC studies conducted in various industrial, governmental and academic organizations and enable laborsaving and acceleration in the series of procedures from basic and applied research to industrialization.

3 Global status of progress in research related to CTs

The U.S. is promoting CTs as a part of a Science and Technology Policy, but what is the actual status of progress in CT research in the U.S.? Is it possible to understand the global status of CTs? Since CTs cover various fields of research, it is very difficult to evaluate the progress of CTs themselves. As an attempt to overcome such difficulty, the author evaluated the progress in CTs by analyzing the number of research papers.

Moreover, this chapter introduces a report by a U.S. think tank, RAND Corporation, which has made a global comparison of capacity to conduct bio/nano/material/information studies, and describes the global status of CT studies based on the report.

3-1 Bibliometric analysis regarding CTs

Using the Web of Science (Thomson) as a research paper database, papers published from 1980 to January 16, 2007 (1,468 papers) were searched by the keywords "converg* AND technolog*." In order to extract papers related to NBIC, a further search was conducted using the keywords "nano* OR bio* OR info* OR cogn*" (* at the end of the string represents any letter(s). For example, "converge," "convergence" and "converging" are simultaneously retrieved by "converg*").

The targets searched were "titles," "keywords set by the author" and "abstracts." The following analyses were performed with the assumption that all retrieved papers were related to CTs. The transition of the number of papers, the number of papers published in individual countries, the study field classification and the number of related papers were analyzed using the Analyze of the Web of Science. The study field classification used here conformed to the Thomson classification.

(1) Transition of the number of papers and breakdown

The search retrieved 452 papers as CT papers related to NBIC. The annual number of papers showed an increasing trend and was particularly large in 2004 (Figure 2).

Among NBIC, information technology had the largest share (61%) in the gross number of papers, followed by biotechnology (24%),

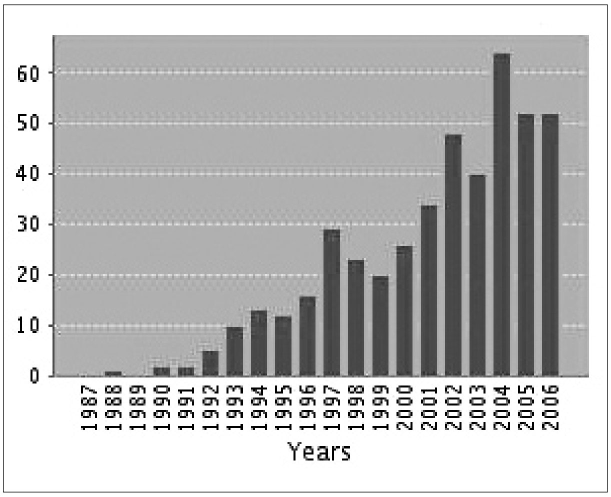

Figure 2 : The transition of the number of papers retrieved by keyword searches

Prepared using a function of Web of Science

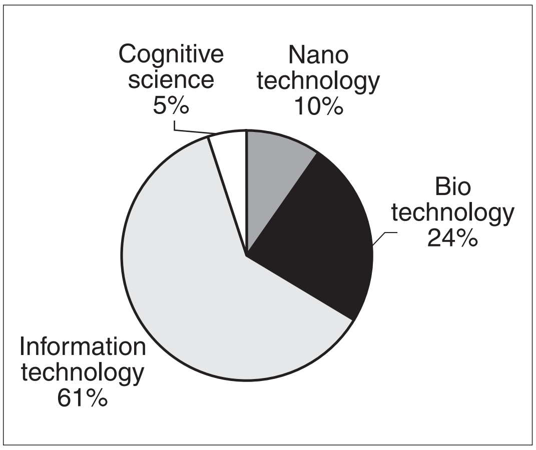

Figure 3 : Breakdown of retrieved papers by NBIC field (gross number of papers)

Prepared by the STFC

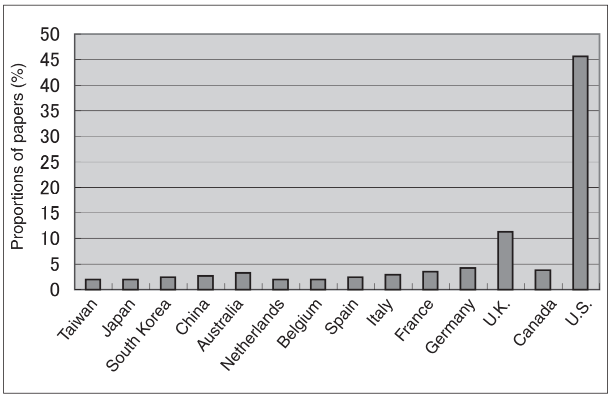

Figure 4 : Country-by-country proportions of papers

Prepared by the STFC

nanotechnology (10%) and cognitive science (5%)(Figure 3). About 2% of the papers were potentially related to all four fields of nanotechnology, biotechnology, information technology and cognitive science. Among the papers related to more than two fields, such as "nanotechnology and biology," "information technology and cognitive science" or "biotechnology, nanotechnology and cognitive science," those related to "biotechnology and information science" were most commonly found, accounting for 7%.

Further analysis of the papers published in 2003 and 2004 revealed that the number of papers drastically increased during this period, not only in the field of nanotechnology but also in the other three fields of NBIC. This increase might be attributed to the enforcement of the U.S. CT promotion policy in 2002.

Table 3 : The study field classification and the number of related papers

Study field classification	Number of papers	Proportion (%)
Engineering, Electrical & Electronic	67	14.8
Telecommunications	67	14.8
Computer Science, Information Systems	64	14.2
Computer Science, Theory & Methods	46	10.2
Information Science & Library Science	39	8.6
Computer Science, Hardware & Architecture	23	5.1
Computer Science, Interdisciplinary Applications	23	5.1
Management	23	5.1
Multidisciplinary Sciences	23	5.1
Computer Science, Software Engineering	20	4.4
Operation Research & Management Science	18	4.0
Chemistry, Multidisciplinary	16	3.5
Engineering, Multidisciplinary	15	3.3
Biochemistry & Molecular Biology	14	3.1
Biotechnology & Applied Microbiology	14	3.1
Pharmacology & Pharmacy	14	3.1

Prepared by the STFC

(2) Number of papers published in individual countries

Figure 4 shows the country-by-country proportion (%) of papers to the total number of papers. The U.S. had the largest share (46%) followed by the U.K. (11%), while the rest of the countries had substantially the same shares (5% or less). The European countries collectively accounted for around 33% of the total, being the second to the U.S.

(3) Study field classification and number of elated papers

Table 3 shows the study field classification and the number and proportion (%) of related papers. Papers related to "Engineering, Electrical & Electronic" and "Telecommunications" had the largest shares (15%), followed by "Computer Science" and "Information Science." Papers related to "Management" and "Operation Research" came next, followed by "Chemistry" and "Biotechnology."

The above results demonstrated that, as

Table 4 : The top 16 technologies related to bio/nano/materials/information having potential impact on society

1. Cheap solar energy
2. Rural wireless communications
3. Communication devices for ubiquitous information access anywhere, anytime
4. Genetically modified (GM) crops
5. Rapid bioassays
6. Filters and catalysts for water purification and decontamination
7. Targeted drug delivery
8. Cheap autonomous housing
9. Green manufacturing
10. Ubiquitous RFID tagging of commercial products and individuals
11. Hybrid vehicles
12. Pervasive sensors
13. Tissue engineering
14. Improved diagnostic and surgical methods
15. Wearable computers
16. Quantum cryptography

From Reference[5]

expected, the U.S. has published the largest number of NBIC-related CT papers, followed by European countries as a whole.

Moreover, although Tables 1 and 2 included many CT topics related to biotechnology, Table 3 showing the study field classification and the number of related papers demonstrated that research papers related to biotechnology were still few. CT studies are currently focused on information science and perhaps will be gradually shifted to biotechnology and nanotechnology. In practice, we still seem to have a long way to the realization of CTs based on NBIC.

