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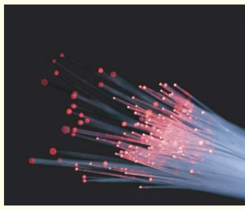
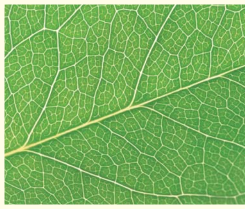
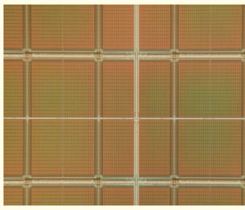



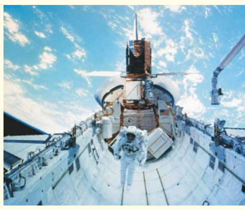

Foreword

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

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

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

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

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

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Executive Summary

Life Sciences

1 Brain Imaging
— Necessity for Reinforcement of Research and Development for Application of Non-Invasive Technology to Diagnosis and Treatment of Mental Disease —

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In recent years, with the increase in the population of the elderly, the diagnosis and treatment of geriatric diseases has become one of important problems in Japan. Particularly, in cases of Alzheimer's disease, the number of patients has increased year after year, and not only treatment of the patients but also heavy burden of nursing on the patient's families has become a large problem in the society. Meanwhile, rapid restructuring of the Japanese society is increasing the number of patients with mental disease such as stress-induced depression, which caused various social problems including a rapid increase in the number of suicides. On the other hand, recent technological developments of brain imaging, measurement of morphological brain structure and neurological activities by non-invasive methods, are rapidly advancing basic brain researches on humans. Now, researches on mental diseases using brain imaging technologies are conducted all over the world, and their research data, including changes in brain blood flow related to dementia and neurotransmitter release associated with depression, are being accumulated. Along with the technological progress, it is necessary to further promote basic and clinical brain researches on humans in Japan, and it will be possible to realize the diagnosis and treatment of neurological diseases, such as dementia and depression, in near future. For promoting these researches, I would like to propose to form a collaborative research organization to act as the core for organizing the data collected separately in the individual researches currently conducted. In the organization, research and technological development will be conducted interdisciplinary among different fields such as biology, medicine and engineering, with the aim of establishing general medicine for diagnosis and treatment of mental diseases in citizens for the whole country.

(Original Japanese version: published in April 2003)

2 Need for Epigenetic-Based Cancer Research
— Cancer Research in the Post-Genome Era

p.18

With the analysis of the human genome complete (actually, 98.8%), the world is now experiencing the advent of a genuine post-genome era. In this context, research focusing on the causal relationship between diseases and the human genome has become internationally widespread. In recent years, it has been reported that histone protein (which binds to genome DNA) or genome DNA in the cells from patients with various types of cancers and with common diseases might be modified by enzymes such as methylase (methylation) or acetylase (acetylation). This type of modification is considered to affect gene transcription and expression, arousing interest among researchers in this field as possible causes of diseases. The modification is a reversible reaction catalyzed by any of the biological enzymes and its rate of occurrence depends on external factors including exposure to chemicals contained in food or in the environment.

Referred to as "epigenetic," this modification is an essential mechanism for normal cells to sustain life, and its abnormality may cause diseases including cancer.

Remarkable advancement has been made in the field of epigenetic-based research since the development of techniques for detecting modified sites in DNA. A search for articles with keywords showed that the number of articles on epigenetics increased seven-fold from 1993 to 2002. This indicates that epigenetic-based research is a rapidly-emerging new field.

Meanwhile, in Europe, the Human Epigenome Consortium was established in 1999. Under the support of the Consortium various epigenetic-based research has been conducted in cooperation with the members of the EU, and the Epigenetic-based Research Project on Cancer Protection is progressing in the U.S.

Thus, following this worldwide movement as mentioned above, the need for systematic epigenetic-based research will also arise in Japan in the near future as part of its post-genome research.

(Original Japanese version: published in May 2003)

3 Trends in Insect Studies in Life Science

p.28

The insect has the largest number of species and individuals in the Animal Kingdom and is the most prosperous organism on the earth. Insects have adapted to every environment on the earth and have obtained properties specific to them through their evolutional process. Most of these properties have not yet been discovered and are biological resources to be developed.

Insect studies in life science have been carried out mainly with silkworms (*Bombyx*) and fruit flies (*Drosophila*). These two insects contributed especially to classic genetics. Since sericulture was a major industry in Japan, forefront research in life science such as genetics, physiology and pathology has been pursued using the silkworm , and, even now, Japan plays a leading role in studies on this insect.

In contrast, European and U.S. researchers have advanced studies on the fruit fly in developmental biology, molecular genetics and molecular biology. The whole genome of the fruit fly has already been sequenced, so the fruit fly, like the mouse, is a useful model organism for analysis of gene functions.

In order to exploit characters of not only model organisms but also various insects, we need to investigate the features peculiar to each insect from its gene functions. For example, the fruit fly does not have diapause, which many insects have.

Meanwhile, the silkworm is thought to be more favorable than the fruit fly in applying insect properties to industry, chiefly because it produces and secretes a large amount of uniform silk proteins outside its body.

Life science of insects is about to enter the post-genome era. Whole genome sequencing of the silkworm, which is far distant from the fruit fly and the anopheles on the phylogenetic tree, will help deepen our understanding of insects in the realm of life science. Particularly, it is meaningful to promote the silkworm's whole genome sequencing project in Japan, where researchers have pursued various biological studies on this insect.

Furthermore, on such research basis, it is also crucial as a field of life science to enhance analysis of functions specific to insects, such as research on growth control and hormones, the defense mechanism and symbiotic microorganisms of insects.

(Original Japanese version: published in June 2003)

Information and Communication Technologies

4 Trends in RFID Technology

p.36

As a variety of electronic devices are being networked, it is becoming more realistic that, as a step toward the next phase, physical objects in the real world will also be networked through small IC chips embedded into individual objects for identification, thanks to the advancement in LSI and network technology. On the other hand, social demand for completely tracking the movement of every object has been on a sharp rise these years for such purposes as improved efficiency in distribution supply chain management and antiterrorism or other security protection measures.

In these background, radio frequency identification (RFID), a concept for allowing built-in IC chips in objects to automatically communicate with a network through electronic devices via radio frequency, has recently been attracting an attention as a key technology to link “physical objects” with networks. In the future, this technology is highly likely to have a significant impact on the realization of a ubiquitous network society. In the application to distribution, it would be best if RFID were available seamlessly worldwide, but its standards have yet to be unified, with several organizations actively working toward the standardization of specifications. With respect to commercialization, manufacturers and distributors are preceding other businesses, aiming at more efficient supply chain management and prevention of shrinkage or shortage through the use of RFID tags as a replacement to existing bar codes.

RFID, since it covers every object, may change social infrastructures and people’s living environments in the future. To allow this technology to widely spread into society, studying business models in industries is not enough. Government and society should thoroughly discuss how to operate RFID systems, with due attention to security and privacy aspects.

(Original Japanese version: published in May 2003)

Energy

5 Creation of Power Supply Systems Incorporating Distributed Power Sources

— A Quest to Construct Systems Meeting Regional Demands in Japan —

p.47

Japan’s energy supply structure is becoming increasingly diversified with the liberalization of the domestic electricity market, which is encouraging new comers and distributed power sources to substitute for part of the existing large-scale power supply systems. The framework of the whole society should thus be created in consideration of this trend, which is expected to continue into the future.

Various R&D efforts are underway in Japan to solve the problems related to the power quality when distributed power sources introduced on a large-scale basis; the basic idea is to consider multiple distributed power sources and power storage facilities as a single system. The future challenge lies in effectively incorporating such system into the national power supply system.

Energy-related issues including energy demand, wind conditions and the amount of biomass resources vary from region to region in Japan. While power supply systems incorporating distributed power sources will be designed for specific regions or areas, it has yet to be determined how additional costs associated with these system will be shared among the parties concerned.

For these reasons, the construction of power supply systems incorporating distributed power sources inevitably involves region-specific approaches, and the cooperation of municipalities is essential to materializing these systems. As distributed power sources are usually set up near the market to which the power is supplied, municipalities are expected to play a leading role in sponsoring debates between energy suppliers and local residents in each region, shedding light on issues and needs unique to each region, and keeping track of the characteristics of the energy resources available in each region - which together will contribute to constructing power supply systems incorporating distributed power sources (through concerted efforts of the municipalities and local residents concerned).

(Original Japanese version: published in April 2003)

6 R & D Trend in Innovative High-Temperature Gas-Cooled Reactors (HTGRs)

p.56

In recent years, Japan and other countries have had a rapidly increasing interest in the safety of engineering systems, or in hydrogen energy systems. Under these circumstances, much attention has been concentrated internationally on high-temperature gas-cooled reactors (HTGRs) as the new reactors that may be introduced in the short- or medium-term or as 4th-generation nuclear energy systems that are to be commercialized by 2030. The reasons are; (i) that HTGRs have high inherent safety, (ii) that their nuclear heat may be used in applications including the production of hydrogen, and (iii) that several promising designs have been proposed for small- and medium-sized modular reactors that are flexibly adaptable to the changing environment of the energy markets.

In Japan, the Japan Atomic Energy Research Institute (JAERI) has conducted researches on the utilization of nuclear heat by using a High-Temperature Engineering Test Reactor (HTTR) since the 1990s, and these researches have been ranked world-class. Many countries are involved in the full-scale research and development projects of HTGRs, considering them as the most promising options for next-generation reactors. Under these circumstances, it is important for Japan to implement the R & D projects focusing on the various potentialities of HTGR. Furthermore, it is necessary for the public and private sectors in our country to undertake examinations on the construction of reactors including an alternative prototype reactor to HTTR as well as a small and high-efficient power generation test reactor.

Especially, the mass production of hydrogen free of CO_2 by using the HTGR for a heat source may probably provide more applications to atomic energy, used only for power generation, and bring about a great change in the role of HTGRs in overall energy systems. In its budget requests for the 2004 fiscal year, the US Department of Energy (DOE) proposed a new Nuclear Hydrogen Project as a part of its Hydrogen Fuel Initiative. In Japan as well, it is desirable to launch into an R&D project for the production of hydrogen by using a reactor such as a HTGR.

(Original Japanese version: published in May 2003)

Manufacturing Technology

7 Role of Universities in the Research on Silicon Semiconductor Devices

p.68

The research on silicon semiconductor devices, which has already entered the area of nanometer order, deals with the finest area among the crowd of nanotechnologies. Information-oriented society will not allow the development of semiconductor devices to come to a standstill and the present high growth rate of the semiconductor industry is expected to continue worldwide. At one time, from the latter half of the 1980s to the early part of the 1990s, Japan was a leader of this world. The research in this field drove the development of technologies in many other domestic industries. However, even in those days, the contribution of universities was very little in Japan and the situation has still not changed. All existing projects and consortiums are still undertaken mainly by private companies, and there is no project that is actually promoted by universities. Such an imbalanced phenomenon can be observed only in Japan. In contrast, universities in the other countries have been significantly involved. Presently, the Japanese industry is in a recession labyrinth and this seems to be a good opportunity for universities to move in. This report requests for reconsideration of the role of the universities in Japan, based on technology foresight after 10 years in this area.

(Original Japanese version: published in April 2003)

Science and Technology Policy

8 U.S. Science and Technology Policy Trends
— Report on the 2003 AAAS Colloquium on Science and Technology Policy —

p.84

The deficit increase caused by the war with Iraq and support for its reconstruction is leading to pressure to control domestic spending. The government research and development budget for fiscal 2004 will likely be a zero sum game, with increases for R&D related to defense and homeland security, and decreases for non-defense research.

The government is vigorously pushing R&D for hot-button issues such as homeland security and SARS, but there is still room for improvement. It is important that industry, government, and academia work together.

Visa processing is being delayed by enhanced homeland security. This is having a profound effect on the scientific and higher education communities. To maintain and enhance its R&D competitiveness, the U.S. must work quickly to solve the problem. The concrete measures described by Director Marburger are a major step in the right direction.

(Original Japanese version: published in April 2003)

9 Futur
— German Demand Side Science and Technology Policy Formation —

p.88

Futur is a project operated by Germany's Federal Ministry of Education and Research. It attempted to form research development policies based on future social demand. It features demand orientation, future orientation, dialog between experts and citizens, diverse participation and an interdisciplinary approach.

The project began in June 2001 after about six months of preparations. A consortium of five organizations headed its implementation, with Section Z22 of the Federal Ministry of Education and Research managing its progress. A total of 1,462 participated.

The project consisted of topic formation followed by a topic narrowing process.

The topic formation process began with eight workshops at which approximately 2,000 topics were suggested before being reduced to 21. Following discussions in an open conference, 12 topics were chosen during the first topic selection.

In the topic narrowing process, topic content was determined via an online workshop and focus group sessions. Two subsequent topic selections led to 5 topics being chosen, with one added later to make a total of 6 candidates for what became known as lead visions. Through workshops to prepare lead visions and scenarios, lead vision reports were created for 5 topics, not including the one added later.

The Federal Ministry of Education and Research finally decided on 4 topics as lead visions: (1) Understanding thought processes, (2) Creating open access to tomorrow's world of learning, (3) Living healthy with vitality through prevention, and (4) Living in a networked world: individual and secure. Beginning this fiscal year, the Ministry will reflect the lead visions in its priorities for distributing research funding.

One must look at the historical context to understand the significance of Futur. Because of a shift to R&D management at research institutes, Germany suffered from a lack of demand orientation. Beginning in the second half of the 1990s, Germany began working to shift to demand orientation, and Futur was the first step in that process.

Japan should examine the potential for introducing and modifying the Futur method.

(Original Japanese version: published in June 2003)

1

Brain Imaging
— Necessity for Reinforcement of Research and Development for Application of Non-Invasive Technology to Diagnosis and Treatment of Mental Disease —

RYOJI YANO (*Affiliated Fellow*)

1.1 Introduction

The 1990s was regarded as "the decade of the brain" by the U.S. government, and brain research made rapid progress in those 10 years. Also in Japan, Brain Science Institute in RIKEN (the Institute of Physical and Chemical Research) and other similar organizations were established, with basic brain research was extensively advanced in the years. Brain researches have been conducted mainly on experimental animals such as mice and monkeys, while, in recent years, the research on humans is advanced with the development of brain imaging techniques, measurement of morphological brain structure and neurological activities by non-invasive methods. Particularly, technologies of functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have been remarkably progressed, making it possible to investigate changes in local neuronal activities and molecular movements in the brain. Using these techniques, brain science research on humans has been rapidly progressed, analysis of neuronal activities related to the higher brain functions, such as learning and memory, has advanced, and researches on the changes in neuronal activities associating with mental diseases, such as dementia and schizophrenia, came to be conducted.

In recent years, modern societies have taken more and more highly complicated structures according to the rapid development of science and technologies, and, as the result, the number of patients with mental diseases, including stress-induced depression and psychosomatic diseases, have increased and attracted considerable attention from the society. In addition, the increase of the elderly population has led to an increase of the number of patients with dementia, such as vascular dementia and Alzheimer's disease, and care of these patients has become an important social problem. Therefore, it should be an important theme in the future policy of science and technology in Japan to develop the technologies to diagnosis and treatment of these mental diseases and enrich the care of the patients. In this report, the author proposes establishment of an organization for collaborative research which can play the core role in tackling the above theme.

1.2 Major techniques for brain imaging

1.2.1 Methods for morphological measurement

Among the techniques for brain imaging, X-ray computerized tomography (CT-scan) and magnetic resonance imaging (MRI) are mainly used for observation of the brain shape and its detailed structure (Table 1). These methods of morphological measurement are used widely, and have become essential for diagnosis and treatment of neurological diseases, especially cerebrocardial infarction and brain tumors. In addition, diffusion tensor magnetic resonance imaging (DT-MRI) was recently developed, making it possible to observe the connection of nerve fibers in the brain[4, 5].

Table 1: Characteristics and comparison of typical morphological measuring methods

Measuring method	CT scan	MRI	DT-MRI
Principle of measurement	X-ray; tissue differences are distinguished by the difference in X-ray absorbency.	Nuclear magnetic resonance; tissues are distinguished based on the difference in the characteristics of resonance of hydrogen atoms in biological tissues.	Nuclear magnetic resonance; the diffusion of water molecules in tissues is examined to investigate the structure of fibrous tissues.
Subject for measurement	Bone, hematoma, and calcified tissues.	Difference in the structure of soft tissues and blood vessels.	Direction of fibers in tissues.
Advantages	Suitable for the measurement of skull fracture caused by head injury, and cerebral hemorrhage.	Suitable for the measurement of the minute brain structure, brain tumor, cerebral infarction, and cerebrovascular disease.	Provides observation of the shape of nerve fiber and the connection.
Disadvantages	Exposure to radiation.	Limitation due to an intensive magnetic field and long measurement time.	Same as those of MRI.

*For details of the respective methods, see Appendix [1].

Source: Author's compilation based on reference material

Appendix [1] Major methods for morphological measurement

(a) CT-scan

X-ray radiography was the first technique introduced as a non-invasive method for measurement and diagnosis of human tissues including the brain. In a CT-scan, the X-ray beam is radiated through narrow slits, and data collected with a detector on the opposite side are processed on a computer to produce the sliced images of the tissues. With a CT-scan, the difference in the absorption and transparency efficiency of X-ray is measured to distinguish tissue structures, such as bone, tumor, hematoma and so on, similarly to X-ray pictures. Since its introduction in the early 1970s, CT-scan rapidly spread and became an essential device for the diagnosis and treatment of diseases. For neurological diseases, the device made it possible to diagnose brain tumors, cerebral hemorrhage, cerebral infarction, and chronic subdural hemorrhage that were difficult before, and the treatment of these diseases advanced revolutionarily. The spatial resolution of the CT-scan has been improved year after year, and the interval between sliced images was narrowed down to 0.5mm. This higher spatial resolution is one of the advantages of the CT-scan method. On the other hand, what may be given as disadvantages is the exposure to a relatively high dose of X-ray and the unavoidable low contrast in the brain images due to the surrounding skull. MRI was introduced to overcome these disadvantages of the CT-scan, and now both CT-scan and MRI are being used for diagnosis of neurological diseases. For hemorrhage, fracture and calcification, the CT-scan is still advantageous and it is the first choice for emergency treatment of head injury.

(b) MRI

MRI is a measurement technique based on the principle of nuclear magnetic resonance (NMR). The nucleus of each atom constituting substances is spinning with a specific character. If the spinning is arranged into one direction in a strong static magnetic field, each atomic nucleus absorbs electromagnetic waves at a particular frequency and resonances. The nuclear resonance depends on the state of each atom, and we can discriminate molecules in which each atom is incorporated and environment surrounding the molecule, such as tissues inside the body, with observation of the state of the resonance. Ordinary MRI is a device to measure the nuclear magnetic resonance of hydrogen atoms inside bodies as signals, and as the result, the device can discriminate the tissues containing the atoms, such as blood vessel, adipose tissue and cerebral cortex. The technique was advocated in the early 1970s, and put into practical use a few years later. MRI can provide observation of the detailed structure of tissues inside the body due to the functional character of the device, and it is particularly useful in observation of brain tumors and cerebral infarction because of its less influence from the skull surrounding the brain. It also provides observation of cerebrovascular structure (magnetic resonance angiography; MRA) without using a contrast medium, therefore, being used for diagnosis of cerebrovascular diseases. There are some limitations in the application of the device due to the strong static magnetic field and its relatively long time, at least 30min. to 1hr., for data acquisition from one patient.

(c) DT-MRI[4]

DT-MRI is a novel measurement method developed in the late 1990s based on the ordinal MRI technology. In this method, the fibrous structure of the tissues can be observed by following the movement of hydrogen atoms contained in water molecules. Water molecules usually show the Brownian movement and randomly diffuse in every direction, but the direction of the diffusion is limited internally in fibrous tissues such as muscles and neuronal axons. Therefore, we can determine the direction of fibrous structure in each tissue with measurement of the movement of water molecules inside the tissue. In the brain research, this method makes it possible to observe the state of axons inside the white matter of the brain, which was hardly observed by the ordinal MRI, and it reveals the extension of nerve fibers during development of infant brains, and the degeneration of nerve fibers with the disease, such as cerebral infarction[5].

1.2.2 Methods for nerve activity measurement

Major methods for measuring nerve activities are functional magnetic resonance imaging (fMRI, functional MRI) and positron emission tomography (PET), used for basic and clinical brain researches (Table2). Using fMRI and near-infrared spectroscopy (NIRS), change in the local blood flow is observed to monitor the local neuronal activities in the brain. Both MRI and fMRI are using basically the same data collection technology, however, they are using different method for data analysis to reveal morphology and nerve activities in the brain, respectively. Their performance is determined by the intensity of the static magnetic field used. For fMRI, more intensive magnetic field (1.5~7T) is used than that (1~1.5T) for ordinal MRI. Tesla (T) is a unit representing the intensity of a magnetic field, and 1T is corresponding to 10,000 gauss. Using PET and single photon emission computed tomography (SPECT), movement of specific type of molecules can be traced in association with nerve activities, to reveal the function of the molecules for nerve activities. On the other hand,

Table 2: Characteristics and comparison of typical measuring methods of nerve activities

Measurement technique	fMRI	PET and SPECT	SQUID	NIRS
Principle of measurement	Nuclear magnetic resonance; measures the difference in the influence of the oxidized condition of hemoglobin on the local magnetic field to determine the change in local blood flow.	Measurement of gamma rays; measures the metabolism of molecules containing radioisotope.	Flux density; the distribution of flux density on the head surface is measured to determine the intracerebral distribution of current.	Near-infrared light; the difference in absorption of near-infrared light due to the difference in oxidation of hemoglobin is measured to determine the change in local blood flow.
Subject for measurement	Change of local blood flow.	Movement of molecules such as neurotransmitters.	Movement of nerve current in the brain.	Changes of blood flow on the cortical surface.
Advantages	The space resolution is good (approx. 1 mm.).	The metabolism of specific molecules can be measured.	The time resolution is good (a few millisec.).	The degree of freedom during measurement is high, and it is advantageous for measurement of infants and patients.
Disadvantages	The time resolution is poor (a few dozens of sec.)	Use of radioisotope in the living body. Establishment of a radiation facility.	The space resolution becomes poor in some cases.	Due to the influence of absorption and diffusion from biological tissues, the deep brain is difficult to measure.

*For details on the respective methods, see Appendix [2].

Source: Author's compilation based on reference material

Appendix [2] Major methods for nerve activity measurement

(a) fMRI

The 1990s was regarded as the decade of the brain by the U.S. government, and the brain research made rapid progress in the 10 years. During this term, the technique of fMRI was highly developed, and it may be possible to say that it was a decade of fMRI [8]. fMRI uses the principle technique of nuclear magnetic resonance similarly to ordinal MRI, however, its purpose is to measure not the morphology of the brain but the status of activities in the brain. In this device, the technique, advocated by Dr. Seiji Ogawa (currently transferred to Ogawa Laboratories for Brain Function Research, Hamano Life Science Research Foundation, Japan) et al. in 1990, is generally used for measurement of the change of brain activities. With this technique, the change of blood flow in the brain is observed by blood oxygenation level dependent (BOLD) contrast method, and thereby the change of local brain activities is revealed [9]. Hemoglobin (oxyhemoglobin), which carries oxygen to tissues including the brain inside the body, transfers to deoxyhemoglobin after releasing oxygen in each tissue. Oxyhemoglobin and deoxyhemoglobin have different characters as a magnetic body. Oxyhemoglobin has no influence on the surrounding magnetic field, while deoxyhemoglobin is a paramagnetic body which causes a small distortion in the intensive magnetic field produced by MRI, resulting in a local decline of MRI signal (BOLD effect). The degree of the effect is proportionate to the concentration of deoxyhemoglobin, therefore changes in the local concentration of deoxyhemoglobin can be measured by the observation of the changes in the intensity of the BOLD effect on the MRI signal. In the brain, it is known that local vasodilation is caused by increasing of nerve activity, and thereby the blood flow is increased to meet the demand for oxygen at the site. The increment of the blood flow exceeds the actual oxygen consumption, and, as a result, it causes increase in the local amount of oxyhemoglobin and relative decrease in the concentration of deoxyhemoglobin, producing enhancement of the MRI signal at the site. Therefore, increase of nerve activity can be observed as more intensive MRI signal locally. In fMRI, these slight changes in the MRI signal from hydrogen atomic spinning is detected to reveal nerve activities in the brain. To strengthen the MRI signals, stronger static magnetic field (1.5-7T) is applied in fMRI than that (about 1-1.5T) in ordinal MRI used for usual morphological observation, and a device with further more intensive magnetic field (9.4T) was introduced. Increasing of the intensity of the static magnetic field can lead to strengthening of the signal, however, at the same time it also enhances the noise in the detection. Therefore, the technique of information technology for signal processing is important in the fMRI method, and close cooperation between brain researchers and engineers for information technologies is essential for development of the device.

The spatial resolution of fMRI is as high as less than 1mm, similarly to ordinal MRI used for morphological observation, whereas its time resolution is not so high, about a few dozens of a second, mainly attributed to the time for onset of the change in blood flow after increasing of the nerve activity and data acquisition from the faint signal.

(b) PET and SPECT

PET and SPECT measure gamma rays emitted from radioisotope with a short half-life, administered into the body to observe the state of intracerebral metabolism of molecules containing the isotope. In PET, positrons (one type of gamma rays) are emitted from the isotope and bind to surrounding electrons in the tissues to release two 511 keV gamma rays (annihilation) to the opposite direction on a straight line. The position and timing of the binding between the positrons and electrons can be specified precisely by simultaneous detection of these two gamma rays with one pair of gamma ray detectors located at opposite sides of the body. Using of these two detectors results in the high definition of the measurement by PET. In SPECT, gamma rays are directly emitted from the isotopes and detected with one gamma ray detector. This method can be conducted using a relatively simple device as compared to PET, whereas spatial resolution and ability of quantitative analysis of the detection is lower than that of PET. With selection of the molecules containing radioisotope, these method have the advantages for obtaining information about the metabolism of specific type of molecules, such as blood flow, glucose consumption, binding of neurotransmitters to the receptors, and so on, associated with nerve activities. In PET, 11C, 13N, 15O and 18F are used as positron emitting nuclides, and their half-life is about 10-100 min. Therefore, a radiation facility such as cyclotron must be installed to produce the isotopes at the institution where the devices, PET and SPECT, are used. On the other hand, regardless of this limitation, observation of the molecular metabolism using the PET and SPECT is getting more and more important to elucidate the functions of the molecules, that are discovered and identified in the brain with the recent progress of molecular biological research, such as the completion of the human genome analysis, inside the living body for the diagnosis and treatment of neurological diseases.

(c) SQUID (EEG/MEG)

Nerve activity is principally based on the electric activity caused by movement of ions. Therefore, the most direct approach for measurement of the brain activity is to observe changes in the electric potentials and the magnetic field. Electroencephalogram (EEG) is a measurement method for the difference in the electrical potential between two points on the head surface, while magnetoencephalogram (MEG) is a method for observation of the density distribution of magnetic flux on the head surface, generated by the electric activity inside the brain. Using the superconductivity technology, superconducting quantum interference device (SQUID) made it possible to measure faint magnetic flux on the head surface. Recently, the device with a large number of channels (e.g., 256 channels) for detecting points was developed to improve the spatial resolution, and it became possible to determine intracerebral electric current distribution from the observed distribution of magnetic flux on the head surface.

The advantage of SQUID for observation of nerve activity is its direct measurement of the electric activity in the brain, whereas the other methods measure indirect indexes, such as blood flow and metabolism of bio-molecules, as a result of nerve activity. SQUID has very high time resolution to measure the nerve activity in the order of millisecond. The device also shows good spatial resolution for detection of the intensive signals such as the spike current in epilepsy to specify its focal point. However, changes in the magnetic flux associated with normal nerve activity are too slight to be detected with good spatial resolution by SQUID. With all the non-invasive methods including SQUID, it is necessary to determine the status of nerve activity within the brain from information obtained outside of the head. Among the devices, SQUID detects magnetic flux on the head surface with poorer positional information in comparison with the other methods which detect signals from inside the brain, i.e. electromagnetic waves including radiation and near-infrared light. Therefore, it is more difficult to determine the precise position as a mathematical single-meaning solution with SQUID. It would be necessary to improve the device to raise the detection ability, and, at the same time, to raise the spatial resolution by the development of analytical technique for reverse problems with mathematical engineering.

(d) NIRS

NIRS is a method to detect changes in intracerebral blood flow using near-infrared light around the wavelength of 800 nm. The near-infrared light shows a low absorbency in biological tissues as compared with other visible lights, and its tomography through the brain or its topography on the surface layer of the brain can be detected although the signal intensity is very weak. Between oxy- and deoxy-hemoglobin, the absorption spectrum is reversed and the difference in absorption is enlarged for the light around 800nm wavelength. The changes of local blood flow can be measured through monitoring of the changes in concentration of oxy- and deoxy-hemoglobin in the tissue. Similar to fMRI, the blood flow changes according to the nerve activity, therefore, the local nerve activity can be revealed by observation of the changes in the local blood flow. The data collection device of NIRS is small and the subject can move freely during the measurement, making it effective for observation of infants and patients who have difficulty in staying in one position for long time. On the other hand, comparing with X-rays and gamma rays, near-infrared light cannot avoid being absorbed and scattered by biological tissues, therefore, it is difficult to obtain information of the deep inside of brain, in addition to its poor spatial resolution. In the future, the usefulness of NIRS may increase for monitoring of the brain activity, because of the raising ability of the device for measurement through technological development including the use of a laser diode as a light source and a multi-channel detector (64-channel) [10].

using superconducting quantum interference device (SQUID), the density distribution of magnetic flux is observed on the surface of the head, to determine the current distribution within the brain.

The performances of these measuring methods, i.e. sensitivity, time- and spatial- resolution, are not yet sufficient, and further technological development of the devices is still necessary for progress of the brain research. Particularly, engineering technologies, such as electronics and information processing, are important for data analysis which is one of core parts of these measuring methods. In some few cases researchers and engineers are collaborating together for the technological development of the device in Japan, however, in most cases these methods are based on the technologies from U.S.A. and Europe. For example, fMRI of 3T or more and PET are imported from U.S.A. and European countries, such as England and Germany. In Japan, further cooperation between the fields of medicine and engineering should be attempted to develop further these measuring techniques in the future and to bring forward basic and clinical researches for human brains based on these technologies.

Table 3: Number of introduced CT and MRI in major countries (No. of units per population of 1 million)

Country	CT	MRI
Japan	84.4	23.2
Korea	22.9	4.3
Italy	19.6	6.7
Germany	17.1	6.2
U.S.	13.2	7.6
France	9.7	2.5
England	6.1	4.5

Source: Author's compilation based on the OECD statistic material [6]

1.3 Recent status of the introduction of the measuring technologies in Japan (in comparison with other major countries)

According to the newest OECD report (1999 edition)[6], the number of CT and MRI (per population) introduced in Japan is the highest in the world, outstandingly high even among advanced countries (Table 3). These devices are commonly used for morphological observation of the brain in Japan for the diagnosis of nerve diseases, such as cerebral infarction and brain tumor, although they are applied for other tissues.

On the other hand, techniques to measure brain activities are being used for basic researches of the human brain, and devices of advanced technology with higher performances in resolution and sensitivity are being introduced. For example, about 10 units of 3~4 tesla (T) fMRI were introduced to universities and other research institutes in Japan (Table 4). fMRI of 7~9.4 T are being used on humans in the United

Table 4: Major institutions that introduced fMRI in Japan (devices of 3T or more for use on humans)

Institution name	Intensity of static magnetic field	Year of introduction
Iwate Medical University (Iwate)	3T	Fiscal 2000
National Institute for Physiological Science, Okazaki National Research Institutes (Aichi)	3T	Fiscal 2000
Ogawa Laboratories For Brain Function Research (Tokyo)	3T	Fiscal 2001
Kyoto University Hospital (Kyoto)	3T	Fiscal 2002
Institute of Biomedical Research and Innovation (Hyogo)	3T	Fiscal 2002
Neuroscience Research Institute, National Institute of Advanced Industrial Science and Technology (Ibaraki)	3T	Fiscal 1997
Brain Research Institute, Niigata University (Niigata)	3T (vertical type and horizontal type)	Fiscal 1995
BF Research Institute (Osaka)	3T	Fiscal 1998
Fukui Medical University (Fukui)	3T	Fiscal 1997
Brain Science Institute, RIKEN (Saitama)	4T	Fiscal 1996

Source: Author's compilation based on published materials

States, and the device of 7T will be operated at the Niigata university this year in Japan.

For PET device, a radiation facility is required to be accompanied with the device to produce short half-life radioisotopes; therefore, the number of the devices is not large in Japan, about 50 units having been introduced in the whole country, mainly in university hospitals. In some facilities, PET is the main device applied for diagnosis of cancer or other diseases, and the number of devices will gradually increase in Japan.

For SQUID method, the large equipment is required for ultra-low temperature cooling, and the machines only provided a small number of detective points and the corrected information was not so much, and, therefore, the number of devices is small, about 20 units introduced in the whole country of Japan.

1.4 Establishment of a core collaborative research organization and reinforcement of the research for brain imaging

1.4.1 The present status and problem of research on neurological diseases

Based on recent development in brain imaging technology, basic researches on neurological diseases have been widely conducted in the world including Japan, achieving various results. For example, it has been observed using fMRI and PET that decreases in the rate of blood flow and saccharometabolism occur in the brain of patients with Alzheimer's disease, prior to morphological changes such as cerebral degeneration and atrophy. For other neurological diseases such as depression, it became known that the release and movement of neurotransmitters changed in the brain of the patients. Advancing of the researches might reveal the cause and mechanism of the neurological diseases.

On the other hand, based on these results of basic researches, it is necessary to develop application techniques for clinical diagnosis and therapies of neurological diseases including depression and dementia among general citizens, returning the profits of the results of basic researches to the society. At this time, it is possible to delay progression of Alzheimer's disease thorough taking medication, although it is difficult to cure the disease. Medication method has also been developed for the therapy of other neurological diseases such as depression. It is important to make early and exact diagnosis of the diseases for application of these therapeutic treatments, in order to improve the quality of life of patients and their families and to reduce various social burdens caused by the care of the patients.

In fact, considering the technological progress of fMRI and PET and the results of basic researches on neurological diseases using them, it will be possible to make the early and exact diagnosis of the neurological diseases by the brain imaging methods. To promote utilities of the brain imaging technologies, it might be necessary to spread the most advanced devices across the whole country for the daily diagnostic and therapeutic use of them. However, it may be economically difficult and take time to spread them all over the country, because of the expensive price (more than 1,000 million yen) of the 3T fMRI device. Instead of it, it may be more realistic to attempt utilization of MRI devices already introduced in hospitals, more than 3,000 units, across the whole country for morphological observation, as stated in the previous chapter. For this purpose, it is necessary to develop application technologies for general diagnosis utilizing MRI with low intensity of the magnetic field, based on the results of basic researches obtained using fMRI with higher intensity of the magnetic field. PET requires a radiation facility next to the device, and, therefore, the number of units spread out in Japan is small as compared with MRI, about 50 units in the whole country. On the other hand, using PET, we can investigate not only the changes of blood flow rate but also the metabolism of important substances (e.g., saccharometabolism), realizing a detailed analysis of brain activity. It would be necessary to develop a diagnostic technique combining MRI and PET for medical care of neurological diseases among general citizens.

1.4.2 Establishment of a core collaborative research organization

In Japan to date, as stated in the above paragraph, brain imaging devices were dispersedly introduced in universities and research organizations across the whole country. In each institution, results of basic researches relating to neurological diseases have been achieved by experienced researchers and their colleagues. These basic researches are important to clarify the fundamental mechanism of the brain function and to elucidate the cause of neurological diseases, and it will be necessary to promote them continuously in future. On the other hand, at these small-scale, dispersed institutions, researchers are busy with doing their own basic researches, and, therefore, it is difficult to develop simultaneously application techniques, such as a general diagnostic method, for neurological diseases in addition to the basic researches.

In this situation, for establishment of general diagnostic methods based on the results of basic researches, it may be necessary to establish a core organization for collaborative researches to conduct development of application techniques systematically. The purpose of the organization is to establish application techniques for general diagnosis and therapies of neurological diseases. For this purpose, newest devices should be introduced to reinforce its research system and the technological development of brain imaging methods should be conducted in the organization.

There are several possible structural forms for the organization: (1) An organization constructed of the assembly of several small-scale institutions selected from already existing research sites in the country. (2) An organization centered with a newly constructed institution. Whatever form it may take, the organization must create close relationships with existing related research institutions to form a collaborative research system, efficiently promoting research of neurological diseases and development of technologies for cure of them. For example, after construction of a network connecting research institutions distributed across the whole country and a database collecting and organizing their results of basic researches, it may become possible to utilize their results mutually and effectively for efficient researches on neurological diseases in Japan.

1.4.3 System required for a collaborative research organization

There are several important points for the system to establish therapeutic techniques for neurological diseases, in addition to the above.

(1) Interdisciplinary research system

All the imaging techniques as stated above (Table 2) are still in the halfway of development for optimal measurement of neuronal activities, and, therefore, it is necessary to promote research and development of the technologies in each research institute for advancing them. Particularly, development of information technologies for signal processing is important to determine the range of monitoring subject and the precision of measurement, and specialists for engineering of electronics and information technologies have significant roles for the development of brain imaging methods.

Owing to the recent development of molecular biology, functions of molecules inside the brain are being revealed, and collaborative researches between molecular biologists and physiologists using the brain imaging technologies are necessary to combine their results together for the integrated viewing of the brain activities and functions. As stated above, in this organization, it is necessary to form research groups including researchers of different fields, such as medicine, basic science and engineering, creating an interdisciplinary research system, irrespectively of the ordinal academic fields, to develop efficiently the brain imaging technologies and to advance effectively the researches using them.

(2) Training system of researchers and engineers

The number of members of the society for neuroscience in Japan is 2,000~3,000, 1/10 as compared with that of the United States, and those who are engaged in brain imaging research are only part of them. Considering that basic researches of higher functions in the brain (e.g., thinking, learning and memory) and diagnosis and therapy of neurological diseases, such as dementia and depression, will become more and more important in the future, the number of researchers relating to the brain imaging is considerably small and insufficient in Japan. To realize general medical care of neurological diseases on the whole country, it is necessary to train a large number of medical engineers who operate the machines to conduct the measurements. Therefore, at present, the important problem is training of researchers and engineers for the brain imaging, in order to promote the research on neurological diseases and realize medical care of them for general citizens. Brain imaging methods are fusion technologies of different fields, such as medicine, basic science and engineering, and, therefore, training of researchers and engineers in the brain imaging research needs special education, combining these fields together. However, curriculum is divided into the ordinal research fields in the present educational system of universities, so it is difficult to effectively conduct education of the fused region from different categories of technology. Education of brain imaging techniques is only being conducted at each of the research institutions on a small scale. Therefore, it is necessary to create an interdisciplinary training system in the newly constructed research organization, giving professional education of brain imaging using machines with advanced technologies to students, researchers and engineers of different fields from universities and research institutions across the whole country.

