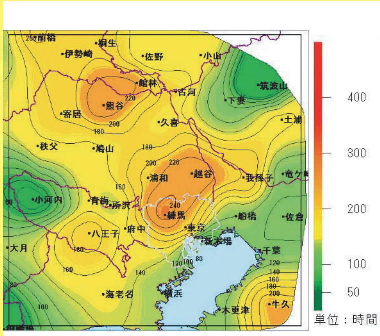
ISSN 1349-3671

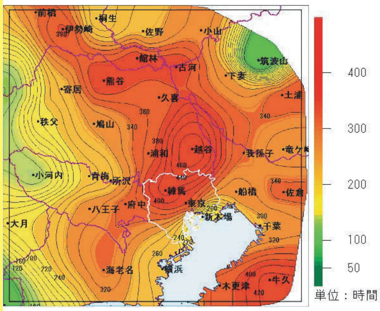
Science & Technology Trends

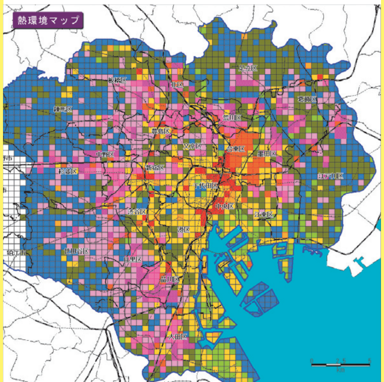
Quarterly Review

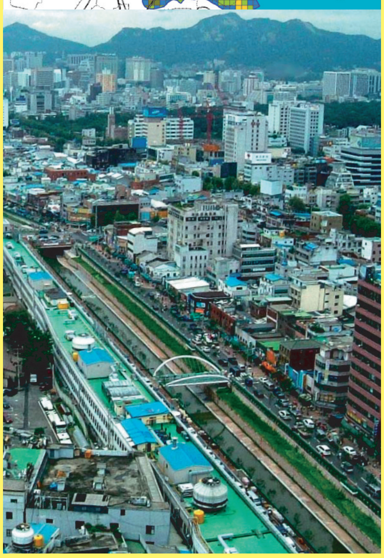
Science & Technology Foresight Center, NISTEP

2006 January No.18









Foreword

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

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

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

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

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

Terutaka KUWAHARA
Deputy Director General
National Institute of Science and Technology Policy

Contact information : Science and Technology Foresight Center
National Institute of Science and Technology Policy
Ministry of Education, Culture, Sports, Science and Technology (MEXT)
2-5-1, Marunouchi, Chiyoda-ku, Tokyo 100-0005, Japan
Telephone +81-3-3581-0605 Facsimile +81-3-3503-3996
URL http://www.nistep.go.jp/index-e.html
E-mail stfc@nistep.go.jp

Executive Summary

Life Sciences

1

Present State and Advances in Personalized Medicine

— Importance of the Development of Information Service Systems for the Public —

p.13

The International Human Genome Sequencing Consortium, which launched the Human Genome Project in 1990, announced a draft sequence of the human genome in cooperation with Celera Genomics in 2001. The consortium released the finished version of the sequence and announced the completion of the project in October 2004. The complete sequence of the human genome serves as a foundation to realize medicine based on an individual's genome information, i.e. personalized medicine.

Intensively researched areas related to personalized medicine include pharmacogenomics and the development of molecular-targeted anticancer drugs. The field of pharmacogenomics attempts to determine the differences in drug efficacy among individuals based on genome information. The development of molecular-targeted anticancer drugs is based on the genomic information of molecules responsible for causing cancer and to target these abnormal molecules. To a minor extent, both technologies have already been applied clinically.

Research and development based on the results of the Human Genome Project have rapidly progressed, especially in the area of medical research. In the near future, the results of the project will be returned to the public through personalized medicine. Since genome information has a great impact on the health or lifestyle of individuals and potentially raises family issues in relation to genetic diseases, or social issues with respect to health insurance, it needs to be fully and properly understood.

For the implementation of personalized medicine, the public, who are the ultimate recipients of medical services, must obtain sufficient information regarding the use of the human genome and have a clear understanding of the information that it contains. Moreover, the significance of drug discovery research based on public understanding of genome and translational research that bridges the gap between basic research and clinical research, has increased. Such research requires public participation. Thus, information provision and educational activities to provide the public with a thorough understanding of the genome have become increasingly important.

The social acceptance of personalized medicine requires the establishment and improvement of a system to provide genome-related information. The system would be Internet-based, and would allow high-quality information selected by specialists to be provided to the public. The information would be broadly classified into specialized information and basic information; the former to deal with details and the latter to serve as a foundation for understanding the specialized information. If required, one-on-one counseling should be performed to provide the specialized information, while integration of basic information into school education should also be considered. Such a system would involve various areas and requires cross-ministry linkage and linkage among industry, government and academia for its management.