3-2 Global comparison of capacity to implement bio/nano/material/information studies

In 2006, a U.S. think tank, RAND Corporation, published a report titled "The Global Technology Revolution 2020, In-Depth Analyses: Bio/Nano/Materials/Information Trends, Drivers, Barriers, and Social Implications,"[5] which evaluated the capacity of 29 countries to implement 16 advanced technologies related to bio/nano/materials/information by 2020. Cognitive science was not included in the scope of the evaluation.

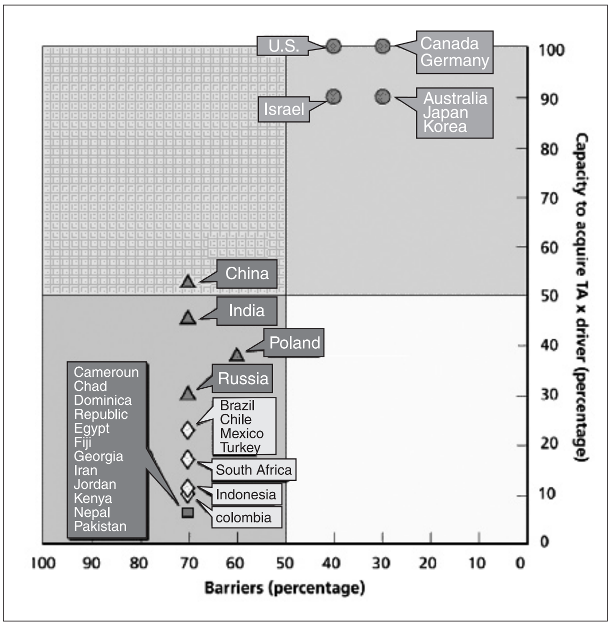

Figure 5 : International comparison in capacity to implement the top 16 technologies related to bio/nano/materials/information

From Reference[5]

The evaluation was performed on the "top 16 technologies related to bio/nano/materials/information having potential impact on society (Table 4)." The "top 16 technologies" were selected based on technological forecasting papers (scenarios) regarding individual fields of bio/nano/materials/information by 2020 and factors such as "technical feasibility," "social feasibility (nontechnical barriers such as market demand, cost, infrastructure, policies and regulations)" and "global diffusion" by 2020.

Individual countries were evaluated on "cost/financing," "laws/policies," "social values, public opinions and politics," "infrastructure," "privacy concerns," "resource use and environmental health," "investment in R&D," "education and literacy," "population and demographics" and "governance and stability."

As shown in Figure 5, along with the U.S., Canada, Germany, South Korea, Australia and Israel, Japan appears in the upper right section, indicating that the country has a high level of science and technology capability and many drivers and few barriers to technology implementation. The barriers in Japan were assumed to be "laws/policies," "social values, public opinions and politics" and "governance and stability," which were also pointed out as barriers in South Korea.

Combining the results of this global comparison with the country-by-country proportion of research papers on CTs shown in Figure 4, the U.S. indeed has an advantage over other countries, but its technological capability is not much different from those of other countries. China has a high level of science and technology capacity and many drivers of technology implementation but faces many nontechnical barriers to the implementation. Compared to China, India has a lower science and technology capacity and fewer drivers of technology implementation.

As can be seen, the U.S. views Japan as one of the countries capable of implementing bio/nano/materials/information studies. However, countries such as South Korea, China and India, are rapidly developing their science and technology capacities and shifting their social systems and environments towards research promotion. Thus, there is no guarantee that Japan can keep its current global position in the next decade. There is no need to copy U.S. or European policies, but it is important that we adopt policies enabling efficient implementation of science and technology through further development of science and technology capacity, promotion of convergence between different fields of science and technology, removal of conventional barriers and shortening of the process to technology accomplishment.

4 Status of country-level policies for promoting CTs in Japan

Although Japan has no specific country-level policy regarding CT promotion, the concept of CTs may be added to the existing national policies regarding science and technology. As an example of such approach, this chapter discusses the "Coordination Program of Science and Technology Projects," which is a national policy for collectively promoting similar research projects conducted among different ministries.

The Coordination Program of Science and Technology Projects was adopted by the Council for Science and Technology Policy in 2004 and launched in July 2005. About a year later, in November 2006, the Council for Science and Technology Policy announced "Achievements and future topics and plans of the Coordination Program of Science and Technology Projects (interim report)[6]."

The purpose of the Coordination Program of Science and Technology Projects is that "the Council for Science and Technology Policy will establish important national and social themes to be promoted through collaboration among various government ministries concerned, eliminate unnecessary redundancies among policies related to each theme and strengthen collaboration, with an eye to linking together the vertically arranged policies of individual

Table 5 : Themes and research topics of the Coordination Program of Science and Technology Projects corresponding to U.S. CT topics

Themes and research topics	Goals
Ubiquitous networks – development of electronic tag technology, etc. – "Demonstration experiment for the application of electronic tags in the medical field (from 2005)" "Research and demonstration of innovative application of ubiquitous networks (from 2006)"	Establishment of core technology platforms for realizing ubiquitous network society
Next-generation robots – establishment of common technology platforms – "R&D of basic models of environmental information structuring platforms (from 2005)" "Establishment of robot software platforms that can be accumulated and reused (from 2005)" "Project for delivering structured environmental information services to people traveling indoors and outdoors (from 2006)" "Project for structuring environmental information for handling objects in workspace (from 2006)"	Establishment of common technology platforms covering various application fields of next-generation robots
Nanobiotechnology "Aid for nano-drug delivery systems based on molecular imaging (from 2005) (from 2006)" "Nanobiosensors (from 2005) (from 2006)"	Realization of good health, longevity and a safe and secure society through research that integrates nanotechnology and biotechnology

Prepared by the STFC referring to Reference[6] ministries. This should create synergistic and integrated effects to bring an excellent outcome as a whole.[6]" (The underlined part was added by the author.)

The expected outcomes are maximizing research results and generating innovation. Table 5 shows the themes, targets and related fields of the Coordination Program of Science and Technology Projects. Some of the CT topics presented in Table 1, such as ubiquitous systems and robots, also appear as themes for the Coordination Program of Science and Technology Projects. The original purpose of the program is to "collaborate among ministries," and to "create synergistic and integrated effects to bring an excellent outcome as a whole," which is claimed in the underlined part of the purpose, overlaps with the effects expected from CT promotion. Therefore, regarding these themes, the Coordination Program potentially brings more than just the collaboration among ministries by taking advantage of the strong mission-oriented nature of CTs and strategically integrating multiple research topics.

The interim report suggested that the future topics would be "consistent strengthening of collaboration, from basic research and R&D through application," "information sharing among ministries as well as the private sector" and "further exploitation of the Coordination Program of Science and Technology Projects." Future plans suggested in the report included "the expansion of the scope of the Coordination Program to the Strategic Prioritized Science and Technology for effective implementation of the promotion strategies for prioritized areas of the Third Science and Technology Basic Plan." Regarding the expansion of the scope of the Coordination Program, the report suggests that the plan is to "select and intensively promote the target Strategic Prioritized Science and Technology from the standpoint of collaboration promotion, innovation creation, etc." Since the scope of the Coordination Program will be expanded in hope of generating innovation, it is strongly suggested that the Program will be implemented by setting specific agendas and actively incorporating concepts such as CTs.

5 Measures to be taken in Japan

CTs differ from the so-called integration technologies or fusion technologies in the following three aspects: (i) CTs are mission-oriented and strongly needs-oriented, (ii) CTs are truly (both technologically and socially) revolutionary and (iii) CTs are interdisciplinary technologies based on NBIC.

Japan has recently become aware of the importance of integration and fusion of technologies, and implementation measures have been proposed by government, industry and academia. Yet, none of these measures has covered all the above three aspects. Vertical driving powers within individual science and technology fields are strong in the Japanese government-industry-academia systems, which are said to be hindering the creation of interdisciplinary technologies. However, interdisciplinary technologies based on NBIC are potentially important technologies (CTs) having a great impact on society, so these Japanese systems need to be modified to enhance creation of interdisciplinary technologies. It might be effective to establish, for example, a government -industry-academia platform that links the NBIC fields together.