(3) System for effective usage of human resources and long-term research and development

In some cases, the present dispersed research system may lead to lacking of the mutual cooperation between individual laboratories and institutions, and even inflexible sectionalism of them. This may be one of the causes of inhibited mobility of human resources. On the other hand, this dispersed system may also cause problems in accumulation of the research results and continuation of the research and development in the long-term research field, such as brain imaging. In the new research organization, research themes will be selected among candidates applied from the whole country, and access to the research facilities with advanced technologies and the budget for research expenses will be provided for the adopted theme. This system will give an opportunity for using non-invasive measuring devices to researchers, who could not use them before, and, at the same time, it may be necessary to promote mobility of human resources, researchers and engineers for brain imaging, all over the country centering on the organization. The organization should have not only constancy to carry through the researches and accumulate their results, but also flexibly to change its research themes in corresponding with the changes in the social demand, if it is necessary, with periodical review of the performance of the organization.

1.5 Conclusion

As stated above, it is necessary to establish a collaborative research organization which can play the core role for promoting more research and development of brain imaging techniques, in order to develop and spread the techniques for medical care of neurological diseases, such as dementia.

In the United States, the National Institute of Biomedical Imaging and Bioengineering (NIBIB) was established within the National Institutes of Health (NIH) in 2000, and plays a major role in the development of imaging techniques for not only the brain but also the whole body, conducting researches in collaboration with other institutes. The mission of the NIBIB is to "improve health by promoting fundamental discoveries, design and development, and translation and assessment of technological capabilities. The Institute coordinates with biomedical imaging and bioengineering programs of other agencies and NIH institutes to support imaging and engineering research with potential medical applications and facilitates the transfer of such technologies to medical applications. [7]"

The theme of the core research organization of the brain imaging in Japan proposed in this article is the same as the NIBIB, returning the results of scientific research to the society. The organization should have a purpose “to promote fundamental and clinical researches in neurological diseases, and, based on the results, to develop diagnostic and therapeutic techniques for these diseases in order to improve the national health.”

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References

[1] Yukio Tateno: “Diagnostic Imaging”; Chuo-Koron-Shinsha, 2002. (in Japanese)

[2] Eric R. Kandel, James H. Schwartz, Thomas M. Jessell: “Principles of Neural Science” Fourth Edition, McGraw-Hill, 2000.

[3] Ryo Kamiya, Hiroshi Inomachi, Terutake Ueno: “Medical Bioengineering”, Baifukan, 2000. (in Japanese)

[4] Lauren O’Donnell, Steven Haker, Carl-Fredrik Westin, W. Eric L. Grimson: “New approaches to estimation of white matter connectivity in diffusion tensor MRI,” Massachusetts Institute of Technology (MIT) (http://www.ai.mit.edu), 2002.

[5] Constance Holden: “Deconstructing schizophrenia,” Science 299: 333, 2003.

[6] Uwe E. Reinhardt, Peter S. Hussey, Gerard F. Anderson: “Cross-National comparisons of health systems using OECD data, 1999,” Health Affairs 21: 169, 2002.

[7] NIBIB, web site, http://www.nibib1.nih.gov/index.htm

[8] Afonso C. Silva, Hellmut Merkle: “Hardware considerations for functional magnetic resonance imaging,” Concepts in Magnetic Resonance Part A, 16A(1): 35-49, 2003.

[9] Seong-Gi Gim, Seiji Ogawa: “Insights into new techniques for high resolution functional MRI,” Cur Opin Neurobiol 12: 607, 2002.

[10] Shin-ichi Mogi, Mariko Shoji: “Trends of ‘brain science and education’ Researches”, Science & Technology Trends - Quarterly Review No. 8, 2003.

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2

Need for Epigenetic-Based Cancer Research — Cancer Research in the Post-Genome Era

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2.1 Introduction

With analysis of the human genome complete (actually, 98.8%), the Human Genome Project was declared complete on April 14, 2003, heralding the arrival of a genuine post-genome era.

In fact for about five years now, research strategies have been targeted to suit this post-genome era. In Japan, genome-based research has also been promoted such as that on protein structure/function analysis, sugar-chain structure/function analysis and disease-related SNP analysis as part of post genome research.

In this context, research focusing on the causal relationship between diseases and the human genome has become internationally widespread. In recent years, it has been reported that histone protein (which binds to genome DNA) or genome DNA in the cells from patients with various types of cancers and with common diseases might be modified by enzymes such as methylase (methylation) or acetylase (acetylation). This type of modification is considered to affect gene transcription and expression, arousing interest among researchers in this field as possible causes of diseases[1]. The modification is a reversible reaction catalyzed by biological enzymes and its rate of occurrence depends on external factors including exposure to chemicals consumed in food or present in the environment.

Referred to as "epigenetic," this modification is an essential mechanism for normal cells to sustain life. Therefore, an abnormality within this mechanism may result in diseases including cancer.

This report provides descriptions of "epigenetics" as a likely area of cancer research, including an introduction to epigenetics, its causal relationship with cancer and the current international trend in epigenetic-based cancer research.

2.2 What does epigenetic mean?

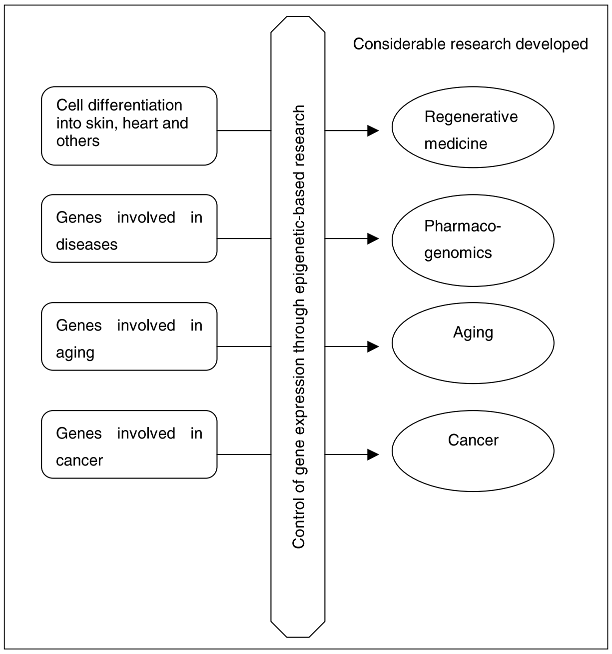
The word "epigenetic" is derived from epigenesis as opposed to ontogenetic preformation, a philosophy that prevailed in the biological field in the 17^{th}-18^{th} centuries. According to preformation, an individual living organism is established through a course of development from the potential properties it has inherently, whereas in epigenesis, the living organism undergoes internal and external effects sequentially in the process of ontogenesis, ultimately evolving into an individual.

At this time, "epigenetic" is a phenomenon that affects gene expression by a mechanism other than genomic mutation. Epigenetic-based research is expected to reveal the mechanism for suppression of gene expression, facilitating progress in the research on gene expression in various interdisciplinary fields (Figure 1).

2.2.1 Epigenetics in normal living organisms

Epigenetics play an important role in sustaining normal living organisms. The genome DNAs, which are extracted from the cells of the skin, heart or liver of a human body, are basically the same. Contrary to the description above, it has been reported that each gene in these cells has different expression patterns. This means that only genes associated with the formation of the skin, heart or liver are expressed. This type of suppression of gene expression is achieved through epigenetics, which develop in the process of cell differentiation after the genome

Figure 1: Considerable research areas developed by epigenetic-based research



is determined. In other words, gene expressions of all the cells in the living organism (excluding germ cells) are controlled by epigenesis.

Epigenetic suppression of gene expression in normal somatic cells has been shown to inactivate the X-chromosome and genomic imprinting in the cells[2].

One of two X-chromosomes in a female cell, one inherited from the father and another from the mother, is inactivated. This means that usually, a female's cells have mosaic patterns in which "inactivated cells with the X-chromosome inherited from the father" and "deactivated cells with the X-chromosome from the mother" are randomly mixed. Daughter cells inherit X-chromosomes deactivated at the early stage of embryonic growth through cell division. Inactivation of X-chromosomes in female cells compensates for the imbalance in the number of genes between the male, who has one X-chromosome and the female, who has two X-chromosomes.

A human has 23 chromosomes each inherited from both his/her mother and father, totaling 46 in one normal cell. The chromosome consists of a DNA-protein complex (chromatin). Therefore, there are two sets of genes in the cell, one is from the father and the other is from the mother. Gene imprinting is when the genes from the mother's and father's families express differently. The suppressed gene is referred to as an imprinted gene.

It has been reported that either of the two epigenetic mechanisms mentioned above occurs at an early stage of embryonic growth and differentiation. However, the details of their mechanism and significance to the living organism have not yet been revealed.

2.2.2 Epigenetic mechanism for suppression of gene expression

The epigenetic mechanisms for suppression of gene expression include DNA methylation, histone acetylation/methylation and chromatin remodeling (Table 1).

These epigenetic mechanisms are caused by modifications of enzymes in DNA or protein. Techniques such as the Sanger method could not detect the modification, because the modification is lost during the chemical treatment used for detection. Since no modification could be detected in a trace amount of sample, fewer studies have been reported on the causal relationship between diseases and epigenetics. The bi-sulfite sequence method developed in 1992 enabled detection of DNA methylated patterns in a trace amount of DNA sample. In addition, the DMH (differential methylation

Table 1: Epigenetic mechanism for suppression of gene expression

Mechanism	Action
DNA methylation	It causes methylation of cytosine in the CpG sequence of genome DNA, inhibiting gene transcription or gene expression by disturbing access of transcription factors and some enzymes to the DNA.
Histone, acetylation and methylation	It causes acetylation or methylation in histone, changing the structure of a DNA complex, histone and others, and affecting gene transcription and expression.
Chromatin remodeling	It causes the chromatin structure to condense or relax, inhibiting or facilitating gene transcription or gene expression by controlling access of transcription factors and some enzymes in the chromatin (which is composed of DNA, histone and others).

hybridization) method using micro arrays developed in 2000 and the MethyLight method, a real time PCR method using fluorescent dyes reported in 2001, dramatically improve the DNA methylation detection accuracy and rate[3,4].

These innovative detection techniques have enabled research on the causal relationship between diseases such as cancer and DNA methylation. Therefore, researchers specializing in cancers have recently focused attention on DNA methylation. In the following paragraphs of this report, DNA methylation is highlighted and discussed.

2.2.3 Mechanism for suppression of gene expression by DNA methylation

In the process of DNA methylation, a methyl group binds to the 5th position of the cytosine base in the DNA molecule by DNA methyltransferase, producing 5-methylcytosine. Since methylation at site 5 does not affect base paring, 5-methylcytosine can pair with a guanine base. This means that DNA can be replicated normally. However, the structural difference of 5-methylcytosine can affect gene expression.

Generally, gene expression requires gene regulatory protein and transcription factor to bind to the promoter region of the gene (the DNA sequence of the promoter region involved in gene transcription). During gene expression, the gene regulatory protein and the transcription factor bind to the promoter region, which prevents DNA methyltransferase structurally from approaching the DNA sequence in the promoter region. At this stage, DNA methylation cannot occur.

When most of the gene regulatory protein and the transcription factor are released from the promoter region, DNA methyltransferase can approach the DNA in the region. Accordingly, the DNA in the promoter region is readily methylated. The DNA, once methylated, is specifically bound by internal protein to prevent the DNA from being demethylated. This means that DNA methylation is maintained, with gene expression stably inhibited.

In addition, the methylation pattern occurring in a parent DNA chain is readily inherited by its daughter DNA chain through maintenance methylase. In other words, when the DNA is methylated in the genome in a cell, all its daughter cells will have the methylated DNA at the same site as those of their parent genome.

An especially important mechanism is that which occurs in the course of cell differentiation, for example, preventing skin cells from transforming into heart, liver cells or any other cells except skin cells after cell differentiation.

2.2.4 DNA methylation in normal living organisms and that involved in diseases

DNA methylation inhibiting the expression of unnecessary genes in the living organism at the normal stage has been described. This suggests that DNA methylation is involved in diseases through the following: (i) DNA methylation occurring in any way at a different region from the normal region, inhibits the expression of essential genes for sustaining a living organism, or (ii) although the DNAs have been stably methylated in a normal region, when the same region is demethylated, this facilitates the expression of unnecessary genes, which disturb the development of a normal living organism.

How this relates to cancer caused by DNA methylation will be discussed in Chapter 2.4.

2.3 Scientific publications in the field of epigenetic-based research

To analyze the trend in epigenetic-based research, the number of scientific articles published (from 1993 to 2002) on epigenetic-based research was investigated using the keyword search function of PubMed, a database containing medical articles (Figure 2).

The result of the search for reports using the keyword “epigenetic” showed that the number of reports relatively increased in 1996 and 1998 compared with those in the previous years, while it indicated a remarkable increase in 2000 and later. The search by the keywords “epigenetic and cancer” or “methylation and cancer” also showed almost the same results as those mentioned above.

In recent years, it has been reported that epigenetics might be involved in aging and diseases other than cancers, suggesting that the rapid increase in the number of articles reflects the results of these studies. Specifically, this is the reason why the number of articles on epigenetic-based research drastically increased in 2000. At that time, as the Human Genome Project was approaching its end, epigenetic-based research began to attract greater attention as a post-genome target, and the useful techniques for detecting DNA methylation mentioned before were identified.

The increase in the number of articles mentioned above suggests that epigenetic research and epigenetic-based cancer research are rapidly growing new research fields.

2.4 Epigenetics can be linked to cancer

Progress in molecular biological research has contributed to the great dissemination of the realization that cancer may be caused by any anomaly in the genome or genes. In recent years, epigenetic-based research has attracted worldwide attention because it has been revealed that epigenetics may cause cancer[5].

2.4.1 What is cancer?

Cancer can be defined as a disease where: (i) cells proliferate uncontrollably , and (ii) the proliferated cells then invade a region generally occupied by other cells, and remain there (Molecular Biology of THE CELL, 3rd edition). When cancer cells having the characteristic defined in (i) remain in a fixed region, this is referred to as a benign tumor. Usually, a benign tumor can be completely cured by excising the affected area. However, it is difficult to treat cancer referred to as a malignant tumor because it invades neighboring tissues or metastasizes to other organs.

Recent progress in molecular biological research has widely disseminated the realization that the cause for inducing the behavior of cancer cells described in (i) and (ii), is the abnormality in the gene involved in genes such as the "oncogene" or the "tumor suppressor gene." It has been revealed that abnormal genes can largely be grouped into two types, qualitative and quantitative abnormality.

2.4.2 Cancer development by qualitative and quantitative abnormality

Cancer development caused by qualitative abnormal genes has attracted the greatest attention because many abnormal genes (mutant genes) are found in cancer cells, and these are involved closely in cancer development as well as the malignant differentiation of cancer.

In the course of cancer development due to quantitative abnormal genes in cancer cells at the gene expression level, the normal cell cycle

Figure 2: Scientific publications in the field of epigenetics (1993-2002)

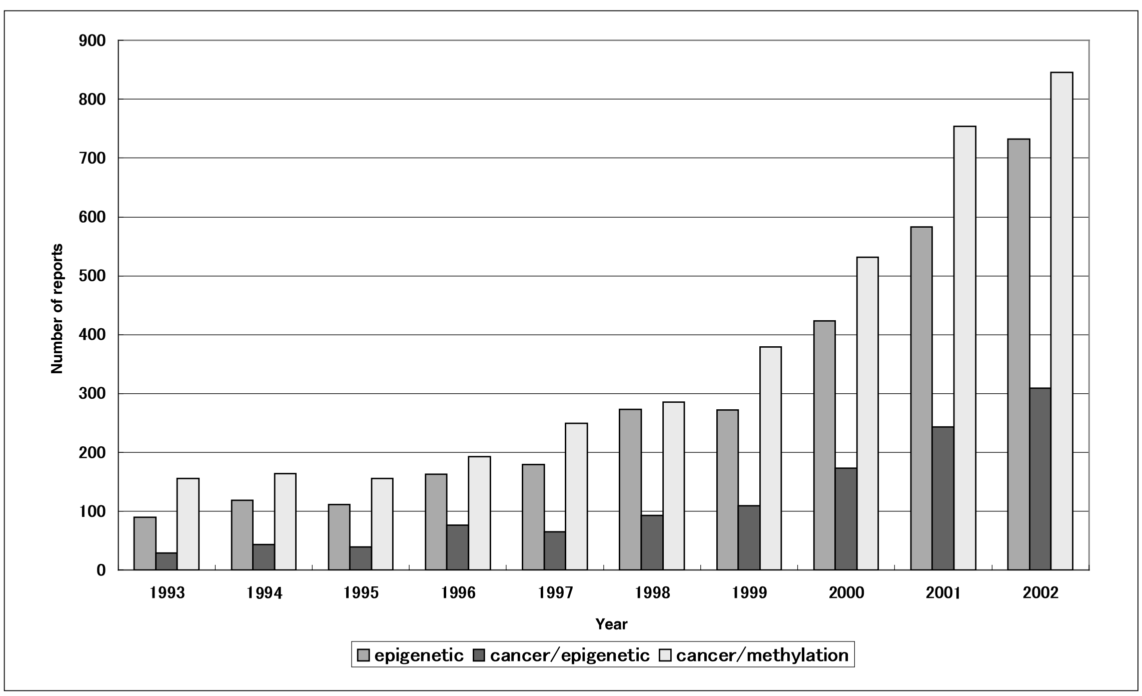


Table 2: Methylated genes observed in cancer cells

Gene	Gene function	Cancer type
P14 (ARF)	cell cycle	colon and rectum cancer, stomach cancer
P16 (INK4a)	cell cycle	lymphoma, pancreatic cancer, colon and rectum cancer, stomach cancer
hMLH1	DNA repair	colon and rectum cancer, cervical cancer
BRCA1	DNA repair, cancer suppressor	ovarian cancer, breast cancer
MGMT	DNA repair	colon and rectum cancer, brain tumor
GSTP1	neutralization of toxicity	liver cancer
DAPK	apoptosis	lymphoma
CDH1	cell adhesion	esophageal cancer
TIMP3	proteolysis inhibitor	kidney cancer
APC	tumor suppressor	stomach cancer, pancreatic cancer, liver cancer

Source: Author's compilation based on a reference[6]

cannot be maintained. This is because redsuced or suppressed transcription activities of the tumor suppressor and DNA repair genes may lead to a decrease in proteins. An enhancement in the transcription activity level may cause cancer by increasing the amounts of oncogene and oncoprotein, disabling control of the cell cycle. This suggests that in addition to abnormalities in the genomic DNA itself, epigenetic factors can also be involved in cancer development.

2.4.3 Methylation of DNA in cancer cells

Methylated genome DNAs are frequently observed in a cancer cell. In recent years, the causal relationship between DNA methylation and cancers has been revealed.

Table 2 shows cancer types and the methylated genes. It has been reported that methylated genes have been observed in various types of genes associated with every stage of the cell cycle including the tumor suppressor gene[6]. While some genes are commonly methylated in many types of cancers, other genes are methylated in specific types of cancers. This suggests the existence of different causal mechanisms for cancer depending on cancer type.

Collecting and collating information on methylated genes to be integrated into a database for use as fundamental information may be a requirement for facilitating future research on cancer toward treatment.

2.4.4 The pattern of methylated DNA in cancer cells

Many patterns of methylated DNA patterns are observed in a cancer cell[1] including a wide range of hypomethylation/demethylation[2] and site-specific (ex., a gene promoter region) hypermethylation[7,8].

Hypomethylation or demethylation has been reported to disable control of the expression of unnecessary genes in the cells which form each tissue or organ (for example, all the genes expressed in liver cells are not necessary for the gene expression of skin cells). This might lead to inducing instability in chromosomes and increasing the risk of abnormal development of cells. Hypomethylation is observed over a wide range of genes in many cases.

In site-specific hypermethylation, methylation has been concentrated in the specific region related to gene expression, that is, the gene promoter region. This leads to inhibition of expression of the tumor suppressor gene and the DNA repair gene, which play roles in the suppression of tumors or cancer development.

Table 3 shows differences in the patterns of methylated genes between normal and cancer cells.

2.4.5 Substances possibly involved in DNA methylation

Recently, it has been shown that deficient or excessive intake of some substances contained in food might affect the methylation of normal cells.

Table 4 shows the substances, which have been reported to affect DNA methylation. Although details on the mechanism have not been revealed, it is suggested that when deficiency exists in any substance with a chemical structure that can provide a methyl group, hypomethylation (instable chromosomes) is likely to be induced in the DNA of cells[9-12].

It has been reported that ingesting particular foods (not containing choline and folic acid) containing an environmental pollutant such as arsenic may accelerate DNA hypomethylation in animal experiments. This means that further investigation is required to establish safety standards for arsenic.

2.4.6 Chemical substance deficiency-induced cancers, and cancer prevention by supplementation of deficient substances

The causal relationship between deficiency of chemical substances that can provide a methyl group and cancer development has been studied since the mid-1980s. One report showed that cancer and tumors developed in the livers of experimental animals (rats) at a high rate of incidence by continuous feeding with food containing no choline for one to one and a half years. The DNA methylation patterns of their cells were different from .those of normal cells and exhibited hypomethylation. At that time, since sufficient techniques for detecting DNA methylation were not available, no further detailed research was conducted.

At present, it is believed that the deficiency of chemical substances can be correlated with the increased risk of cancer development. Thus, the target of research has been changed to cancer

Table 3: Methylated genome DNAs observed in normal and cancer cells

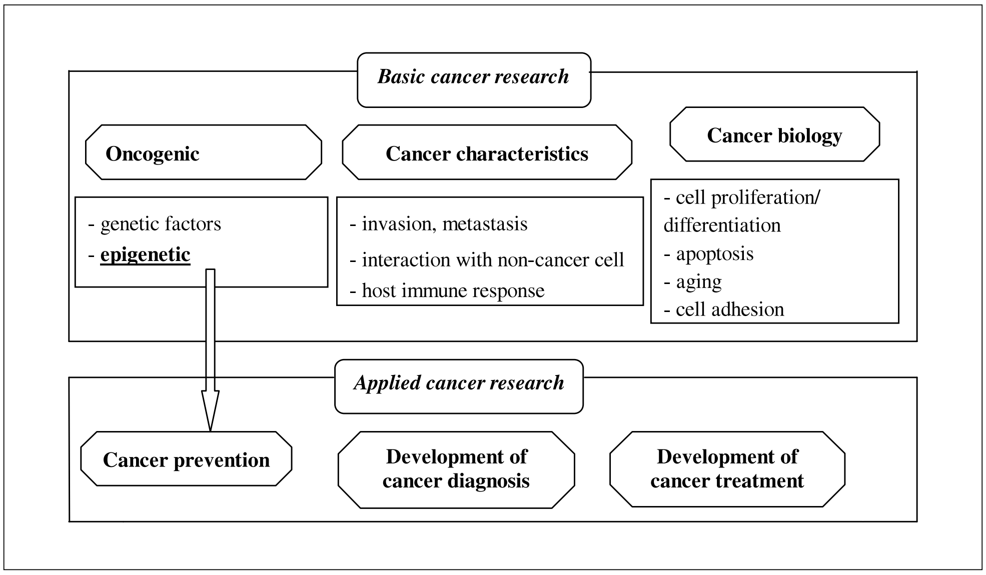
Example of genome DNA sequence	Normal cell	Cancer cell
Repetitive DNA sequence with the same pattern such as CTG	methylation	demethylation (hypomethylation)
Viral sequences in human genome DNA	methylation	demethylation (hypomethylation)
Promoter region of tumor suppressor gene	demethylation (hypomethylation) methylation	methylation

Table 4: Substances possibly involved in methylation

Substance	Food containing the substance	Intake	Methylation type	Gene state
methionine	animal protein	deficiency	hypomethylation	unstable
Choline	yolk	deficiency	hypomethylation	unstable
folic acid	green and yellow vegetables	deficiency	hypomethylation	unstable
folic acid	green and yellow vegetables	deficiency	methylation	inhibits tumor suppressor gene p53
Vitamin B_{12}	egg, seafood	deficiency	hypomethylation	unstable
Zinc	shellfish	deficiency	hypomethylation	unstable
selenium	mushroom, sea weed	deficiency	hypomethylation	unstable
Retinoic acid	eel, liver, yolk	excess	hypomethylation	unstable
alcohol	alcoholic beverages	excess	hypomethylation	unstable
Arsenic	environmental pollution (contaminated drinking water)	excess?	hypomethylation	unstable

Source: Author's compilation with reference to NCI HP and references[9-12]

Figure 3: Cancer research map



prevention by the supplementation of deficient chemical substances.

In 2000, a study was conducted on the effect of folic acid contained in food (fed for 1-2 months) on experimental animals (mice), whose genes were altered so that carcinoma of the colon and rectum could be induced[13]. In the group (folic acid group) to which food containing folic acid was given, the normal state of methylation was observed compared with the non folic acid group. In the group to which the food containing folic acid was continuously given prior to the development of intestinal tumors, a lower rate of polyp incidence was observed compared with the non folic acid group. However, giving food containing folic acid after tumor formation had no effect. This suggests that folic acid should be supplied at a proper timing to prevent cancer development.

2.5 Worldwide trend in epigenetic-based cancer research

External factors including exposure to chemical substances in the environment, food and lifestyle may increase the risk of cancer development. To reduce the risk of cancer development, external factors, which may induce cancer development, should be eliminated or controlled. This may be achieved by applying the results of epigenetic-based research.

As shown in Figure 3, epigenetic-based cancer research falls within the category of "studies on the elucidation of the oncogenic mechanism." The results of this research may directly contribute to the research on cancer prevention.

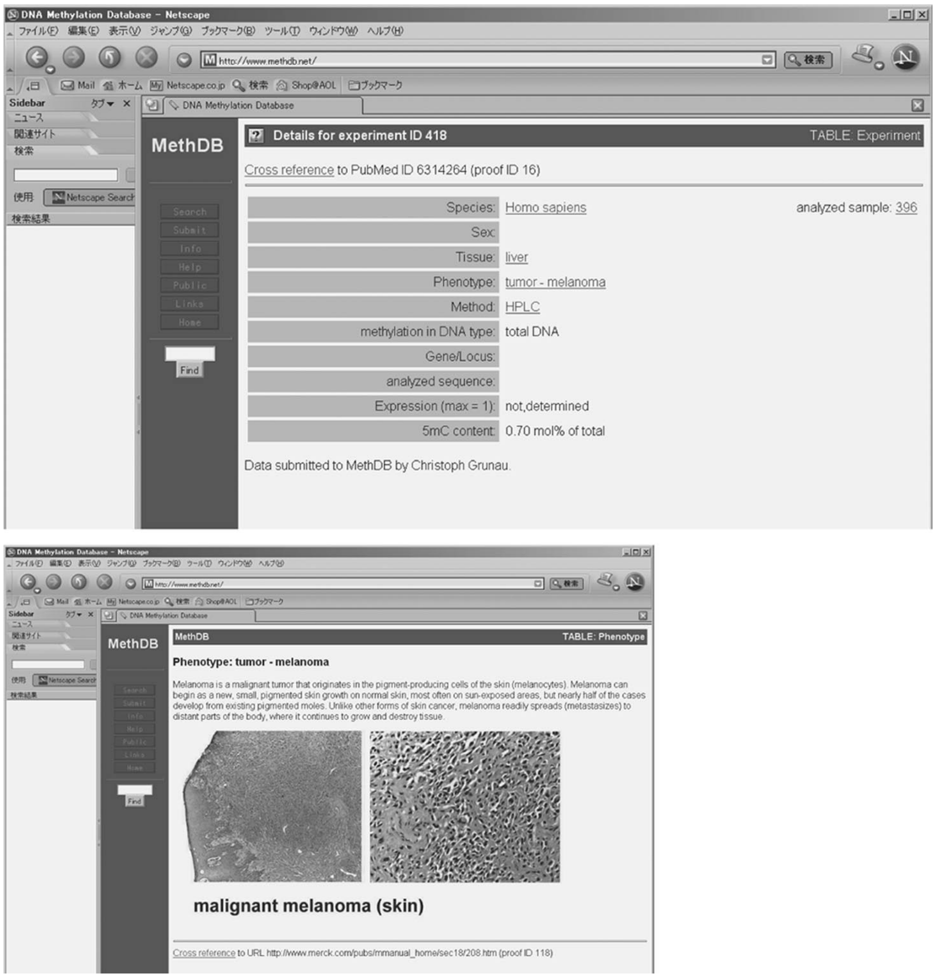
International epigenetic-based research has been progressing as part of the Post Genome Project for about five years in collaboration with EU members. In the U.S., a research project has also been launched.

Regrettably, in Japan, no international projects on epigenetic-based cancer research or research projects in collaboration with multiple domestic institutes have been launched yet.

2.5.1 Trend in epigenetic-based research in the U.S.

In the U.S., although no large-scale projects on epigenetic-based research have been launched, various workshops and conventions focusing on the 'epigenetic' theme have been held: "Diet, DNA methylation processes and health" supported by the NIH, FDA and the U.S. Nutritional Science Society in August 2001, "Epigenetics in Cancer Prevention: Early detection and risk assessment"at which researchers from the Cancer Prevention Department, NCI, attended as the main members in December 2001, and "Cancer genetics & epigenetics" as part of the Gordon Conference in January 2003, in which studies on the causal relationship between epigenetic phenomena such as methylation and cancer development were presented and the possibility for further study

Figure 4: DNA Methylation DB (Example: Transfer of malignant melanoma to liver)



Source: HP of DNA Methylation DB

was discussed. Additionally, in September 2002, the call for research on a new theme, "Diet, DNA methylation and other epigenetic events, and cancer prevention," was announced. Researchers can apply for an NIH Research Grant (R01 or R21) for this. The NCI will allocate about 2.5 million dollars (3 million yen) to grants from the fiscal year 2004 budget.

2.5.2 Epigenetic-based research strategy in Europe (Human Epigenome Project)

Europe has launched an epigenetic-based research project ahead of the U.S. and Japan. Aiming at the elucidation of epigenetic information in the human genome, the Human Epigenome Consortium was formed in 1999. The Sanger Center (UK), Centre National de Genotypage (France), German Cancer Research Center, Berlin Institute of Technology, and Max Planck Institute of Molecular Genetics (Germany) have participated in the consortium as members.

In the first stage, the Human Epigenome Project focused on making a detailed methylated gene map. The map will be useful for further studies on epigenetics.

Epigenomics, a biotechnology company based in Berlin (Germany), has also been participating in the project as a team member. Epigenomics (http//www.epigenomics.com) aims at the development of epoch-making technologies using the human genome including that of drugs tailored to individuals. Through joint research, the company has formed an international business network and, furthermore, strengthened its business network in the U.S. by operating a branch in Seattle.

2.5.3 Building of a DNA Methylation Database in Germany

Germany has built the world's first DNA methylation database[14,15]. Called MethDB, this is the first methylation database accessible to the public(http//www.methdb.net). As of September 4 in 2002, 6,667 methylation data on 46 kinds of species, 160 kinds of tissues and 72 kinds of expression phenogenetics are contained in the database. The number of accesses to the database per month has increased on a monthly basis from 810 in June 2000 to 8,884 in July 2002. This database has incorporated various innovative ideas. One of them, stoichiological image data, in which gene expression phenogenetics is represented in a micro graphical format, is available to users (Figure 4).

This database contains a wide range of data on DNA methylation in cancer cells. It is expected to play an important role as a source of information for future epigenetic-based cancer research.

2.6 Conclusion

Although epigenetic-based research is still at the development stage, this area will undoubtedly progress rapidly and enlarge to eventually become an international trend. Therefore, Japan needs to refine its domestic research system for epigenetics, while paying strong attention to the current movement of international epigenetic research.

Listed below are the points to be considered when discussing the refinement of a system for future epigenetic-based cancer research under the leadership of the Japanese government.

(1) Enlargement of future epigenetic-based cancer research.

An interdisciplinary research group (across the fields of medical science, natural and physical science, food, nutrition, health, and immunology) should be formed for the epigenetic research project.

(2) Building of a domestic human epigenetic database.

Data on epigenetic research such as DNA methylation, conducted at each institute and university, should be integrated into the main database to allow researchers to use and share the data for disease prevention and diagnosis studies. The database can be controlled by a satellite system, meaning that the database is located at each institute and university, while the main database can be located in cyber-space.

(3) Giving epigenetic-based research the status of post-genome research.

In Japan, post-genome research has focused on the protein structure/function analysis and SNPs. Epigenetic-based research must also be positioned as a pillar of post genome research.

References

[1] Jones, P.A. and Laird, P.W. Cancer-epigenetics comes of age, Nature genetics, 1999, 21(2): 163-167.

[2] Wolffe, A.P., Matzke, M.A. Epigenetics: Regulation through repression. 1999 Science 286 (5439) : 481-486.

[3] Yan, P. S., Perry, M. R., Laux, D. E., Asare, A. L., Caldwell, C. W., Huang, H.-M. CpG island arrays: an application toward deciphering epigenetic signatures of breast cancer. 2000 Clinical Cancer Research 6: 1432-1438.

[4] Trinh, B. N., Long, T. I., Laird, P. W. DNA methylation analysis by MethyLight technology. 2001 Methods 25(4): 456-462.

[5] Esteller, M., Corn, P.G., Baylin, S.B., Herman, J.G. A gene hyper-methylation profile of human cancer. 2001 Cancer Research 61: 3225-3229.

[6] Croce, L. D., Raker, V. A., Corsaro, M., Fazi, F., Fanelli, M., Faretta, M., Fuks, F., Coco, F. L., Kouzarides, T., Nervi, C., Minucci, S., Pelicci, P. G. Methyltransferase recruitment and DNA hypermethylation of target promoters by an oncogenic transcription factor. 2002 Science 295: 1079-1082.

[7] Jones, P. A., Gonzalgo, M. L. Altered DNA methylation and genome instability: A new pathway to cancer. 1997 Proc. Natl. Acad. Sci. USA 94: 2103-2105.

[8] Chen, R.Z., Pettersson, U., Beard, C., Jackson-Grusby, L., Jaenisch, R. DNA hypomethylation leads to elevated mutation rates. 1998 Nature 395: 89-93.

[9] Davis, C. D., Uthus, E. O., Finley, J. W. Dietary selenium and arsenic affect DNA methylation in vitro in Caco-2 cells and in vitro in rat liver and colon. 2000 Journal of Nutrition 130: 2903-2909.

[10] Halsted, C. H., Villanueva, J. A., Devlin, A. M., Niemela, O., Parkkila, S., Garrow, T. A., Wallock, L. M., Shigenaga, M. K., Melnyk, S., James, S. J. Folate deficiency disturbs hepatic methionine metabolism and promotes liver injury in the ethanol-fed micropig. 2002 Proc.Natl.Acad.Sci.USA 99(15): 10072-10077.

[11] Sohn, K.-J., Stempak, J. M., Reid, S., Shirwadkar, S., Mason, J. B., Kim, Y.-I. The effect of dietary folate on genomic and p53-specific DNA methylation in rat colon. 2003 Carcinogenesis 24(1): 81-90.

[12] Okoji, R. S., Yu, R. C., Maronpot, R. R., Froines, J. R. Sodium arsenite administration via drinking water increases genome-wide and Ha-ras DNA hypomethylation in methyl-deficient C57BL/6J mice. 2002 Carcinogenesis 23(5): 777-785.

[13] Song, J., Sohn, K.-J., Medline, A., Ash, C., Gallinger, S., Kim, Y.-I. Chemopreventive effects of dietary folate on intestinal polyps in Apc+/− Msh−/− mice. 2000 Cancer Research 60: 3191-3199.

[14] Grunau, C., Renault, E., Rosenthal, A., Roizes, G. MethDB- a public database for DNA methylation data. 2001 Nucleic Acids Research 29(1): 270-274.

[15] Amoreira, C., Hindermann, W., Grunau, C. An improved version of the DNA methylation database (MethDB). 2003 Nucleic Acids Research 31(1): 75-77.

Others

- Molecular Biology of THE CELL, 3rd edition; Alberts, B., Bray, D., Lewis, J., Raff, M., Roberts, K., Watson, JD.
- Formal U.S. NCI Web site : http://www.nci.nih.gov/
- The Epigenome, Beck, S. and Olek, A., Wiley-vch 2003

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3

Trends in Insect Studies in Life Science

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3.1 Introduction

Insect studies in biology and life science have been carried out mainly with silkworms (*Bombyx*) and fruit flies (*Drosophila*). These two insects contributed especially to classic genetics in the 1910s. For example, while Mendel's laws in plants were discovered in 1865, those in animals were first discovered in *Bombyx* silkworm by Dr. Kametaro Toyama of Tokyo Imperial University in 1910. Also, Dr. Thomas H. Morgan of Columbia University, U.S., used fruit flies to conduct basic research in genetics such as studies on mutation induction and salivary chromosome engineering. In 1972, Dr. Yoshiaki Suzuki of the Carnegie Institution of Washington succeeded in isolating the messenger RNA of fibroin, a silk protein, from the silkworm for the first time in eucaryote. Suzuki's research was a remarkable achievement in molecular biology.

In the meantime, studies with fruit flies have played crucial roles in the development of biology through improvement of the chromosome engineering technology using salivary chromosomes, the gene-transferring technology, and establishment of experimental methods with mutation and gene functions employed. The whole genome of the fruit fly was sequenced in 2000, the first time in insects, thereby ensuring its position as a model organism in the molecular biology of insects.

However, we cannot unveil functions and biological phenomena peculiar to each insect with studies only on the fruit fly, a model organism. Accordingly, we need to enhance researches on various insects with special functions. For example, fruit flies do not have dormancy although it is an essential characteristic of insects. Furthermore, most of the biomolecules involved in specific functions of insects have not been identified yet and are biological resources to be developed. Analysis of properties specific to insects, which may lead to the discovery of new biological resources, will not only contribute to life science but also greatly advance industry through applied researches for exploiting biological resources.

In this report, we will introduce to you the trends in insect studies in life science.

3.2 Position of insects in the Animal Kingdom and importance of insect studies

An insect is defined as an organism comprising of a body divided into three parts (head, thorax and abdomen) and six legs. Insects belong to the Arthropoda, which includes crustaceans, such as prawns and crabs, and arachnids, both of which have legs with segments as insects do.

3.2.1 Position of the insect in the Animal Kingdom

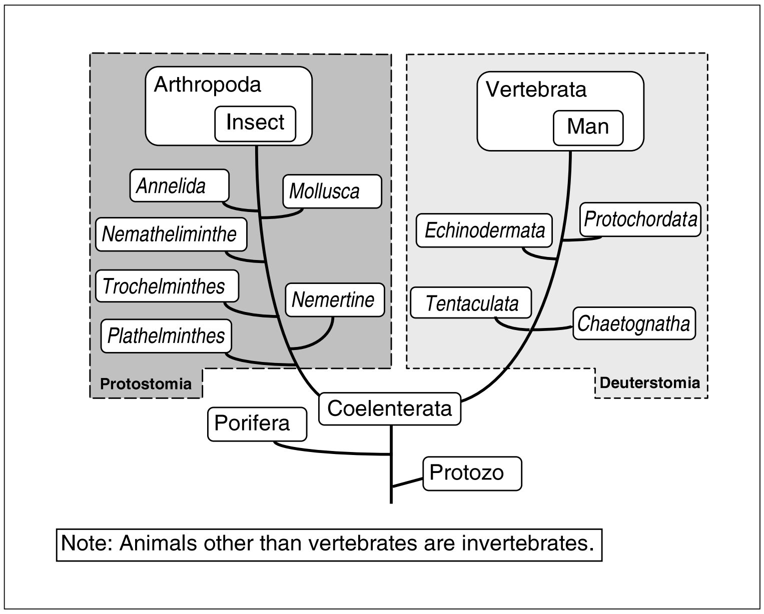
The earth was born 4.6 billion years ago and life began to exist about four billion years ago. The birth of the insect is estimated to be 350 million years ago, while the birth of man five million years ago.