(Original Japanese version: published in August 2005)

Information and Communication Technologies

2 Foresight on Information Society Technologies in Europe

p.24

In March 2000, leaders of the European Union member states gathered in Lisbon and set a strategic policy, or goal, called the "Lisbon Objective." To support its aim of building a "competitive knowledge-based economy," Europe promotes the European Research Area (ERA) and seeks to develop and facilitate information society technologies (ISTs).

In order to define future visions for ISTs, a foresight study was conducted under the leadership of the Institute for Prospective Technology Studies (IPTS), a joint research institute of the European Commission. FISTERA (Foresight on Information Society Technologies in the European Research Area) was launched in September 2002, and finalized at the international conference held in Seville, Spain in June 2005, toward the end of the study's three-year schedule.

FISTERA started by reviewing earlier national-level foresight exercises in European Union member states from a pan-European perspective. Then, it analyzed patent data to examine technological competitiveness, conducted Delphi studies on social transition, and constructed scenarios on future environments for technology applications, while discussing a wide range of issues.

The concept known as "Technology Trajectories" has been used to summarize the results. FISTERA has accumulated knowledge that will assist in fulfilling the goal by constructing and discussing from a pan-European perspective Technology Trajectories that contribute to information society development. The result is a knowledge base concerning future visions of ISTs that serves as a bird's-eye view of the future. The project has also organized a forum on ISTs through which study results are published and IST-related experts can deepen mutual understanding. Total investment in the project was around 1.5 million euros.

FISTERA concluded that Europe generally lags behind the U.S. and Japan, and that the gap has not diminished since the Lisbon Objective was set in 2000. It proposes increasing expenditure on R&D between now and 2010 in order to attain the Objective.

FISTERA adopted multiple perspectives in performing foresight studies and analyses for the selected period. Each phase of the project was made widely accessible so that feedback could be used in next-phase discussions within the working groups. This process was facilitated by use of the Internet. These approaches undoubtedly helped deepen awareness of the goal among experts, and contributed to development of a broader, more solution-oriented consensus. There is much that Japan can learn from FISTERA's methodology in respect of research aimed at formulating national science and technology policies.

((Original Japanese version: published in July 2005)

3 Current Trends in Digital Cameras and Camera-Phones

p.35

The digital camera industry in Japan plays a major role in the currently flourishing digital-home-appliance business. Riding a wave of rapid sales growth since 1995, Japanese digital camera manufacturers have demonstrated their strong competitive edge to capture an 80% share of the global market. Japan's domestic digital-camera market is nearing saturation point, prompting a drastic shakeout in the industry. Surviving companies are competing fiercely to extend their business into unsaturated foreign markets. Established manufacturers of conventional cameras are focusing on developing markets for advanced digital SLR models.

Meanwhile, "camera-phones" equipped with miniature digital camera modules have become a rapidly expanding market category since 2001. Of the 500 million mobile phones manufactured up to the end of fiscal 2004, some 180 million were camera-phones. Japanese companies supply 80% of the imaging devices and optical modules used in camera-phones, giving the Japanese industry a major competitive advantage in this new global business.

This article analyzes the basic construction of and world market for digital cameras. It demonstrates that strength in the world market is powered by dynamic technological development of an imaging device (works like film in a conventional camera) and lens optics. Taking into account a new phase in global competition driven by the rapid growth of the camera-phone, the report considers the future trends of digital-camera technology and marketing.

Expected to drastically reduce the size of optical modules and to be installed in camera-phones, a new technological innovation called the "tunable-focal-length liquid lens" has been developed by a French university-originated venture company, Varioptic (collaborating with South Korea's Samsung for business development), and the European electrical appliance giant, Philips. The report describes this development and discusses Varioptic as a good example of industry-university collaboration, which the Japanese government has also been promoting.

Having surpassed the 1,000 target number set forth in planning for a well-organized promotion by the Japanese government, university-originated venture companies are now at a stage where they should be assessed in terms of business quality. The Varioptic example is used to demonstrate that a quality-oriented, university-originated venture company has the potential to evolve in a market dominated by foreign companies, particularly in the current globalized economic environment.

A venture company that obtains patents has the potential to contribute significantly to improving the quality of a university-originated venture, given a "competitive core strength" underpinned by long R&D experience, as shown in the case of Varioptic.

Japanese government institutes that fund research and university institutes that manage research should take the long view, exercise patience and resist raising their expectations too high when promoting core competitiveness. And, they should manage research taking into account the personalities and independence of researchers, accompanied by assessment of research validity, particularly in the early stages.