In order to create many CTs and consequently accomplish the targeted topics, management systems and methodologies for performing the topics need to be established, which should accelerate technology development and shorten the time for accomplishment. Research and technology development should be conducted by analyzing the current status and prospects for science and technology development, predicting the future market scales from social needs (personal concerns, etc.) and social changes (population composition, disasters, crime, employment, medical care, etc.), incorporating science and technology forecasts and technology roadmaps in the early stages of technology development and analyzing them through an integrated approach to obtain results that serve as the basis for research and technology development. By combining these approaches, we should be able to specify which science or technology in the NBIC fields is effective for accomplishing the topics at a certain time point. Under the current circumstances in which science and technology seeds are created everyday, these approaches should serve as a compass for reaching the island of innovation in the ocean of science and technology.

The following country-level activities regarding CTs are considered to be effective for Japan in the future:

(i) Holding of workshops on CTs regarding specific themes by government-industry-academia groups concerned with common missions and topics, where participants can exchange opinions and share knowledge on CTs.

(ii) Reconsideration of the Strategic Prioritized Science and Technology areas of the Third Science and Technology Basic Plan for individual purposes from the viewpoint of CTs, and collective promotion of those expected to be effective in developing innovation through interdisciplinary implementation.

(iii) Government-industry-academia collaboration in the selection of topics that are considered to be important in the future Japanese society and can be accomplished by science and technology, the investigation of their status of progress and the formulation of promotion policies.

In addition to field-specific promotion policies, which have already been adopted in the current Third Science and Technology Basic Plan, policies for promoting the construction of "bridges" between different fields need to be formulated in the Fourth Science and Technology Basic Plan, probably launched in 2011. Whether or not CTs would be the "bridges," it should be meaningful to discuss country-level promotion based on such viewpoint.

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(Original Japanese version: published in February 2007)

7

Trends in Electronic Scientific, Technical, and Medical Journals
—The Research Information Gathering Environment and Business Innovation—

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1 Introduction

Academic research in the area of science and technology is communicated and made available in many forms[1]. Researchers announce their results in some type of medium to make them widely known to other researchers, to have them accepted, and to build a record of their achievements. In the case of scientific, technical, and medical researchers, they most often present their results to their peers at academic conferences before writing papers for submission to journals. In the journal editing process, examination and review (peer review) by other researchers allows a certain quality standard to be maintained as articles are regularly compiled and published. Universities, academic societies, and publishers have engaged in this business since the 17th century. Even today, journals are the most important medium for the presentation of research results.

Recently, especially since about 1995, the development of full-fledged information services on the Internet has made it possible to transmit information in ways that bypass periodicals. Even the journals themselves have repeatedly experimented with new ways of utilizing these services. At first, there has been a shift to electronic formats for work and information that were formerly paper based, namely, the digitization of journal information and the conversion of review work to electronic media. Subsequently, various electronic journal services that utilize the unique characteristics of the Internet and that would have been impossible with paper-based journals have been examined, enabling the realization of functions such as citation links. Now, electronic journals are even able to offer everything from search functions to provision of final primary data as integrated services, including links to databases. The result is that many more people now have opportunities to see scientific and technical information, which formerly circulated only among a few experts.

Meanwhile, a vigorous debate from the perspective of journal publication as a business, including electronic journals, is now underway regarding the proper form for journal publication. In particular, the appearance of open-access activities has begun to have a major impact on the publishing model, which formerly focused on subscriptions by libraries.

This article, therefore, examines the classic yet new topic of trends in electronic journals and the ways in which the publishing industry is being shaken by open-access activities. It describes electronic journal services and their surrounding environment in 2007 and offers proposals for improving the management of Japanese electronic journals.

The research information gathering environment, including electronic journals, is constantly undergoing innovation. In order to clarify this report's arguments and provide a fixed point of reference in this constantly changing environment, the report describes the general process and services as of January 2007 of electronic scientific, technical, and medical journals (STM journals) from article submission to Internet publication. It adds an explanation and examination based on this description.

2 The role of electronic journals in research activities

2-1 Electronic journal services today

Many international STM journals now have article-submission functions on their websites. With the introduction of electronic submission, submissions by mail have fallen dramatically[2]. For articles submitted online, fellow researchers (editorial board members and reviewers) still carry out conventional review (peer review) and judge suitability for publication, but do so using electronic files. Articles accepted for publication proceed to publication processing. Some biology journals publish reviewed articles on the Internet as received. Until around the year 2000, the development of electronic submission and review systems itself was an issue, but today system specifications and development costs are stable, and already businesses that provide general-use systems and take advantage of economies of scale are in development. In concrete terms, these include an Editorial Manager service[3], which handles electronic review for over 1,800 journals, mainly those of Elsevier, which is the world's largest science, technology, and academic publisher, and ScholarOne[4], which provides electronic submission and review services for over 1,000 journals.

One advantage of electronic journal services is that there is no need for binding, and so individual articles can be released on the Internet as soon as they have been proofread. Many journals carry out such advanced online release. The creation of portals providing economies of scale for electronic journal release services has advanced even faster than the above-mentioned electronic submission and review systems. Led by ScienceDirect[5], Elsevier's vast electronic journal release platform, a number of publishers provide electronic journal services for up to several hundred titles.

Furthermore, a number of e-only experiments are underway[6]. These include halting publication of paper journals and issuing a number of journals only in electronic form and creating new journals only as electronic ones. Among journals considered to be the leaders in their respective fields in Europe and the United States of America, however, few have completely halted publication of the paper form.

Issuance of an electronic journal requires appropriate subscription management. For paper journals, this is carried out by sending copies after payment of subscription fees. In the case of electronic journals, however, usually only access rights are provided. Generally, library subscriptions are managed by IP addresses, and individual subscriptions are managed by IDs and passwords. Furthermore, billing on a per-article basis is possible with electronic journals, and these days, many journals have single-article sales services. This enables readers to purchase only the articles they need even if they are not subscribers. The service is an effective method particularly in cases where readers obtain their desired information from the results of a database search.

So that more researchers will quickly become aware of newly published articles, many journals have content alert services that send tables of contents to readers, who have registered their e-mail addresses. In most cases, the tables of contents include links to the articles so readers can directly view the ones that interest them.

In addition, new-arrival notification services utilizing the RSS 1.0 and 2.0[7] formats have begun spreading. Reportedly, growth in the number of people registered for content alerts has leveled off, while RSS usage is increasing[8].

Electronic journal services can use access counts to determine relatively accurately which journals and articles are read most often. In order to compare journals from different publishers, however, rules for access counting are necessary. This led to the creation of the COUNTER project by libraries and publishers in England[9]. Currently, major publishers provide access statistics services that follow the rules (Code of Practice) set by the project mainly to libraries.

Digitization back to the first issue is necessary in order to fully utilize the convenience of an electronic journal, and many leading journals have already completed the digitization. In other words, the need to visit a library in order to find past articles is already diminishing steadily. In particular, the volume of interlibrary loans for journals in English, for which digitization is advanced, is declining[10,11].

This is the situation surrounding standard electronic journal services as of 2007.

2-2 Comprehensive electronic journal services: collaboration among electronic journals and with databases and portal sites

Below, this article describes services related to electronic journals as well as electronic journal services from a more comprehensive standpoint.

(1) Article identifiers for the age of electronic journals: OpenURL, DOI, and link resolvers

First, this article will discuss the article identifiers that make collaborative services utilizing electronic journals possible. Since the age of paper journals, there have been identifiers, such as ISSN, which specifically identify each publication. These are in widespread use for periodical management. However, although there were identifiers, such as PII and SICI[12], to specify individual articles, their use was not so widespread. With the shift to electronic journals, the existence of each article's URL has become important. Organizations that have extracted secondary information since the paper-journal age, such as PubMed[13] in the medical field and Chemical Abstracts (ChemPort)[14] in chemistry, have developed identifiers that follow proprietary rules. These were part of the organizations' particular services, but generalization and standardization of such identifiers have advanced. OpenURL has spread with the goal of broadly identifying articles through the use of fixed and relatively easy-to-understand URLs[15]. Meanwhile, the Publishers International Linking Association, Inc. (PILA), which is controlled by major publishers, and the CrossRef project were established[16] in order to insert links in publications that cite one another. Journals belonging to this organization receive Document Object Identifiers (DOIs). Management of the DOIs and articles' URL data (they have link resolvers) enable links to each article. In other words, URLs can be constructed and accessed for each article in journals with these identifiers, and individual links can be inserted. As will be discussed below, this has made collaboration with databases and portals more efficient.