While man is the most highly evolved animal among vertebrates in the phylogenetic tree, the insect is regarded as the most highly evolved invertebrate because it has excellent sensory functions and includes species having sociality (Figure 1).

Meanwhile, among all animals, which presumably contain one million species, the number of insect species accounts for about 70%, while the number of vertebrate species including man is about 4% (Figure 2).

There are many factors for such prosperity of insects on the earth. For instance, they have

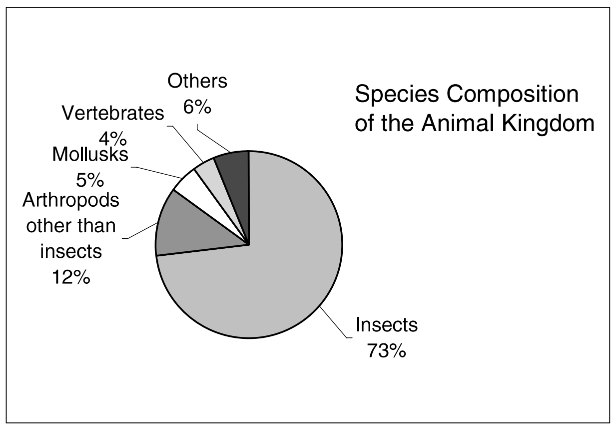
Figure 1: Position of insects in animals' phylogenetic tree



Source: Prepared based on material made by Dr. Shunji Natori, an invited researcher of the Institute of Physical and Chemical Research, with some added changes

short life cycles (10-14 days in fruit flies and 50 days in *Bombyx* silkworm), high reproductivity, diapause and metamorphosis, which help them to survive severe environments, and defense mechanisms effective in protecting themselves from enemies. Insects have obtained these functions in their long evolutional process to adapt to the environment. Insects, which have infinite diversity obtained through such variable adaptation, are very attractive research objects as biological resources, too.

Figure 2: Insects account for about 70% of all animal species



Source: Prepared based on E. O. Wilson (1992), "The Diversity of Life" (Harvard University Press, Cambridge, 1992) translated by Masako Oonuki and Shunichi Makino (Iwanami Shoten Publishers) with some added changes.

3.2.2 Importance of insect studies in life science

Basic knowledge in developmental biology, genetics and molecular biology has been obtained through studies using fruit flies and silkworms. Such studies realized, for instance, gene recombination in fruit flies and *Bombyx* silkworms. Useful substances produced by the recombination of the silkworm genes are thought to have high safety because silkworms do not have pathogenic microbes in common with man and domestic animals and, thus, these substances do not contain microbes harmful to us. Actually, the technology for producing useful substances like interferon in the silkworm using transgenic viruses has been improved, and interferon for cats has already been commercialized.

In the meantime, the insect, the most highly evolved invertebrate, has many biological mechanisms different from us. Analysis of such mechanisms specific to insects will give us a fresh insight into life science. For example, a bacteria-resistant substance produced by an insect that does not have an immune system with the antigen-antibody reaction, which vertebrates have, shows resistance to methicillin-resistant *Staphylococcus aureus* (MRSA), and its application to insect-derived pharmaceuticals is greatly expected.

In addition, applied researches on insects in the fields of medicine and industry are necessary. It is also crucial to study insects that serve as vectors of diseases, like *Anopheles* mosquitos transmitting malarial parasites and tsetse flies transmitting trypanosomes that cause sleeping sickness. The anopheles is the second insect whose whole genome was sequenced following the fruit fly. If artificial control of insect growth becomes possible through studies on insect hormones, extermination of these vectors will be enhanced.

Furthermore, insects are focused on as a reservoir of new compounds beneficial in industry as their various biologically active substances and useful biopolymers are discovered. For instance, it is hoped that useful substances produced by symbiotic microorganisms of insects will be applied as pharmaceuticals for man and livestock.

3.3 Major fruits and trends in recent insect studies in life science

In this chapter, we will introduce to you major fruits and trends in recent insect studies in life science. Specifically, we will deal with "Molecular Biological Studies on Insects," which serve as the base of every research in life science including fundamental and academic studies led by universities. Then, we will refer to "Research on Growth Control and Hormones of Insects," "Research on the Defense Mechanism of Insects" and "Research on Symbiotic Microorganisms of Insects" as studies for analyzing functions peculiar to insects.

The Insect Technology Project of the Ministry of Agriculture, Forestry and Fisheries of Japan is an example of an applied research based on such basic studies as described above. This project aims at exploiting and industrializing insect properties. It includes such research objects as the promotion of the *Bombyx* silkworm genome sequencing, development of new agrichemicals for selectively exterminating targeted vermin by making good use of genomic information, mass production of useful proteins of insects by silkworms with gene recombination applied and improvement of new materials that can be employed in the field of medicine by engineering and processing substances specific to insects (Figure 3).

Figure 3: Trends in insect studies in life science

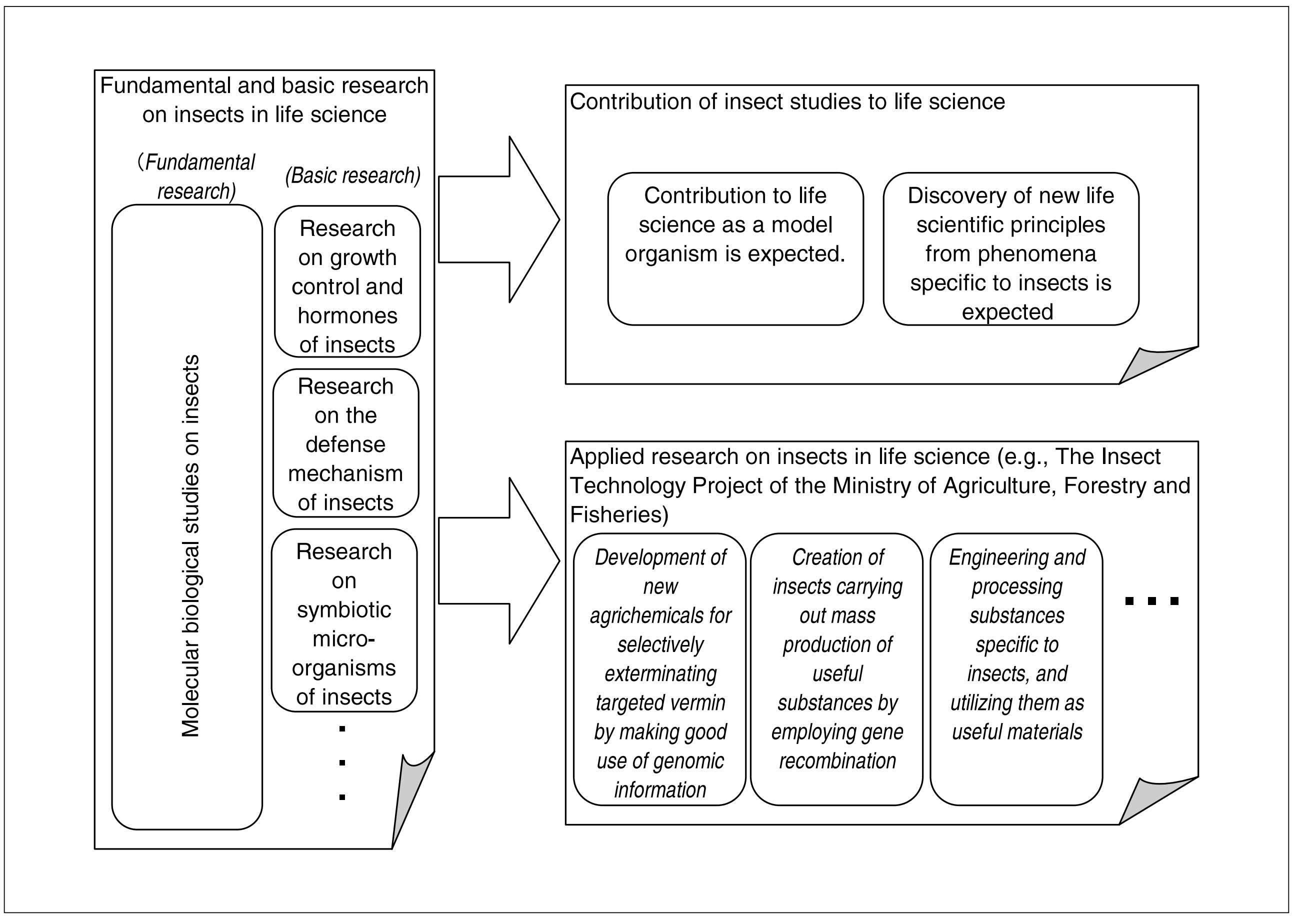


Table 1: Current status of insect genome sequencing projects

	Classification of the insect	Genome size	Genome sequencing project
Silkworm *(Bombyx mori)*	Lepidoptera	540Mbp	In progress (Japan)
Fruit fly *(Drosophila melanogaster)*	Diptera	180Mbp	Completed in 2000 (U.S.)
Anopheles *(Anopheles ganbiae)*		280Mbp	Completed in 2002 (Europe)

Source: Reference[3]

3.3.1 Molecular biological studies on insects[1,2]

Research on fruit flies has been the most advanced among molecular biological studies on insects.

Fruit flies have been focused on as experimental materials of biology since Dr. Thomas H. Morgan of Columbia University employed them as materials for genetic studies in the 1910s. Since then, fruit flies have acquired their importance as experimental materials and have been used in the improvement of the mutation induction method, gene mapping of salivary chromosomes and application of balancer chromosomes for maintaining mutation and even lethal genes.

Furthermore, a transposon, or a moving gene, called P factor was discovered and transformation technology in fruit flies using it was established in the 1980s. In 2000, the fruit fly's whole genome was sequenced, a first for insects, and the position of the fruit fly as a model organism was secured. Now, gene functions of the fruit fly are investigated with genome informatics based on the genomic sequence, gene expression analysis using microarray, gene expression suppression with RNA interference and gene targeting (gene knockout).

Completion of the whole genome sequencing in a model organism radically changed the gene function analysis method. That is, it became possible to estimate the function of a particular gene from the genome database. This method is called reverse genetic analysis and enables the supposition of the functions of other organisms' homologous genes from the fruit fly's genomic information. In this way, whole genome sequencing of a species not only helps unveil every biological feature of the species but also gives various advantages to other fields of study.

In insects, whole genome sequencing of the fruit fly was completed in 2000 by a consortium of Celera Genomics, U.S., and university researchers, and whole genome sequencing of the anopheles was completed in 2002 by an international consortium including Celera Genomics and European research institutions. Meanwhile, Japanese researchers are promoting *Bombyx* silkworm genome studies (Table 1).

The silkworm belongs to Lepidoptera, whereas the fruit fly and the anopheles, whose whole genome sequencings have been completed, belong to Diptera. Lepidoptera and Diptera are thought to have diverged at least 240 million years ago. This distance corresponds to that of mammals and birds, so even though whole genome sequencings of the fruit fly and the anopheles have been completed, whole genome sequencing of the silkworm is still highly necessary.

Researchers not only in Japan but also in other countries recognize silkworm genome studies to be crucial in life science of insects. The Ministry of Agriculture, Forestry and Fisheries of Japan included the silkworm's whole genome sequencing using the shotgun method into the extra budget for FY 2002. The ministry will vigorously promote the sequencing with the shotgun method even in and after FY 2003 in the Insect Technology Project to complete the whole genome sequencing as soon as possible (Table 2). However, silkworm genome sequencing has just been launched and we need to complete it immediately in order, for example, to apply the genomic information to gene function analysis and genomic-based drug discovery. Further cooperation of Japanese institutions that have experiences in human, mouse and microbe genome sequencing is essential in order to complete the silkworm's whole genome sequencing as early as possible.

The silkworm is thought to be more favorable than the fruit fly in industrializing the production

Table 2: Projects which have promoted the silkworm's genome research and their results

Year	Projects	Results
FY 1996 – 1998	CREST: "Mechanism of molecular responses between viruses and host insects"	Construction of the silkworm's EST*1 database, construction of a BAC*2 library, etc.
FY 1999 – 2003	Research for the Future Program: "Gene network upon sex decision of insects"	Analysis of the structure of the silkworm's sex chromosomes, construction of the silkworm's EST database, analysis of EST microarray, construction of BAC contig, etc.
FY 1999 – 2002	Ministry of Agriculture, Forestry and Fisheries: "Analysis of animal genomes--insect genomes"	
FY 2000 – 2004	Bio-oriented Technology Research Advancement Institution:"Establishment of the gene function analysis system of the silkworm"	
FY 2002	Ministry of Agriculture, Forestry and Fisheries: "Analysis of animal genomes — insect genomes" (subsidized from the extra budget)	Initiation of the silkworm's whole genome sequencing using with the whole genome shotgun method
FY 2003 –	Ministry of Agriculture, Forestry and Fisheries: "Insect Technology Project"	

***1 Expressed sequence tag (EST)**
Partial nucleotide sequence of complementary DNA (cDNA) of mRNA is called EST. Since cDNA reflects the nucleotide sequences of the genes expressed in the cell, EST helps estimate which genes are expressed in the cell.
***2 Bacterial artificial chromosome (BAC)**
Bacteria-derived artificial chromosomes into which genome fragments of more than 100kbp can be inserted. Since BAC can be easily handled, it is used to construct the genomic library covering the whole genome sequences.

Note: Some names in this table are abbreviated.

Table 3: Functions and structures of major insect hormones

Names of insect hormones	Molecular classification	Chief functions	Isolation of the hormone and clarification of its structure
Molting hormone	Steroid	Regulation of molt and metamorphosis	Butenandt et al. (Germany 1954)
Juvenile hormone	Terpenoid	Regulation of molt, metamorphosis and reproduction	Röler et al. (Germany 1967)
Peptide hormone			
Bombyxin	Peptide	Induction and enhancement of cell proliferation	Hiromichi Nagasawa, Akinori Suzuki et al. (Japan 1984)
Prothoracicotropic hormone	Peptide	Regulation of molting hormone secretion	Atsushi Kawakami, Akinori Suzuki et al. (Japan 1990)
Diapause hormone	Peptide	Induction of the silkworm's egg diapause	Kunio Imai, Okitsugu Yamashita et al. (Japan 1992)

of useful substances with insects by gene engineering, mainly because it produces and secretes a large amount of uniform silk proteins outside the body. Yet, the hard shell of the silkworm's egg is unfavorable for conducting gene engineering on the egg.

3.3.2 Research on growth control and hormones of insects

Among insect hormones, it has been known for a long time that the molting hormone and the juvenile hormone control molt and metamorphosis. Recently, researchers unveiled the structures of various peptide hormones, which serve as brain hormones for regulating the molt and juvenile hormones. As shown in Table 3, Japanese researchers play a leading role in studies on the insect hormone, especially the peptide hormone. For example, they clarified the structures of the prothoracicotropic hormone and the diapause hormone.

Particularly, since the prothoracicotropic hormone holds the key to insect growth control, its research bears a profound meaning. We should note that such remarkable fruits could be obtained because large amounts of silkworms, which serve as materials for the purification of hormones, were available in Japan.

In advance of world researchers, Dr. Akinori Suzuki of the Faculty of Agriculture, The University of Tokyo, and his colleagues successfully unveiled the structures of various peptide hormones in the brain, such as the prothoracicotropic hormone, in the "Structures, functions and dynamics of insect brain peptides, especially the prothoracicotropic hormone" project that was supported by the Grant-in-Aid for Scientific Research (Specially Promoted Research) of the then Ministry of Education, Science, Sports and Culture from FY 1989 to 1992. His group also advanced functional analysis of these hormones.

Moreover, analysis of hormone action in insects such as the operation mechanism of the silkworm's diapause hormone, environmental response and neuroendocrine regulation of the hormone was accelerated in the "Molecular mechanism of metamorphosis and diapause of insects" project (representative: Dr. Okitsugu Yamashita; FY 1996-1999), which was supported by the Grant-in-Aid for Scientific Research on Priority Areas. In this study, Dr. Yamashita and his colleagues analyzed biosynthesis, secretion control, dynamics in the blood and action in the targeted organ of peptide hormones and expression of molting hormone receptor genes. These research objects have been taken over and further promoted by the "Expression mechanism of insect-specific functions and their development" project (representative: Dr. Okitsugu Yamashita; FY 1999-2003) of the Research for the Future Program.

3.3.3 Research on the defense mechanism of insects

A highly developed defense mechanism is a major factor of insects' prosperity.

When the body surface of an insect is injured, antibiotic compounds are produced to combat invading microbes. Dr. Shunji Natori of the Institute of Physical and Chemical Research has pursued his research on antibiotic proteins of the flesh fly *Sarcophaga peregrina* in the "Defense mechanism of insects" project, which was supported by the Grant-in-Aid for Scientific Research on Priority Areas in FY 1996-1999, and the "Defense mechanism" project in FY 1999-2002 in the Core Research for Evaluational Science and Technology (CREST) of the Japan Science and Technology Corporation (JST). In this study, he found that *Sarcophaga* produces various defensive chemical compounds from low-molecular-weight compounds to peptides and proteins in order to protect itself from enemies. Furthermore, he suggested that production of these defensive compounds is induced not only when the body surface of *Sarcophaga* is injured; they also serve as growth factors of the imago primordium at the molting period.

Defensive compounds have been discovered from many insects such as the silk moth and the beetle as well as *Sarcophaga.* More than 200 kinds of such compounds have been reported since a defensive compound of an insect was first found in the 1980s.

Table 4 shows some examples of antibiotic proteins among defensive compounds of insects. As this table indicates, antibiotic proteins are classified into several groups according to the homology of amino acid sequences.

Dr. Minoru Yamakawa of the National Institute of Agrobiological Sciences has isolated antibiotic proteins from the silkworm and the beetle, and investigated their operational mechanism in the "Research on utilization of insects' functions" project from FY 1996, which was supported by the Special Coordination Funds for Promoting Science and Technology for encouraging Centers of Excellence (COE). This research has been taken over and put forward by the "Property analysis and engineering of antibiotic proteins of insects" project of the Bio-oriented Technology Research Advancement Institution from FY 2001. Among antibiotic proteins, cecropin- and defensin-type proteins show bactericidal effects by perforating the cell membrane of the bacteria and are even effective against methicillin-resistant *Staphylococcus aureus* (MRSA; a Gram-positive bacterium), which causes a nosocomial infection. Their application as insect-derived pharmaceuticals is highly expected.

3.3.4 Research on symbiotic microorganisms of insects

Insects account for about 70% of all animal species, and 60% of all insects presumably have symbiotic microorganisms. Symbiotic microorganisms

Table 4: Examples of insect-derived antibiotic proteins

Classification of the protein	Examples of insects in which the protein is found	The protein is active to:
Cecropin type	Silk moth, *Sarcophaga peregrina, Drosophila melanogaster*	Gram-positive bacteria and Gram-negative bacteria*
Defensin type	*S. peregrina, Apis mellifera, Aeschna mixta,* a kind of stinkbug, beetle	Mainly Gram-positive bacteria
Attacin type	Silk moth, *S. peregrina, D. melanogaster*	Gram-negative bacteria
High-glycine-containing antibiotic protein type	*S. peregrina, D. melanogaster, A. mellifera,* a kind of Tenebrionidae, a kind of Pyrrhocoridae	Gram-negative bacteria
High-proline-containing antibiotic protein type	Silk moth, Fruit fly , *A. mellifera,* a kind of stinkbug	Gram-negative bacteria

*** Gram-positive and Gram-negative bacteria**
Bacteria can be classified into Gram-positive and Gram-negative bacteria. Gram-positive bacteria are dyed purple with the Gram staining method. Lactic acid bacteria and MRSA are examples of Gram-positive bacteria. On the other hand, Gram-negative bacteria are not dyed with the Gram staining method. Escherichia coli is an example of Gram-negative bacteria.

Source: Prepared based on Reference[4] with some added changes.

living in insect bodies are regarded as a reservoir of unknown useful substances. In addition, further advancement of studies on insect-microorganism symbiosis will help us to understand not only the basic mechanisms of biological phenomena but also the process of evolution.

Dr. Hirofumi Watanabe of the National Institute of Agrobiological Sciences revealed that termites as well as their symbiotic microorganisms have cellulase (cellulose-decomposing enzyme). Research for utilizing the cellulase of termites and their symbiotic microorganisms is accelerating in order to globally exploit cellulose as biomass.

Meanwhile, research on symbiotic microorganisms of insects in evolutionary biology has been conducted on *Wolbachia*, which is a symbiotic microorganism of about 17% of arthropods including insects and controls sex and reproduction of its host in several ways, and on *Buchnera*, a symbiotic microorganism of the aphid. These studies were promoted in the “Analysis and utilization of the molecular mechanism of the insect-microbe parasitic and symbiotic system” project (representative: Dr. Hajime Ishikawa; FY 1996-2000) of the “Promotion project of basic research for creation of new technology and realms” of the Bio-oriented Technology Research Advancement Institution. Recently, horizontal gene transfer (a phenomenon that the gene of a particular organism is transferred to the genome of another species) from *Wolbachia*, which is a procaryote and intracellular symbiotic microorganism, to *Callosobruchus chinensis*, an eucaryote, was experimentally proved, and *Wolbachia* came to be focused on as a key to unveiling the mechanism of gene transfer. In the meantime, sequencing of the whole genome of *Buchnera*, a symbiont of the aphid, was completed in 2000 for the first time in the world as a symbiotic microorganism of the insect.

Research on symbiotic microorganisms of insects has fallen behind because their artificial cultivation has been impossible. Yet, as technology to amplify their DNAs and sequence them has been improved, researchers have discovered interesting phenomena without artificially cultivating symbiotic microorganisms. For example, it was realized that a general start codon of AUG is unnecessary to initiate translation in a parasitic RNA virus of an insect. This is a significant discovery that may change the principle of the translation mechanism. In this way, studies on symbionts can trigger the new development of life science. Symbiotic microorganisms of insects are regarded as a reservoir of future pharmaceuticals and agrichemicals, and construction of their gene libraries will be a base for research in pioneering new insect-related industries.

3.4 Conclusion

Life science of insects is about to enter the post-genome era in which researches are based on the whole genome sequence of each insect. If, following the fruit fly and the anopheles, we complete whole genome sequencing of the silkworm , which is far distant from the fruit fly and the anopheles on the phylogenetic tree, we can further enhance the clarification of every biological feature of model organisms like the fruit fly and the silkworm. Moreover, our understanding of insects in the realm of life science will be greatly deepened. Therefore, it is meaningful to promote the silkworm's whole genome sequencing project in Japan, where researchers have pursued various biological studies on this insect.

Furthermore, on such research bases, it is also crucial as a field of life science to enhance analysis of functions specific to insects, such as research on growth control and hormones, the defense mechanism, and symbiotic microorganisms of insects.

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References

[1] The Molecular Biology Society of Japan, Developmental genetics of the fruit fly, Maruzen Co., Ltd. (1989).(in Japanese)

[2] Aigaki, Toshiro, Analysis of the functions of the fruit fly genome, Protein, Nucleic Acid and Enzyme, pp. 2436-2440 (2001).(in Japanese)

[3] Takeda, Satoshi, Future of Insect Properties, Kogyo Chosakai Publishing Co., Ltd. (2003).(in Japanese)

[4] Suzuki, Koichi; Takeda, Satoshi; Kuwano, Eiichi; Yamakawa, Minoru; Bando, Hisanori; Honda, Hiroshi; Tamura, Toshiki; and Kimura, Kiyoshi, Studies on insect function utilization, Asakura Publishing Co., Ltd. (1997).(in Japanese)

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4

Trends in RFID Technology

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4.1 Introduction

4.1.1 Every "physical object" will be networked before long

The Internet, on which research started more than 30 years ago for military purposes, was originally a network connecting only four U.S. research institutes. The technology continued to develop for academic applications until its commercial use by for-profit organizations was allowed in the 1990s, a change that led to an explosive spread of the Internet across a wide range of regions and users, driven by the improved capability of personal computers (PCs) and the establishment of the backbone network infrastructure. More recently, with the increased user population of mobile information terminals such as PDAs and Internet-enabled cellular phones and with the commercialization of networked digital home appliances, we have seen the approach of a ubiquitous network society in which every individual can gain access to the Internet anytime, anywhere.

Some say, however, this is only the beginning.

Devices that formed the networks have been electronic equipment, typically the computer, and thus the "virtual" world they created has been separated from the "physical objects" in the real world. The data running through the networks have been nothing but the information held by electronic devices, while the data regarding the "physical objects" existing in the real world beyond such information has been exchanged on a limited basis.

Today, as every electronic device is being networked, it is becoming more realistic that, as a step toward the next phase, the "physical objects" in the real world will also be networked before long.

4.1.2 Higher need for traceability

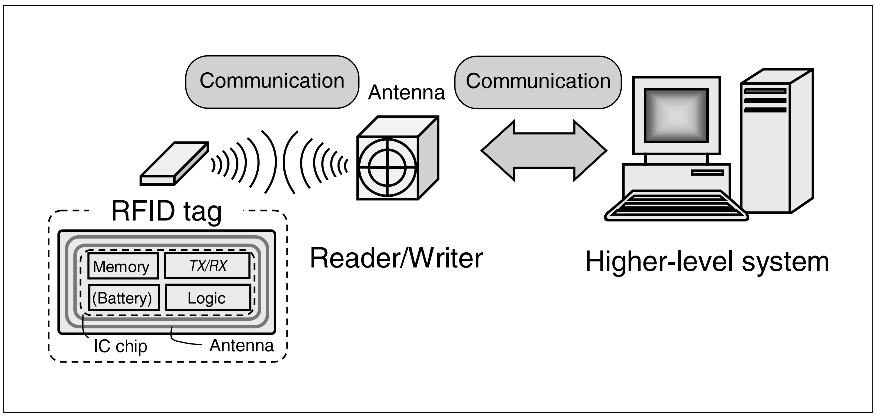
Aside from the above technological development, a demand for complete traceability of every object is surging in society for the reasons listed below.

(1) More efficient supply chain management
(2) Protection against loss of merchandise due to theft such as shoplifting
(3) Ensured security and strengthened counterterrorism
(4) Ensured safety of food and other products

In the distribution industry, supply chain management, which helps minimize inventory while eliminating loss of sales opportunities by preventing stock shortages, is an important tool for securing profits. In addition, given a report[1] that estimates there is a significant amount of loss of merchandise during distribution and sale due to freight theft, shoplifting and other forms of theft in the U.S., the establishment of a system to track and trace products (traceability) is an urgent issue especially for producers and distributors. This motivated the 1999 foundation of the Auto-ID Center[2], a consortium that is pushing for the development of a distribution management system as a replacement for bar code systems under the sponsorship of such leading manufacturers and retailers as Procter & Gamble, Gillette and Wal-Mart.

Since 9/11 and the subsequent anthrax cases, the U.S. government, for improved security, has been more seriously urging the real-time management of any flow of goods into and any distribution within the nation, including their history records. Now, the target is being expanded beyond commodity products to cover every object. Meanwhile, in the wake of the outbreak of widespread E. coli food poisoning,

Figure 1: Basic structure of an RFID system



BSE (Bovine Spongiform Encephalopathy) and a series of false indications on the origin of food products, a need for traceability is increasing in Japan, even among consumers, who demand ensured safety on what they purchase.

In the technology domain, the recent advancement and further integration of LSI technology, in addition to the development of computers and networks, are enabling commercial use of the technique to embed miniature IC chips for identification into every object at reasonable costs.

These are why radio frequency identification (RFID), or using radio waves for automatic identification, has become a recent focus of attention as a concept of enabling direct exchanges of information between networks and "physical objects." Allowing networks, which have been completely "virtual," to exchange information with "physical objects" will have a significant impact on society. Not only will it change the living environments of individual persons, but will generate new values, services and problems no one has ever seen. This report provides an overview of recent trends in RFID, followed by a discussion on RFID's potential impact on society.

4.2 What is RFID?

4.2.1 Basic structure of an RFID system

Figure 1 shows the basic structure of an RFID system. An RFID tag, which consists of an IC chip and an antenna and has a unique identification number, communicates with a reader/writer, a device that reads the ID number, to exchange information using radio waves. While the tag is usually called an RFID tag when embedded in an object, it is referred to as a "contactless smart card" when being carried by a person, even if both provide the same functionality. The key feature here is that exchange of information between an RFID tag and a reader/writer occurs automatically, with no human assistance. This is in contrast to existing bar code technology, which requires people to scan tags. RFID is also different from bar code systems in that information contained in an RFID tag can be rewritten as needed while bar codes are read-only. The IC of an RFID tag is run by the power drawn from the reader/writer through electromagnetic induction over its antenna. In addition, some RFID tags have a built-in battery. IC chips in RFID tags can have either read-only or read-write memory.

Data that is automatically read/written on an RFID tag through radio communication are exchanged, together with the records of such revisions, with a higher-level computer via the network. The data including the revision history is stored on the network's host computer or in the internal memory of the RFID tag for accessibility from the outside as needed.

4.2.2 Movement of objects and the flow of information

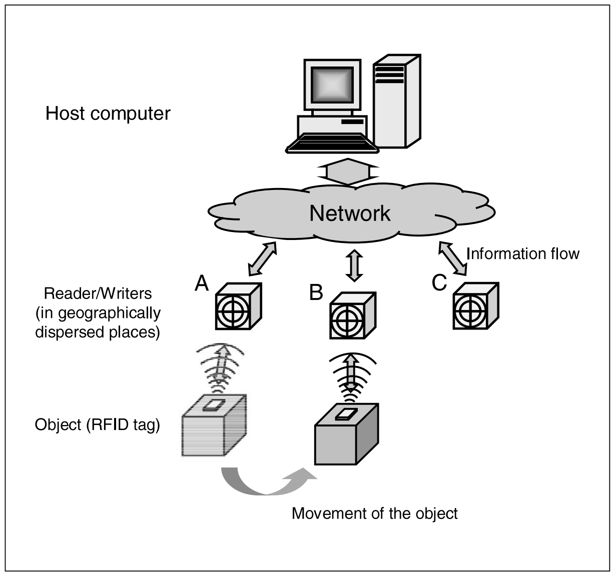
Let us look at a situation where multiple reader/writers are installed in geographically dispersed places and RFID tags maintain communication with the closest one of them at all times (Figure 2). In such a situation, it is possible to track down the current location of a specific object, based on the location information captured by the reader/writers, by constantly monitoring which reader/writer communicates with the object containing the RFID tag with the specific ID number. Even when switching from reader/writers as the object moves, continuous monitoring of the communications status enables the tracking of temporal changes in its location, which provides the item's distribution details including the history. This is how constant communications between RFID tags and reader/writers can make the online location information completely identical to the physical location of objects.

When capturing the location information of physical objects so as to be linked with online data, three different cases as shown in Table 1 are possible depending on how data processing tasks are shared between the RFID tag and the host computer.

Case 1 assumes that all the information about the distribution history is sent through the network to the host computer for storage. This helps minimize the functionality loaded on the RFID tag. Case 2, the opposite concept of Case 1, maximizes the capability of the RFID tag. Case 3 is a mixture of Case 1 and Case 2.

Since Case 1 allows for narrowing the functions of the RFID tag, possibly enabling reduction of the cost of RFID tags, its commercialization will most likely start in cost-oriented areas such as the replacement of bar codes. Case 2, by contrast, requires the most complicated capabilities among the three to be added to the RFID tag, resulting in higher costs. However, this type of system will prove effective where security and privacy are given the highest priority, as in the case with smart cards intended to be carried by people, and where network loads must be reduced. Developers of each type of technology are vying for more applications and setting up technical standards.

Figure 2: Movement of objects and the flow ofinformation



In RFID, information may be exchanged between tags and the host computer either globally through the Internet or locally through a LAN. The network configuration, the RFID tag's data structure and the volume of information traffic vary depending on the type of network to be used. Technologies for exchanging distribution information worldwide through the Internet are expected to grow toward the future. For applications that are designed only for reading the ID numbers of goods in a closed network, there are already many examples of the commercial use of the RFID tag combined with a POS[*1] system in a local environment as a replacement of bar codes. Table 2 compares features of traditional bar code technology with those of its possible successor, RFID.

4.2.3 RFID's history and recent trends

RFID is said to have originated in World War II, for which Britain developed the technology to distinguish between friendly and enemy aircraft. In the 1970s, research and development on its basic technologies

Table 1: Scenarios for information processing

	RF tag function	Object's history	RF tag costs	Network loads
Case 1	ID number only (Read-only memory)	Stored on the host computer via the network	Low	Heavy
Case 2	ID number and history (Read/write memory)	Stored on the RF tag	High	Light
Case 3	ID number and history (Read/write memory)	Stored on the RF tag and the host computer	Mid to High	Mid to Heavy

Table 2: Bar code vs. RFID features

System	Bar code	RFID	Notes
Reading method	Optical	Electromagnetic induction	
Max. read range	up to 50 cm	Several meters	RFID's range depends on the radio wave's frequency, etc.
Human assistance in reading	Yes	No	With RF tags, no cashier is needed at checkout counters
Susceptibility to environments	Large	Small	Soiled labels, etc.
Data capacity	1 - 100 Bytes	128 - 8K Bytes	Several Kbytes in two-dimensional bar codes
Simultaneous reading of multiple codes	Not enabled	Enabled	
Unauthorized copy	Easy	Difficult	
Costs	0 - several yen	Up to 10 yen	For RFID, current costs for Rread-only
Reading occurs	Limited times	Fequently	

was conducted in the U.S. with an eye to application to cattle tracking, identification of railroad cars and so forth. In the 1980s, RFID was used at manufacturing sites in Japan for automated distribution control. The technology gained widespread recognition in the 1990s, when automatic ticket gate systems that use contactless smart cards instead of conventional magnetic cards became commercially available in Hong Kong and Singapore.

In recent years, contactless smart cards have been moving into actual use in Japan as well. Applications include automatic ticketing systems such as East Japan Railway's Suica, employee entry/exit registration, automatic lift ticketing and cashless payment systems in ski areas, and electronic toll collection (ETC) systems for highways.

In the low frequency range (125 kHz), which is the range most proven for the use of RFID tags in Japan, the technology has found application in areas such as the entry/exit control of uniforms sent to the laundry, rail containers, and at the checkout in revolving sushi bars. Table 3 shows typical application examples. Because of the Radio Law, radio wave output in the HF shortwave band (13.56 MHz) has been restricted more in Japan than in other countries. Since the communication range was limited to only about 30 cm under the law, the use of RFID tags was not as prevalent in Japan as overseas. However, the Radio Law was finally revised in September 2002 to relax domestic restrictions on this frequency band to levels equivalent to other nations, a change that is expected to contribute to increased applications of RFID tags in years to come.

4.2.4 Developments surrounding standardization

In the RFID arena, just as in the case with contactless smart cards and RFID tags, which are replacing magnetic cards and bar codes respectively, commercialization has begun with applications aiming at adding functions to and improving the reliability of existing systems. In the near future, these systems based on traditional local networks are expected to be transformed, through interconnected networks and other means, into systems that use worldwide networks to cover wider areas. A hurdle for RFID technology in expanding its application fields is technical standardization.

Table 4 shows recent developments in RFID standardization.

A physical communications protocol for RFID tags, for example, is being established under the leadership of the ISO, which intends to issue an international standard in 2003. In an effort independent of the ISO-led standardization, the Auto-ID Center is scheduled to propose the first version of its original technical specifications in September of this year. In Japan, with a view to realizing a ubiquitous society, the Ubiquitous ID Center was established in March 2003 as part of the TRON Project. As described above, there has been no unified standardization activity for RFID technology so far, leaving individual institutes to develop their own drafts.

Table 3: Major RFID applications

Field	Application purpose or system name	Operator	Status	Format
Train/bus tickets	Town-operated bus fare collection	Toyoda-cho, Iwata-gun, Shizuoka	Deployed in 10/1997	Smart card
	Daikanyama loop-line bus fare collection	Tokyu Transe	Deployed in 07/1998	Smart card
	Bus tickets/commuter passes	Yamanashi Kotsu	Deployed in 02/2000	Smart card
	"Suica" ticketing system	East Japan Railway	Deployed in 11/2001	Smart card
Highways	"ETC" automatic toll collection system	Japan Highway Public Corporation, et al.	Deployed in 03/2001	Smart card
Sports and amusement facilities	Ski lift ticket gates	Shiga Kogen Ski Cable Association	Deployed in 11/1992	Smart card
	Cashless payments within the pool area	Toshimaen	Deployed in 06/1996	RF tag
	Information management within the facility	"Yunessun" spa resort	Deployed in 01/2001	RF tag
Entry/exit control	Entry/exit control and cafeteria payments	Komukai plant, Toshiba	Deployed in 02/1989	Smart card
Vehicle control	Entry/exit control ofin the underground parking	Ebisu Garden Place	Deployed in 10/1994	Smart card
Distribution	Airline baggage control	Land, Infrastructure & Transport Ministry and airport authorities	Field tested in 10/2001	RF tag
	Product traceability	Economy, Trade & Industry Ministry	Study group formed in 02/2003	RF tag
Retail	Book sales management	Publishing trade group	Initiative launched in 03/2003	RF tag
Others	Rail car number reading	East/Central Japan Railway	Deployed in 1991	RF tag
	Automatic checkout counters in cafeteria	Nippon Steel Trading	Deployed in 04/1994	Smart card
	Revolving sushi bar checkout	Japan Crescent	Deployed in 2000	RF tag
	Library checkout	Kitakata-cho, Miyazaki	Deployed in 05/2001	RF tag

Source: Authors' compilation based on a reference[3]

Table 4: Activities at individual organizations

Organization	Year					
	'99	'00	'01	'02	'03	'04
International Organization for Standardization / International Electrotechnical Commission					RF tag standards (communications protocol) ▼ Final draft (May) ▼ Publication (Nov.)	
Auto-ID Center (MIT)	▼ Inauguration				▼ Establishment of Japanese unit (Keio Univ., Jan.) ▼ Technical proposal (Sept.)	
Ubiquitous ID Center (TRON Project)					▼ Inauguration (Mar.)	

4.3 Standardization activities

4.3.1 The frequencies for RFID

As RFID uses radio waves to allow RFID tags to communicate with reader/writers, the frequencies for these radio waves must be secured first, in addition to the physical specifications such as the communications method. In an era of distribution across borders, development of an international standard for built-in RFID tags is also indispensable if RFID tags are to be shared across different countries. However, a major hurdle exists before standardization because parts of the spectrum available for RFID, which serve as the standard for the initial physical interface (air interface) between the RFID tag and the reader/writer, are sometimes varied across nations depending on their allocation of the spectrum.

The first step is to decide, from a technical point of view, which band of the spectrum should be used. Factors such as the range of radio waves, directivity and antenna size must be taken into consideration in choosing the band appropriate and suited for each expected application. Contactless smart cards, which are intended to be carried by people, should preferably be in sizes that are easy to handle. These cards are available in the same form as magnetic cards and are increasingly replacing magnetic cards as they become more widely available, driven in part by the fact that they can have a relatively large antenna and use the HF shortwave band (13.56 MHz) as standardized by ISO.

In the case of embedded RFID tags, on the other hand, developers cannot help but move toward miniaturization of tags, including antennas, to reduce costs for the purpose of displacing bar codes. As smaller antennas have characters that are more fitted for higher frequencies, frequencies higher than the HF band will be needed for them. Frequencies around 13.56 MHz of the HF band, in which the RFID tag will communicate with the reader/writer through electromagnetic induction, provide poor antenna directivity and a short read range of no more than a few tens of centimeters. If an RFID tag is embedded in an object larger than this size, reading may be impossible, rendering the HF band an undesirable choice. In much higher frequencies such as the microwave frequency band (2.45 GHz), by contrast, radio waves are attenuated by molecules of water, limiting application to objects with high-water content such as food products. The above discussion leads us to the conclusion that the UHF band[*2] is the most prominent candidate to win the position of the most preferable frequency band for RFID tags, because it provides better directivity and longer read ranges.

In the development of international standards in ISO/IEC[*3], working draft proposals on the air interface standards targeting the frequencies ranging from low to as high as 5.8 GHz were followed by additional proposals from the U.S. and Europe on 860-930 MHz (ISO/IEC 18000-6) and 433 MHz (ISO/IEC 18000-7). Table 5 shows the proceedings of the discussions on the air interface standards (ISO/IEC 18000) in ISO/IEC.

Table 5: Proceedings of the discussions on the air interface physical standards

Name	Number	Frequency	Working Draft (WD)	Committee Draft (CD)	Final CD (FCD)	Final Draft of IS (FDIS)	International Standard (IS)
Air Interface	18000-1	(Generic Parameters)	2000.12	2001.09	2003.02	2003.05	2003.08
	18000-2	Below 135 kHz	2001.03	2002.03	2003.02	2003.05	2003.08
	18000-3	13.56MHz	2000.12	2002.03	2003.02	2003.05	2003.08
	18000-4	2.45GHZ	2000.12	2002.03	2003.02	2003.05	2003.08
	18000-5	5.8GHz	2002.06	2002.11	withdrawn		
	18000-6	860-930MHz	2002.06	2002.11	2003.05	2003.08	2003.11
	18000-7	433MHz	2003.01	2003.01	2003.05	2003.08	2003.11

Source: Authors' compilation based on references[3,4]

It demonstrates that while ISO/IEC 18000-1 to 18000-4 took more than two years to evolve from the working draft to the final committee draft, ISO/IEC 18000-6 and 18000-7, the late proposals, were quickly developed into standards. Although this was probably in response to the strong market demands, expeditious formulation of standards can act in favor of specific companies that promote the individual proposals. The issue is particularly critical to Japan, where both ISO/IEC 18000-6 and 18000-7 frequency bands have been assigned for other uses[*4]. As it is obvious that Japan cannot adopt the standards, if established as-is, without any impact on its existing systems, Japan must speak up to have its point of view reflected in international discussions.

The U.S., as part of its antiterrorism measures, is already moving toward enforcing the government-designated RFID tags to be attached to any item imported into the country in 2004 and later. If they start using tags that are incompatible with the tags used in Japan, this will have an immeasurable economic impact on Japanese industries that are highly dependent on exporting to the U.S. Furthermore, as long as the designated frequencies are not available in Japan, no one in Japan will be able to verify even the correctness of data stored in U.S.-designated RFID tags attached to goods imported from the U.S. or other nations. For the time being, Japanese companies could adopt such temporary approaches as dual mode[*5], in which they need to affix their original RFID tags at additional costs. Over the long term, measures at the government level, including measures for reviewing the current spectrum allocation, will have to be taken.

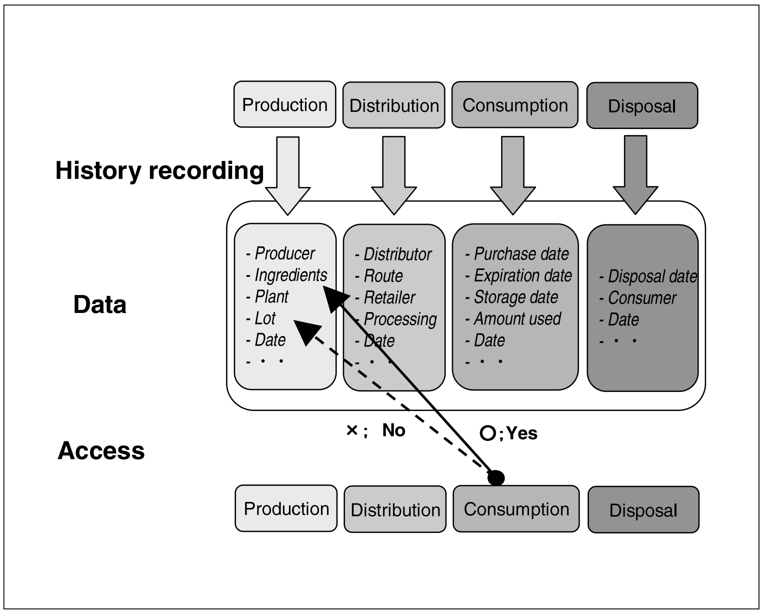
4.3.2 Coding scheme

What needs to be standardized after the frequency and other physical communications methods for RFID is the format of information to be communicated. This is equivalent to unique codes assigned to individual items in bar code systems. Currently, there are some different coding schemes for the bar code and, as different industries use different coding schemes, existing systems are not tailored for packaging and specifications that vary as the product goes through a number of production and distribution stages. To cope with this problem, the International Article Numbering Association (EAN International[*6]), which finally became a unified organization with the participation of the Uniform Code Council, Inc. (UCC[*7]) in the U.S. in November 2002, has just begun discussing coding standards specific to individual products and their types of packaging. The coding structure for RFID tags will probably follow the general concept of the bar coding scheme or, in some cases, will possibly secure backward compatibility with it. What should be noted here is the data length of the code. The greatest challenge for RFID in replacing existing bar code systems is its costs. Given that research and development for smaller antennas and IC chips[5] to reduce costs to the minimum is ongoing, the IC chip's memory should also be given minimal memory capacity, which means that the data length of the code to be assigned should remain at the shortest possible size.

The data length of the code, which is in direct relation to the data volume that runs on the network, is also dependent on the type of information transmitted over the network. This can affect the configuration of networks and host computers in the future. If all of the distribution information comes to be exchanged over the Internet, there may be considerably more frequent sending and receiving of data than is now occurring between PCs. Perhaps there is no need to connect even an item as small as a pencil to the Internet worldwide. In this context, it would be safe to say that all we need to track and trace goods imported or exported across borders is their information by the actual distribution unit such as the container or the pallet, as long as the location of individual items can be captured locally during packing.

The Japanese media more often reports on activities in the Auto-ID Center and the Ubiquitous ID Center. The Auto-ID Center is working toward assigning 96-bit code to individual objects, with a plan to extend the code up to 256 bits. The fact the Center seeks to promote the code allocation in collaboration with EAN International suggests that the Center is aiming for a de facto world standard with its

Figure 3: Conceptual illustration of access to product history



scheme. In the technology advocated by the Auto-ID Center, only code is assigned to objects with all the remaining information stored on the host computer on the network (Case 1 in Table 1). In contrast to this approach, the technology proposed by the Ubiquitous ID Center gives RFID tags more sophisticated functions with an eye to enabling the terminal to process information on the spot (Case 2 in Table 1). This will take part of the load off the network and allows RFID tags to process information in real time. Adding a multitude of functions to the RFID tag, however, results in more expensive tags, posing a number of challenges in terms of costs that must be overcome before embedding RFID tags in every object. It is likely that the Auto-ID Center, which seeks to make the most of network capacity, and the Ubiquitous ID Center, which moves toward integrating functions into the RFID tag that is expected to act like a microcomputer, will continue to contend for the development of an ideal technology.

4.3.3 Restrictions on data usage

In a traditional bar code system, the code given to an object is not read so frequently, partly because code scanning cannot be completed without human assistance. Typically, a code is scanned only once, at the cash register for checkout, or if more often, a few times at most. Thus the use of the information captured is limited, for instance, to checking whether the item has passed through a checkout counter. In RFID, on the other hand, codes are automatically read at desired places as often as the number of reader/writers in operation for the system. The captured data, which contains any kind of distribution history of the object, is accumulated over time on the online host computer and/or in the built-in memory of the RFID tag itself.

A database of the distribution information accumulated in this way should include every data element, whereas in contrast reference to the database would require varied levels of restriction from user to user (Figure 3). In the case of food products, for example, what kind of ingredients were used to produce them and whether any allergenic substance is contained in them are the information most demanded by consumers. Such information, except for the trade secret part, would have to be made accessible to consumers. However, information related to detailed production control, such as the production site and the lot number of individual products, would not have to be made directly available to consumers. Also, access to the distribution information after the product has been purchased by a consumer should only be given to such consumer for the protection of privacy.

This indicates that the data must be either structured to begin with or hierarchically stored in such a way that allows for user-specific access control to the accumulated data containing the product's history and other information.

4.4 RFID business models

Whether or not RFID technology comes into widespread use in the future will be determined by how it will be able to improve the efficiency of existing businesses and generate new added values. The initial objective for a U.S. company to deploy RFID is assumed to be for improved efficiency in its overall distribution supply chain. By replacing RFID with its existing bar code system, the company could expect a range of improvements such as enhanced operational efficiency, prevention of human errors and less frequent checks at various stages of distribution. Outside the supply chain, there would also be improvements in the following areas, for example:

(1) Ensured safety and human error prevention in businesses handling hazardous materials;
(2) Improved productivity and minimized equipment downtime in the manufacturing industry; and
(3) Enhanced customer service in the retail industry.

Through the deployment of bar code systems, which enable operators to scan bar codes instead of keying in merchandise information, companies must have successfully improved efficiency in their supply chain. RFID can bring additional benefits as it allows input of information to terminals with no human involvement. With RFID, businesses will be able to further reduce labor, eliminate errors and speed up operations. The diffusion of the technology in the distribution field is dependent on whether or not RFID can improve operational efficiency to the extent that compensates for the deployment costs or can produce new added values.

In terms of increasing corporate profits, loss of merchandise due to theft is another area that requires consideration. Earlier this year, Gillette attracted attention when it announced a plan to buy a total of 500 million RFID tags in the next three years to conduct a market test of RFID. While the company stated that the implementation was intended for the reform of its supply chain management, there was a report that pointed out Gillette took the measure to actually prevent loss of merchandise due to theft[6]. When retailers have an average profit margin of around 3%, it is said they lose as much as 2% of sales to loss of merchandise arising from internal and external theft. Stolen product problems should be discussed from two points of view: direct damage from theft and the impact to the supply chain deriving from gaps between the number of products registered on the system and the actual product count. This is becoming an issue of vital importance to bookstores, as it is reported bookstores across Japan suffer an average annual loss of 2.10 million yen (1-2% of sales) per store due to shoplifting[7]. A problem here is “who will pay” the cost for implementing RFID, because the party who will benefit from the system is, in general, not the party who will have to pay. This is not an issue related to a single company or a single store, but an issue involving the entire supply chain. An industry-level approach from a long-term perspective is required to solve this problem in combination with the standardization of specifications.

In another move led by the Ministry of Land, Infrastructure and Transport, application of RFID to manage air travelers’ baggage is being planned. Their scenario is attaching an RFID tag to a packed suitcase when it is picked up at the traveler’s home by someone from the baggage delivery company. The tag is automatically passed to the airline company and tracked until the traveler receives the suitcase at the destination. In this application example, not only will travelers benefit from the service, but also delivery service operators will profit because the RFID system will save them the trouble of issuing baggage slips and passing them along. In addition, the system may even help immigration officers detect the possession of hazardous materials or drugs. In developing such a system, all of the four parties—travelers, delivery companies, airlines and the immigration authorities—need to participate in the discussion on how to implement RFID.

4.5 Hurdles before widespread use in society

From this August, Basic Resident Register cards will be distributed to the residents across the nation. It is understandable that rigorous security measures are needed to protect these contactless smart cards on which the resident identification number and other sensitive information to verify the identity of the holder are to be encoded. However, for the Suica system, a precedent application of the smart card, a small reader designed specifically for the system, with which anyone can easily read out from a Suica card information on when and where the card was used, is already commercially available[8]. Figure 4 shows an example of the usage status of a Suica card displayed on a PC. The card reader, which should do no harm as long as it is used by a cardholder to review what has been written on the card, can be a threat to privacy in some cases.

Compared to these smart cards, what are the potential risks of having RFID tags attached to objects? Since the RFID tags, which are intended to replace bar codes, must be inexpensive, they are read-only and thus no accumulated information is stored in the tags. Instead, all the history of a person's belongings is sent over the network to the host computer for storage. If you happen to be carrying any item with a built-in RFID tag, its signal might be captured by a reader without your knowledge, allowing the reader to recognize what you have. If you were carrying a few things such as a laptop, a digital camera and a magazine, for example, you would be easily identified based on that information. This poses a risk of enabling others to keep close track of specific individuals, a situation that must be avoided.

We should keep in mind that RFID is a technology that can potentially cause an invasion of privacy.

Other than the privacy issue, there are other areas that should be addressed. Once the RFID system has been implemented, how is it going to be operated, how are the new values, services, and problems going to be managed and by whom? As the system covers any "object,"

Figure 4: An example of usage status read out from a Suica card

there are a number of ministries and agencies concerned. They include not only the Ministry of Public Management, Home Affairs, Posts and Telecommunications and the Ministry of Economy, Trade and Industry, which both have already been working toward setting up technical standards, but also the Ministry of Land, Infrastructure and Transport, which should take the initiative in discussions regarding transport and traffic, and the Ministry of Agriculture, Forestry and Fisheries, which should lead activities for the use of RFID to establish traceability that can ensure food safety. With respect to the distribution of medical supplies, the Ministry of Health, Labour and Welfare could make proposals on new applications with some attention to the prevention of malpractice as well as to the establishment of traceability. In the security and privacy domains, the National Police Agency and the Ministry of Justice should promote debates on the legal aspects of RFID applications.

To allow RFID technology to widely penetrate into society in the future, not only standardization of technical specifications is needed but also building a social infrastructure that supports the technology. This means that simply considering RFID as one of the new technologies is not appropriate. Now is the time for government and society to thoroughly discuss the issue of RFID as a technology that has the potential of developing into an element of the social foundations and of changing the future social system as well as individuals' living environments.

Notes

*1 Point of sale is a system that records merchandise sales data at the time of sale in a store, so that the collected information can be used for inventory management and marketing.

*2 The Auto-ID Center and the EU have been developing technologies based on 915 MHz and 868 MHz, respectively.

*3 These international standards have been instituted by Sub Committees (SC) of the Joint Technical Committee (JTC 1), an organization subordinate to both the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). RFID is discussed in the technical direction "Data Capture and Identification Systems" in Sub Committees 17 and 31, whose secretariats are held by Britain and the U.S. respectively.

*4 In Japan, the frequencies of 433 MHz and 860-930 MHz have been assigned for amateur radio and mobile telephone use, respectively.

*5 The RFID tags that are designed for use at two different frequencies. They require a larger number of components and higher costs.

*6 The International Article Numbering Association was originally established in 1977 under the initiative of European countries to supervise the use of the European Article Numbering system, which has now become an international article coding system supported by an increasing number of member states around the world. The current membership consists of 97 countries.

*7 The Uniform Code Council, an organization established in 1973 and consisting of two member states (the U.S. and Canada). The code given according to UCC standards is called Universal Product Code (UPC).

References

[1] "2001 National Retail Security Survey Final Report," University of Florida, http://web.soc.ufl.edu/SRP/NRSS_2001.pdf

[2] http://www.autoidcenter.org/main.asp

[3] "2003 Guidebook to Contactless IC Cards and RFID", edited by Committee to Promote Contactless IC Cards and RFID (in Japanese)

[4] http://www.uc-council.org/

[5] http://www.alientechnology.com/

[6] "Nikkei Computer," March 10, 2003, p.17 (in Japanese)

[7] Web site of the Ministry of Economy, Trade and Industry, http://www.meti.go.jp/policy/media_contents/downloadfiles/1024Manbiki_gaiyou.pdf

[8] http://www.sony.co.jp/Products/felica/pcrw/sfcard_dl.html

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5

Creation of Power Supply Systems Incorporating Distributed Power Sources
— A Quest to Construct Systems Meeting Regional Demands in Japan —

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5.1 Introduction

Supported by the ever-increasing demand for electricity, large-scale centralized power supply systems have been enhancing power generation efficiency by expanding their operations, which in turn has improved their cost effectiveness, eco-friendliness and credibility. On the other hand, there is a growing movement to make use of distributed energy supply systems such as fuel cells and biomass as a means to curb global warming[1].

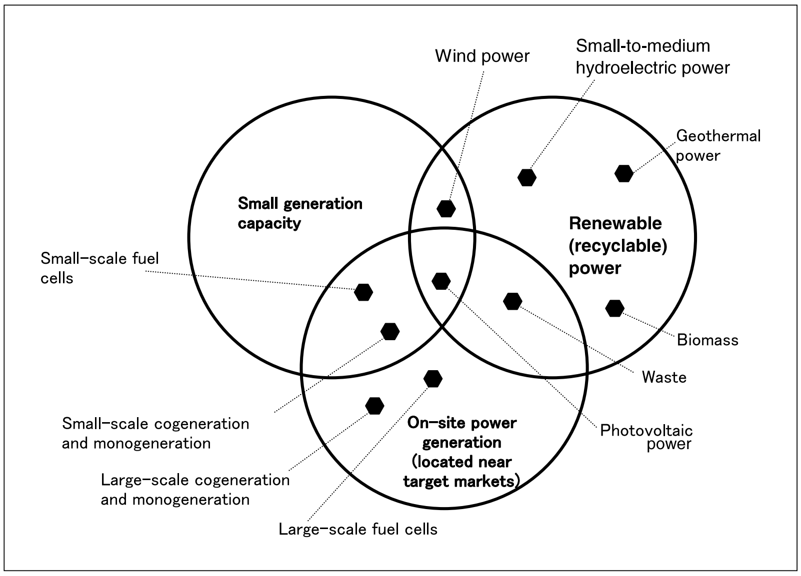
"New-energy Measures in the Future," a report prepared in June 2001 by the New Energy Subcommittee under the Advisory Committee for Natural Resources and Energy, established an innovation: it incorporated hydroelectric power generation (excluding pumping-up power generation) and geothermal power generation into the "supply-side new energy*1" to establish a category termed "renewable energy" with an aim to increase its share of the total supply of primary energy from 4.9% in 1999 (29 million kl out of 593 million kl) to about 7% in 2010 (about 1.4 times the amount in 1999, or 40 million kl out of 602 million kl) on a crude-oil basis. With regard to the "demand-side new energy,*2" namely natural-gas cogeneration and fuel cells, the plan is to increase their share by 3.1 times (4.64 million kW) and 183 times (2.2 million kW), respectively, compared with the 1999 levels. In the meantime, the RPS (Renewable Portfolio Standard) system*3 came into full operation on April 1, 2003. This system mandates power suppliers to use a certain amount of new energy in proportion to the amount of power they sell - they are obliged to use new energy equivalent to 1.35% (or 12.2 billion kWh) of the total amount of power they will sell in 2010.

The market for distributed power sources centered on cogeneration systems using generating machinery (gas engines and turbines, etc.) is expected to grow in the future.

In response to the recent deregulation in the electric industry*4 and the introduction of the RPS system, the circumstances surrounding Japan's power supply system is changing. While the conventional power supply system is relatively simple in its structure (i.e., a one-way flow, from supply to conversion and utilization of power), a system incorporating distributed power sources involves backflow of power - distributed power sources supply power to the electricity grid (i.e., energy flows back and forth through the system). In this case, however, power fluctuations of distributed power sources may have an impact on the grid to which they are connected[2]. It is thus necessary to create a power supply system that harmonizes distributed power sources with the power of grids.

This report, therefore, takes a broad view of the characteristics of distributed power sources in the framework of Japan's current power supply system, and points out what is needed for the future power supply system that is expected to incorporate an increasing number of distributed power sources. Furthermore, it provides an overview of the recent trends in the development of power supply systems incorporating distributed power sources in Japan, Europe and the U.S., and explores possibilities for constructing power supply systems responding to regional demands.

Figure 1: Classification of distributed power sources



Source: Author's compilation based on a reference[3]

Table 1: Characteristics of large-scale power sources and distributed power sources

	Power sources	① Power quality (frequency) characteristics	② Cost effectiveness	③ Eco-friendliness (CO_2 emissions)
Large-scale power sources	Nuclear power	— (see Note 1)	○	○
	Thermal power	○		×
	Hydroelectric power			○
Distributed power sources	New energy	×	△	
	Cogeneration system	△	○	△

Note 1: Base supply capacity

5.2 The Characteristics of distributed power sources in power supply systems

While large-scale power sources generally refer to nuclear and thermal power generation, distributed power sources include small-to-medium on-site power generation (located near target markets) that is renewable (recyclable) and limited in output power, as shown in Figure 1 (there is no clear definition at home and abroad of "distributed power sources" in terms of generation method and capacity).

Table 1 shows the power quality (frequency) characteristics, cost effectiveness and eco-friendliness of both large-scale power sources and distributed power sources. Of distributed power sources, photovoltaic and wind power generation is subsidized by the government and their surplus power is purchased by electric power companies because of their eco-friendliness. In particular, Japan leads the world in the introduction and total output of photovoltaic power generation. With respect to cogeneration systems, the ESCO (Energy Service Company) project is expanding, offering energy-saving services to the business sector including office buildings -e.g., improving energy-use systems by installing cogeneration systems, quantifying energy-saving effects after installation, and controlling the operations of the systems. This project enjoys part of the profits generated by energy-saving measures as a reward, which indicates that the running costs of cogeneration systems are approaching those of large-scale power sources.

With an increasing number of distributed power sources connected to the grid, the power quality of the entire power supply system may fluctuate, as mentioned earlier.

"Power quality" usually refers to the quality of voltage or frequency. An increase in power supply from distributed power sources to the grid (back flow of power) raises the voltage of the grid. There is thus a need to regulate the voltage (low voltage: 101V±6V) through regulators installed in the distribution lines or by the distributed power sources themselves.

With regard to frequency, a major problem involves frequency fluctuations caused by the connection of unstable power sources to the grid. Power demand fluctuates daily and seasonally[4], and hence the output of thermal power generation (oil, LNG, etc.) and hydroelectric power generation (pumping-up type or pondage type) is controlled in response to load fluctuations in order to strike a balance between supply and demand, maintaining a frequency of 50Hz or 60Hz. Distributed power sources, on a relatively limited scale of introduction, need not to contribute to maintaining frequency (which is not the case when they are introduced on a large-scale basis).

Of distributed power sources, those using generating machinery such as gas turbines and engines are highly controllable and can contribute to maintaining frequency technically. These power sources, however, are not used for this particular purpose due in part to their relatively limited number. With regard to new energy sources such as photovoltaic and wind power generation, their stability needs to be secured if they are to contribute to maintaining frequency, because their output fluctuates in response to weather conditions.

5.3 Requirements for the future power supply system

Japan's power supply system is expected to evolve in the future, from the existing, relatively simple system into a complex system comprising of various factors -i.e., a shift to create a new system incorporating distributed power sources into centralized ones.

This chapter addresses requirements for the future power supply system, which is expected to become complicated in response to the introduction of distributed power sources.

5.3.1 The viewpoint of cost minimum

In introducing various types of distributed power sources in the future, there is a need to create a mechanism that minimizes incremental costs.

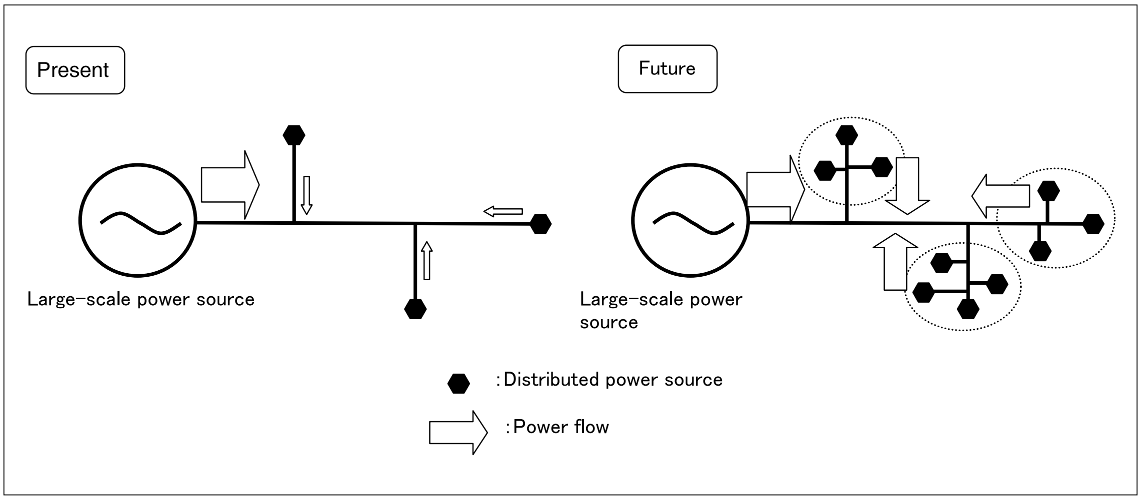
"The Framework for an Ideal System of the Future Electric Industry," a report prepared in February 2003 by the Power Industry Subcommittee under the Advisory Committee for Natural Resources and Energy, argues that it is appropriate to facilitate power supply by making use of distributed power sources and that measures should be taken to prevent detrimental effects to society associated with dual investment in distribution facilities. "Dual investment" in this particular case refers to capital investment by electric power companies (i.e., existing suppliers) and by new comers planning to install distributed power sources, whose payout period is relatively short.

In the meantime, the RPS system enforced in April 2003 regulates the use of power generated by new energy (over the next three years or so) to the extent that it does not require specific measures for the grid. Underlying this policy is that specific measures required for the grid as well as the distribution of their costs have yet to determined. Thus, incremental costs associated with the increasing introduction of distributed power sources remain an issue in constructing a system that is required.

In consideration of these circumstances, there is a need to pursue regional economic benefits (i.e., energy conservation and cost reductions through the installation of distributed power sources within the precincts of users taking a cue from the ESCO project) and to minimize an increase in costs for the entire power supply system.

As shown in Figure 2, the existing grid system is designed to supply power from upstream (large-scale power sources) to downstream. However, the introduction of distributed power sources will result in a multi-directional power flow. For this reason, it becomes necessary to: consider multiple distributed power sources as one unit; conduct evaluations and analyses based on simulations; and assess the impact of the introduction on cost efficiency and power quality.

Figure 2: Example of increased introduction of distributed power sources



5.3.2 The viewpoint of users

Since power failures happen infrequently in Japan, the need for low-quality, low-cost power may arise in the future. In other words, demand for low-cost power with sporadic failures may outpace demand for high-quality power with enhanced credibility in supply. For that matter, it should be necessary to develop technologies for supplying power in accordance with the need of each user (in terms of cost, credibility and quality), rather than pursuing standardized credibility and quality.

5.4 R&D efforts to construct power supply systems incorporating distributed powersources

5.4.1 Power storage technology

Methods using power storage equipment are being studied in order to level off the load and stabilize the power generated by new energy power sources (photovoltaic and wind power generation). Power in its nature should be generated and consumed simultaneously, a characteristic often described as "the same amount at the same time" or just "power cannot be stored." The utilization rates of power facilities, however, can be raised by storing surplus power (during night hours) in power storage equipment, which is released during daytime peak hours to level off the load.

From the viewpoint of environmental conservation, new energy power generation such as photovoltaic and wind power generation should be promoted. But this particular type of power generation usually involves an imbalance between supply and demand because it cannot generate power in accordance with fluctuations in demand. Power storage equipment is one of the means to reduce the instability in such power sources.

Table 2 shows power storage technologies currently under study at home and abroad, each of which is designed to store "otherwise unstorable power" by converting it into other energy such as kinetic energy, potential energy and chemical energy.

In addition to already commercialized centralized power storage equipment such as pumped hydropower, there are growing expectations for distributed power storage that aims to reduce the instability of distributed power sources (photovoltaic power generation, etc.) located near the market. Whatever the case may be, the effective utilization of power storage equipment in the power supply system requires considerable cost incentives that would encourage capital investment in this technology.

5.4.2 R&D trends in energy network systems

In connecting distributed power sources to the grid in Japan, measures are taken not for the gird but for distributed power sources in compliance with the technical guidelines for the connection to the grid - an arrangement to maintain supply credibility and safety of power. These measures, however, are unique to each distributed power source; the increased introduction of distributed power sources would result in connection

Table 2: Power storage technologies under study

Energy storage mode			Power storage method	Issues, etc.	Scale
Mechanical energy	Dynamic	Kinetic energy	1) Fly-Wheel Energy Storage : FWES	• Vibration and noise	Distributed
	Static	Potential energy	2) Pumped hydropower	• Limited location • Harmonization with surrounding environment	Centralized
		Pressure energy	3) Compressed Air Energy Storage : CAES	• Ground ssubsidence • Conservation of groundwater	
		Electromagnetic energy	4) Superconducting Magnetic Energy Storage : SMES	• Magnetic leakage • High-temperature superconduction	
Chemical energy			5) Battery Energy Storage: BES	• Measures to prevent the leakage of active substances • Fire defense law	Distributed

Source: Author's compilation based on a reference[5]

difficulties due to constraints on the part of the grid. Hokkaido Electric Power Co., Inc. (HEPCO), for instance, announced the upper limit of power supply from wind power generation in order to maintain its power quality: 250,000kW, up 100,000kW from the current level[6]. This in turn raises an awareness of the need for systems free of constraints from the connection to the grid. With the recent progress in power storage technologies as a backdrop, new systems such as the "Demand Area Power System" and the "Flexible, Reliable and Intelligent Energy Delivery System" (FRIENDS) have been proposed in Japan[7,8].

(1) Demand Area Power System

In order to solve the problems related to power quality and other issues associated with the increased introduction of distributed power sources, the Central Research Institute of Electric Power Industry (CRIEPI) proposed the "Demand Area Power System" (see Figure 3) as a new power supply system that makes use of distributed power sources and power storage equipment[7].

This system flexibly accommodates power flow fluctuations caused by an increase in power demand (primarily in cities) and distributed power sources, without complicated control settings.

To control voltage and equalize power flow, the system is primarily composed of a loop grid. Each loop point has a loop controller that controls voltage and power flow. In addition, supply-demand interfaces are installed in the loop grid for each group of users (including distributed power sources) to control distributed power sources, based on the information provided by suppliers and users - an arrangement to pursue cost efficiency.

The Central Research Institute of Electric Power Industry will set up demonstration facilities to materialize this system; the immediate plan is to demonstrate and evaluate the system and to develop the necessary technologies.

(2) Flexible, Reliable and Intelligent Energy Delivery System (FRIENDS)

A research group led by Hokkaido University has proposed the "Flexible, Reliable and Intelligent Energy Delivery System[8]." This system accommodates control, protection and operations appropriate for future power supply systems that are expected to incorporate a large number of distributed power sources, while supplying multi-quality power according to users' needs.

The existing power distribution systems are generally designed to supply standardized power through pole-mounted transformers installed along distribution lines radiating in all directions.

FRIENDS, on the other hand, sets up a "Quality Control Center" (QCC) between a distributing substation and users; it incorporates distributed power sources and power storage equipment to supply various types of power to users -i.e., a service to supply multi-quality power. Each QCC is set up near the users to which it supplies power, and the entire electric energy delivery network is composed of QCCs connected with one another through high-tension distribution lines (see Figure 4).

5.5 Trends in Europe and the U.S.

5.5.1 The U.S.

The Department of Energy (DOE) announced the "Strategic Plan for Distributed Energy Resources" in September 2000[11]. The essence of this plan is to make full use of low-cost distributed energy resources and to construct clean, efficient and reliable energy systems. It also sets out federal and national objectives in developing distributed power sources and their related technologies.

Technological development themes involved are: (1) basic research on combustion systems, etc.; (2) development of technologies for utilizing distributed energy resources (natural gas, renewable energy, etc.); and (3) energy storage and transportation technologies. In addition, relevant systems will be improved to solve institutional problems.

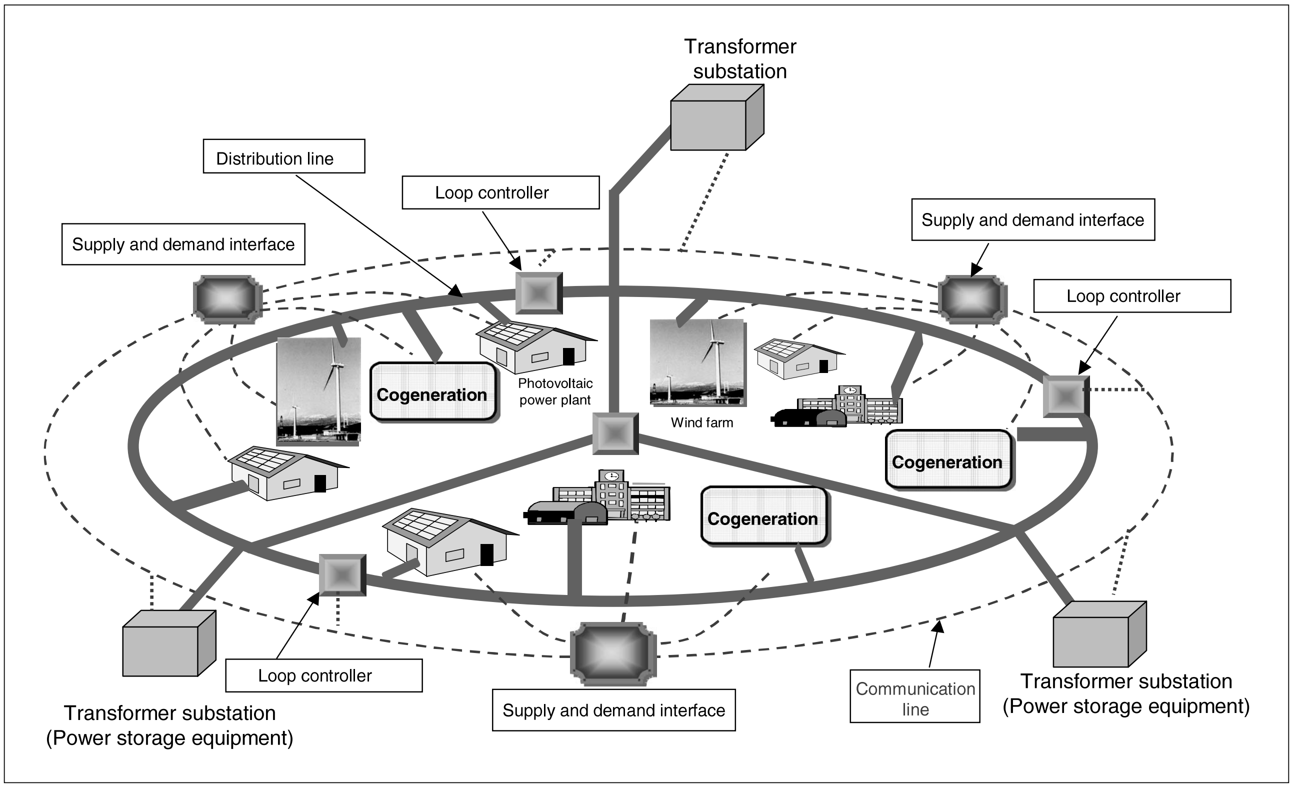
In the U.S., competition has been brought to the power-generation and power-retailing markets, while new billing systems are becoming widespread to encourage competition among power suppliers. On the other hand, there have been restrictions in capital investment in power distribution facilities, which in turn is bringing about unstable power supply and lower power quality (as is evident from the recent serious power failure in California). To address power shortages and surges in power rates, therefore, applications of distributed power sources are being expanded in line with the conventional themes comprising: (1) accommodation of dispersed demand; (2) co-existence with cogeneration systems; (3) maintenance of credibility; (4) maintenance of power quality; (5) management of energy and sales of power; (6) establishment of ancillary services in which distributed power sources and power distribution facilities cooperate with each other to maintain power quality; and (7) sales of power to the domestic power market.

5.5.2 Europe

As an EU Directive was announced in September 2001 concerning the introduction of renewable energy[12], a series of measures to promote distributed power sources are being discussed. Promotional programs for distributed power sources in Europe include the "Target Action Integration Program (2001-2002)," which facilitates the access of distributed power sources to energy network systems, and the "Cluster Integration Program (2002-2006)," which ensures stable supply and credibility through the integration of distributed power sources into the EU and regional distribution networks. The latter program aims to develop next-generation technological programs to create new power supply systems incorporating distributed power sources; it also sets out major technological development themes -i.e., (1) innovative control of stand-alone power generation systems in the case of increased renewable energy and its storage, (2) development of distributed power sources primarily using renewable energy resources, and (3) promotion of a European network project for renewable energy resources and the integration of distributed power sources.

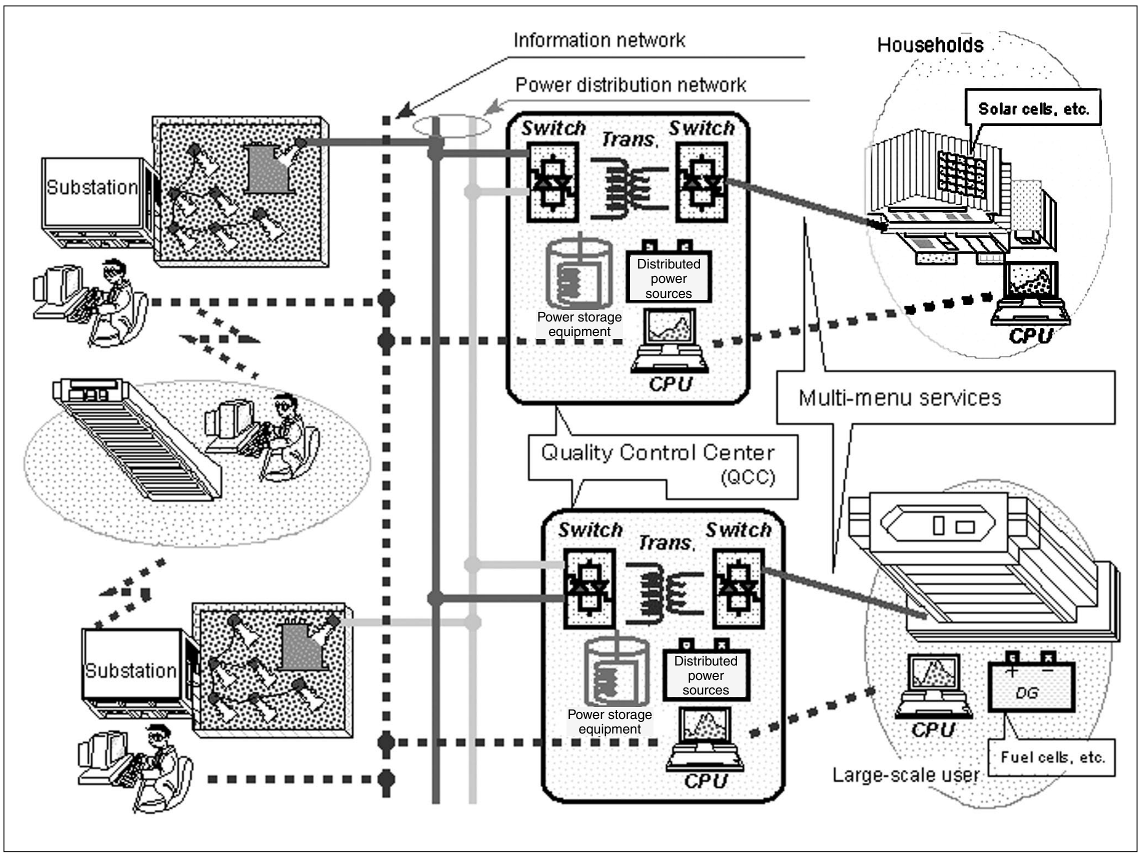
As discussed above, backgrounds in introducing distributed power sources differ between the U.S. and Europe. In the U.S., the recent trend has been to restrict construction of new power plants and to use distributed power sources as a means to ensure stable power supply, which situation can be attributed to the problems such as power shortages and surges in power rates. In Europe, on the other hand, distributed power sources (with particular emphasis on renewable energy) are being promoted from the viewpoint of environmental conservation, an effort to create sustainable energy systems.