(2) Links to various kinds of databases

Before the introduction of the kinds of electronic journal services existing today, there were so-called secondary information services, such as the above-mentioned PubMed and Chemical Abstracts. Their information was already in databases before the spread of the Internet, but digitization on a per-article basis and hyperlinking has enabled this to move from secondary information databases to articles that are primary information. This coordination between secondary and primary information has had a significant impact on researchers' information gathering. Instead of looking through thick books of abstracts and then finding individual journals, scholars are now able to use their PCs to conduct searches using keywords, allowing them to easily view relevant articles from the results they obtain. This is a radical change in the research information gathering environment. Because articles may not be found in searches of specialty-field databases, many journals actively seek to establish links with such specialized databases. On the other hand, a major change brought about by digitization and collaboration with databases is that, like the long tail phenomenon found with booksellers, such as Amazon.com, search results find journals that were not widely read in paper form alongside major journals, leading to greater readership for their articles. In particular, this has increased opportunities for Japan's English-language journals to receive exposure overseas[17]. (See Figure 1.)

The same trend has been seen with citation databases. Thomson Corporation's (formerly ISI) Web of Science (WOS)[18] was one of the earliest databases to link a cited-works database with primary information. Elsevier released its similar SCOPUS cited-works database in 2004[19]. From its inception, SCOPUS has collaborated with Elsevier's ScienceDirect and other primary information sources.

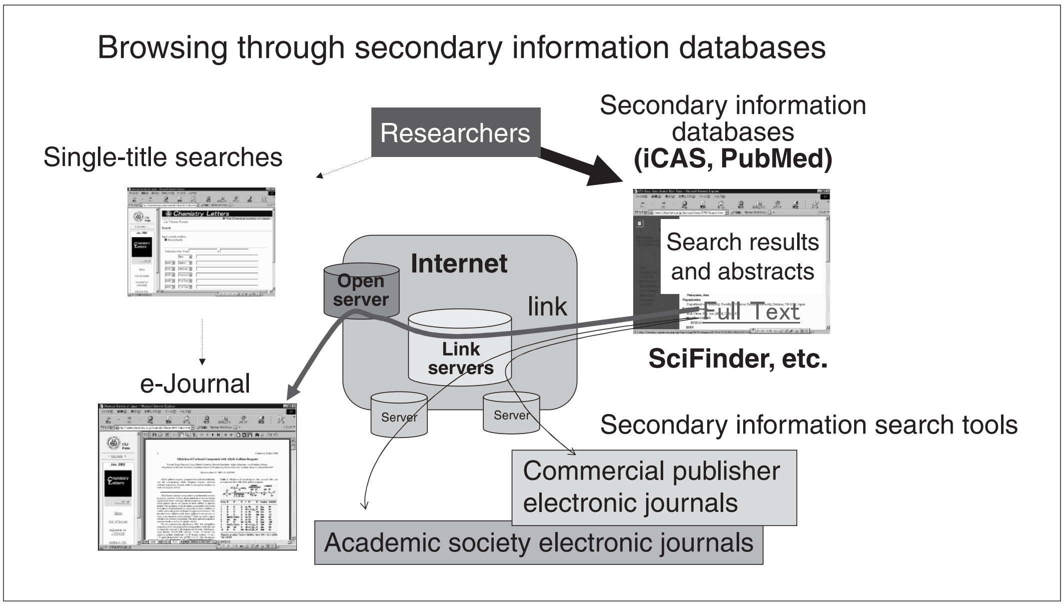

Figure 1 : The importance of searches from secondary information databases

Revised from Journal of Information Science and Technology Association, Vol. 53, No. 9, pp. 441-447 (2003)[17]

(3) Traffic from search portals

In addition, general search portal sites began adding scientific, technical, and scholarly information to their search services a few years ago. Google Scholar has already launched a scientific, technical, and scholarly information portal site, using its own search engine to provide citation information services[20]. Microsoft's Windows Live Academic has been established to compete with Google[21]. Purchase of PPV services and other concrete uses of Google Scholar search results are beginning to be reported[8]. The direction of these search portal trends, including status of utilization, bears watching. Of particular interest is how researchers in the pharmaceutical and chemistry fields, which have secondary information databases characterized by a high degree of specialty and reliability, will handle these more generalized portal sites.

(4) Links to works cited and citing works

As mentioned in 2-2 (1), through the CrossRef project that creates mutual links among cited works, major publishers have become able to shift efficiently from cited works to articles in other journals. In addition, not only have links to cited works been achieved, but links to citing articles can be inserted in cited works. Once an article is released, links can be added to the article if other works cite it (forward linking). Because the number of such forward links is generally held to be equivalent to the number of articles citing, if all journals have this function, in theory it would allow the level of usage to be ascertained without reliance on citation databases.

(5) The appearance of digital resource management tools

Finally, the libraries of various institutions are using integrated management systems (digital resource management tools) to manage electronic journals, databases, and electronic books (eBooks, which this article does not discuss). Active steps are being taken to realize efficient navigation functions that will facilitate the finding of desired materials, allow cross-material searches to be carried out, and provide other efficient end-user services[22].

(6) Diverse access methods brought about by the shift to electronic journals

In the above forms, local services for electronic journals, from primary information creation to article release, are becoming quite fixed while adhering to the old peer review system. The next stage will be an examination of how journals and individual articles can be linked to databases and portal sites and managed.

Furthermore, as depicted in Figure 2, the information search environment for researchers can be divided into four routes. These are: A)

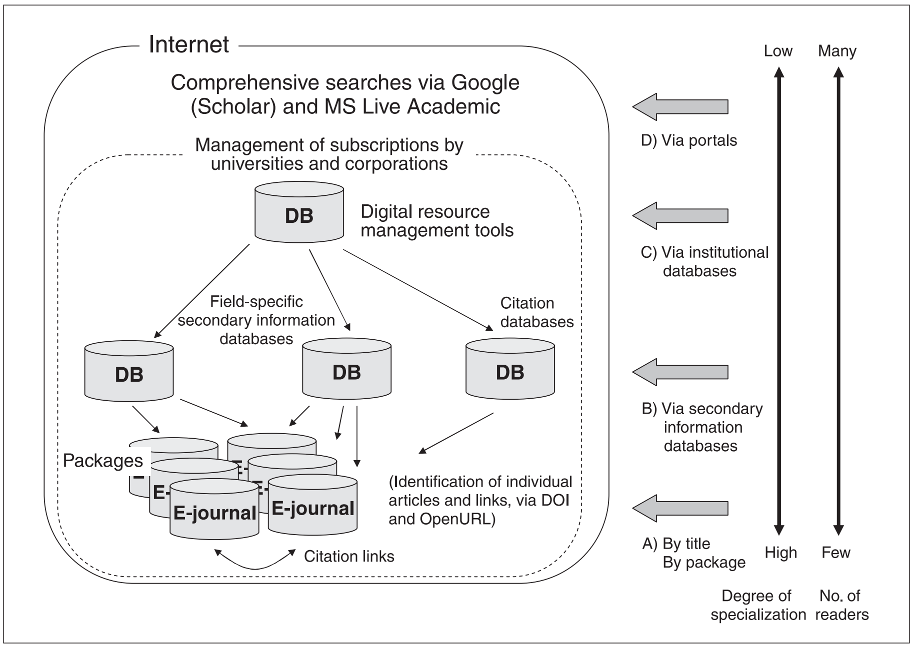

Figure 2 : Conceptual diagram of access routes to electronic journals

Prepared by the STFC

directly accessing electronic journals by title or package; B) database searches of highly specialized secondary information and citation information managed primarily by libraries; C) integrated searches of the databases of digital asset management tools, which are also primarily library-managed; and D) searches via free portal sites. This provision of access through multiple routes and to a broad range of users including the general public through Google and so on is impossible with paper journals. With the digitization of archives now almost complete, the age when paper copies are available at libraries is now ending. At the same time, the publishing bodies of each journal cannot ignore the existence of these routes and must ensure that the contents of their publications are constantly available through multiple routes.