Figure 3: Example of Demand Area Power System



Source: Author's compilation based on a reference[9]

Figure 4: Flexible, Reliable and Intelligent Energy Delivery System (FRIENDS)



Source: Author's compilation based on a reference[10]

5.6 Conclusion

Japan's energy policy aims to "ensure stable supply of energy and accommodate the need for environmental conservation and efficiency," which seems difficult to achieve under the current circumstances[13]. The energy suppliers in Japan are increasingly diversified in response to the liberalization of the domestic electricity market; in addition to the existing large-scale power supply system, new comers are branching out into the market and distributed power sources are becoming widespread, which situation is expected to continue into the future, and thus should be taken into account in creating a system for society.

Since Japan shares little in common with other countries in terms of electric power infrastructures, geographical conditions and the availability of energy resources, Japan's power supply system should be tailor-made, paying particular attention to the recent trends in energy policies and technological developments in Europe and the U.S.

In the meantime, relevant factors such as energy demand, wind conditions and the amount of biomass resources differ from region to region in Japan. As mentioned in Section 5.4.2, power supply systems incorporating distributed power sources are designed for specific regions (town/ward/city) or areas (designated areas such as industrial parks). However, it has yet to be determined how additional costs associated with these system will be shared among the parties concerned.

For these reasons, the construction of power supply systems incorporating distributed power sources inevitably involves region-specific approaches, and the cooperation of the municipalities is essential to materializing these systems.

There has been some progress in the system designating special zones for structural reform, in which each party concerned such as a municipality voluntarily implements structural reform in specific areas through the introduction of special regulations in accordance with the regional demand and characteristics. The authority started accepting applications for the plans for these special zones on April 1, 2003. In the energy-related fields, the "Special Model Zone for the Promotion of New Energy" has been applied for the system.

As distributed power sources are usually set up near the market to which the power is supplied, municipalities are expected to play a leading role in sponsoring debates between energy suppliers (electric power companies, constructors and owners of distributed power sources, etc.) and local residents in each region, shedding light on issues and needs unique to each region, and keeping track of the characteristics of the energy resources available in each region - which together will contribute to constructing power supply systems incorporating distributed power sources (through concerted efforts of the municipalities and local residents concerned).

Notes

*1: "Supply-side new energy" refers to power-generation including those using photovoltaic cells, wind power, waste and biomass as well as heat utilization based on heat sources such as solar, untapped energy (snow and ice energy, etc.), waste, biomass, black liquor and waste materials.

*2: "Demand-side new energy" refers to automobiles using clean energy, natural gas cogeneration and fuel cells.

*3: Energy sources to be covered by the RPS system are wind power generation, photovoltaic power generation, geothermal power generation, hydroelectric power generation (limited to conduit type power plants with less than 1,000kW output) and biomass power generation.

*4: Deregulation in the electric industry :
The retailing of electricity was liberalized in March 2000, exclusively for users of special high voltage power (with a receiving voltage of more than 20kV and a usage of more than 2,000kW). In order to provide users with more options, further liberalization is expected to take effect by April 2005, targeting all areas whose demand exceeds 50kW (or by April 2004 for areas whose demand exceeds 500kW). In view of

diversifying power sources, it is considered appropriate to facilitate power supply by making use of distributed power sources.

References

[1] The Fuel Cell Commercialization Strategy Study Group (Ministry of Economy, Trade and Industry) and the Biomass Nippon Strategy (Ministry of Education, Culture, Sports, Science and Technology, Ministry of Agriculture, Forestry and Fisheries, Ministry of Economy, Trade and Industry, Ministry of Land, Infrastructure and Transport, and the Ministry of Environment). (in Japanese)

[2] Taniguchi, H. Control of the Power Systems for Distributed Power Sources. The Institute of Electrical Engineers of Japan: Collected Papers B, vol. 121-9, 2001. (in Japanese)

[3] The Electric Technology Research Association. The Electronic Technology Research, vol. 56-4, 2001. (in Japanese)

[4] The Website of Tokyo Electric Power Co., Inc. (http://www.tepco.co.jp/custom/LapLearn/ency/cmb01-j.html)

[5] Shimada, R., 2002. Illustration of Power System Engineering. Maruzen Co., Ltd. (in Japanese)

[6] Press release by Hokkaido Electric Power Co., Inc. (August 28, 2002) (in Japanese) (http://www.hepco.co.jp/press/index.html)

[7] Power Supply of the 21st Century: Creation of Demand Area Power System. OHM, 2002. (in Japanese)

[8] Nara, Hasegawa et al., New and Flexible Electric Energy Distribution System. The Institute of Electrical Engineers of Japan: Collected Papers B, vol. 117-1, 1997. (in Japanese)

[9] The Institute of Applied Energy. Report prepared by the New Power Supply System Technology Study Group, 2002. (in Japanese)

[10] The Website of the FRIENDS Study Group (http://ee30-si.eng.hokudai.ac.jp/friends/frame/index-j.htm)

[11] DOE/STRATEGIC PLAN FOR DISTRIBUTED ENERGY RESOURCES/Office of Energy Efficiency and Renewable Energy, Office of Fossil Energy/2000.9.

[12] DIRECTIVE 2001/77/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market.

[13] The General Subcommittee and the Supply-Demand Subcommittee under the Advisory Committee for Natural Resources and Energy. Energy Policies in the Future, July 2001. (in Japanese)

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6

R & D Trend in Innovative High-Temperature Gas-Cooled Reactors (HTGRs)

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6.1 Introduction

Today, the environment surrounding the atomic energy sector has become more and more complicated with movements such as the promoted liberalization of energy markets, the diffusion of decentralized power sources, the withdrawal from nuclear power generation especially in Europe, and the re-appreciation of nuclear energy in the U.S.

According to the OECD-International Energy Agency (IEA), it is estimated that nuclear energy's share in the world supply of primary energy will decrease from 7% at present to 5% in 2030, with a high uncertainty, because many of the existing nuclear power plants are being closed in turn especially in Europe, while the construction of new power plants are expected mainly in Asian countries[1]. On the other hand, the important role of nuclear power generation is now recognized from the viewpoints of solving the environmental problems of the Earth and ensuring the stable supply of energy.

Under these circumstances, R&D efforts have been activated worldwide to develop innovative nuclear energy systems with excellent features such as safety, resistance to nuclear proliferation, economical efficiency, and social acceptance. Various options on reactors and fuel cycles are being proposed in terms of innovative nuclear energy systems, and the target time for commercialization varies from the year before 2010 to 2030. However, it is noticeable that HTGRs are attracting higher interest in the world, as described in the next chapter.

At present, HTGRs use helium gas for the coolant and graphite for the moderator, while light water reactors (LWRs) as the current main commercial reactors use water (light water) both for the coolant and moderator. R&D efforts on HTGRs started in the 1950s, and several commercial units were introduced into the nuclear power sector by the 1980s. Today, however, there is no commercial HTGR under operation. Notwithstanding, in recent years, HTGR has been re-appreciated as one of the promising options for next-generation reactors. The reasons are; (i) that it has high inherent safety, (ii) that the high exit temperature of the coolant allows the nuclear heat to be used in various applications including the production of hydrogen, and (iii) that several promising designs have been proposed for small- and medium-sized modular reactors that are flexibly adaptable to the changing environment of the energy markets.

In Japan, the Japan Atomic Energy Research Institute (JAERI) has conducted researches on the utilization of nuclear heat by using a High-Temperature Engineering Test Reactor (HTTR) since the 1990s, and these researches have been ranked world-class, though many problems remain to be solved before a commercial plant using nuclear heat is realized.

In recent years, however, Japan and other countries have had a rapidly increasing interest in the safety of engineering systems, or in hydrogen energy systems. Under these circumstances, the U.S. and France are involved in full-scale R&D projects on HTGR, recognizing it as one of the promising options for future reactors. Given these conditions, we suppose that it is necessary for Japan to prepare its R&D strategy focusing on the various potentialities of HTGR, taking into account the social needs for future nuclear energy plants.

In this report, the next chapter covers the worldwide trends in research and development projects for innovative nuclear energy systems as well as the higher expectations aroused in the world for HTGRs. Chapter 6.3 describes the R&D history and features of HTGRs, and Chapter 6.4 focuses on the production of hydrogen to which special attention is given as a new application of the HTGR. Chapter 6.5 presents the main R&D and introduction projects for HTGRs being implemented worldwide, and Chapter 6.6 examines the problems to be solved under the Japanese R&D projects for HTGRs.

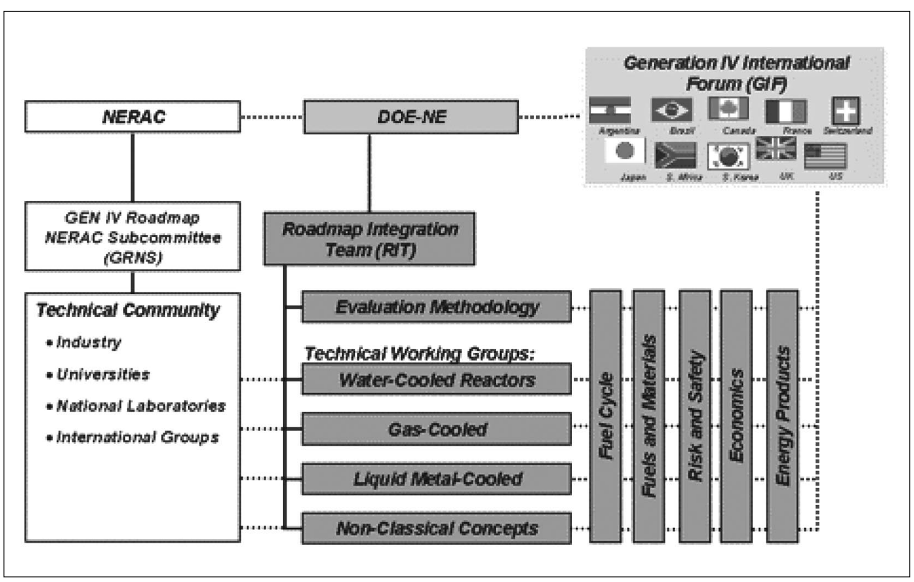
6.2 Development of innovative nuclear energy systems and expectations for high-temperature gas-cooled reactors

Today, international efforts are being more actively made in the field of research and development for innovative nuclear energy systems. And, it is the U.S. that leads these R&D efforts. The US Department of Energy (DOE) has implemented its technological development project for an innovative nuclear energy system as part of its Nuclear Energy Research Initiative (NERI). Ten countries (Argentine, Brazil, Canada, Japan, Korea, France, South Africa, Switzerland, the U.K. and the U.S.) are participating in the Generation IV International Forum (GIF)*1 for the 4th-generation nuclear energy systems, which was organized by the DOE (see Figure 1). This Forum is engaged in selecting promising nuclear energy system options and examining internationally cooperative research projects to develop the generation IV nuclear energy system that is to be commercialized by 2030.

The concept of the generation IV nuclear energy system will be described hereinafter. Figure 2 shows the evolution of the generation I to IV nuclear reactors[2]. The generation I includes the initial light water reactors (LWRs) developed in the 1950s and 1960s. The generation II includes the light water reactors, PWRs and BWRs that were introduced after the 1960s and that now constitute the main reactors under operation. The advanced light water reactors such as advanced boiled water reactors (ABWRs) are classified into generation III. The generation IV includes the reactors that are to be commercialized by 2030. The group of reactors that is to be put into practical use earlier (by 2015) than the generation IV is called the International Near-Term Development (INTD).

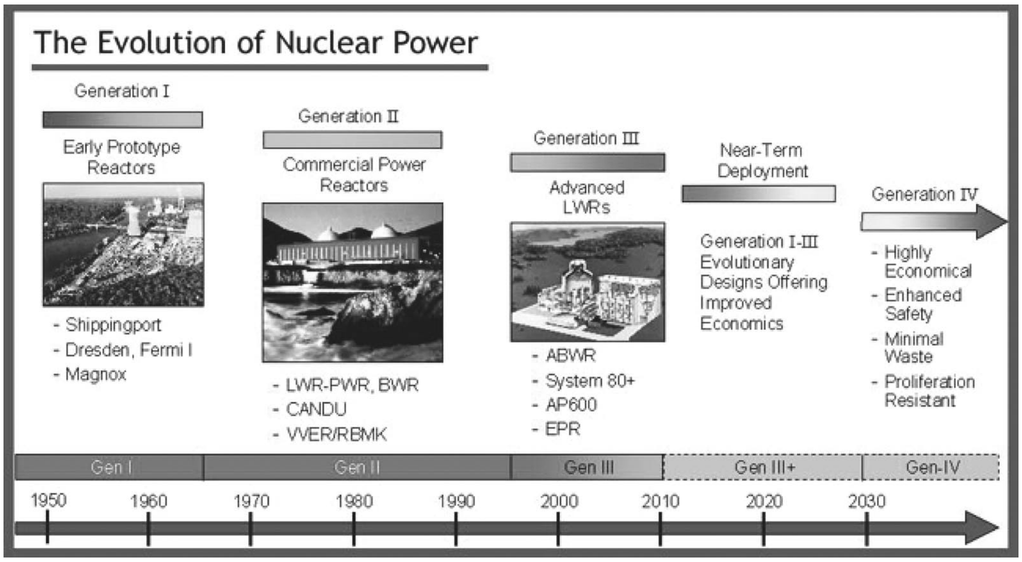
In September 2002, the GIF Policy Group held a meeting in Tokyo and selected 6 types of generation IV nuclear energy systems, as listed below, as the subjects for internationally cooperative research and development projects. It should be specially mentioned that 2 types of gas-cooled reactor systems were selected, and that 3 types are fast reactor systems.

Figure 1: Structure of the Generation IV International Forum (GIF)



Source: DOE homepage[2]

Figure 2: Evolution of nuclear power system



Source: DOE homepage[2]

- •Gas-cooled fast reactor system
- •Sodium-cooled fast reactor system
- •Lead-cooled fast reactor system
- •Supercritical pressure water-cooled reactor system
- •Molten-salt reactor system
- •Ultrahigh-temperature gas-cooled reactor system

Short- and medium-term introduction projects for commercial high-temperature gas-cooled reactors (HTGRs) are being implemented in foreign countries. For high-temperature gas-cooled modular reactors, introduction projects are being implemented to start operation by 2010, including the PBMR being developed by ESCOM in South Africa as well as the GTMHR developed mainly by the U.S. and Russia to be introduced into the U.S. and used in Russia for the disposal of plutonium from dismantled nuclear weapons. These may probably become the first next-generation reactors to be commercialized and introduced into the world, and they are classified into the INTDs as mentioned above.

These HTGR systems that are classified into the Generation IV and INTDs will be individually described in Chapter 6.5.

On the other hand, the Long-Term Program on the Researches, Development and Utilization of Nuclear Energy (hereinafter referred to as the "Long-Term Nuclear Energy Program") in Japan[3] prepared in 2000, describes that the industrial, academic and governmental circles should work together to examine the R&D projects for innovative reactors, regardless of reactor sizes and systems, and take into consideration the effective utilization of various ideas. In November 2002, the Atomic Energy Commission of Japan (JAEC) published the document titled "How to Implement Future Research and Development Projects for Innovative Nuclear Energy Systems[4]," which overviews the actual situation of R&D efforts made in Japan, points out the necessity of R&D efforts and describes JAEC's policy for its R&D strategy. This document lists 9 concepts for innovative nuclear energy systems (17 types of reactors), including 3 types of HTGR, namely the pebble bed type HTGR, the prismatic type HTGR and a large type helium gas-cooled fast reactor.

In the 2002 fiscal year, the Ministry of Education, Culture, Sports, Science and Technology started to implement its proposal invitation type project "Technological Development of Innovative Nuclear Energy Systems" (with a budget of 4.3 billion yen for the 2002 fiscal year). In the 2000 fiscal year, the Ministry of Economy, Trade and Industry also started to implement its proposal invitation type project "Development of Innovative and Practical Nuclear Energy Technologies" (with a budget of 2.3 billion yen for the 2002 fiscal year).

France, which is the leader, like Japan, in the field of researches on sodium-cooled fast

Table 1: Main commercial reactors under operation

Type of reactor	Country	Number of units	Fuel	Coolant	Moderator
Pressurized water reactor (PWR)	U.S., France, Japan, Russia	252	Enriched uranium	Light water	Light water
Boiled water reactor (BWR)	U.S., Japan	93	Enriched uranium	Light water	Light water
Carbon acid gas-cooled reactors (Magnox & AGR)	U.K.	34	Natural uranium, enriched uranium	CO_2	Graphite
Pressurized heavy water reactor (CANDU)	Canada	33	Natural uranium	Light water and heavy water	Heavy water
Graphite-moderated light water reactor (RBMK)	Russia	14	Enriched uranium	Light water	Graphite

Source: Author's compilation based on the materials published on the homepage of the World Nuclear Energy Association[6]

reactors, not only decided to decommission its demonstration reactor "Super-Phoenix" and postpone the commercialization of this type of reactor to 2050 or a subsequent year, but also worked out its policy that the development of innovative reactors would be focused on gas-cooled reactors, paying attention to the high safety and economical efficiency of these reactors[4]. In its long-term program, France aims to commercialize very high-temperature gas-cooled reactors and high-temperature gas-cooled breeders. In September 2002, the Japan Atomic Energy Research Institute (JAERI) and Le Commissariat à l'Énergie Atomique (CEA) updated the "Comprehensive Agreement for Cooperation in the Field of Atomic Energy Development," to which cooperation for the development of high-temperature gas-cooled reactor systems was newly added[5].

6.3 Development history and features of high-temperature gas-cooled reactors

6.3.1 Development history of gas-cooled reactors

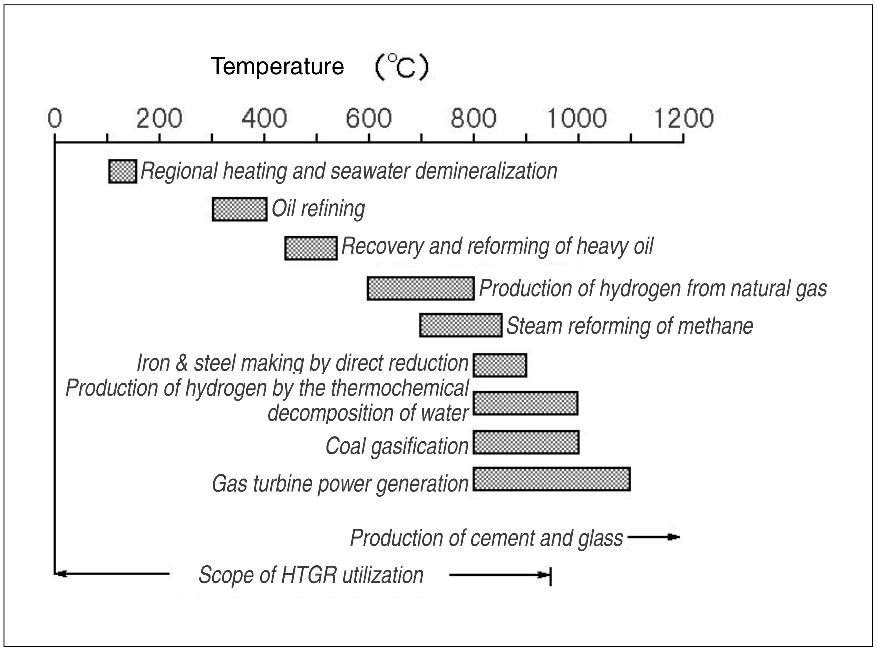
Light water reactors - pressurized water reactors (PWRs) and boiled water reactors (BWRs) - account for about 80% of existing commercial reactors under operation, and use water for both the coolant and moderator, as indicated in Table 1. In addition, Canadian type heavy water reactors (CANDUs), carbonic acid gas-cooled reactors (Magnox and AGRs), and graphite-moderated light water reactors (RBMKs) are operating in Canada, the U.K. and Russia, respectively.

As gas-cooled reactors, Magnox reactors and advanced gas-cooled reactors (AGRs) were mainly introduced into the U.K. during the period from the second half of the 1950s through the 1970s. The two types of reactors use CO_2 gas for the moderator. The Magnox reactor uses fuel rods of natural uranium covered with magnesium alloy and a coolant temperature of about 400°C. The advanced gas-cooled reactor (AGR) is an original type of reactor developed in the U.K. to improve the economical efficiency of Magnox reactors. It uses fuel rods of uranium oxide covered with stainless steel plates and a coolant temperature of about 650°C. A reactor of this type has not been constructed since the 1980s, and there are more than a few AGRs that have stopped operating. Today, however, most of the existing reactors under operation are still AGRs in the U.K.

On the other hand, the HTGRs as described in this article use helium for the coolant and a high coolant temperature of about 800°C or more.

R&D projects for such HTGRs[7] were drawn up and implemented in the 1950s, and several experimental and prototype reactors of this type were constructed in Germany and the U.S. in the 1960s, though they have already stopped operating. In the 1970s, the introduction of commercial HTGRs was planned, but not realized in the U.S. In 1980s and 1990s, the design concepts of plants having a high inherent safety were proposed in the U.S. and Germany, and R&D

Figure 3: Diversified utilization of nuclear heat



Source: The atomic energy encyclopedia ATOMICA[8]

projects were implemented mainly in Germany, Japan and Russia to use HTGRs in various applications other than power generation; for example, the gasification of coal, the production of ammonium, and cogeneration systems. In Japan, the High-Temperature Engineering Test Reactor (HTTR) reached its criticality in 1998, and experiments and researches have since been conducted on subjects such as the production of hydrogen. Today, however, there is no commercial HTGR plant under operation in the world.

6.3.2 Features of HTGR

The past R&D and introduction projects for HTGRs in the world were not always smoothly implemented, as described in the previous section. Some of the reasons were that the cost for producing fuels was high, that the construction costs were high due to the low exothermic density of cores, and that the spread of light water reactors had a lock-in effect on technologies. However, several new designs of HTGR have been proposed on the basis of the accumulated R&D results. These designs present advantages such as high inherent safety, high economical efficiency and diversified utilization of nuclear heat including the production of hydrogen. With this as the background, HTGRs have been re-appreciated in recent years. The features of HTGRs will be described hereinafter.

(1) Applicability of nuclear heat to uses such as the production of hydrogen

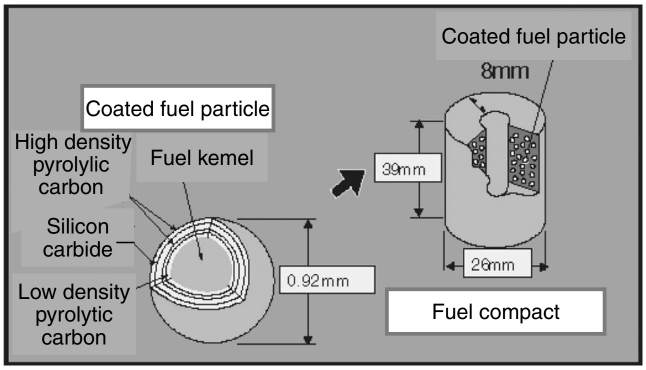
The temperature of a coolant at the exit of a reactor is about 800 to 950°C for a HTGR, while it is about 330°C for a LWR. Therefore, the power generation efficiency may reach 45 to 50% for a HTGR if a gas turbine is used for power generation.

Recently, much attention has been devoted to the utilization of the coolant, having a high temperature as heat source, especially in the application for mass production of hydrogen. The processes of producing hydrogen by using nuclear energy include the electrolysis of water, the steam reforming of fossil resources, and the thermochemical decomposition of water. The thermochemical water decomposition process using a HTGR as the heat source has a high efficiency, and has attracted much attention because it ensures the mass production of hydrogen with substantially no emission of CO_2. The other applications of nuclear heat include iron & steel making, coal gasification, oil refining, seawater demineralization and regional heating, as shown in Figure 3. The production of hydrogen by using a HTGR will be detailed in the next chapter.

(2) High inherent safety

The HTGR uses pebble beds (balls) or blocks of compacted fuel particles having a diameter of

Figure 4: Fuel in the High-Temperature Engineering Test Reactor (HTTR) of the Japan Atomic Energy Research Institute (JAERI)



Source: JAERI homepage[9]

about 1mm and made of low enrichment uranium dioxide coated with multiple layers of ceramics such as silicon carbide. Figure 4 shows a schematic view of the fuel (of block type) used in the High-Temperature Engineering Test Reactor (HTTR) of the Japan Atomic Energy Research Institute (JAERI)[9]. The fuel compact as shown in the Figure will be inserted into a fuel rod.

The ceramics with which the fuel particles are coated have such high heat resistance that they remain intact at a temperature of 1600°C or more. If the helium coolant is lost through an accident (depressurization accident) in the HTGR, it is anticipated that the removal of decay heat only by the natural radiation of heat may prevent the temperature of the coating material from reaching 1600°C or more, so that any radioactive substance inside the coating material will not be released[10]. In addition, graphite as the moderator has such large heat capacity that the temperature of the system changes more slowly in the event of an accident. Therefore, the operator may have sufficient time to take an appropriate action against the accident. Furthermore, the HTGR has other safety factors such as a high negative temperature coefficient throughout the operation and the helium coolant is inactive.

(3) Economical efficiency improved by smaller module and flexible adaptability to the environment of the energy markets

Many LWR plants have a maximum output of 1 million kWe or more. As for HTGRs, however, much attention is concentrated on the modular reactors with outputs of 0.1 to 0.3 million kWe, as described in Chapter 6.5. In general, a larger sized plant has higher economical efficiency (scale merit). For small HTGRs, however, economical efficiency is improved through the simplification of the safety system based on high inherent safety and improvement of power generation efficiency due to the use of a gas turbine.

Today, liberalization of the energy markets is being promoted in many countries. As a result, smaller power producers, especially independent power producers (IPPs), are more often than ever exposed to risks such as changes in electricity fees and the changing environment of the energy markets, making it more difficult for them to launch into the construction of large plants that require a longer period of time to recover the invested capitals (especially nuclear power plants for which the percentage of fixed costs is higher). Thus, much attention is concentrated on the smaller modular reactors for the reasons that they have a lower initial cost and consequently a smaller risk in recovering invested capitals, that the output of the whole site can be adjusted by changing the number of modules constructed in the site, and that they may be flexibly adaptable to future changes in the environment (such as electric power prices and the supply and demand of energy).

6.4 Production of hydrogen by HTGR

At present, there are growing expectations for hydrogen energy systems including fuel cells. To spread these systems substantially, however, one of the challenges is in how to produce hydrogen

Figure 5: Pyrolytic process of water by using the IS process

	Bunsen reaction	$2H_2O + I_2 + SO_2 = 2HI + H_2SO_4$	At room temp. to 100°C
	Decomposition of hydrogen iodide	$2HI = H_2 + I_2$	At 400°C
+	Decomposition of sulfuric acid	$H_2SO_4 = H_2O + SO_2 + 1/2O_2$	At 800°C
		$H_2O = H_2 + 1/2O_2$	

Source: Developed by General Atomics (U.S.)

as fuel. One of the reasons for the increasing interest in HTGRs is that these reactors are applicable to the clean and economical mass production of hydrogen.

The industrially established process of producing hydrogen uses the reforming of fossil resources such as natural gas. In this case, a great amount of carbon dioxide is emitted during the production of hydrogen. From the viewpoint of the 3E problem, therefore, it is desirable to commercialize and spread the process of producing hydrogen from water or biomass[11]. Especially, the thermochemical decomposition of water by using a HTGR is expectable as a mass production process for clean hydrogen.

A high temperature of 2500°C or more is required to pyrolyze water directly. However, several thermochemical cycles comprising the different combinations of several thermochemical reactions respectively have been proposed to pyrolyze water at around 800°C. A HTGR may be used as the heat source in this range of temperatures.

The Japan Atomic Energy Research Institute (JAERI) has conducted tests and researches on the pyrolytic process of water by using the IS process [12]. The IS process is a technique developed by GENERAL ATOMCS (U.S.), which comprises of 3 chemical reactions as shown in Figure 5. In this process, the compounds produced by the reactions of water with iodine and sulfur are circulated inside the process so that any detrimental substance is not emitted to the exterior.

In 2001, the JAERI completed a continuous hydrogen production system (with the output of 50 liters/hour) by using the IS process, and started to conduct tests and researches on the pyrolytic process of water. It plans to connect this system with its High-Temperature Engineering Test Reactor (HTTR) by 2008.

In the U.S., the Freedom CAR Initiative (with a budget request of $150.3M for the 2003 fiscal year) was started last year in a technological development partnership between the Federal Government and automobile makers under the direction of the Department of Energy (DOE). In addition, the DOE bill of budget for the 2004 fiscal year published in February 2003[13] proposed a new Hydrogen Fuel Initiative[*2] under which R&D efforts are made on the production and storage of hydrogen and the infrastructure, and requested a budget of $273M both for the Freedom Car and Hydrogen Fuel Initiatives.

A Nuclear Hydrogen Initiative (with a budget request of $4.0M for the 2003 fiscal year) was also proposed in the framework of the Hydrogen Fuel Initiative. In this new initiative, the HTGR or liquid-metal cooled reactor was selected as a candidate heat source, and will be demonstrated in commercial sizes by the 2015 fiscal year [14].

The hydrogen production processes using nuclear energy as listed in Table 2 have been proposed in addition to the above-described thermochemical decomposition of water by using a HTGR. All the processes have the feature that they can be used for the mass production of hydrogen, because they provide high plant outputs, compared with the processes using renewable or other energy[*3].

For example, the Research Meeting on the Fuel Cell Commercialization Strategy set an expected target of 5 million automobiles with fuel cells (in total) to be introduced by 2020[16]. If all the automobiles with hydrogen run, the required supply of hydrogen will exceed 6 billion Nm^3 [17]. On the other hand, the thermochemical decomposition of water by using a HTGR and the electrolysis of water by using a LWR may annually produce 3.4 billion Nm^3 and 1.7 billion Nm^3 of hydrogen respectively per output of 1 million kW[18]. Therefore, several nuclear energy plants may satisfy the demand for hydrogen as mentioned above.

From the viewpoints of economical efficiency and technical feasibility, it is considered that the steam reforming of fossil resources such as natural gas by using the nuclear heat from a HTGR or fast breeder as the heat source may be introduced earlier than the thermochemical decomposition of water. To develop this process, therefore, the Japan Atomic Energy Research Institute (JAERI) and the Japan Nuclear Cycle Development Institute (JNC) are individually taking leading roles in extending R&D efforts.

6.5 R&D projects in Japan and foreign countries

Table 3 lists the typical R&D projects and commercial reactor introduction projects being implemented in Japan and in foreign countries. The test reactors under operation include HTTR (JAERI) and HTR-10 (China), the commercial reactors to be introduced by 2010 include PBMR (South Africa) and GTMHR (U.S. and Russia), and the reactors to be introduced in the

Table 2: Actual situation of the main hydrogen production processes using nuclear energy

Material	Supplied nuclear energy		Hydrogen production process	Price ratio of each system to the combustion and steam reforming of fossil fuel*
	Energy form	Plant (Temperature level)		
Water	Electricity	Power reactor	Electrolysis	2.5
	Heat	HTGR and high-temperature liquid-metal reactor (800 to 1000°C)	Thermochemical process	1.5
Fossil fuel and water			Steam reforming process	0.9
		Na fast breeder (450 to 600°C)		

* Estimated by the JAERI (without taking into account any carbon dioxide disposal cost).

Source: Reference[15] (partly omitted)

Table 3: Key HTGR development and introduction projects

	Reactor name	Development organization	Output (MWt/MWe)	Fuel	Start of operation	Remarks
Test reactors under operation	HTTR	JAERI (Japan)	30/-	UO_2 (Block)	Critical in 1998	H production & material development
	HTR-10	Tsinghua University (China)	10/-	UO_2	Critical in 2000	Power generation + reforming of heavy oil, etc.
Commercial reactors for near-term introduction	PBMR	ESCOM (South Africa)	302/120 (1 Module)	UO_2 (Pebble bed)	Expected in 2007	Gas turbine power generation
	GTMHR	GA-Minatom (U.S. & Russia)	600/285 (1 Module)	PuO_2 (Block)	Expected in 2009	Combustion & disposal of Pu from weapons, and gas turbine power generation
		GA (U.S.)	600/285 (1 Module)	U-based (Block)	By 2010	H production
Reactors under future initiatives	VHTR	JAERI (Japan), GA (U.S.), etc.	Not published	Not published	By 2020	Exit gas at 1000 to 1500°C, and ZrC-coated fuel
	GCFR	CEA (France), TIT (Japan), MIT (U.S.), etc.	Ex. 600/288, 1400/not published	Pu- or U-based	By 2025	Exit gas at 850°C, and re-treatment and recycling of spent fuels

Source: Reference[19]

far future under the initiatives include a very high-temperature gas-cooled reactor VHTR and a gas-cooled fast reactor GFR. This chapter will describe each of the projects.

6.5.1 HTTR (High-Temperature Engineering Test Reactor) (Japan)

The High-Temperature Engineering Test Reactor (HTTR), for which R&D efforts are being made mainly by the Japan Atomic Energy Research Institute (JAERI), received approval for installation as a test reactor for developing applications in the field of nuclear energy except electric power in 1990, started constructing in 1991, and reached the first criticality in November 1998. It uses block type fuel elements and a coolant temperature of 850 to 950°C at its exit. It will be connected with a hydrogen production system by 2008.

In the future, it is planned to conduct high-performance fuel irradiation tests, safety demonstration tests, nuclear-heat utilization tests (by using the hydrogen production - thermochemical process, the high-temperature steam electrolysis process, etc.), advanced basic researches (including ceramics irradiation tests, tritium recovery tests, and the development of high-temperature resisting materials and instrumentation systems), and researches on hydrogen/methanol production systems using a steam reforming process.

The JAERI is performing the system design of the modular gas turbine high-temperature gas-cooled reactor GTHTR300 developed by the Japanese. This reactor has an output of 100 to 300MWe, and its demonstration machine will be introduced in the 2010s.

6.5.2 HTR-10 (High-Temperature Gas-Cooled Test Reactor) (China)

HTR-10 is a high-temperature gas-cooled reactor (with an output of 10MW) developed by Tsinghua University in China with technical assistance provided by Germany. It was constructed for the purposes of; (i) obtaining the know-how on the designing, construction and operation of HTR, (ii) constructing the experimental equipment, (iii) demonstrating the inherent safety, (iv) testing cogeneration and gas turbine technologies, and (v) implementing the R&D project for a high-temperature utilization process, and reached the criticality in December 2000. At present, tests are being made on this reactor to raise the output up to 100%.

The reactor HTR-10 uses pebble bed type fuel elements of 17% enriched uranium. Although a steam turbine is now used, a gas turbine will be installed to demonstrate the direct cycle gas turbine power generation system.

6.5.3 PBMR (Pebble Bed Type Modular High-Temperature Gas-Cooled Reactor) (South Africa)

PBMR is a small type modular reactor being developed mainly by ESCOM, the national power company in South Africa. This reactor is expected to be introduced ahead of the other small type modular HTGRs being researched and developed in the other countries.

In South Africa, projects to introduce the commercial prototype demonstration reactor No. 1 and to construct 10 additional commercial reactor modules are currently being developed with the capital participation by power companies and manufacturers in South Africa, Europe and the U.S. These projects are also receiving technical cooperation from Mitsubishi Heavy Industries (He gas turbine) and the Atomic Fuel Industry (fuel manufacturing equipment) in Japan. If the reactor project is smoothly implemented, it is expected that the reactor No. 1 will start to be constructed by 2004 and operated by 2007, after having received the final decision on whether or not it should be constructed as well as the license issued by the regulatory agency in South Africa. At the same time, the project of constructing 10 additional modules will be implemented.

In the U.S., however, uncertainty about the construction of new reactors is attracting much attention, because no reactor has been constructed in about 30 years. The U.S. power company Exelon, which planned to construct these reactors, started to explain its license application plan to the Nuclear Regulation Commission (NRC) in January 2001, and, in response to this, the NRC began to make its preliminary review of the license application submitted by the company. It was expected that several reactors would be introduced by 2010 if the project went as planned. In April 2002, however, Exelon expressed its desire to withdrawal from the capital participation in the above-mentioned project in South Africa. As a result, the NRC stopped the review.

6.5.4 GTMHR (Block Type Modular High-Temperature Gas-Cooled Reactor) (U.S. and Russia)

Russia and the U.S. formed an internationally cooperative research consortium with the other countries to introduce GTMHRs (Gas Turbine-Modular Helium Reactors) into the two countries. The participants in this consortium include not only manufacturers and research institutions in Europe and the U.S., but also Fuji Electric in our country. The Russians consider GTMHR as a candidate reactor applicable to the disposal of plutonium taken out from dismantled excess nuclear weapons, while the Americans regard it as a reactor that is excellent in safety, economical efficiency and applicable to the production of hydrogen. The safety review is being prepared so as to start construction of GTMHRs by 2006 in Russia and by 2007 in the U.S.

The standard GTMHR plant comprises of 4 modules with an output of 286MWe each. Power generation efficiency as high as 45 to 50% may be attained by the direct cycle gas turbine power generation system. This reactor may consume a greater part of the quantity of Pu239 taken out from dismantled nuclear weapons, once it is loaded with fuel and operated. The plant with 4 modules may dispose of about 1 ton of plutonium from nuclear weapons annually.