3 Electronic journals as a business: conditions outside Japan

3-1 The unchanging commercialization and oligopoly of academic publishing

Even before the shift to electronic journals began, the academic publishing business was based on a subscriber-fee model. In other words, the business developed with subscription fees, paid mainly by libraries, as its primary income source. Some journals also collect publication and reprint fees from authors, but subscriptions are the primary source of income for all journals.

Commercialization and oligopolization have been advancing in academic publishing since the era of paper journals. Steep price increase meant that since libraries had to paid higher subscription fees, they were able to subscribe to fewer titles, leading to the “serial crisis”[23]. The economies of scale characteristic of the shift to electronic journals are accelerating this process of oligopolization. For example, Elsevier's ScienceDirect covers more than 1,700 titles, and journals are sold not by the title but as an entire electronic journal platform or package (the “Big Deal”)[24].

However, library budgets in most countries are falling. Even where budgets are increasing, they are insufficient for libraries to maintain the number of titles or to subscribe to new ones[25], so libraries have formed consortia to resist this kind of Big Deal, negotiating the lowest prices they can on package purchases and working to keep as many titles as possible available for viewing in their institutions. A recent report claims that due to the Big Deal, the number of titles per library has increased, as has usage[26]. Utility is being debated in the closed world of the Big Deal and consortia.

Meanwhile, small and medium-sized publishers unable to participate in such schemes are finding that their businesses are faced with a serious handicap. Relatively large academic societies in Europe and the USA have created packages with several top journals in their fields, developing their businesses in the same way commercial publishers do with their journals. Furthermore, some small and medium-sized publishers are attempting to join forces to package their electronic journals[27]. There are, however, currently no other ways for publishers with only a few titles or a single title to develop their electronic journal businesses.

3-2 Is barrier-free access possible? The open access movement

Under the above-described conditions, concern is rising regarding excessive commercialization in the distribution of scientific, technical, and scholarly information, which should be broadly disseminated on a not-for-profit basis. Numerous initiatives opposing commercial journals have been introduced. These initiatives are led mainly by libraries. The Association of Research Libraries (ARL) began developing the SPARC movement[28] even before the shift to electronic journals began.

Furthermore, there has been an upsurge in “open access” activities[29]. There are various definitions of open-access activities, but here, they are defined as activities designed to provide access to article data (including full texts) to anyone, free of charge. The basic idea behind these activities is that because the majority of research is tax-supported, the results should be widely and generally available. In the medical field in particular, there are barriers (the need for paid subscriptions) to taxpayer access to the latest medical information. Open-access activities have developed out of an awareness of this problem.

Furthermore, characteristics peculiar to electronic journals are driving these activities. If the information is placed on an Internet server without authentication, anyone can access article data. A major advantage of electronic journals over paper is the simplicity and economy of their distribution, and it is driving these activities.

Currently, there are many methods that facilitate open access, and innovation is unceasing. Below are some examples.

(1) Preprint servers and self-archiving by field: from the researchers' perspective

First, even prior to the advent of the open access movement, physics and a few other fields have had a culture of placing manuscripts on preprint servers before submitting them for publication. This came about in response to the desire of researchers to expose their work to colleagues as early as possible. arXive is a typical example[30].

Furthermore, Stevan Harnad and others have long been an advocate of the self-archive movement, by which authors make manuscripts available free of charge on their own servers[31]. However, since self-archiving provides little benefit to the authors themselves, this practice has not become widespread.

(2) Recommendations by foundations: the activities of research funding organizations

Research funding organizations have also reacted to the open access movement. In 2003, the USA’s National Institutes of Health (NIH), the UK’s Wellcome Trust, and leading members of the above-mentioned SPARC joined to issue the Bethesda Statement to promote open-access activities. In response, in 2004, NIH began requesting that authors of papers related to NIH-supported research place them on PubMed Central, where they can be accessed without charge[32]. This request was made more strongly in 2005. The UK's Wellcome Trust makes a similar recommendation and provides mirror servers for PubMed Central.

NIH’s series of actions related to this recommendation has had a significant impact on academic societies, commercial publishers, and libraries. Although it has engendered debate on a number of issues, it has also been a driving force behind open-access activities undertaken from various perspectives, as will be discussed below.

(3) Institutional repositories: new library activities

In order to resist the above-described commercialization of journal publishing

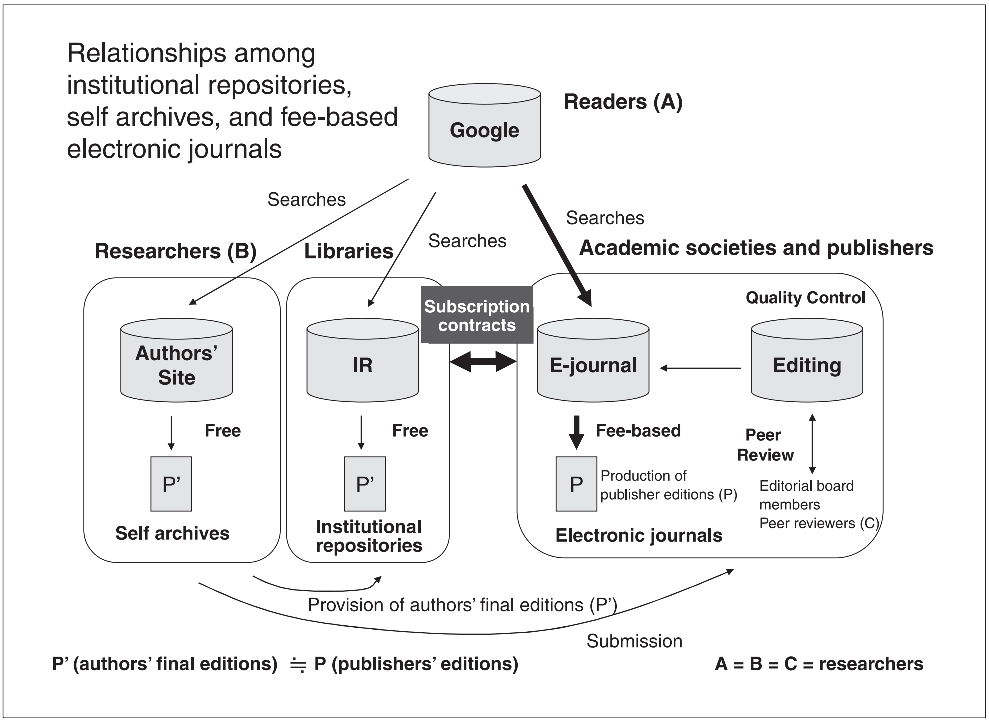

Figure 3 : Correlation diagram of those involved in the open access movement

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and sharp price rises, libraries are actively recommending self-archiving to researchers. Furthermore, they are preparing open information servers (institutional repositories[33]) at the institutions to which they belong. Along with bulletins, doctoral dissertations, and other information belonging to universities, they insert articles by affiliated authors in place of the authors. Depending on approval conditions (including insertion in institutional repositories) granted by publishers, the inserted manuscripts are either the authors' final editions after review has been completed or the final publishers' editions prepared for release. These files are usually in PDF format.

Although such institutional repositories, which can be seen as an extension of self-archiving, do not yet have extensive collections of article data, most of them are searchable with Google. This means that once all research institutions have these repositories, the majority of scientific, technical, and scholarly articles will be searchable and viewable free of charge. When this free distribution channel is fully realized, it will have a significant impact on the distribution of scientific, technical, and scholarly information. Libraries are also working towards this end. For publishers, however, this is a matter of life and death, so it is a subject of great debate[34]. (See Figiure 3.)

(4) Open access journals: publishers' response

Publishers have no objection to the concept of open access itself. Publishing, however, costs money[35], and so, the response of commercial publishers and others who endeavor to make profits from publishing has been negative. Furthermore, some not-for-profit academic societies in Europe and the USA also earn money from publishing and apply it to their educational and other activities[36]; so, while they are not vehemently opposed to a quick shift to open access, most are adopting a cautious attitude.