6.5.5 Generation IV reactors

Last year, the Generation IV International Forum (GIF) selected 6 types of generation IV nuclear energy systems as the subjects of internationally cooperative researches and development projects. Of the six systems, two were gas-cooled reactors - VHTR (Very High-Temperature Gas-Cooled Reactor) and GFR (Gas-Cooled Fast Reactor). The system concepts of the reactor types will be described hereinafter, mainly based on the Technology Roadmap for Generation IV Nuclear Energy Systems[20].

(a) VHTR (Very High-Temperature Gas-Cooled Reactor)

The VHTR is a reactor having a coolant exit temperature of 1000°C or more, and its final target is set at about 1500°C. The most important application for this reactor is considered the production of hydrogen using the IS process. The reference design of VHTR shows an output of about 600MWth and uses the ZrC-coated particle fuel of low enriched uranium oxide (block or pebble bed type).

If a VHTR is used for a hydrogen production plant, the heat taken out of an intermediate heat exchanger will be introduced into an IS process plant. If a VHTR is used as a power reactor, the use of the direct cycle is supposed, and the power generation efficiency is estimated at 50% or more. In either case, it is assumed to use the one-through cycle that does not recycle any spent fuel. The future challenges include R&D efforts related to fuels coated with ZrC having a high heat resistance, heat resisting ceramics materials, a passive decay heat removing system, an intermediate heat exchanger, etc. JAERI (Japan), GA (U.S.) and others are currently extending R&D efforts, aiming to start operation of VHTR by 2020.

(b) GFR (Gas-Cooled Fast Reactor)

GFR is a helium-cooled fast reactor for which the use of a closed cycle is assumed to improve the efficiency of resource utilization and control actinides. Especially, the CEA in France has taken an attitude of attaching importance to the R&D efforts for this type of reactor. The Commission has set the target time for commercialization of GFR at around 2025.

The reactor GFR will be mainly used to recycle uranium, plutonium and actinides, and minimize the contents of long-lived nuclides in radioactive wastes. The reference design of GFR shows an output of 600MWth/288MWe and a coolant exit temperature of 850°C. The nuclear heat may be used for the production of hydrogen. However, the most important application for the nuclear heat is assumed to be the power generation by a direct cycle helium gas turbine, of which the efficiency is estimated at 48%. The most promising fuel option is a ceramic compound fuel called "cercer" (UPuC/SiC (70%/30%) containing about 20% of Pu). Examinations will be made on spent fuel reprocessing systems including wet and dry options.

6.6 Conclusion

Focusing on high-temperature gas-cooled reactors (HTGRs), in which there is a rapidly increasing interest as the most promising options for short- and medium-term introduction reactors and generation IV reactors, this article described the current enhancement of expectations for HTGRs, the international R&D efforts related to these reactors, the features of the reactors, and the utilization of the reactors for the production of hydrogen, and provided an overview of the key R&D and introduction projects for HTGRs in Japan and foreign countries.

The HTGRs, which have a high inherent safety, may be used in various applications including the production of hydrogen and the high-efficient power generation by small- and medium-sized reactors. It can be considered that these features of HTGRs may be in harmony with the social needs for nuclear energy systems.

Today, many countries are involved in full-scale R&D projects for HTGRs, considering them clearly as the next generation reactor candidates. Under these circumstances, it is important for Japan to extend R&D efforts focusing on the various potentialities of HTGRs, taking into consideration the social needs for nuclear energy plants in the future. In addition, it is necessary for the public and private sectors to undertake examinations on the construction of reactors such as an alternative prototype reactors to HTTR as well as a small high-efficiency power generation test reactor.

Currently, we are facing an important problem of how to satisfy the enormous demand for hydrogen brought forth by the future diffusion of hydrogen energy systems. The mass production of clean hydrogen by using a HTGR as the heat source is attracting much attention, and may probably provide more applications to nuclear energy, used only for power generation, and make a great change in the role of HTGRs in overall energy systems. The DOE budget requests for the 2004 fiscal year proposed a new Nuclear Hydrogen project as part of its Hydrogen Fuel Initiative. In Japan as well, it is desirable to launch into an R&D project for the production of hydrogen by using a reactor such as a HTGR.

Notes

*1: Japan signed into the GIF Chapter in July 2001.

*2: This was initially announced as the Freedom Fuel Initiative, and has recently been called the Hydrogen FUEL Initiative, or Freedom CAR and Fuel Initiative, combined with the Freedom CAR Initiative.

*3: Large plants distant from consumption districts may face the problem of hydrogen transportation cost.

References

[1] International Energy Agency, World Energy Outlook 2002 (2002)

[2] Reprinted from the DOE homepage (http://gen-iv.ne.doe.gov/)

[3] Atomic Energy Commission of Japan, Long-Term Program on the Researches, Development and Utilization of Nuclear Energy, November 24, 2000 (in Japanese)

[4] Atomic Energy Commission of Japan, Advisory Committee on Researches and Development, Innovative Reactors Review Meeting, "How to Implement Future Research and Development Projects for Innovative Nuclear Energy Systems," November 7, 2002 (in Japanese)

[5] Publication in the press by the Japan Atomic Energy Research Institute, September 20, 2002 (http://www.jaeri.go.jp/english/press/2002/020920/)

[6] http://www.world-nuclear.org/info/inf32.htm

[7] Atomic energy encyclopedia ATOMICA, Technological Evolution of Gas-Cooled Reactors (03-03-01-01), (in Japanese) http://mext-atm.jst.go.jp/atomicaf.html

[8] Atomic energy encyclopedia ATOMICA, Diversified Utilization of Nuclear Heat Energy thanks to High-Temperature Gas-Cooled Reactors (03-03-05-01) (in Japanese) (http://mext-atm.jst.go.jp/atomicaf.html)

[9] http://httrntsv.oarai.jaeri.go.jp/index_top.html

[10] Hitoshi Hayakawa et al., New Development of High-Temperature Gas-Cooled Reactors, "Features of Reactor: Mainly Principle of Inherent Safety," Atomic Energy Society of Japan's Journal, Vol. 44, 846 (2002) (in Japanese)

[11] Ryota Omori,Non-fossil-resources-based Hydrogen Production Technology, Science & Technology Trends-Quarterly Review, No. 7 (2003)

[12] Publication in the press by the Japan Atomic Energy Research Institute, May 15, 2001, (http://www.jaeri.go.jp/english/press/2001/010515/index.html)

[13] http://www.mbe.doe.gov/budget/04budget/content/highlite/highlite.pdf

[14] Material from the DOE homepage (http://nuclear.gov/infosheets/Hydrogen%20J.pdf)

[15] Hidemasa Naka, Dreams and Problems on the Emerging "Production of Hydrogen by Using Nuclear Energy," Atomic Energy Eye, Vol. 48, No. 5, 34 (2002) (in Japanese)

[16] Ministry of Economy, Trade and Industry, Research Meeting on the Fuel Cell Commercialization Strategy, Report, January 2001 (in Japanese)

[17] Nori Kobayashi, Hydrogen Introduction Scenario, Special Course on Energy organized by the Energy & Resources Society in 2002, "Hydrogen Energy Technology Trend and Introduction Scenario," November 27, 2002 (in Japanese)

[18] Japan Atomic Industrial Forum, Social Meeting for Researches on Nuclear Energy Systems, Production of Hydrogen Energy by Nuclear Energy, NSA/COMMENTARIES: No. 10 (2002) (in Japanese)

[19] Yasuo Tsuchie and Hiroshi Sekimoto, New Development of High-Temperature Gas-Cooled Reactors, "History of High-Temperature Gas-Cooled Reactors in the World," Atomic Energy Society of Japan's Journal, Vol. 44, 840 (2002) (in Japanese)

[20] U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum, A Technology Roadmap for Generation IV Nuclear Energy Systems (2002)

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7

Role of Universities in the Research on Silicon Semiconductor Devices

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7.1 Introduction

The research on silicon semiconductor devices, which has already entered the area of nanometer order, deals with the finest area among the crowd of nanotechnologies. Despite the fact that there is a physical limit due to the size of a silicon atom, high integration of silicon semiconductors is expected to continue until around 2020 to 2030 at the present pace. Today's information-oriented society will not allow the development of semiconductor devices to come to a standstill, and the present high growth rate of the industry is expected to continue worldwide.

In the past from the latter half of the 1980s to the beginning of the 1990s, research activities for silicon semiconductor devices in Japan led the world and drove other domestic industrial technologies. However, the situation has now drastically changed and there is concern that silicon semiconductor technology cannot be developed in Japan any more. This report presents an overview of the present situation of research activities for silicon semiconductor technology in Japan in a fresh light, and reviews the role of universities in the research on semiconductor devices while anticipating the situation a decade from now.

7.2 Development of silicon semiconductor devices

7.2.1 Values representing the development of technology

Figure 1 shows typical sizes that represent the development of silicon semiconductor devices. As the values that represent the level of miniaturization technology, the line width of wiring of integrated circuits and the gate length of transistors are usually used. To improve these values, the performance of lithography plays an important role. In the United States, a research consortium has been formed to develop the exposure technology that enables the finest fabrication at present using EUV (extreme ultraviolet rays)[1], and the performance of transistors with a gate length of 10 nm or less has been reported[2]. Following this, a project related to EUV exposure technology has been started in Japan[3].

To carry out research on semiconductor devices, silicon wafers of a size appropriate for the fabrication equipment must be used for the preparation of circuits on an experimental basis even when the research is related to a part of the device. Facilities that will be built in the future are mainly for 300 mm (12 inch) wafers, and the development of new semiconductor fabrication equipment is also focused on this size. In semiconductor fabrication equipment, most of the new technology know-how is incorporated into the equipment itself, and the new technology is actualized through the newly developed equipment. Therefore, even the research work cannot neglect the wafer size and it is an important value that represents the generation of research and development as in the case for the assembly of manufacturing lines.

At least until the end of the 1990s, the change of generations of research on semiconductor devices was expressed by quantitative performance indices such as the wafer size and clock frequency. The ITRS (International Technology Roadmap for Semiconductors), which is recognized internationally as a common view, is reviewed every year[4]. In this roadmap, the duration of research and the timing of actual production are shown on a specific schedule. This means that the results of research are evaluated quantitatively and the evaluation methods have been established.

7.2.2 Trends in the research on miniaturization

The ITRS[4] predicts that the line width of most miniaturized silicon semiconductor devices will reach 100 nm or less by 2004, and mass production technology will enter the nano-area soon. Recently, logic ICs aiming at higher operating speeds have become the leader of the frontier technology instead of memory ICs that aim at larger capacities (Figure 2), and the gate length of transistors is now more often used as the index for the development of semiconductor devices than the line width.

The gate length has already become less than 10 nm on the research level, and it was reported in December 2002 that transistors

Figure 1:Typical values representing the development of research on silicon semiconductor devices

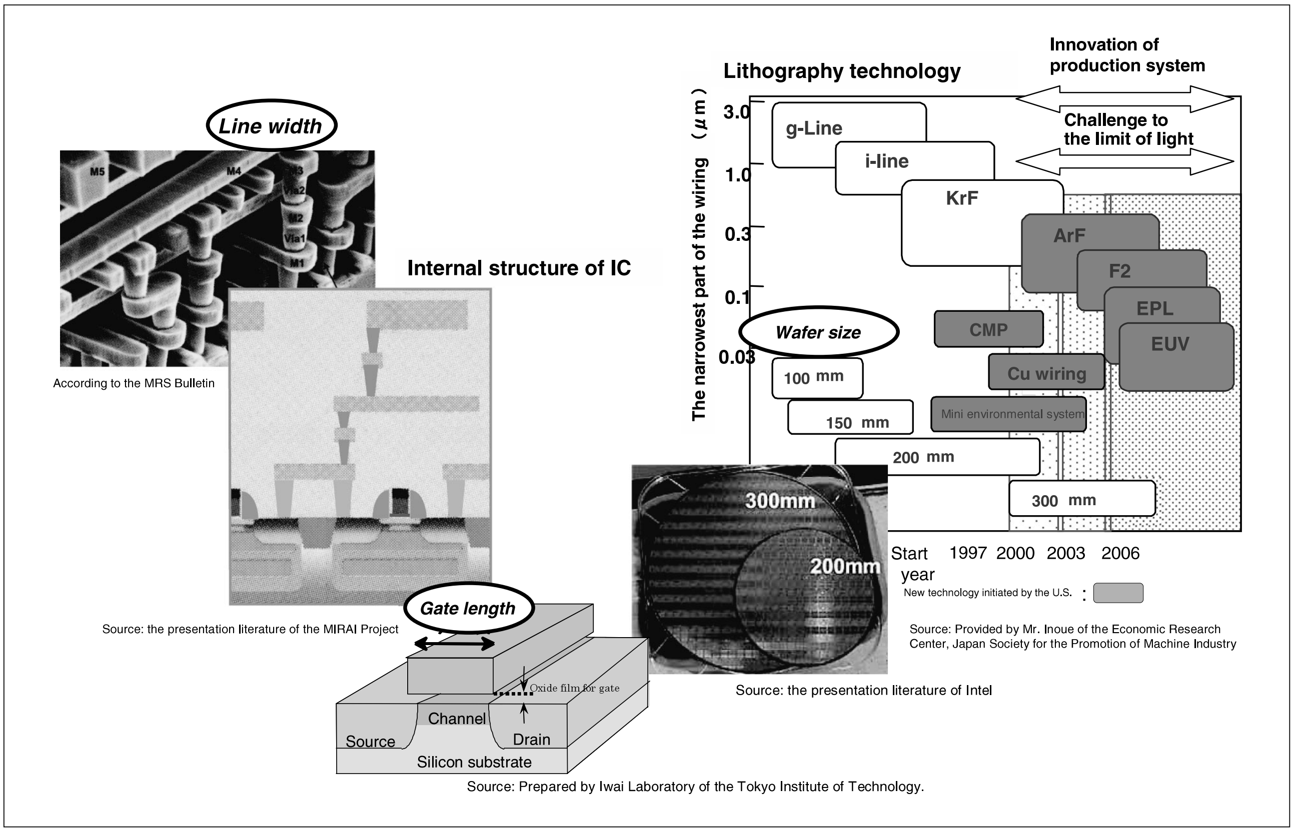
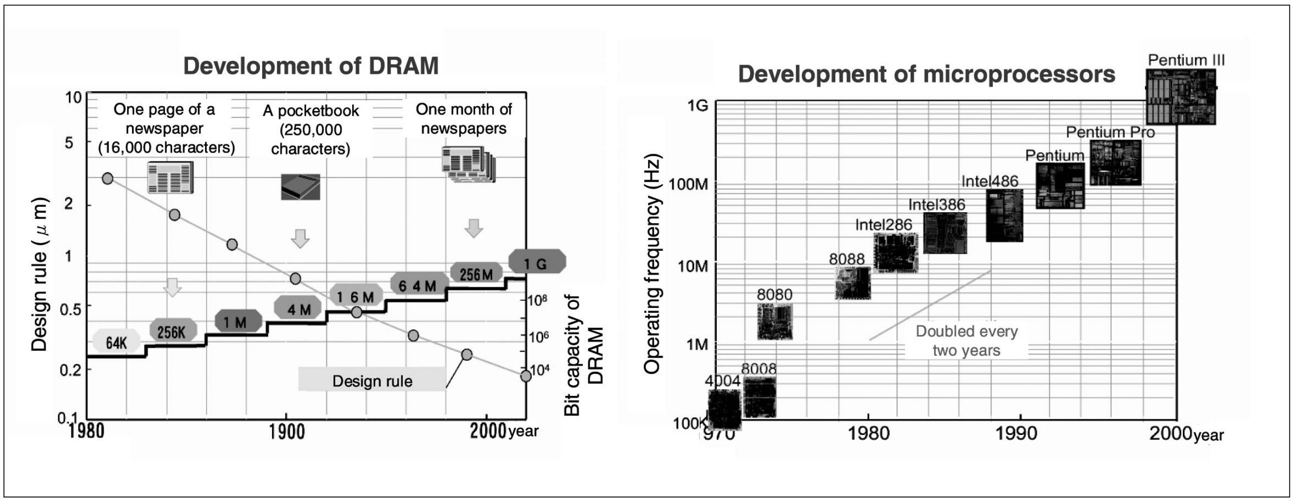
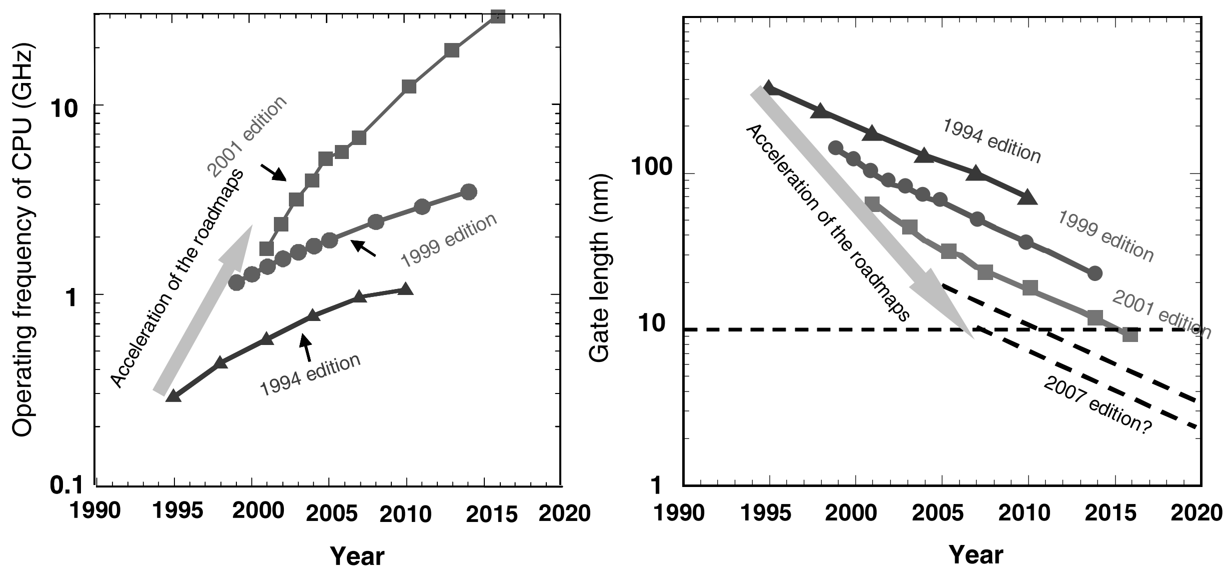


Figure 2: Development of typical semiconductor devices



Source: Prepared by Prof. T. Kuroda of Keio University

Figure 3: Acceleration of the roadmaps



Source: Prepared by Iwai Laboratory of Tokyo Institute of Technology

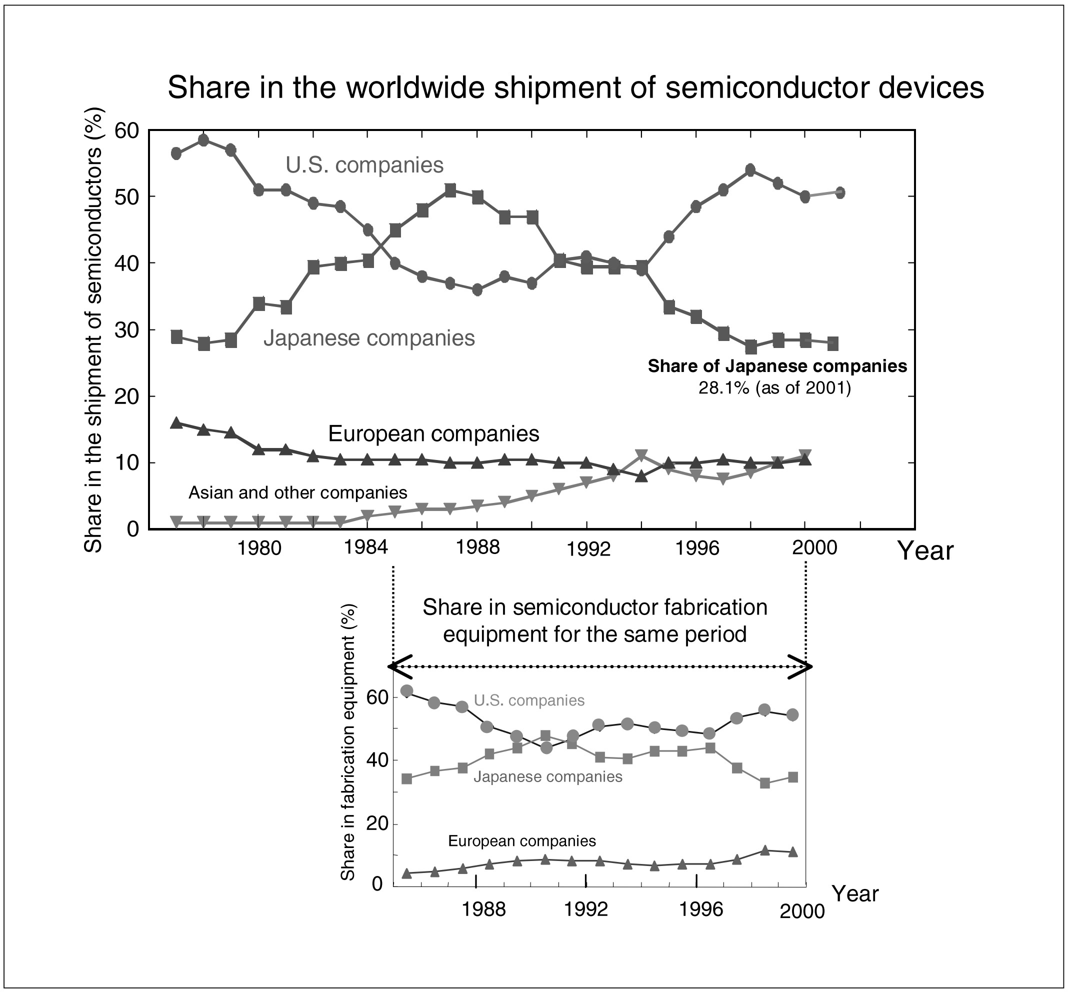
operated with a gate length of as low as 6 nm[2]. Elemental technologies are being developed at a much higher speed than expected. Particularly in the miniaturization and improvement of performance indices in logic ICs, the revision of ITRS is accelerated every year following up on the quickly advancing research results (Figure 3). Furthermore, concerning the silicon oxide films that compose the transistor gates, it has been reported that the devices can be fabricated with a film thickness of as thin as 7 nm[7].

Considering the distance between the atoms of a silicon single crystal (about 0.3 nm) or the distance between silicon and oxygen ions in silicon oxide (0.4 to 0.5 nm), there are only a little more than 10 atoms within a distance of 6-7 nm. It is really amazing that such thin films actually function, which is the basis of the view that the end of the development of silicon semiconductor devices will come between 2020 and 2030. In addition, semiconductor devices cannot be composed using only the above-mentioned elemental technologies. Even in the range that will surely be reached within several years, there are many critical technical problems to be solved (Red Brick Walls)[8], and, furthermore, it is not certain whether these problems can be solved or not.

In the past, however, as has been described above, results of research on elemental technologies for semiconductor devices have always advanced ahead of the roadmap, with the technologies that had not seem possible having been made possible by keeping pace with the development of elemental technologies. As a result, the development of semiconductor devices appears as if it proceeds linearly following a law as shown in Figure 2. This relationship is called Moore's Law, named after its proponent. In other words, the history of the research on semiconductor devices is a series of breakthroughs of anticipated technical limits.

Recently, it has been commonly recognized that the excessive heat generation due to the concentration of consumed electricity, rather than the limits of miniaturization, may become a critical problem[9]. To reduce electricity consumption, low-voltage driving is the key and prompt review of the circuit design is required. In this respect, devices based on a new principle superior to the semiconductor transistor[10] have been proposed, and research on the improvement of conventional semiconductor devices and research on the creation of new devices will proceed alongside each other in the next decade or two. However, we cannot rely only on the results of research for the creation of new devices based on unforeseeable technologies.

Figure 4:Trends in the position of Japan in the semiconductor device industry



Source: Provided by Mr. Inoue of the Economic Research Center, Japan Society for the Promotion of Machine Industry

7.3 Situation surrounding research on semiconductor devices

7.3.1 *Situation of the Japanese semiconductor industry*

At one time, from the latter half of the 1980s to the early part of the 1990s, Japan led the world in research on semiconductor devices. Owing to superior technical development concentrating on large-scale integrated memories, “Japan is an electronics state,” and “semiconductors are the rice for industry” were the catchwords for Japan[11]. The average growth rate of Japan’s semiconductor device industry since the 1970s was 11% in value of production, and the value in 2000 reached about 1% of Japan’s GDP[12]. In the 1990s, the ratio of investment in research and development and equipment to the total amount of sales was kept at a high level of about 15 to 20%. These values show that the semiconductor device industry led research and development and equipment investment in Japan.

While the semiconductor device industry in Japan showed remarkable development in the past, it rapidly declined in the latter half of the 1990s as shown in Figure 4[5, 12]. At present, Japan’s share in the world market is at the level of the 1970s. The amount of production in the world during this time has constantly increased with some margin of fluctuation, however, Japan is the only country that has lost competitiveness. Following the decline of the device business, related industries such as semiconductor fabrication equipment manufacturers are also losing their world market share. Specifically, in the production of DRAM (Dynamic Random Access Memory: volatile random access storage device) that used to represent the competitiveness of Japan, Japanese companies are now far behind those of Korea, the United States and Europe, being pushed into a corner where a comeback is groped for by integrating the business into one company. The technology of the United States for MPU (Micro Processor Unit) is far ahead of other countries. Although Japan still holds a dominant position in game machines, CCD (Charge-coupled device), and Flash memory (nonvolatile memory), these fields are also being attacked by foundries—the new Asian business model of the 1990s that provides only the production part. Since many reports have been published on this subject[5], additional detailed data are not given here.

Furthermore, Japan has a particularity that the semiconductor device industry belongs to the electric industry. As the Japanese electrical industry has its structural problems[13], it is not possible to discuss the semiconductor industry separately. Because the Japanese electrical industry has adopted the strategy of exhaustive assortment of merchandise (conglomerate integration) like a department store, which is considered to be effective only for certain limited areas, the overall competitiveness of semiconductor devices is being lost in the world even if there are some product groups that have their own advantages. The Japanese semiconductor industry is burdened with serious problems. In any event, it is apparent that Japan made a misjudgment around 1990. There is an analysis that the past successful experience delayed the noticing of changes in technologies and business models[14].

7.3.3 Changing the direction of the perspective on research and development

When Japan took international initiatives in silicon semiconductor devices around 1990, the field in which Japan showed the highest strength was memory production technology centered around DRAMs with miniaturization leading the development of technology. In the 2000s, however, "DRAM" and "miniaturization" are not necessarily keywords any more. As a background for this phenomenon, a business model that specializes in specific products or application fields, or in a particular part of production steps was established in the 1990s. Only Japanese business firms stuck to the old-fashioned business model of department store strategy, enclosing every step of the production process within the company, which used to be prevalent until the beginning of the 1990s. Now, the strategy to specialize in a particular field of products or a particular stage of the production process, thereby obtaining a worldwide lion's share in the narrow areas, brings about high profits. Consequently, targets of research and development differ according to the devices and application fields that are aimed at, and it does not make sense to simply pursue miniaturization. For example, now that many Japanese companies have withdrawn from the DRAM business, setting targets for the next-generation to "SoC (System on Chip)" and "communication devices", priority of research and development is not placed on "miniaturization" as it once was and, instead, "reduction in power consumption" has become a more important subject. In retrospect, concentration on DRAM and emphasis on miniaturization were results of pursuing industrial efficiency. From the viewpoint of users, "DRAM" is not necessarily an ideal memory. Although "miniaturization" brings about merits in performance such as low capacitance, the primary objective is the reduction of production costs due to the small size and large capacity. That is, these keywords did not represent the customer's perspective. On the other hand, "SoC" and "reduction in power consumption" are somewhat closer to the pursuit for customer satisfaction. Based on what has been described above, some people doubt the importance of serious discussion on the limits of miniaturization for silicon devices.

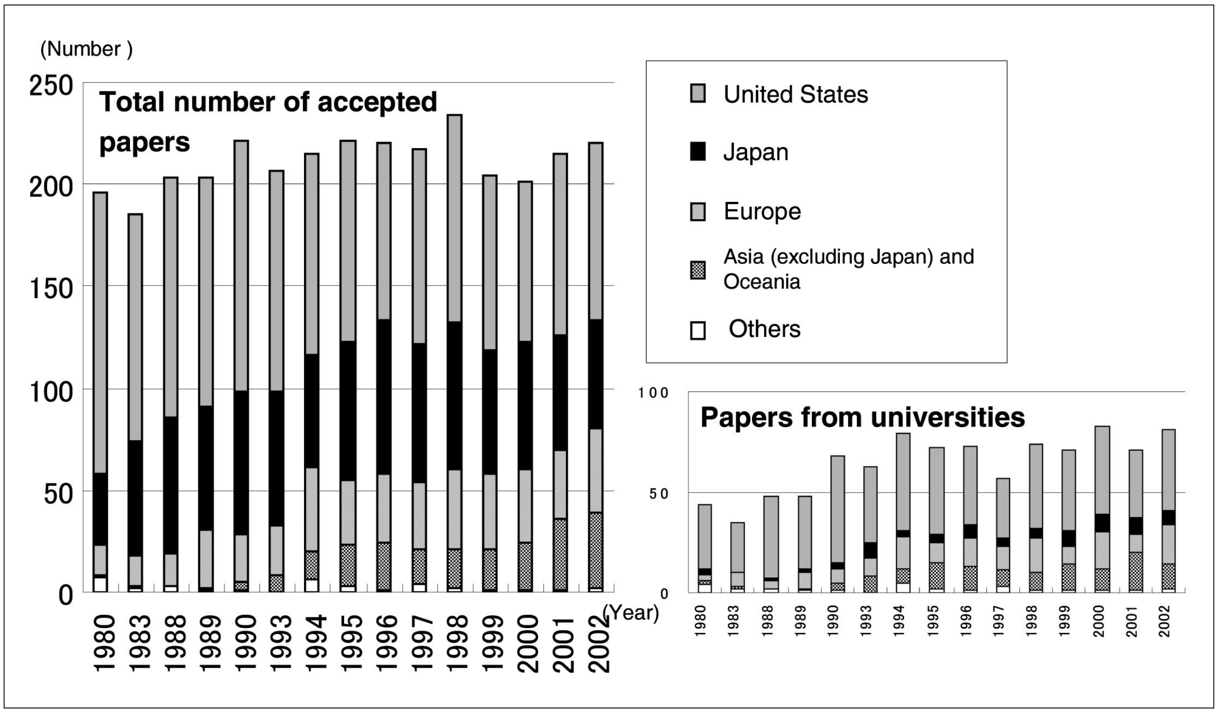
7.4 Leading organization conducting research and development in Japan

7.4.1 Number of papers presented in international conferences

In around 1990, when Japan was taking international initiatives in silicon semiconductor devices, Japan showed the highest strength in the field of memory production technology centered around DRAM, for which miniaturization was the key. A question here is who contributed to such research activities in Japan. Figure 5 and 6 show the results of investigation on the numbers of papers that were accepted by the two international conferences, IEDM (International Electron Devices Meeting)[15] and ISSCC (International Solid-State Circuits Conference)[16]. These international conferences are known to have a relatively severe standard for accepting papers, requiring completeness as device research as well as originality.

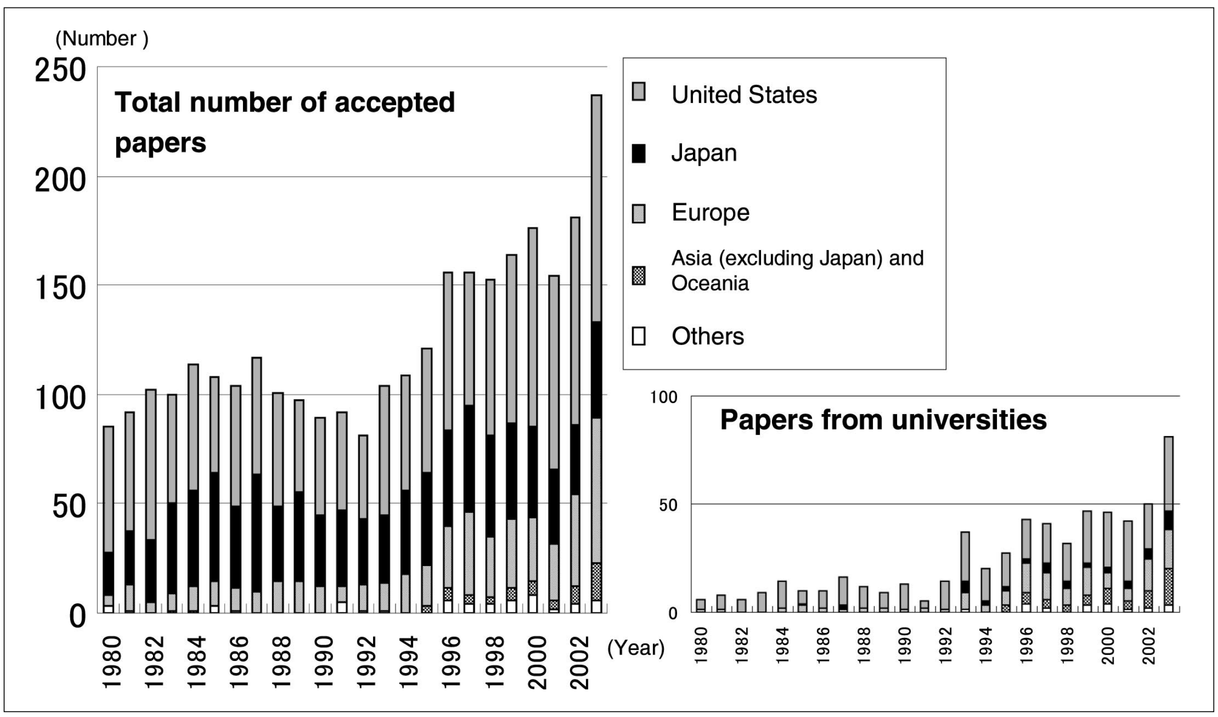
The number of papers presented from Japan maintained moderate levels during the 1990s, before it started to show a downward trend in 2000. While the United States has held the dominant position since the 1980s, the number of papers from European and Asian countries has been indicating a remarkable growth since the latter half of the 1990s. This increase of

Figure 5:Number of papers accepted by IEDM (comparison by areas)



Source: Provided by Iwai Laboratory of the Tokyo Institute of Technology

Figure 6:Number of papers accepted by ISSCC (comparison by areas)



Source: Provided by Iwai Laboratory of the Tokyo Institute of Technology papers from these countries directly reflects their leap in industrial competitiveness. What is particularly notable is that the papers presented from Japan around 1990 consisted in large part of those from private companies and included few papers from universities. This is in contrast to the United States, where universities have constantly been making substantial contributions. Another noticeable point from Figure 6 is that almost all of the papers from Asian and Oceanic countries, excluding Japan, have been presented from universities. The imbalance between business and academia in Japan was rather unusual in such a large research field at the early stages when the industry was not mature. A detailed look at Japanese research activities reveals another unique trend in Japan: research on semiconductor devices at universities has been more focused on compound semiconductors than silicon semiconductors.

The research on silicon semiconductor devices including production technology cannot be carried out without research facilities of a considerable scale, which require a large amount of investment. In the period around 1990 in Japan, such research funds were only available in private companies, where research work was conducted within the closed environment of each company. The industry in those days considered the universities only as a supply source of graduates, and expected little research achievement from the universities.

In the latter half of the 1990s, there was an increase in the number of papers presented by Japanese universities, although it is still small in total number. Some measures based on the First Stage Basic Program for Science and Technology Policy may have attributed for it. For example, some university faculties were recruited from private companies and an organization began to support university laboratories by commission of prototyping to private companies (VLSI Design and Education Center: VDEC, started in 1997)[17]. Similarly, in the United States in the latter half of the 1980s, many researchers moved to universities from the Bell Laboratory, which had been the center of research on semiconductors, and these researchers are said to contribute as major players in the U.S. in the 1990s[18]. In Japan as well, the flow of human resources since the latter half of the 1990s must have led to the increase in the number of papers in international conferences. Furthermore, it is believed that the presence of the VDEC and other private foundry services allowed universities to enhance their research ability particularly in the area of design technology. This is an example of successful industry-academia collaboration that effectively linked the research efforts at universities with private manufacturers. Now, the system LSI design technology in universities has reached a level acceptable for the industry. Some laboratories in universities have started up businesses by using foundry services for their prototyping and productions[19]. In this technological field, a researcher can participate in a research project wherever in the world he/she is, which potential suggests even a virtual research institute would prove effective. Disadvantages of universities are thus being removed in research areas that do not require large-scale investment.

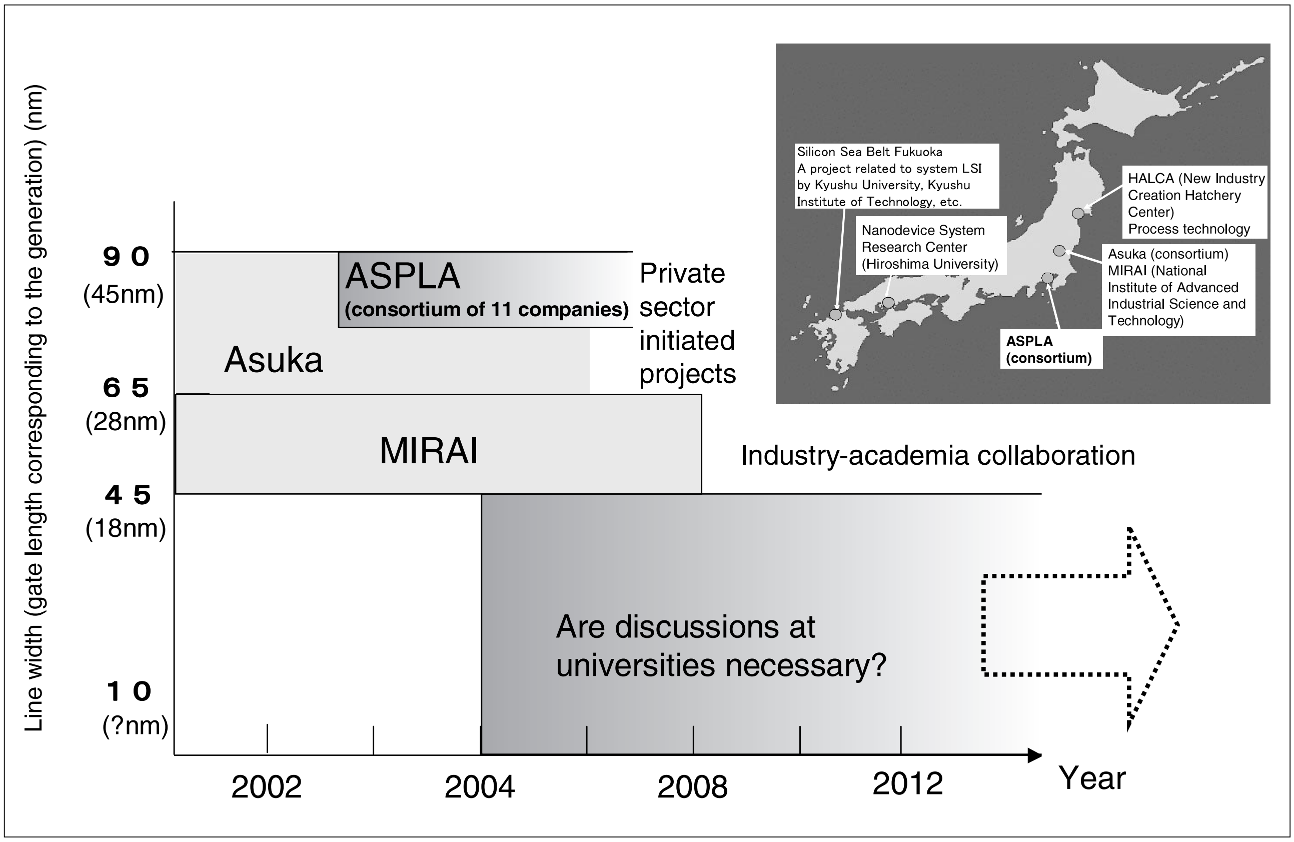
7.4.2 Research and development projects (consortium) under way in Japan

Figure 7 shows an overview of research projects (consortium) in Japan related to silicon semiconductor devices in terms of line width (and gate length) and time. It indicates that several projects spanning through 2007 are already under way. These projects share an objective of improving research efficiency by concentrating research investments. Most of them aim at breaking through the above-mentioned Red Brick Walls.