Partly as a response to the activities of libraries and government institutions, however, some are seeking alternatives to the conventional subscription-fee model. Initiatives underway as of January 2007 are fully open access through author-pays models, optional author fees, and partially open access through adjustment of release periods.

Examples of early adopters of the author-pays model are BioMed Central[37] in life sciences and the New Journal of Physics[38], a joint production of the UK's Institute of Physics Publishing and German Physical Society (Deutsche Physikalische Gesellschaft). The most representative current examples actively applying this model are the scientific journals of the Public Library of Science (PLoS)[39]. For example, PLoS Biology requires a publication fee of US$2,500 from authors to pay for operations, whereas access to the electronic journal is completely free. However, the initial publication fee, when the journal started in 2003, was US$1,500, and this rise in only its third year of operation raises the question of whether the author-pays model is viable.

With optional author fees, payment of an optional fee on a per-article basis makes articles immediately available to readers free of charge. For example, with Springer's Open Choice[40], an author payment of US $3,000 enables free access to that article. Springer is actively urging research funding organizations to use the option. In this way, the idea of research funding organizations paying the fees in place of authors has begun to gain some traction. With this mode, if all authors choose to pay and if there is an option that reduces subscription fees to zero, a shift to the fully open access journals discussed above is theoretically possible. Existing journals have begun to act with alacrity to make this option available and are presently observing the results.

Finally, open access through adjustment of release periods is the provision of free access after a specified period has elapsed, and some publishers began doing this prior to the start of the open access movement. This mode is characterized by the fact that the subscriber-fee model can be maintained, and on a per-article basis, some will require payment, and some will be free, depending on the timing. The preceding two methods are therefore usually at the center of discussions on the introduction of open access.

3-3 What open-access activities have brought about: the appropriate way of distributing scientific, technical, and scholarly information in the age of electronic journals

This article has described some initiatives aimed at bringing about open access. The question that constantly dominates this discussion is, “Who should pay for the cost of distributing scientific, technical, and scholarly information?” Consequently, research funding organizations, libraries, and publishers, including academic societies, are now involved in numerous experiments aimed at finding a practical resolution to this question from their own perspectives. Noteworthy trends among these experiments are libraries beginning to take on information-transmission functions and research funding organizations beginning to contribute to policies on research publication and distribution. In other words, rather than simply addressing cost issues, they have begun to deal with the question “Who is responsible for the distribution of scientific, technical, and scholarly information?” The possibility that those involved may have to change has arisen[41,42].

Furthermore, under these circumstances, attention is being given to what researchers, who have the greatest essential interest in the matter, think of open access and how they will act. With the exception of the UK's Royal Society[43], however, researchers in general show little interest. This is because the desire of researchers is to have their research well regarded by their peers and to receive the career benefits that accompany this. Their first priority is publication in so-called high impact journals, and they have little interest in whether those journals are not-for-profit or open access. With so much research funding coming from taxes, however, they may not be able to remain indifferent given the increasing societal demand for accountability in the use of tax monies.

Thus, although there is now a general consensus on the basic services to be provided by electronic journals, from a business perspective the situation is chaotic. In particular, since the move to electronic journals raises the possibility that not only will business forms change but that responsibility for information distribution activities will shift, it is necessary to carefully observe this reorganization.

4 The impact of electronic journals on Japanese academic societies

4-1 The status of Japan's shift to electronic journals

(1) The environment supporting electronic journals in Japan

Figure 4 depicts those involved in Japan's distribution of scientific, technical, and scholarly information. Within the framework of the Ministry of Education, Culture, Sports, Science and Technology, the Japan Science and Technology Agency (JST) and the Japan Society for the Promotion of Science (JSPS) provide research funding. Both support Japanese academic publishing through J-STAGE and Grants in Aid for Scientific Research for Publication of Scientific Research Results. There are researchers affiliated with both the academic societies that publish journals and the libraries that subscribe to them. Furthermore, the National Institute of Informatics (NII) supports academic societies through SPARC/JAPAN[44], which provides steady support for library activities. In addition, the National Diet Library is involved with the permanent storage of scientific, technical, and scholarly information. Surrounding this are the academic and commercial publishers of Europe and the USA with their strong brand power, and many Japanese researchers submit articles to overseas journals. Against this background, this article will discuss several Japanese initiatives (by category) in the electronic journal business and its support systems.

(2) Completely independent type: a case in physics

The Institute of Pure and Applied Physics (IPAP) is an organization formed by the publishing arms of the Physical Society of Japan and the Japan Society of Applied Physics. Its major journals are the Journal of the Physical Society of Japan and the Japanese Journal of Applied Physics. The organization developed an electronic submission and review system and an electronic journal publishing platform on its own. It offers paid subscriptions to its electronic journals and includes various types of links, such as CrossRef and Google.

(3) Domestic collaborative type: cases of independent administrative agencies

Currently, Japan's approximately 130 English-language journals use the Japan Science and Technology Agency's (JST) J-STAGE[45] to open their electronic journals. Some academic

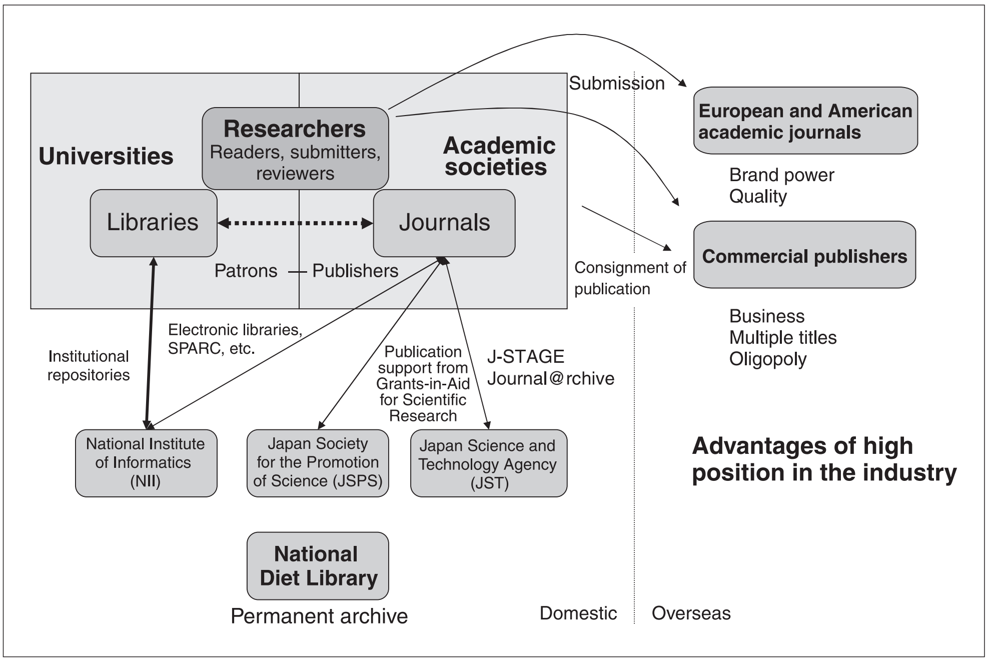

Figure 4 : Correlation diagram of those involved in distribution of scientific, technical, and scholarly information

Prepared by the STFC

societies also utilize electronic article submission and review. In addition to collaborating with PubMed, ChemPort, and CrossRef, J-STAGE also provides access statistics services equivalent to COUNTER standards. The Chemical Society of Japan's Chemistry Letters effectively utilizes J-STAGE for prompt and efficient continuous realization of standard electronic journal services. The average time it takes from receipt of an article to publication on the Internet is among the shortest in the world for general chemistry journals[42].

Furthermore, the National Institute of Informatics' (NII) NII-ELS publishes scanned files of paper journals as well as book and periodical data and makes them available for free or for a fee, depending on the policy of the publishing academic societies[46].