Since only simple explanations of the parent organizations of each project (consortium) are given below, please refer to the respective websites for the objectives and scale of these projects.

"Asuka", that is led by the private sector with a view to developing the technology for system on chips (SoCs), is promoted by Semiconductor Leading Edge Technologies, Inc. (SELETE)[21], a company that is under the control of the Semiconductor Consortium Committee (consisting of 11 companies) of the Japan Electronics and Information Technology Industries Association

Figure 7:Schedule of semiconductor related projects



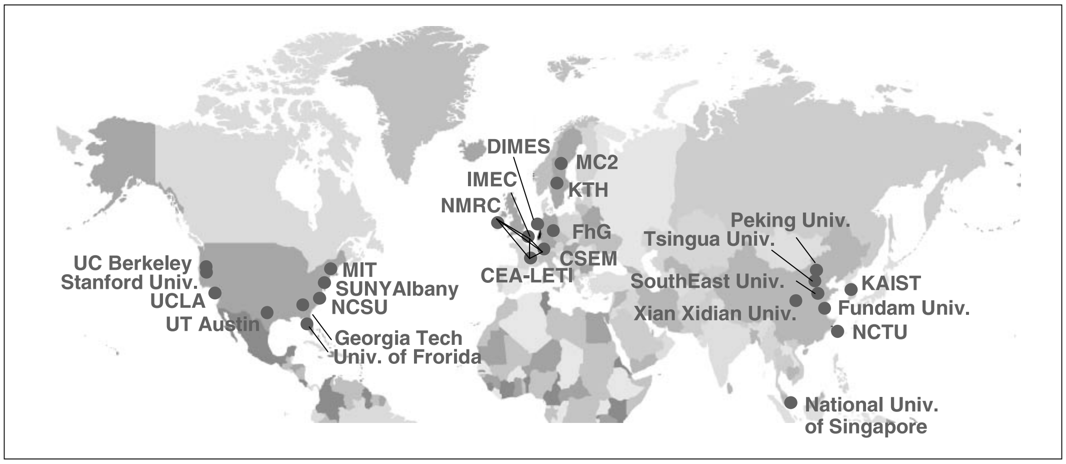
Source: Prepared by Iwai Laboratory of Tokyo Institute of Technology

(JEITA)[20]. Most of the researchers involved in this project are on loan from the corporate investors (11 companies) and contractors (2 companies). These companies are all device makers, including a foreign company participating as one of the contractors. The participants of the "MIRAI" [22] include the Advanced Semiconductor Research Center of the National Institute of Advanced Industrial Science and Technology (AIST), the 25 member companies (14 semiconductor manufacturers + 11 equipment manufacturers and material suppliers) of the Association of Super Advanced Electronics Technologies (ASET)[23], and 20 university laboratories. Although this is an industry-academia -government collaboration project, most of the personnel are on loan from private companies or persons with experience in private companies. The "HALCA", which is another industry-academ ia-government initiative, has a different objective from others. This project seeks to enhance semiconductor production technologies tailored for wide variety of production with limited quantity, which is therefore not listed in Figure 7. Manufacturers of fabricating and peripheral equipment have been playing an important role in the project, although little of the results have been disclosed.

These three projects are mainly implemented in the "Super-Clean Room Industry-Academia-Government Joint Research Building"[24] in AIST (Tsukuba), which was built at a total cost of ¥25.2 billion in June 2002. The laboratory has two clean rooms: a Class 3 room of 3,000 m^2 in use for the Asuka Project and a Class 5 room of 1,500 m^2 in use for the MIRAI and HALCA projects. It is reported that a total of more than 400 engineers and technicians work there and the total investment exceeds ¥100 billion. Even though originating in separate schemes, these projects have recently started joint efforts on a limited basis[25].

Furthermore, Advanced SoC Platform Corporation (ASPLA)[26] has been established, that is expected to yield results ahead of the other projects ongoing in this area. While being a private-sector project, it has been treated like an industry-government collaboration, since it is scheduled to receive national funding of about ¥35 billion under the second supplementary budget for fiscal 2001 as one of the "joint research

Figure 8:Research institutes for semiconductor devices throughout the world (excluding Japan)



Source: Prepared by Iwai Laboratory of the Tokyo Institute of Technology

facilities for next-generation semiconductor design and fabrication technology" to be set up by AIST. The actual facilities of ASPLA are located within the clean rooms of a private company. This project intends to embody the research results of SELETE[21] and STARC[27], which are under the umbrella of JEITA. Any university does not directly contribute to its activities. Another attempt is "Advanced Assessment of Next-Generation Semiconductor Nano-Materials Project," a three-year project starting from fiscal 2003 that focuses on the development for materials in wiring process. Private companies will bear 50% of the cost of this project.

In the period through 2007, semiconductor research community should place the highest priority on achieving concrete results from these projects, because they are fully need-oriented initiatives launched with an eye toward overcoming the Japanese semiconductor industry crisis. Their failure to yield results might lead to further deterioration of the competitiveness of Japanese industry.

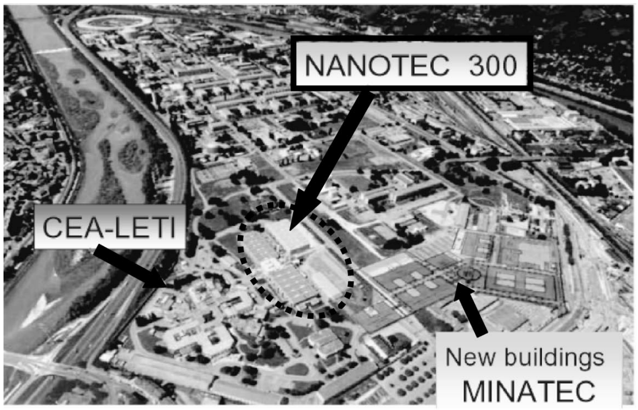
The present ongoing projects in Japan concerning the fabrication technology of silicon semiconductor devices are still heavily dependent on private companies, with virtually no project that is led by universities. Furthermore, as of now, there is no research project in Japan that pursues devices of a line width of 50 nm or less (10 nm or less for gate length) with a view a decade ahead. Based on these facts, the FED (Research and Development Association for Future Electron Devices) Salon discussed as the 2002 conference challenges about the sub-10-nm generation semiconductors (coordinated by Prof. T. Hiramoto of Tokyo Univ.), that are expected to appear in about 10 years, and proposed the concept of a university-led project [28].

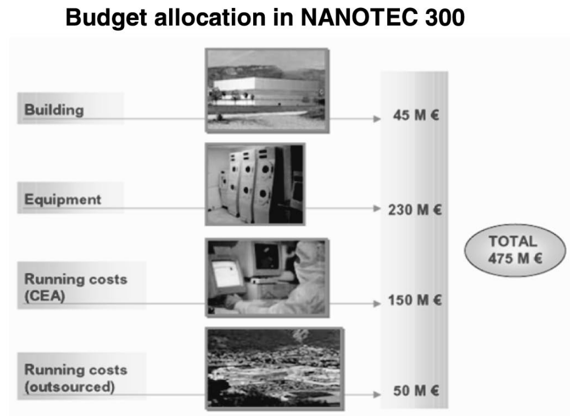
7.5 Examples of overseas research facilities

7.5.1 Research facilities for silicon devices in the world

Figure 8 is a world map showing the locations of advanced device prototyping facilities that are readily available to university researchers. As seen from the map, most of these facilities are located within or adjacent to universities, indicating that forming regional high-technology clusters through industry-academia-government collaboration is the key to facilitating research. The active involvement of universities is crucial in providing companies with personnel who can immediately bring benefits to business, while it promotes the progress of university faculty members themselves. Of the institutes shown in Figure 8, SUNY Albany, IMEC and CEA-LETI (MINATEC) serve as the homes of projects sponsored by national or local governments. Some of these institutes are already equipped with lines to treat 300 mm wafers or are ready to upgrade their existing equipment to them. The construction of a 300 mm wafer line requires a massive investment of over several tens of billion yen. In these countries, what justifies such enormous investments is a common perception that silicon-based devices will continue to be in the mainstream of high-technology electronics for the next few decades or more.

Figure 9:Research facilities under construction in Europe





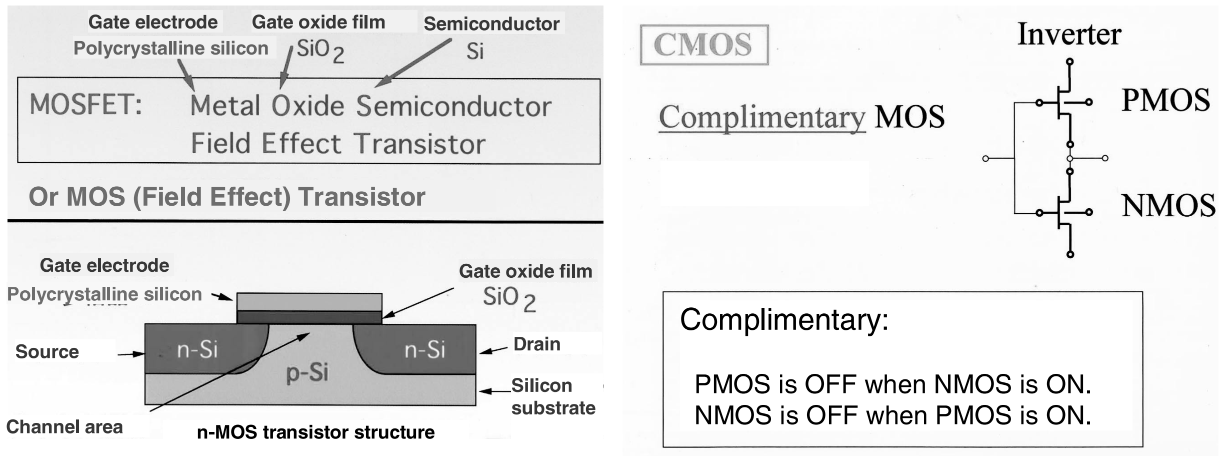
7.5.2 An example in Europe

An example in Europe is NANOTEC 300, that is a research establishment on 300 mm wafers, under construction as part of the French MINATEC Project (Figure 9)[29]. Details of MINATEC have already been introduced in the fourth issue of this bulletin[30]. It consists of laboratories for common use with the most advanced equipment, science and technical universities and graduate schools and incubation centers for venture businesses. Research for silicon integrated circuits are placed at the center. The expected numbers of personnel for each platform are: 500 faculty members and 1,500 students in the university and the graduate school; 800 personnel in applied research and 400 personnel in basic research (1,000 in the field of miniaturization technology) in the laboratories; and 500 to 1,000 people in the business sector. The city of Grenoble, where MINATEC is located, has had solid industrial organizations of semiconductor, biomedicine, and other electronic devices, as well as a heavy concentration of affiliated research laboratories of national and European institutions and of universities. These organizations form the parent body of MINATEC. As shown in Figure 9, the facilities of the MINATEC project are located adjacent to CEA-LETI (Electronics and Information Research Center of the French Atomic Energy Commission), which is one of the supporting organizations. Since CEA-LETI places emphasis on the procurement of funds from the industry, the external research funding for silicon semiconductor devices accounts for 60% (41 M euro) of the total funds, and silicon technology is positioned as the "Driver in CEA-LETI." In addition, many divisions of STMicroelectronics, K.K.[31], which is the largest communication device manufacturer in Europe, are located in the neighborhood.

7.5.3 Examples in Asia

In Asia, not only semiconductor research facilities but also the other industrial and interdisciplinary research facilities are centralized in a more distinct manner because of the national policy of each country. One example is the Hsin Chu Science-Based Industrial Park, which was established by the government of Taiwan in 1980. Various privileges have been granted to this area. There are Industrial Technology Research Institute (ITRI), National Qinghua University, National Chiao Tung University, and more than 290 companies related to the six major industries (semiconductor, computer parts, information and communications, optoelectronics, precision instruments, and biotechnology). The estimated population of researchers and engineers working in the area totals to as many as 72,000. National Chiao Tung University (NCTU) is known as a community-based technical college since 80% of the graduates find jobs in the industrial park. The university owns a semiconductor prototyping facility (Semiconductor Research Center)[32] since the 1980s, which is made available to anyone for a fee. The fabrication lines are easily accessible through its website. The main purpose of this facility is offering fabrication services for outside as well as training students. While the current facility is a mix of machines fitted for different wafer sizes ranging from 4 to 6 inches, a new

Figure 10:CMOS structure expected to be maintained as the basic principle over the next decade



Source: Prepared by Iwai Laboratory of the Tokyo Institute of Technology

nanotechnology one is soon to be added with clean rooms covering a total area of 3,300 m^2 and will start operations in 2004. However, what this university emphasizes most from now is not research on hardware but the national project called as Si-Soft (the National Si-Soft Project)[33]. This large-scale scheme intends to increase the number of professors dedicated to LSI design by 250 in three years and to produce 1,000 designers every year. It stands on a following perception. Taiwan had successfully made the transition from labor-intensive industry to investment-oriented one during the latter half of the 1980s and through the 1990s. However, it should go on to a next step of a knowledge-based one, because the center of the investment-oriented business is forecasted to move to Mainland China sometime during the 2000s.

7.6 Technological foresight for the next decade

The prospects of semiconductor devices for the next decade based on the opinions of a number of researchers I have interviewed are listed below.

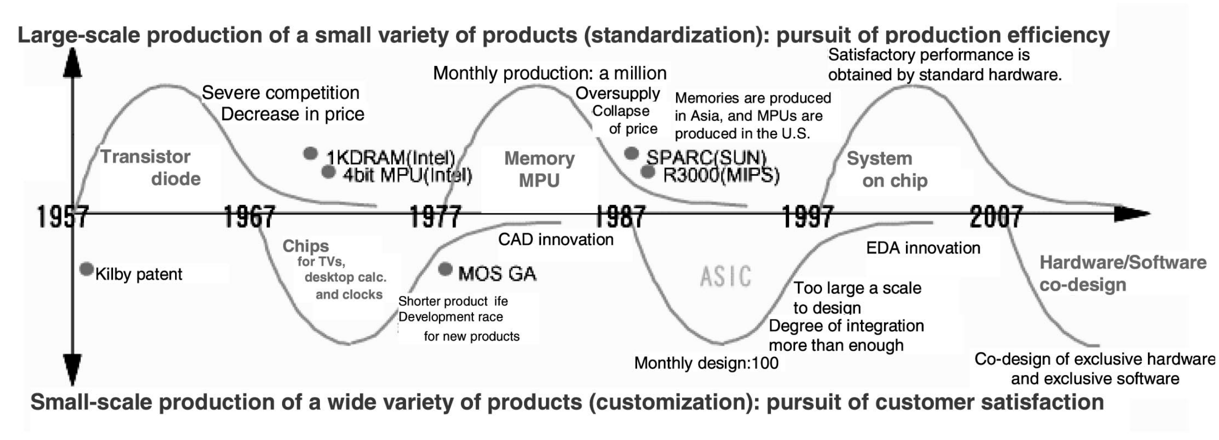
(1) Many researchers believe that at least two features of present semiconductor devices will remain unchanged over the next decade: semiconductors are formed on silicon wafers and have a CMOS structure (Figure 10). That is, the basic principle that complimentary circuits using MOS (Metal-Oxide-Semiconductor) structure are formed on silicon wafers will not change even if the semiconductor materials are changed from silicon to other new materials, for example, carbon nanotube and so on.

(2) Provided that the prospects of ITRS roadmap are realized in general, a ubiquitous computing society will be achieved on the extension of conventional silicon devices without having to wait for the introduction of devices based on a new principle. For example, the operating speed of MPUs for practical use is expected to exceed 10 GHz in 2005 or afterwards.

(3) As an immediate issue, there is an urgent need to lower the operating voltage to reduce power consumption. The realization of (2) is likely to depend more on progress in this aspect than progress in miniaturization technology.

(4) In the history of the research on devices, there has been two trends that appeared alternately: standardization and customization (Figure 11). The present trend is standardization that features SoC technology. However, the research and development enthusiasm about this topic may wane by around 2007, followed by rising interest in customization that will dominate after ten years in the world of semiconductor research. The key concept for this customization trend is thought to be hardware/software co-design.

Figure 11:Trends of standardization and customization in the research on semiconductor devices



Source: Provided by Prof. T. Kuroda of Keio University

(5) In the area of miniaturization research, the size of MOS transistors will be reduced at the fastest pace, with their gate length expected to shrink to 10 nm or less sometime between 2010 and 2016. Miniaturization, however, means not only the establishment of the miniaturizing technology for 10 nm or less, but also obtaining performance corresponding to a line width of 25 nm or less and a gate length of 10 nm or less.

(6) To realize (5), it requires aggressive deployment of new materials, new processes, and new structures. In addition to advances in these new technologies, large innovation in circuit technology is also essential.

(7) It is no doubt that ten years from now the focus of research on miniaturization will have shifted to the range of less than 10 nm. Since this is close to the physical limits, completely different new technologies may begin to emerge from that time forward.

The question is whether research community in Japan should cover all of these technologies or not. The research in the fields stated in (5) to (7), in particular, would not be conducted without large-scale projects comparable to the ones conducted in foreign countries and massive investments. A serious discussion is needed to decide whether Japan should invest in these themes in preference to other research subjects.

Participants of this discussion must recognize that the technical hurdles to be crossed before introducing new materials and so forth are very high, because relatively easy issues have already been resolved. The industry has adopted some of the new solutions, including the intermetallic compound of silicon (silicide), nitrides that can replace oxides, solid-solution metallic films, new wiring materials, and low dielectric constant materials for interlayer films[34]. None of the remaining technological challenges is easy, since they are left unsolved despite a number of attempts over a long time. For example, materials for insulating films with a dielectric constant higher than that of silicon oxide have yet remained to be a issue after investigations for more than 30 years from the early stage of IC development. To put it another way, silicon oxide is an excellent material with stability, and discovering a material superior to it is a task of considerable difficulty. The development of high dielectric constant films to be used for DRAM capacitors has also been attracting so much of the attention of researchers for more than 10 years[35] that a multitude of papers on the subject have been presented at technical conferences. However, none of them could provide reasonable solutions in time to stop most Japanese companies from withdrawing from the DRAM business. These new materials cannot be developed by simply following the strong-arm tactics that have been taken for miniaturization technology based on the principle “a combination of human, material, and financial resources can solve everything.” According to past experience, when it comes to the choice between a change in structure (miniaturizing in most cases) or development of new materials to solve a certain problem, the former has always won.

Another noteworthy concept is the co-design of hardware and software described in (4). In this approach to customization, the optimization of the total system will take precedence over improvement in the performance in individual parts of circuits, while, with respect to hardware in specific, total robustness will become more valued than partial sophistication with limited reliability.

7.7 Consideration to the device research in universities in Japan

7.7.1 Importance of focused investment

Since future research on semiconductor devices requires enormous investment, it is ineffective to spread relatively small amounts of a budget to many research institutes. In order to establish facilities comparable to the major facilities of foreign countries, initial investment of tens of billion yen or more and further maintenance costs are necessary. That is, research activities must be concentrated from the viewpoint of national policy as well as from the viewpoint of budget allocation in a university, and a consensus must be built among parties related to the budget allocation. Although this was a difficult job, a favorable environment is being established with priority in the national policy for measures to develop science and technology and the institutionalization of universities to be independent administrative agencies scheduled to be enforced in 2004, which will accelerate the centralization of authority to the presidents of universities.

There is also an utterly different way of thinking. Recognizing that Japan is already behind foreign countries in the establishment of research systems, some universities prefer to concentrate on the development of design technologies rather than make half-hearted investments on the research on devices. For example, the Silicon Sea Belt Fukuoka Plan [36] is not constrained by the administrative boundaries of Japan, which is viewed from a broader perspective as a member of Asia.

7.7.2 Building a consensus

To realize the concentrated investment on research and development as described above, it is necessary to build a national consensus that such research and development is truly needed. It must be seriously discussed in universities as to what Japan should pursue in the future. Regretfully, it is generally recognized that Japanese universities have not contributed much in this field, and this situation may not be improved so easily. Such a superficial slogan as “it is necessary for the establishment of an electronics state” that was accepted in Japan in the 1990s cannot be tolerated any more. It seems that Japanese universities do not have persuasive reasons, which aim toward a Japan a decade from now, for their research activities to require a large amount of investment. Particularly, it may not directly contribute to the strengthening of Japanese industry to blindly aim at the top level of the world by developing the miniaturization technology in the future, and the keyword “miniaturization” by itself will not help build a national consensus. Until the Japanese economy completely recovers, it will be difficult to obtain a consensus for research that does not conform to the national industrial strategies.

7.7.3 Possible concrete measures

From an objective perspective, the research forces and facilities of present Japanese universities are weakening compared to those of foreign countries. Particularly, facilities of universities are very poor because they have not been changed since the 1980s. The facilities of Tohoku University and Hiroshima University, which are now considered to be effective for research on silicon devices, are setup for 2-inch wafers and have been closed to outside researchers. (Note: experimental production facilities of Tohoku University in the new integrated field are open to the outside, and the facilities of Hiroshima University are now accessible from outside since they have been integrated into the “Nanotechnology Support Project” of the Ministry of Education, Culture, Sports, Science and Technology in 2002.) For this reason, it may be an inevitable result that research leaders in the development of silicon devices have not come on the scene from purely university circles for a long time. The only way to achieve outstanding results on a world level at present is to utilize consignment systems such as VDEC[17].

For Japan to continue research on specific devices and processes, it would be effective to create a high technology cluster placing a university or universities in its center and involving local private companies, or for the government to take over existing research laboratories and experimental production lines owned by private companies and convert them to public research facilities. Yet another idea is to promote the establishment of programs in universities that are contributed by private companies practically creating public research laboratories within private companies. This method does not require building new facilities. In either case, it is necessary to establish a system in which university officials act as intermediaries between their laboratories and private companies.

When Japanese universities intend to carry out research work in this field at the world level, not only investment in facilities but also significant reformation of consciousness is indispensable. It is necessary to make the facilities open to outside researchers and to provide onerous foundry services. Research activities should be made effective by lowering the fences of conventional disciplines and involving material, chemical and mechanical technologies, and by rigorously exchanging researchers among internal and external organizations. Even professors should be able to challenge completely new fields. For this purpose, just one establishment will be enough in Japan. If the transfer of a whole laboratory of a university or transfer of related faculty members among universities is opposed, the benefit of such establishment will be greatly reduced.

More specifically, many technicians other than researchers are required for the maintenance or control of clean rooms and equipment. Since Japanese universities do not have the know-how to control most advanced clean rooms, new facilities cannot be operated based on the conventional university system even if such facilities are built. Regarding this point, it is difficult at present for national and public universities to hire technicians other than researchers. However, this problem will be solved when the institutionalization of universities is realized. It is reported that Japanese companies are suffering from a surplus work force and there are many excess personnel not only in the device industry but also in the instrument and material industries. Therefore, it is a key point as to whether national and public universities can establish a system to flexibly receive the necessary personnel.

7.7.4 When can universities go into action?

In the 2000s, the competitiveness of Japanese industry has been further weakened and will not recover for a while. Although consolidation by product line among large companies is proceeding in Japan, its speed is significantly slow when compared to the world standard. It will take several more years before the consolidation is completed to ensure profits at the level of European countries. For a while, no single company will be able to provide sufficient investment to carry out medium- and long-term research at the world level. It is questionable whether the present projects initiated by private companies can continue to the next-generation if they do not bring about the expected results. They may be even reviewed from a political viewpoint before they are finished. In a sense, this present time of turmoil is a good chance for universities to enter the scene.

From the perspective of the industry, it may become a new key point in how to utilize the force of universities and public research institutes. The “Basic Research Center” boom of private companies that was prevalent around 1990 has gone and medium- and long-term research activities have been significantly cut down. In the future, there will be a type of industry-academia collaboration in which universities and public research institutes bear a part in medium-term and long-term research. There is a strong opinion in Japan’s business world that the academia, whether they like it or not, cannot evade participation in industrial research in the future. Private companies cannot fund research and development as they did in the past. It is difficult for them to keep all the staff required for research and development, and even if they manage to keep the personnel, they can no longer come up with the necessary research expense. Taking the past failure into consideration, the industrial world, moreover, should approach the academia.

7.8 Conclusion

Under the current conditions in Japan, large-scale investment for research on silicon semiconductor devices cannot be unconditionally approved. In the world, however, research on silicon semiconductor devices is on the cutting edge of nanotechnology research, holding an important position in the industries that support today's information society. In the past-day Japan, it was true that universities did not contribute much to the research on silicon devices. At this point, they must decide whether to continue to look on with folded arms waiting for the recovery of the semiconductor industry or to positively participate with the industry in the research work with a perspective for the next decade.

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References

[1] A. Ogasawara, "Trends in research and development of lithography technology for next-generation LSIs," Science and Technology Trends-Quarterly Review, No.1 (2002)

[2] B. Doris et al., "Extreme Scaling with Ultra-Thin Si Channel MOSFETs," IEDM Technical Digest (December 2002)

[3] Practical application of advanced semiconductor technology for extreme-ultraviolet (EUV) light source, http://www.mext.go.jp/b_menu/houdou/14/09/020908bd.pdf

[4] ITRS Public Site: http://public.itrs.net/

[5] K. Inoue et al., Report on the analysis of the competitive environment relating to the semiconductor sector, Research Institute of Economy, Trade and Industry Report (March 2001), (in Japanese) http://www.rieti.go.jp/mitiri/m2001061301.html

[6] T. Kuroda, System LSI - Creating the Future -, http://www.kuroda.elec.keio. ac.jp

[7] D. Kim et al., "A 2 Gb NAND Flash Memory with 0.044 μm2 Cell Size Using 90 nm Flash Technology," IEDM Technical Digest (December 2002)

[8] M. Hirose, "Advanced semiconductor technology for system on chip (SOC)", OYO BUTURI, 71 (9), p.1091 (2002) (in Japanese)

[9] Feature Article; Research on the technology for the reduction of power consumption, Design Wave Magazine, Sep. (1997) (in Japanese)

[10] N. Koguchi et al., "Trends in the research on single electron electronics - Is it possible to break through the limits of semiconductor integrated circuits? -," Science and Technology Trends-Quarterly Review, No.7 (2003)

[11] H. Aida, "Autobiography of Japan, an Electronics State," (seven volumes), Japan Broadcast Publishing Co., (1995 - 1996). (in Japanese)

[12] "Strategic Committee for the Promotion of the Semiconductor Industry", "Problems and Measures for the Japanese Semiconductor Industry," (May 2002), (in Japanese) http://www.meti.go.jp./kohosys/press/0002702/0/020508handotai.pdf

[13] K. Mishina, "Incomplete Corporate Strategy,"

Hitotsubashi Business Review, 50 (1), p. 6 (summer of 2002) (in Japanese)
[14] "Information Subcommittee, Industrial Structure Committee", "Experience and Problems in the Semiconductor Industry - Change in Technology and Change in Organization," (March 2002), (in Japanese) http://www.meti.go.jp/report/downloadfiles/g20308h02j.pdf
[15] IEDM website: http://www.his.com/~iedm/
[16] ISSCC website: http://www.isscc.org/isscc/
[17] VEDC website: http://www.vdec.u-tokyo.ac.jp/
[18] H. Yamada, "Utilization of literature database for analysis of R&D activities," 7th International Forum on Technology Management, p. 382 (1997)
[19] I. Shirakawa, http://www-ise2.ist.osaka-u.ac.jp/shirakawa/farewell_lecture1.pdf, The age when students can develop LSIs: http://www.synthesis.co.jp/other/message.html
[20] JAITA website: http://home.jeita.or.jp
[21] SELETE website: http://www.selete.co.jp
[22] MIRAI website: http://unit.aist.go.jp/asrc/mirai/
[23] ASET website: http://www.aset.or.jp
[24] Super Clean Room for Industry-Government-Academia Collaboration: http://unit.aist.go.jp/asrc/mirai/project/scr.htm
[25] Enhancement of collaboration in industry-government-academia projects for the development of semiconductor fabrication technology; Science and Technology Trends, Jan. 2003 (in Japanese)
[26] ASPLA website: http://www.aspla.com/
[27] STARC website: http://www.starc.or.jp
[28] FED Salon, 10 nm CMOS Committee Report = Proposal of Basic Technology Project for sub 10 nm CMOS devices = (March 2002): http://www.fed.or.jp/salon/10nm/10nm_houkokusho.pdf
[29] MINATEC website: http://www.minatec.com/minatec_uk (Special issue for nanotechnlogy, French Embassy Newsletter): http://www.afii.fr/Japan/Newsroom/Newsletter/nl_japan_103_nano_ja.pdf
[30] A. Ogasawara, "Trends in French Science Technology and Innovation Policy - The MINATEC Industry-academia-government Nanotechnology Innovation Center Project -", Science and Technology Trends-Quarterly Review, No.4 (2002)
[31] STMicroelectronics, K.K. website: http://www.st-japan.co.jp/
[32] National Chiao Tung University SRC website: http://www.src.nctu.edu.tw/
[33] Si-Soft Project: website: http://www.eic.nctu.edu.tw/SOC/doc/Sisoft-Eng.pdf
[34] H. Iwai et al., "Thin film technologies for advanced CMOS ULSIs", OYO BUTURI, 69, p.4 (2000) (in Japanese)
[35] S. Iwamatsu, "Easy-to-understand ULSI Technology - Challenging Gigabit Memories," Kogyo Chosakai Publishing Co. (1993) (in Japanese)
[36] Silicon Sea Belt Fukuoka Plan: http://www.slrc.kyushu-u.ac.jp/

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8

U.S.Science and Technology Policy Trends — Report on the 2003 AAAS Colloquium on Science and Technology Policy—

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8.1 Introduction

The American Association for the Advancement of Science (AAAS) Colloquium on Science and Technology Policy was held on April 10 and 11 in Washington, DC. Held every spring for 28 years, the colloquium is the largest meeting on science and technology policy in the U.S. Over 500 people participated in this year's colloquium, including government officials such as John H. Marburger, director of the White House Office of Science and Technology Policy; Elias A. Zerhounis, director of the National Institutes of Health; Charles A. McQueary, under secretary for science and technology of the U.S. Department of Homeland Security; Congressional staffers such as William Bonvillian, legislative director for the office of Senator Joseph I. Lieberman; academics such as Shirley Ann Jackson, president of Rensselaer Polytechnic Institute and Karen A. Holbrook, president of Ohio State University; as well as think-tank policy analysts, corporate research and development managers, and science and technology leaders from many other countries. Among the topics participants discussed were:

- The estimated federal government research and development budget for fiscal 2004
- Strengthening homeland security through science and technology
- Visa difficulties faced by students and researchers from foreign countries
- Science and technology trends in government agencies.

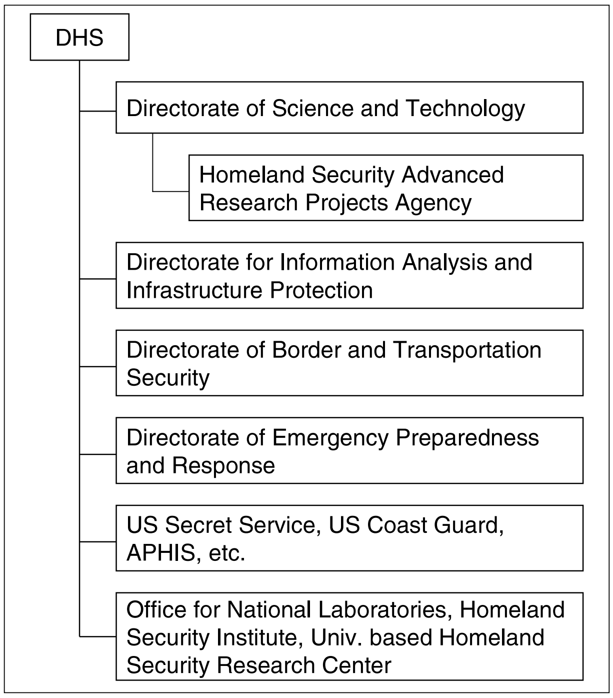
8.2 Federal government R&D budget for fiscal 2004

On February 2, 2003, U.S. president George W. Bush released his fiscal 2004 budget proposal. The proposed research and development budget was $122.7 billion, a 4.4 percent increase. Breaking down the content, defense development and homeland security R&D show major increases, but non-defense R&D remains almost unchanged from last year, with only a 0.1 percent increase. (See "Changes in R&D Priorities Seen in the U.S. President's Fiscal 2004 Budget Message" in the eighth issue of this bulletin for more details.) Congressional budget debate is beginning. Considering the increase in the federal deficit caused by the war with Iraq and support for that country's reconstruction, there is likely to be pressure in Congress to control domestic spending, including R&D. During his presentation at the colloquium, AAAS R&D Budget and Policy Program director Kei Koizumi predicted a "zero sum game," with funding in the fiscal 2004 R&D budget increasing for the Bush Administration priorities of defense and homeland security increasing and that for non-defense research decreasing.

8.3 Homeland security policy

With the colloquium being held during the war with Iraq, interest in topics related to homeland security was high. The Department of Homeland Security (DHS) began operating last March. Under Secretary McQueary oversees science and technology policy related to homeland security. The Directorate of Science and Technology

Figure 1: DHS organization



Source : DHS official website

as shown in Figure 1 is primarily in charge of science and technology within DHS. The DHS under secretary for science and technology is also the head of that directorate. The Homeland Security Advanced Research Projects Agency (HSARPA), modeled after the Department of Defense's Defense Advanced Research Projects Agency (DARPA), is also a part of the directorate. HSARPA funds all types of R&D programs related to homeland security, from basic research to product development. HSARPA's fiscal 2004 budget is expected to be between $350 million and $500 million dollars ("Department of Homeland Security Opens Doors, Proposes $1.0 Billion for R&D," AAAS R&D Budget and Policy Program, March 4, 2003).

During his presentation at the colloquium, Under Secretary McQueary described the tasks of the Directorate of Science and Technology as follows.

- **Internal R&D**

The National Laboratory for Homeland Security carries out interdisciplinary research and development related to homeland security. The laboratory carries out homeland security related R&D programs transferred from the Technology Security Laboratory of the Transportation Security Administration, the Environmental Measurements Laboratory, the U.S. Coast Guard, the U.S. Secret Service, and the former Immigration and Customs Services. It will also work on biological programs with the NIH and the Centers for Disease Control and Prevention (CDC), and on food safety programs with the U.S. Department of Agriculture (USDA).

- **Industry-academia-government cooperation**

In conjunction with industry and academia, the directorate promotes R&D that can enhance homeland security. In cooperation with industry, it promotes technological standardization and technology transfer related to homeland security.

- **Human resources development**

To foster human resources in relation to homeland security, the directorate has a scholarship system and offers doctoral and postdoctoral fellowships.

At the colloquium, Under Secretary McQueary also described the following DHS initiatives.

- **Border Protection and Monitoring**

This initiative develops technologies to discover nuclear weapons and other illegal materials being brought across the U.S. border.

- **Biological Protection**

This initiative develops technologies to oversee pathology laboratories, emergency rooms, and pharmaceutical sales, as well as to detect indications of disease outbreaks.

- **Information Analysis**

This initiative develops information analysis systems to comprehensively analyze information gathered from various kinds of resources and to prevent cyber-attacks and illicit uses of information networks.

8.4 NIH science and technology policy trends

Topics related to severe acute respiratory syndrome (SARS), which is striking Asia particularly hard, also drew much interest at the colloquium. In his colloquium presentation, NIH director Zerhounis stated that NIH is actively pursuing SARS research, mainly through the Centers for Disease Control and Prevention (CDC). Vigorous work to understand the cause and to develop preventative methods is being carried out not only in the U.S., but also in a

CDC laboratory in Hong Kong. Not only do they carry out research, he said, but the CDC website also disseminates SARS information. Director Zerhounis also described a plan to invest $9.5 billion in capital improvements to U.S. medical schools, and warned the academic community of cuts in NIH capital investment. In the president's fiscal 2004 budget message released February 3, NIH, which had just finished a budget-increase campaign, suggested a cut in capital investment funding in order to secure sufficient R&D funding despite stagnant research budgets. (See "Flash Report on 2002 AAAS Annual Colloquium" in the fifth issue of this bulletin.

8.5 Visa difficulties faced by students and researchers from foreign countries

In his keynote address to the colloquium, John H. Marburger, Director of the White House Office of Science and Technology Policy noted that while there may be several trends and high-priority issues that should be discussed at the colloquium, he wanted to speak about a problem that is having a particularly serious effect on the science and higher education communities. Ordinarily the colloquium's keynote address each year is offered by the president's chief science advisor, and it is widely reported as indicating major elements of the federal government's science and technology policies. For example, last year's keynote address by Director Marburger covered a wide range of topics, such as R&D initiatives to enhance the war on terror and homeland security, balancing fields of government R&D investment, strategies to set priorities for fields such as nanotechnology and life science, and reforming federal government R&D management. (See "Flash Report on 2002 AAAS Annual Colloquium" in the fifth issue of this bulletin for details.) Narrowing the topic of this year's address to visa problems therefore took most participants by surprise. It was a clear indication of how serious an effect heightened security screening is having, and will have, on science and technology activity in the U.S.

This section will present an overview, based on Director Marburger's address, of the causes of visa problems and the steps the government is taking to solve them.

8.5.1 Visas issued to foreign students and researchers

A recent special report in the Chronicle of Higher Education (http://chronicle.com) entitled "Closing the Gates" pointed out that enhanced homeland security is "closing the gates" on research by foreign students and scientists who had improved U.S. research and development competitiveness, which in turn contributed to economic development and better lives for the American people. Are the U.S. scientific and higher education communities really trying to shut out foreign students and scientists? In response to this question, Director Marburger pointed out in his colloquium address that while approvals of the F, M, and J visas awarded to foreign students and scientists entering the country for fixed periods have declined over the past five years, the drop is only a slight one. According to Director Marburger, the problem is not that the U.S. is shutting out foreign students and scientists, but rather that the examination process is taking too long.