(4) Overseas collaborative type: a case in electronic information and communications

After review, using its own electronic submission and review system, of articles for a target audience outside Japan, the Institute of Electronics, Information and Communication Engineers (IEICE) goes through the Oxford University Press to use the Highwire[47] electronic journal platform to publish an electronic journal. Articles with a target audience within Japan are published on the IEICE's own servers. For overseas readers, the IEICE utilizes a foreign, large-scale, not-for-profit platform to provide standard services and carries out public relations in other countries.

(5) SPARC/JAPAN and other activities

Through the above-described SPARC/JAPAN project, the National Institute of Informatics (NII) has begun a Japanese information distribution infrastructure improvement project. It is now in the fourth year of its second stage. One of the packages the project has selected is UniBio Press, which bundles seven life sciences academic society journals into a package of electronic journals. Beginning in 2007, the package has been available on the BioOne platform. Furthermore, in addition to support for individual academic societies and journals, the project encourages training activities and works to develop human resources that can take charge of journals.

The Japan Society of Mechanical Engineers (JSME) halted publication of its English-language journals and has progressively set about creating new electronic journals by specialty. These journals are electronic only. JSME sees its mission as publication of electronic journals, supporting this endeavor through member fees and submission (publication) fees.

4-2 The harsh Japanese electronic journal business

As described above, the shift of Japan's scientific, technical, and medical journals to electronic form is already well advanced. Although some positive results have been obtained, as a business, electronic journals are in a vulnerable position. The reasons are examined below.

(1) The impact of Grants in Aid for Scientific Research

Including preceding programs, funding for publication of paper journals through Grants in Aid for Scientific Research for Publication of Scientific Research Results has been carried out since 1955. It is important support for Japanese publishing in this field[48] as well as for English-language journals facing basic structural handicaps, such as publishing in English in a Japanese-speaking country. On the other hand, because funding is given annually and the system does not allow profits since it only covers deficits, there is concern that this approach acts as a disincentive to improving quality. Moreover, although some improvements are being made, because funding standards have required publication in a paper journal, it is difficult to obtain funds to publish in an electronic journal.

(2) The problem of integrating academic societies

There are many academic societies in Japan, and the need for integration and reform has been widely discussed[49,50], however, the number of Japanese academic societies has not decreased. For example, looking at the register of academic societies published by the Japan

Science Support Foundation, in 2001-2003 there were 1,620 societies, while in 2004-2006 the number actually increased to 1,730. This crowd of academic societies lowers the efficiency of their work, including electronic journals, widening the gap with Europe and the USA.

(3) Journal quality control problems and publisher functions

The proliferation of academic societies means that publishing organizations remain small and scattered, without the oversight of the publishing professionals found in Europe and the USA. In most cases, personnel in charge also have other work, making it extremely difficult to improve the quality of electronic journal services or the information published. In addition, public relations activities are essential for raising the profile of journals and getting authors to submit high-quality manuscripts[51], and electronic journals require legal work related to licensing, copyrights, and so on. Very few personnel in academic societies have any expertise in such areas. This is an enormous problem.

5 Proposals for the improvement of Japanese electronic journals and information distribution

As described above, Japanese electronic journal activities face the same problems as Japan’s academic societies themselves. Poor in terms of both financial and human resources, only scant improvements can be brought about by the efforts of individual societies. Based on conditions overseas and in Japan, and in consideration of the reports of working groups under the Council for Science and Technology[52,53], this article will examine proposals for improvements to strengthen Japanese electronic journals.

5-1 Confirmation of the necessity of transmitting information from Japan

(1) The risk of leaving evaluation up to foreign countries

First, a reaffirmation of the necessity of transmitting information originating from Japan is required. Science is borderless, but scientists have countries. This is not merely a concept. Although by nature this does not appear in statistical data, delayed review and unfair handling of articles submitted to overseas journals have been pointed out[54]. Furthermore, even with so-called international journals, a high percentage of editorial board members are university professors who are from the country of publication. In other words, it is necessary once again to confirm the high risk that the latest knowledge and data generated by researchers will be sent to overseas evaluating bodies before they are released to the world. This is not, however, solely a Japanese problem.

(2) Lost business opportunities through reliance on foreign countries to transmit information

Publishing English-language journals internationally inevitably means that the publishing industry will acquire foreign currency. In fact, European and American academic societies and commercial publishers receive high earnings from around the world. In addition, commercial publishers also pass on those profits to their shareholders. The world market for the distribution of scientific, technical, and scholarly information is said to be worth about ¥5 trillion[54]. It is necessary to recognize that Japan's information transmission industry can become a part of international economic activity.

(3) The viewpoint of fostering the information distribution industry

Compared with journals in fields such as literature and economics, the world of electronic scientific, technical, and medical journals is one of rapid permeation. As a result, it is at the forefront of scientific communication on the Internet. In other words, activities to seize the initiative in that world are desirable for the information distribution industry as a whole.

(4) Reaffirmation of the significance of the business of transmitting primary information

In the end, the comprehensive electronic journal services expounded upon in 2-2 above are guides to achieving articles that are of primary information. They are all founded upon the existence of primary information[42]. Japan must reaffirm the significance of producing and transmitting high-quality primary information.

5-2 Reexamination of methods of research evaluation

Above all, researchers are interested in being published in the leading journals in their fields and receiving the respect of the scientific community. The reality, however, is that the leading journals in almost all fields are published in Europe and the USA.

This ambition of researchers must be accepted. It is unrealistic to expect to change their mindset in order to hold back the relative flow of research results to foreign countries. With this in mind, some measures against the problem are still necessary. For example, limiting the discussion to researchers at universities and other not-for-profit institutions, the results of their research are important assets to them personally, but at the same time, they can be seen as benefits generated by activities paid for by taxes. Based on the idea of recovering these benefits through taxation, it may be good policy to transmit a portion of Japan's research results and connect that portion and amount to appropriate evaluation and research funding allocation. For example—and this is only an example—anything left over after taxes could be used in any way the researcher wished. It would be possible for researchers to build names for themselves through publication in leading overseas journals. Those researchers, whose papers end up generating a high tax take, that is, those who submit many influential articles successfully to overseas journals, could be given commensurate ability to transmit. Although the sudden implementation of this kind of extreme policy might draw vehement opposition from some researchers, the significance of transmitting Japanese scientific, technical, and scholarly information must somehow be reaffirmed by researchers themselves. Effective measures to address the issues discussed in this article cannot be realized unless they are predicated upon renewed awareness by researchers.

5-3 Policies of research funding organizations and publishing support organizations

As discussed above, research funding organizations, such as the NIH and the Wellcome Trust, have a significant influence on the distribution of scientific, technical, and scholarly information. In the same way, the policies of Japanese research funding organizations, such as the Japan Society for the Promotion of Science and the Japan Science and Technology Agency, relating to the distribution of the research information they target for support, have a major impact on the form of Japanese information distribution and related business activities. Future debate will turn in the direction of those policies.

5-4 Reexamination of the proper form of funding for publishing

Even giving the most positive evaluation possible to the significance and results of Grants in Aid for Scientific Research funding for publishing, swift reform or reorganization of the framework for support is necessary, with an eye towards electronic journals in particular. The discussion at the special symposium of the Science Council of Japan has been instructive[55].

In China, the National Natural Science Foundation of China (NSFC) is providing two years of support for 30 Chinese journals, forming editorial boards of people invited from China and abroad, selecting targets for support, and performing post-activity reviews. This kind of example is also instructive[56].

5-5 Improving review quality (improving the quality of academic societies)

In order to promote Japanese information transmission, the quality of the content appearing in journals must be maintained. Improving the quality of reviews is essential in order to do this. Academic societies play the important role of maintaining this review (peer review). The efforts of academic societies to form editorial organizations that meet international standards and always retain a pool of international reviewers are indispensable.

5-6 Human resources development for publishing and the internationalization of publishing organizations

In order to build top-rank journals, academic societies and publishers in Europe and the USA make both economic and human resource investments. Furthermore, trade associations of publishers, such as the Association for Learned and Professional Society Publishers (ALPSP) and STM[57,58], provide venues for various types of training and information exchange, foster publishing personnel, and develop leadership within the industry. In Japan too, academic societies and publishers need to train quickly personnel as professionals in science, technology, and academic publishing and create systems so that those professionals can have international influence.

6 Seeking the integration of electronic journal publishing organizations and a Japanese model of not-for-profit publishing

Based on the above examination of the various situations, this article will present more concrete proposals for a Japanese model of not-for-profit publishing in the age of electronic journals.

6-1 A proposal for integration of publishing organizations

First, in order to create economies of scale in the electronic journal business, various academic societies should integrate their publishing arms, forming an organization that can publish dozens of journals. However, organization of the editorial staff and review policy should basically be left up to each academic society so that the personality and originality of each journal is preserved. Support should be provided so that editors-in-chief can operate for long periods in order to fully develop their leadership potential. Even if, as described above, integration of academic societies does not take place, this relatively loose kind of alliance is realistic. Because the Science Council of Japan has recently begun full-fledged examination of the role of academic societies following their becoming public-benefit corporations[59], it is important to remain in step with that discussion. As for an estimate of the scale of integrated publishing, in the case of scientific, technical, and medical journals receiving the above-mentioned Grants in Aid for Scientific Research for Publication of Scientific Research Results (periodicals)[60], 82 of them received such aid in FY 2006. These are journals of sufficient quality to sell copies overseas. Their annual page count is about 110,000, and the amount of aid they received totaled approximately ¥770 million. This amount is the portion of assistance that went towards publishing and printing, and so publishing on a scale larger than this amount can be expected. According to a report by a research committee of the Matsuo Foundation[50], of the 19 academic society English-language journals surveyed, total business costs per page were calculated at ¥33,000, so a business scale of ¥3.6 billion can be estimated from the above page count. This new publishing organization would provide electronic submission and review services, post-review electronic journal publishing services, collaboration with various databases, subscription management, and public relations activities. In addition, it would also have a journal evaluation function, a survey function for the opening of new markets, and copyright and other legal management functions that have been difficult for individual academic societies to handle. Furthermore, in order to raise Japan's global presence, it would carry out international PR activities targeting authors and readers overseas and forge close links with the publishing industry in Europe and the USA. Actively working to improve, it would seek the next forms for its editing, manufacture, and publicity from these new functions. Positioning these editing and publishing activities as new career paths for postdocs would also be an effective approach.

6-2 Operation of an integrated organization

Looking at the status of the electronic journal business outside Japan as discussed in chapter 3, this kind of publishing organization could be operated in either of two ways.

(1) Commercial operation

First, there is autonomous operation similar to the example of large academic societies in Europe and the USA. Thus, for example, at first, the organization would receive government support for five years, while working towards autonomy, seeking to become the core of Japan's scientific, technical, and scholarly information service industry. Because this type of operation would immediately be in direct competition with publishers in Europe and the USA, risk would be high. With the close relationship between activities and outcomes, however, the publishing organization's staff would have a sense of pride, and if this is fostered over the long term, the result could be a Japanese international commercial publisher.

(2) Public operation

The other operating method would be to become a not-for-profit information transmission entity as part of national policy. In other words, it would follow the principle of open access, electronic journals would be free of charge, and the national government would pay operating expenses including various types of databases, links, and reviews. Having the organization generate a certain portion of the research funded from the national budget is an idea worthy of consideration. At this time, the organization operating J-STAGE is closest in character to this one, but it would be necessary to consider its development into a more comprehensive body that could carry out editing and production, as well as subscription management and public relations. In the event this approach were to be adopted, however, the issues would be how, with the government funding it, to give researchers the incentives to consistently provide quality content and give staff the incentives to provide better service and actively engage in public relations activities.

7 Conclusion

The discussion in this article was based on the premise that the importance of peer review by fellow researchers of articles submitted for publication will not waver in the short or medium term. One must add, however, that if entry into the web 2.0[61] era, particularly interactive evaluation through large numbers of readers after electronic journals are opened, changes the nature of research evaluation[62], then the current review system will at least be influenced. In fact, the above-mentioned PLoS launched an electronic journal called PLoS One in December 2006. It operates not based on meeting high editorial standards, but rather on meeting the minimum standard of containing no scientific mistakes, and is then broadly reviewed by readers on the Internet. The future of this electronic journal, which even the operator acknowledges to be a large experiment, is worth watching[63]. In any event, the provision of primary information via electronic journals and its surrounding environment will continue to change as will the methods employed to support researchers' information gathering and distribution activities. This field will therefore need to be monitored through periodic trend surveys.

Acknowledgments

The author wishes to express his thanks to the many people from the Japan Science and Technology Agency, the National Institute of Informatics, the Japan Society for the Promotion of Science, libraries, printing companies, and academic societies who kindly provided cooperation and advice regarding this article.

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(Original Japanese version: published in February 2007)

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

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

The following are major activities:

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

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

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

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

2. Research into trends in major science and technology fields

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

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

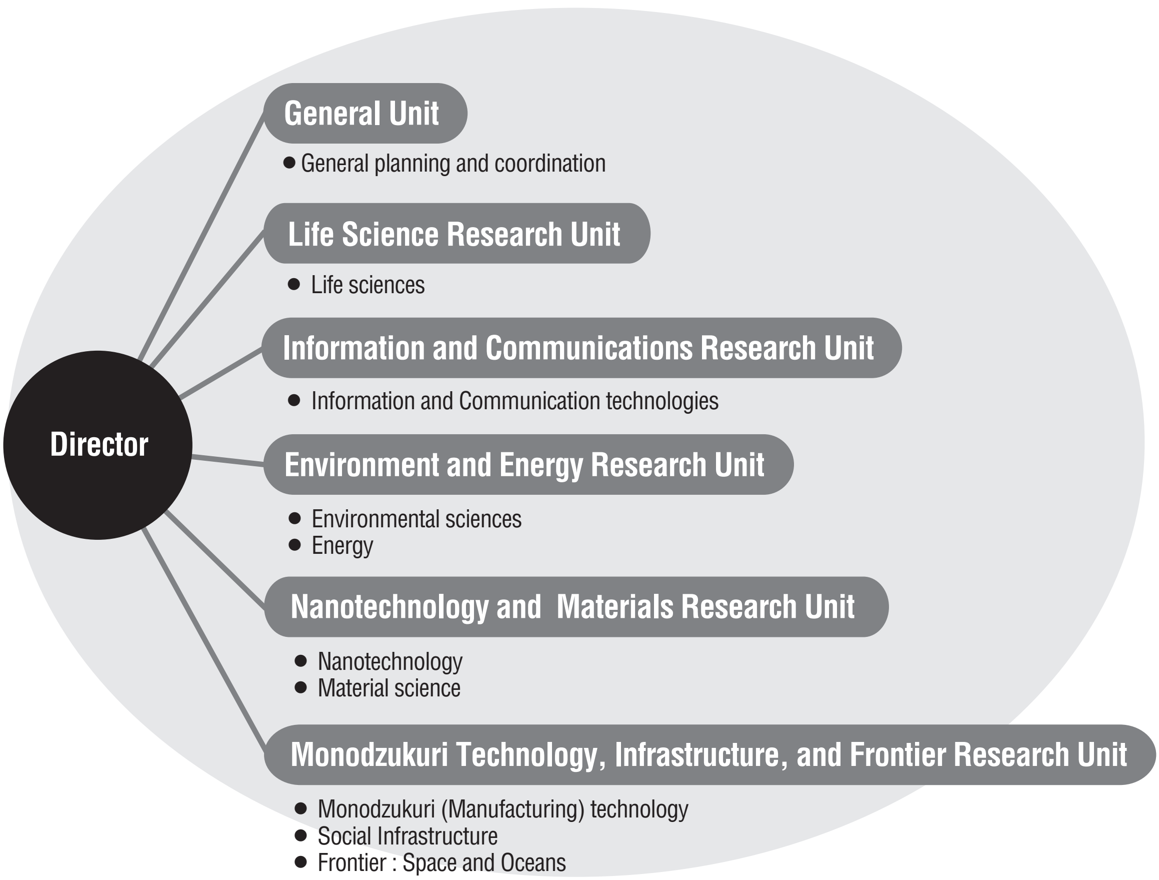
3. S&T foresight and benchmarking

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

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

— The research results are published as NISTEP report.

Organization of the Science and Technology Foresight Center



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

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