8.5.2 The visa examination process

To deepen understanding of visa problems, this section will provide an overview of the visa examination process. Ordinarily, the following three examinations are required to issue an F, M, or J visa for a foreign student or a scientist entering the country for a fixed term:

- CLASS
  (Consular Lookout Automated Support System)
- MANTIS
- CONDOR

CLASS (Consular Lookout Automated Support System) runs the applicant's name through the FBI National Criminal Information Center's criminal database and the CIA's terrorist database. This is done in every case. Any matches are referred to Washington for further examination. According to Director Marburger, about 90 percent of cases referred to Washington for further examination are processed within 30 days, so it cannot be considered a major cause of delays.

MANTIS screens applicants based on a Technology Alert List (TAL) compiled by the State Department and other relevant agencies under section 212 of the Immigration and Nationality Act. It is intended to prevent individuals likely to illegally export products, technologies, or sensitive information from entering the country. According to Director Marburger, cases referred to MANTIS have rapidly increased, from about 1,000 in 2000 to about 2,500 in 2001 and approximately 14,000 in 2002. There usually about 1,000 cases in the system at any given time.

Like MANTIS, CONDOR is an examination reserved only for applications that meet certain special criteria, and was established following the September 11, 2001, terrorist attacks. The purpose of CONDOR is to exclude possible terrorists.

8.5.3 Measures taken by the federal government to eliminate visa examination delays

As mentioned above, since the decline in visa approvals over the past five years is small, it is clearly not the case that MANTIS and CONDOR are keeping the numbers down. Obviously, protecting the public through enhanced homeland security is important. Yet, if the problem of visa delays is ignored and research cannot be carried out at the necessary time, the influence on the scientific and higher education communities will be profound. This is a point that the federal government is well aware of. Although reviews of the examination process and personnel increases are being undertaken, the backlog of unprocessed visas continues to increase. Director Marburger stated that the problem of visa delays will be solved by their efforts, and offered the following plans for doing so.

- Cooperation with external expert communities and the sustained, organized hiring of personnel who can help to expedite the visa examination process.
- Elimination of duplicate examinations among CLASS, MANTIS, and CONDOR to speed up visa processing.
- An improved information reporting system from the institutions involved, and the elimination of unnecessary examinations.

Director Marburger also proposed making the examination process more open to applicants to decrease their worry. This would be good news for anxious students and scientists waiting for results without knowing the reason for the long delays they face.

The gathering of top personnel from all over the world has been an engine of growth for the U.S. The contributions of foreign nationals in science and technology are particularly large, and in many laboratories more than half the staff comes from foreign countries such as India and China. Visa delays are shaking this foundation, and may decrease U.S. R&D competitiveness. Director Marburger's colloquium keynote address on visa delays and his proposals for improving the situation are encouraging news for the scientific and higher education communities and for students and scientists who want to go to the U.S.

8.6 Conclusion

With the annual AAAS held during the war with Iraq and the SARS outbreak, interest in research and development policy related to homeland security and infectious disease was high. The deficit increase caused by extraordinary expenditures associated with the war with Iraq and support for its reconstruction is leading to pressure to control domestic spending. The fiscal 2004 R&D budget is likely to be a zero sum game with increases for R&D related to defense and homeland security, and decreases for non-defense research.

Visa processing delays caused by enhanced homeland security are having a profound effect of the scientific and higher education communities. To maintain and enhance its R&D competitiveness, the U.S. must work quickly to solve the problem. The concrete measures described by Director Marburger are a major step in the right direction.

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9

Futur
— German Demand Side Science and Technology Policy Formation —*

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*The study of Futur forms a portion of research on "Demand Side Science and Technology Policy Formation," as adopted from the "Policy Suggestions" of the "Promotional Coordination Fund" implemented by the Ministry of Education, Culture, Sports, Science and Technology.

9.1 Introduction

Futur*[1] is a project overseen by Germany's Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF). It attempted to form research and development policies based on future social demand. It offers several important points to study when examining the development of science and technology policy from a demand perspective.

Futur can be summarized based on the five following points.

(a) Demand oriented

Futur asked not "What is possible?" but rather "What is necessary?" In other words, rather than setting research and development goals based on opening new frontiers favored by most scientists in the lab, Futur set goals based on what society will require in the future.

(b) It was premised upon future (circa 2020) social demands

Futur imagined a future society desired and considered what must be done now to realize it. It imagined future social problems and considered what must be done now to overcome them.

(c) It adopted the slogan German Research Dialog (Der deutsche Forschungsdialog).

German research & development as well as science and technology policy are clearly predicated upon dialog between experts and citizens from all levels of society due to trend over the past few years of public participation in science and technology. Dialog is also intended to be based on values with a high degree of universality reached through deliberation rather than on glib ideas or biased values.

(d) It sought out diverse participants

(e) It examined interdisciplinary themes

Looking at these five points, we see that the first two can be classified as goals (content of Futur goals), while the latter three can be classified as process (aspects of its processes). Research dialogs, diverse participants, and an interdisciplinary nature are necessary conditions for achieving goals that are demand and future-oriented.

Futur results were epitomized as Leitvisionen (visions to lead society, or "lead visions"). Lead visions describe central social problems of the future and indicate what type of research projects are required to solve them. When Futur began, the necessary conditions of lead visions were considered. The resulting selection criteria were determined and made known to all participants:

- Orientation towards a societal goal such as solving a pressing social problem
- Linking the needs of society with technological & social innovation
- Contributing to the strengthening of Germany as a place for economic production
- High complexity & interdisciplinary aspects
- Easy to understand in its entirety

It is noteworthy that this vision included social as well as technological innovation. The fusion of technology and society will be essential to future science and technology policy. Expressing government policy in understandable terms will be needed in order to form science and technology policy from the demand side, which is dominated by non-experts.

9.2 Structure of Futur

This chapter will describe the structure of Futur. The predecessor of Futur, Futur 0 (Zero) was created through an open Internet debate process that failed miserably. Taking that failure into account, Futur was begun only after much time and preparation.

The Federal Ministry of Education and Research's Section Z22 (in charge of strategy, planning formation, and research coordination) managed Futur's progress. The project was carried out under the Minister's strong leadership.

The Federal Ministry of Education and Research had a clear vision of both results and processes, of lead visions and their selection criteria, right from the very start of Futur. As complex and broad processes would be vital while diverse methods and tools would have to be utilized, project implementation would thus require trained and talented personnel. The experience of Futur 0 made it clear that face-to-face discussions must be at the core of the process. It required six months of preparatory work to refine the details and make this vision come to fruition. The project actually began in June 2001, and the operation period was about one year.

Funding for the project was provided by utilizing approximately half the sum raised by selling radio wave licenses for mobile telephones.

9.2.1 Consortium formation

The Federal Ministry of Education and Research publicly began soliciting for members at the end of 2000. Based on the content of three proposals and a review of the achievements of participating organizations, implementation of the project was entrusted to a consortium of IFOK*2 (process design and management, communication), ISI*3 (advice on science and technology, providing future predictive methods and international comparisons), IZT*4 (scenario writing and contributions to future workshops), VDI/VDE-IT*5 (organization of scientific and technological expertise), Pixelpark AG*6 (design and sponsoring Internet workspaces), and Science & Media (pubic relations; withdrew from project at the outset). On the Ministry's side, contributors to the project included various bureaus, Projektträger (organizations that distribute Federal Ministry of Education and Research funding outside the Ministry; 11 organizations in all), and the Innovation Council (Innovationsbeirat; formed by the Minister of Education and Research in July 2001, it comprises 12 prominent figures from academia, business and society).

9.2.2 Project overview

One characteristic of Futur is that a wide variety of participants was focusing on issues and providing fresh ideas. To achieve this, different groups with a variety of backgrounds (e.g., science and technology, government administration, corporations, management, etc.) and specialty areas were formed using a method called co-nomination. The following is the process by which it was implemented.

Preliminary stage

One hundred fifty-two original members were named by the consortium.

Stage 1

Each original member recommended 4 or 5 candidates based on predetermined criteria. Candidates were selected from this pool based on clear selection criteria.

Stage 2

Original members and those selected through co-nomination in stage 1 recommended candidates. The process continued as in stage 1 and was repeated an appropriate number of times.

Futur effectively utilized the Internet as an efficient tool to distribute data throughout all processes, ensuring transparency and reaching mutual understanding. Participants were divided into an inner circle that actually met for face-to-face discussions and an outer circle that participated only over the Internet. Workspaces for both groups were provided on the Futur website. Most communication among participants took place over the Internet. In addition to give and take over meeting agendas and newsletters, discussions took place in the inner circle workspace, while information was exchanged in the outer circle workspace.

When the inner circle engaged in debates or reviews, it would sometimes become necessary for members of the outer circle to participate. Futur flexibly enabled movement of members between circles and the participation of outer circle members in inner circle debates via the Internet.

Participants as of May 2002 were as shown in Table 1. Total participants numbered 1,462, with the ratio of inner to outer circle members about 6:4. Almost all the original members were in the inner circle, while most self-referred members were in the outer. Participants selected through co-nomination numbered 1,148, almost 80 percent of the whole.

The breakdown of participants by gender and field is shown in Figure 1. About three times as many men as women participated. As for fields of expertise, science and technology experts accounted for approximately half the participants. Among the science and technology experts, half were from science and engineering fields and half were from humanities and social science fields.

As shown in Table 2, Futur comprised six stages. The first stage was the round of discussions, which was held in June and July 2001. The second stage was the Futur conference. These are formally called the first round of discussion and the first conference. First refers to this being the first Futur, with the projected second Futur to have a round of discussions called the second round of discussion. The first Futur round of discussion will simply be referred to as the "round of discussion" in the remainder of this article. The first two stages are a divergent topic formation process that allows ideas to diverge to form topics that are then sorted and

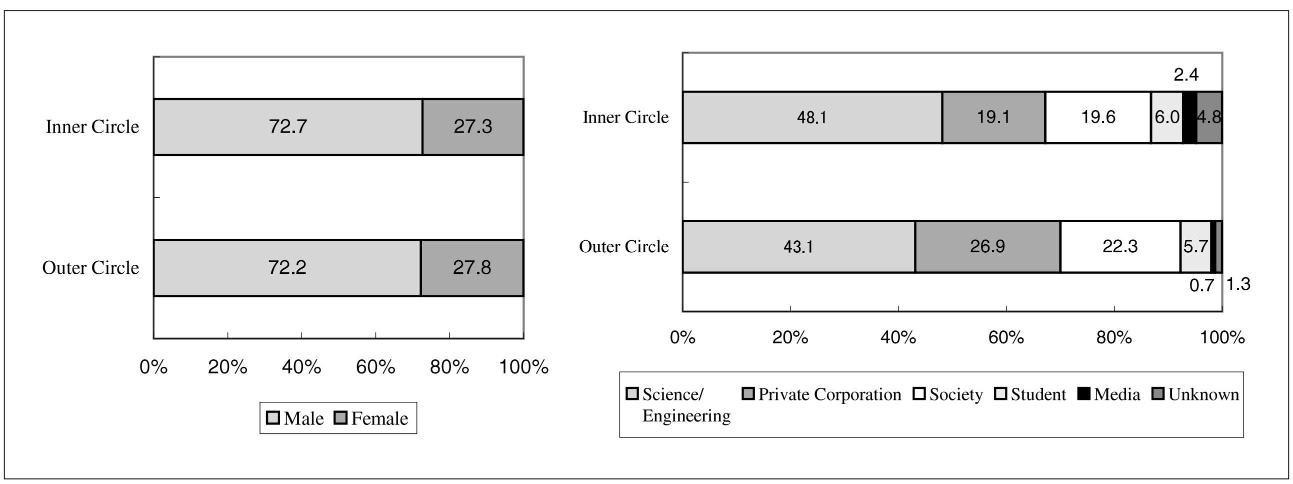
Table1: Number of participants

Selection Method	Inner Circle	Outer Circle	Total
Original Members	152	4	156
Stage 1 Co-nomination*	194	120	314
Stage 2 Co-nomination	489	345	834
Self-referred	30	125	155
Total	865	597	1,462

*Nominated by original members

Source: K. Cuhls, "The German Research & Dialog" 2002 (unpublished)

Figure 1: Gender, field breakdown of participants



Source: Created by author from K. Cuhls, op. cit classified. The latter three stages are a convergent process that narrows down the topics that have been formed.

9.3 Futur processes I: Topic formation process

The topic formation process consisted of the round of discussions and the conference. (see Figure 2) The next 20 years are predicted, and measures required to respond to problems envisioned were considered. Desirable future outcomes were also imagined, and the necessary scientific and technological responses for these problems and outcomes were enumerated as topics. A large number of enumerated topics were divided among groups, in which focus topics were created.

9.3.1 Round of discussion (workshops)

The purpose of the round of discussions was to collect from the participants trends considered likely to be important in society around 2020. Approximately 400 inner circle members attended eight workshops held in Berlin and Frankfurt. Those in similar specialties and fields attended the same workshops. The largest ones divided into groups of less than 20 people. The workshops were set up to enable people to share their thoughts in an atmosphere of freedom. Workshops lasted one day.

Workshops operated in the following two stages.

Stage 1

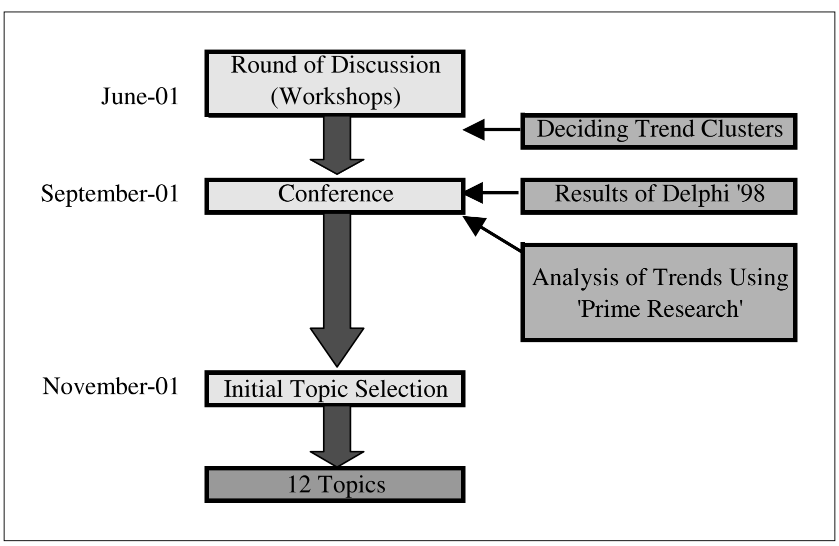
Participants discuss the trends they think of in response to the question, "What will society be like in 2020?"

Table 2: Futur process

No.	Date	Process	Content	Remarks
1	June/July 2001	Round of Discussion	Collection of topics and future trends	Topic formation process
2	September 2001	Conference (Open Space)	Formation of trend clusters	
3	Autumn/Winter 2001	Selection of 12 Focus Groups	Work in online workshops Work in future workshops	Topic narrowing process
4	Spring 2002	Prioritization of Focus Topics	Development of first scenarios	
5	Spring/Summer 2002	Elaboration of Lead Visions	In scenario workshops	
6	Summer/Autumn 2002	Implementation	Lead visions in specific projects	

Sources: Futur website (http: //www.futur.de/en/index.htm), except for "Remarks" from K. Cuhls, op. cit.

Figure 2:Topic formation process



Stage 2

Participants discuss future problems expected to appear in their own fields.

The results were made available on the inner circle website, where workshop participants could comment on them.

Approximately 2,000 topics were suggested at the workshops. Nearly 10,000 were suggested, which included those that were repeated or similar. Clustering resulted in 63 elementary clusters being formed, which were reduced to 21 trend clusters (later called "topic packages"). The consortium foresaw trends that would become most important, and added titles suggesting their meaning as well as three subtitles for each. To deepen subsequent discussions, specific or representative future projections and issues were added as keywords. Each of these was a subject for discussion at the workshops.

9.3.2 Conference (Open space)

The conference was held on November 26, 2001, in Berlin. Its purposes were to deepen the debates which were launched in the round of discussions, to probe into trends that will influence society in the future, and to explain those trends in detail. To eliminate unsupported ideas or personal wishes of participants at the conference, the results of analysis of related projection research were presented. Through these presentations, participants learned the positions of future trend projections at the round of discussions, and were able to make projections that were more objective, universal, and certain. The presentations were the results of Delphi '98[*7] and trend analysis from the Institute Prime Research[*8]. The method used by the former is the same as that utilized by the Ministry of Education, Culture, Sports, Science and Technology's National Institute of Science and Technology Policy in its technology forecast surveys.

Approximately 300 inner circle members attended the conference. The conference process was as follows. When making selection or judgments, criteria such as social needs, interdisciplinary nature, relevance to research and development as well as the possibility of narrowing the focus of the topic were indicated.

(1) Group composition: The 21 topic packages resulting from the workshops were presented, and participants joined the group focusing on the topic in which they were most interested. New groups could be formed and topic titles could be changed (effectively resulting in the formation of new groups). Large groups divided into subgroups.

(2) Preparation for group discussion: Each topic was redefined through discussion in a group and a summary of the topic was created. The groups were then reconfigured so that participants could join the discussions of the topics they found most interesting.

(3) Full-fledged group discussion: The issues that would form the core of a topic from a broad perspective were extracted through detailed discussion. Overlap with other topics, latent topics and fusion with similar groups were considered, as were ways to make topics distinct from each other.

(4) Topic profiling: Topic profiles were clarified. Then the most outstanding topics were selected as best examples and deeper discussions took place with respect to them.

Facilitators and subject advisors were assigned to the discussions to ensure that they progressed smoothly and productively. Their roles were as follows.

Facilitators: They worked to advance the discussions at the initial stage. They subsequently worked to advance debate or to support its advance.

Subject advisors: They were selected from within the consortium because of their expertise. They assisted the facilitators, provided scientific and technical expertise concerning the discussion subject, or prepared target proposals from science and technology aspects. They also assisted with discussion minutes and attached documents, helping ensure that they were technically correct.

9.3.3 First topic selection

Following the conference, topics were selected through the following means.

- Online voting: Voting by 680 members of the inner and outer circles
- Technical evaluation by VDI/VDE-IT: Basic pre-evaluation of the technical content of topics
- Federal Ministry of Education and Research workshops: Ministry bureau chiefs and Projektträger representatives could participate in and vote at internal workshops held by Section Z22
- Expressions of opinion by the Innovation Council
- Workshops with the consortium and the Federal Ministry of Education and Research's Section Z22

Participants, Federal Ministry of Education and Research bureaus, and the Innovation Council were considered most important. Since their results were, in fact, almost identical, the situation did not become serious. Final decisions were made by the Minister of Education and Research, Ms. Edelgard Bulmahn. The 12 focus topics selected are shown in Table 3.

Table 3: 12 Focus topics

1	Long-term planning & organization of motivational work in a knowledge-based society
2	Germany as a place of learning—a learning society as a future factor
3	Living in a networked world: individual and secure
4	Promotion of intercultural potentials
5	Handling information
6	Sustainable mobility
7	Individualized medicine and health care 2020
8	Developing a sustainable culture of nutrition in a changing society
9	Globally responsible sustainable agricultural production
10	Global change—regional change: recognizing challenges and opportunities for global change & local action
11	Decentralization—a strategy for a sustainable economy and lifestyle
12	Intelligent products and systems for tomorrow's society/intelligent products

Note: Numbers 2, 3, and 7 were finally selected as lead visions (with slightly different names)

Source: www.futur.de

9.4 Futur processes II: Topic narrowing process

The 12 focus topics that resulted from the topic formation process were the starting point for the topic narrowing process. The process had the following four purposes.

(a) To narrow the topics and make them more specific based on Futur criteria.
(b) To clarify the key elements to develop relevant fields and to evaluate their importance, uncertainty, and relationship to other elements.
(c) To clarify the need for research and development.
(d) To form basic ideas for each lead vision and scenario.

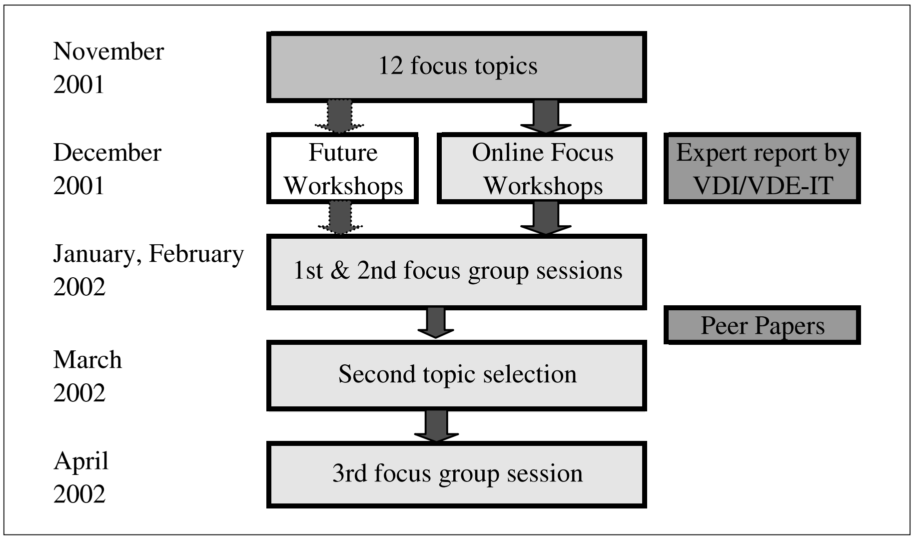
Narrowing process participants were designated by the consortium from conference participants, supplemental inner circle members, and members moving from the outer to the inner circle. Participants selected one topic from the 12, and 12 groups were organized based on that selection. Appropriate personnel were added through the suggestions of group members (co-nomination). The focus groups formed in this way were the basic organizations for the narrowing process that followed.

Two types of events comprised the work of the focus groups.

- Online workshops
- Three focus group sessions: The first two sessions covered all 12 focus topics. Topic selection took place after the second session, thus the third session covered 5 topics.

"Future Workshops," which originally had no direct connection with the narrowing process, were included. This is because it was considered necessary to increase the reliability of insights into the future and to improve the content of the topics. The process is explained in order below (see Figure 3).

Figure 3: Topic narrowing process



9.4.1 Future Workshops*[9] (Zukunftwerkstäte)

The Future Workshop method is a means of imagining (normatively) desirable futures and finding ways to make them a reality. Five topics were covered: the future of health and happiness, balancing work and life, the aging of a sustainable society, amalgamation of tomorrow's cities, and the learning society of the future. The participants comprised 125 inner and outer circle members (25 per topic).

Each workshop was composed of three stages, (1) collection of problems and ideas, (2) clarification of problems that must be overcome, (3) estimation of the degree to which research and development can contribute to supporting solutions for a sustainable society. The results were posted on Internet workspaces where they could be utilized in individual idea formulation and focus group sessions.

9.4.2 Online workshops

Online workshops were held from December 12 to 18, 2001. Their purposes were (1) to organize focus groups, (2) to provide participants with information regarding each topic, and (3) to clarify the conditions for topic selection. The secondary goals were to prepare for the opening of discussion and to clarify focus topics. Web pages for each topic were set up with related information, working papers, and the content of discussions during the topic formation process. Each inner circle member participated in the web pages of the single topic to which they belonged.

9.4.3 First and second focus group sessions

The functions of the sessions were to further settle on contents and select topics. Facilitators played an important role in this. That role had five parts.

(a) Guidance sessions (with the support of subject advisors on matters of technical expertise).
(b) Serving as liaison for participants before the sessions as well as constructing and guiding discussion. After the sessions, minutes were created in cooperation with subject advisors.
(c) Contributing to website creation by summarizing discussion, requiring participation, and other activities.
(d) At the first and second sessions, participant opinions on the topic were gathered and actual subjects that should be debated were clarified. After the second session, efforts were made towards mutual information exchanges and to prepare active development of debate. At the third session, efforts were made to strengthen profiles by confirming topic weak points, obtaining the cooperation of experts, and other activities.
(e) A final summary of session discussion was made.

The first session was held on January 15 and 17, 2002, with about 160 people participating. Its purposes were to decide the fields of innovation needed to achieve the focus topics and to clarify actual research domains related to those fields of innovation. Through this session, the focus topics were made more specific and the fields of innovative research and the research subjects were clarified.

The second session was held on February 19 and 20, 2002. Its purpose was to decide the content of the focus topics. Specifically, this meant (1) the selection of innovation fields considered most important, (2) the creation of topic titles containing their key ideas, (3) deciding on the appropriate fields for innovation through explicit titles, and the clarification of specific fields of application, research needs and the importance of research, (4) deciding on major factors that would contribute to development of topic fields, and (5) the creation of a vision expressing the possibilities of future development related to the topic. (Note that (5) was optional.) At the second session, experts were added as requested by facilitators and the Federal Ministry of Education and Research, and Ministry bureaus concerned with distribution of funds and Projektträger personnel were permitted to attend.

Discussion results were compiled for necessary elements for future development of the field, such as social demand, fields of application and required research and outlook. These results were utilized as basic data for topic selection. The comments of leading experts in the subject fields were also added.

9.4.4 Second topic selection

After the second focus group session, the second topic selection was carried out with the goal of reducing the 12 focus topics to 5. The following methods were used.

- Online voting: Inner and outer circle participants numbered 332. Selection criteria consisted of the importance as lead visions, research prospects and social demand.
- Ranking by Projektträger and Federal Ministry of Education and Research experts: Topics were ranked by suitability for research, social demand, topic maturity, and political viability.
- Innovation Council Debates: The strategic direction of research policies were debated from a broad perspective including bettering lives, health and longevity with respect to innovativeness and topic quality.

Table 4: Futur favorites (5+1)

1	Access a world of learning
2	Living in a networked world: personalized worlds of interaction
3	Efficient knowledge processes
4	Individualized medicine and health 2020
5	Intelligent processes
6	Understanding thought processes

Source: www.futur.de

At the final decision stage, Minister Bulmahn made the final decision after the Federal Ministry of Education and Research carefully scrutinized reports based on the Futur criteria with the assistance of the consortium. At that time, "Understanding thought processes," which had been omitted during the first topic selection process, was revived, which led to 6 Futur favorites (see Table 4).

9.4.5 Third focus group session

The third session was described as an idea workshop to prepare lead visions and scenarios. It was held on April 16, 2002, in Berlin. The purpose of the session was to deepen the focus topics by giving direction to lead visions and creating scenarios. The relationship of topics to people's lives and future prospects for topics were debated. The results of the discussion were utilized in the final lead vision proposals and in the creation of scenarios.

9.4.6 Creation of scenarios and lead visions

The creation of scenarios and lead visions was the mission of the focus groups. Scenarios were created through the following steps.

(1) Profiles of each topic were presented for review, and leading experts in related fields added technical information.

(2) Based on reviews carried out during previous processes, IZT created scenarios for the five focus topics, excluding "Understanding thought processes," which was added later.

(3) Scenarios were revised based on the comments of focus groups, participants and the consortium itself.

Table 5: Structure of lead vision reports

Title	
Goals and Visions	
Description	• Social and economic importance • Issues to be dealt with • Potential for overcoming issues • Danger in delaying resolution of issues
Scenarios	• State of research, including existing research programs • Focus on future research • Scientific-oriented information • Research issues • Potential solution methods • Related research fields

Source: Taken from four lead vision reports available at www.futur.de

Lead visions were created by using the following steps.

(1) A lead vision team was formed for each Futur favorite. Teams comprised IZT, VDI/VDE-IT, ISI, IFOK, the Federal Ministry of Education and Research and focus group participants.

(2) Information regarding the status of research as well as current research programs were integrated with the lead visions by Projektträger experts and leading experts in relevant fields.

(3) IFOK prepared draft lead visions while other teams joined in their revision.

9.5 Futur's results: lead visions

The final determination of lead visions was made by the Federal Ministry of Education and Research. Four favorites (equivalents of 1, 2, 4, and 6 in Table 4) were chosen as lead visions: (1) Understanding thought processes, (2) Creating open access to tomorrow's world of learning, (3) Living healthy with vitality through prevention, and (4) Living in a networked world: individual and secure. "Intelligent products and systems for tomorrow's society/the intelligent product" was recommended to be handled as a cross-sectional topic throughout the Federal Ministry of Education and Research, while "Handling knowledge" was left as a future focus topic.

Completion of its scenario was delayed as "Understanding thought processes" was added by the Ministry which bypassed the scenario workshops. (A PDF version in German only was made available on June 15, 2003.) This has invited criticisms of the Futur process, claiming that it is not transparent, but others see it as demonstrating the flexibility of the process and the government's responsibilities towards it.

The first thing required for further development is the implementation of the lead visions. Within the Federal Ministry of Education and Research, which will play the main role in implementation, the establishment of action teams is already being planned. Changed priorities for the distribution of research support funding are expected. An internal Ministry workshop was held on August 27, 2002, Futur's topics & ideas were summarized while the start of Futur II was confirmed. The goals of the workshop were to further elucidate the concept and content of Futur, to launch ideas, and to implement intra-ministerial brainstorming throughout the Ministry. Underlying this is the clear recognition that innovation is required in science and technology policy, and that a change in the consciousness of policy bureaus is essential for that purpose.

German insiders point to the following as the results of Futur.

- Without adding new funding (unavailable in any event), lead visions will be reflected in priorities for the distribution of research funding beginning next fiscal year.
- Close cooperation on medical issues has been established between the Federal Ministry of Education and Research and the Federal Ministry for Health and Social Security.
- The creation of policies that cross organizational barriers within the Federal Ministry of Education and Research has been streamlined.
  The difficulties of so-called vertical policy formation have been recognized thanks to participation in Futur.

- In terms of future organizational forms, the tendency of horizontal organization to strengthen and vertical organization to weaken has been enhanced. This reorganization is already taking place, and the Z bureaus that handle core issues and strategies have been strengthened.
- There is a changed consciousness within the Ministry, with an awareness of the importance of demand beginning to take hold.

An external international evaluation of Futur was carried out in October 2002, resulting in an evaluation of "Good." An international workshop leading towards Futur II was held on December 12 and 13, 2002. The plan for Futur (as of May 15, 2003) is to take those topics not yet turned into lead visions and develop two or three of them into lead visions each year for the next few years. Futur II will then take place in a new form.

9.6 Conclusion

Although Futur is now underway, it is somewhat premature to offer any final evaluation on it. To understand its significance, however, it is necessary to place it in the context of its times.

Futur did not suddenly appear along with the Schröder's SPD Government. Its seeds were already planted during the CDU government of Kohl's . According to State Secretary Uwe Thomas of the Federal Ministry of Education and Research, Germany's science and technology policy has experienced two periods of transformation.

First period

During the latter half of the 1970s through the first half of the 1980s, reforms led to a shift from research based on the curiosity of individual scientists to research planned by institutions such as the Max Planck Institute. In the generational theory of research and development management, this is seen as a response to the shift from first-generation research and development centered on scientists to a second-generation R&D centered on institutional management.

Because the first generation was centered on the curiosity and interests of individual scientists, numerous problems arose, such as the duplication of research, a lack of research on important subject areas, and the proliferation of research institutions conducting similar research such as system theory and information sciences. Rapid advances at that time had also begun in space development, large high-speed computers, nuclear power, high-speed transportation systems, environmental protection and manufacturing technology. Germany lost the lead it once held in all those areas, then having to chase the USA and Japan led to an acute awareness of the problems. Facing these circumstances, research institutes consolidated and reorganized, attempting to improve the efficiency of research and development and to secure international competitiveness in science and technology.

Second period

The second half of the 1990s and into the early 2000s can also be likened to a generational change in research and development. In this case, the shift is from the second-generation seed-oriented research and development to third-generation R&D oriented towards markets and social needs. Research and development centered on large institutions is linked to increased inflexibility in research funding. Senior researchers heavily influenced internal distribution of the funds as research operation-type funds were going to institutions without their use being clearly delineated. The result was a lack of a demand orientation. There were also strong doubts at the national level that acute social problems were being solved. In light of this situation, the Federal Ministry of Education and Research's first step was to stop distributing research operation funds. The next step was the implementation of Futur with its clear demand orientation.

The following three points are seen as problems with Germany's history of traditional funding distribution.

(1) In its traditional systems and priorities, the Federal Ministry of Education and Research's existing research funding systems are strongly oriented towards seed research,

thus fresh ideas should be introduced.

(2) Negotiations among those concerned are closed and not transparent, and should be made open and transparent.

(3) There is a danger that new serious issues will be overlooked, thus these dangers must be minimized.

Against this background, Futur had the following characteristics.

(1) It added policy based on future social demand to innovation-oriented research policy. Yet it is not a panacea by any stretch of the imagination.

(2) It offered leadership visions for society that were interdisciplinary and solution-oriented.

(3) Without methods for heterogeneous creativity, mutual understanding and analysis from diverse participants, such goals cannot possibly be reached. Development of such methods was one of Futur's goals.

Can Futur be made universal and applied internationally? The Finnish parliament's Special Parliamentary Committee for the Future, for example, is carrying out essentially the same experiment. Japan should examine the question of whether it could be introduced here, and if so, how it should be modified.

Notes

*1 Futur is Latin, and is the root of the English word future. In German, future is Zukunft.

*2 Institute für Organisationskommunikation, http: //www.ifok.de/index.html

*3 Fraunhofer-Institute für Systemtechnik und Innovationsforschung, http: //www.isi.fhg.de/

*4 Institute für Zukunftsstudien und Technologie-bewertung, http: //www.izt.de/

*5 VDI/VDE-Technologiezentrum Informationstechnik GmbH, http: //www.vdivde-it.de/

*6 http: //www.pixelpark.de/

*7 Approximately one-third of the over 1,000 technology subjects covered in this second Delphi survey carried out in Germany made use of technology subjects in Japan's Sixth Technology Forecast Survey (1998).

*8 This report analyzed future journals from Germany and the USA and compiled the results of forecasts in 20 categories such as labor, natural resources/sustainability, science and research as well as learning and education. Prime Research, which carried out the study, is a think tank affiliated with a German newspaper.

*9 A future workshop method developed by Austrian futurologist Robert Jungk during the first half of the 1960s. For details, see Robert Jungk & Norbert Mullert, Future Workshops, Institute for Social Inventions, London (ISBN 0 948826 07 X)

(Original Japanese version: published in June 2003)

About SCIENCE AND TECHNOLOGY FORESIGHT CENTER

It is essential to enhance survey functions that underpin policy formulation in order for the science and technology administrative organizations, with MEXT and other ministries under the general supervision of the Council for Science and Technology Policy, Cabinet Office (CSTP), to develop strategic science and technology policy.

NISTEP has established the Science and Technology Foresight Center (STFC) with the aim to strengthen survey functions about trends of important science and technology field. The mission is to provide timely and detailed information about the latest science and technology trends both in Japan and overseas, comprehensive analysis of these trends, and reliable predictions of future science and technology directions to policy makers.

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

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

The following are major activities:

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

— STFC builds an information network linking about 3000 experts of various science and technology fields in the industrial, academic and government sectors. They are in the front line or have advanced knowledge in their fields.

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

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

2. Research into trends in major science and technology fields

— Targeting the vital subjects for science and technology progress, STFC analyzes its trends deeply, and helps administrative departments to set priority in policy formulating.

— STFC publishes the research results as feature articles for "Science Technology Trends" (monthly report).

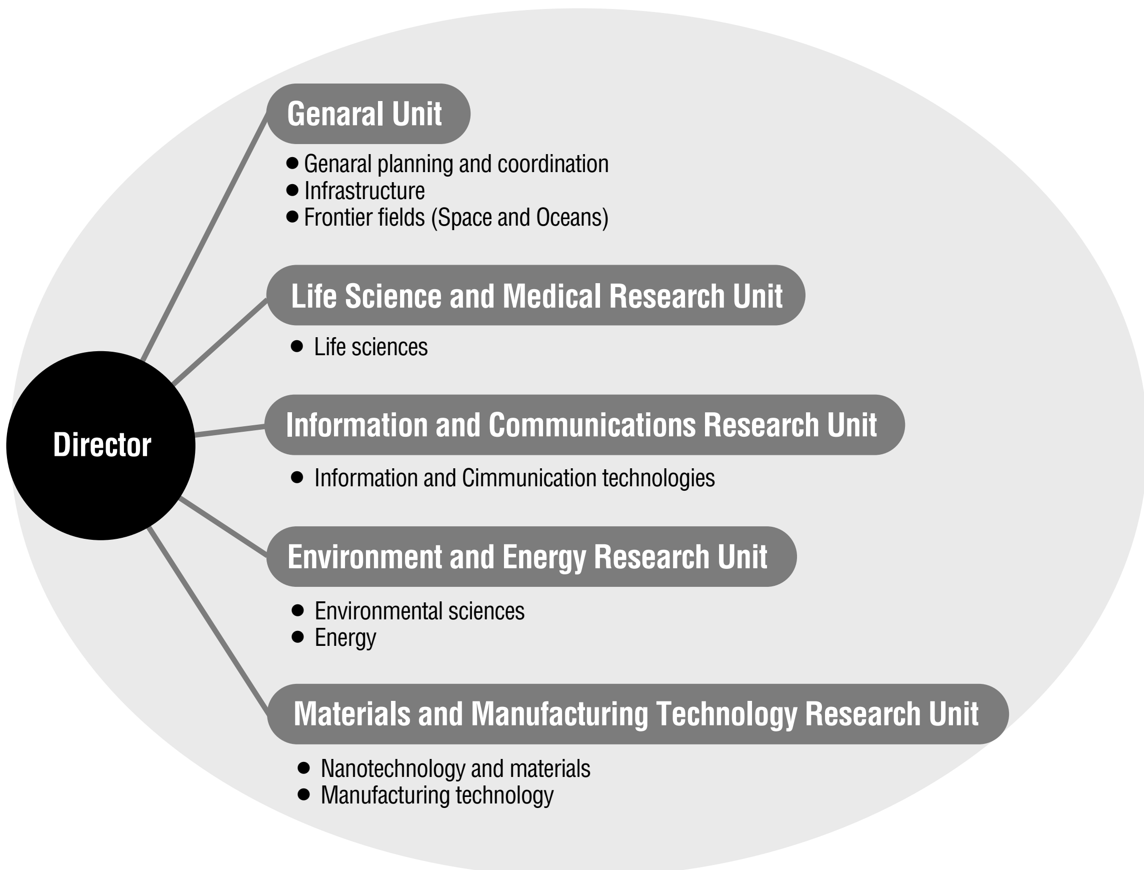
3. Technology foresight and S&T benchmarking survey

— STFC conducts technology foresight survey every five years to grasp the direction of technological development in coming 30 years with the cooperation of experts in various fields.

— STFC benchmarks Japan's current and future position in key technologies of various fields with those of the U.S and major European nations.

— The research results are published as NISTEP report.

Organization of the Science and Technology Foresight Center



* Units comprise permanent staff and visiting reseachers (non-permanent staff)
* The Center's organization and responsible are reviewed as required

- Life Sciences
- Information & Communication Technologies
- Environmental Sciences
- Nanotechnology and Materials
- Energy
- Manufacturing Technology
- Infrastructure
- Frontier
- Science & Technology Policy

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