(Original Japanese version: published in July 2005)

4

PC Grid Computing
— Using Increasingly Common and Powerful PCs to Supply Society with Ample Computing Resources —

p.45

A study show that 80 to 90 percent of most PCs' processing power is untapped. This does not mean that many PCs are off, but that the capacity of the CPU, the brain of the PC, is not fully utilized. PC grid computing collects such surplus computing power from many networked PCs and uses it as a virtual high performance computer. The recent rapid proliferation of PCs, the remarkable improvement in CPU processing speed, and the improved communications infrastructure that has enabled broadband access are all contributing to the development of PC grid computing. With these trends in mind, this article discusses PC grid computing schemes for supplying society with ample computing resources.

Grid computing refers to “an environment in which various information processing resources distributed across the network are used as a virtual computer, ” and it aims to provide on demand the necessary amount of processing resources for its users. Its benefits include the centralized use of distributed processing resources, effective utilization of idle resources, load balancing to reduce peak loads, and ensured fault tolerance for improved reliability.

Among several types of grid computing, PC grid computing, which is constructed existing PCs as a source of rich computing resources, is characterized by easy construction and economical operation. PC grids can be classified into three different structures: an open structure, comprising mainly PCs owned by individuals and connected to the Internet; a closed structure, utilizing PCs owned by companies and other organizations; and semi-open structure, utilizing PCs that exist in several organizations.

Municipal governments that pursue local revitalization should pay attention to the benefits that PC grids in a semi-open structure can have as public infrastructure. Building a public computing infrastructure by PC grid can lead to provide processing power as some sort of utility services. However, practical ways to create semi-open PC grids and ways to utilize them effectively have not been established yet. The first step to moving beyond the status quo would be to conduct feasibility studies from many different perspectives with a view to exploring the potential of PC grid computing. For example, in terms of construction, many PCs owned by the elementary, junior and senior high schools in a prefecture can form a grid to supply major computing resources to the community. In applications, regional PC grids may help develop virtual learning materials for local students, based on computer simulations and animation, or promote local content business by providing abundant computing resources.

As society goes more digitized, it will become replete with networked devices with powerful CPUs, including home information appliances and online game consoles. Future PC grid computing should take the constructing of the CPU power of these devices as its sources into account.

(Original Japanese version: published in September 2005)

Environmental Sciences

5 Air Pollution Monitoring in East Asia
— Japan's Role as an Environmentally Advanced Asian Country —

p.54

East Asian countries have achieved remarkable economic growth in recent years. However, this growth has been accompanied by increasing atmospheric concentrations of sulfur oxides, nitrogen oxides, suspended particulate matter and ozone in these countries, causing serious air pollution. These air pollutants, transported through complex atmospheric circulation, are carried across borders and could have a serious impact on other countries. In fact, recent observations confirmed (1) the occurrence of acid rain in the region along the Sea of Japan, (2) the rise in tropospheric ozone concentrations over Japan, and (3) the formation of brown clouds. As the first step towards addressing such broad-based air pollution, it is essential that a transboundary air pollution monitoring network be established to keep track of the current pollution situation.

Air pollution monitoring (ambient air monitoring and pollution source monitoring) plays a vital role in keeping track of the current air pollution situation, and providing basic data for environmental measures and reviewing the achievement of those measures. In Japan, for example, the promotion of environmental measures based on air pollution monitoring has resulted in a dramatic decrease in the atmospheric concentration of sulfur dioxide, a major cause of acid rain.

Europe was first to address the problem of transboundary acid rain. A monitoring network encompassing the entire continent has been in place since the 1970s. Specifically, the promotion of a series of environmental measures through an international regulatory framework (a transboundary air pollution treaty) has led to a dramatic decrease in the atmospheric concentration of sulfur dioxide. In addition, a fully fledged network is in place to monitor other transboundary air pollutants such as suspended particulate matter and ozone.

While it was not until the 1990s that East Asian countries began to address transboundary air pollution, the Acid Deposition Monitoring Network in East Asia (EANET) has been in operation as part of the United Nations Environment Programme (UNEP). Japan, as an environmentally advanced Asian country, should continue to take the lead in addressing transboundary air pollution in the region. In particular, efforts are needed to increase the number of EANET monitoring stations and to expand the scope of monitoring.

(Original Japanese version: published in July 2005)

6 Measures to Mitigate Urban Heat Islands

p.65

The urban heat island effect is a phenomenon whereby cities become warmer than the surrounding suburbs. In other words, there is a temperature difference between cities and the areas surrounding them. In order to mitigate this phenomenon, the Inter-Ministry Coordination Committee to Mitigate Urban Heat Island, established in September 2002 by the Ministry of the Environment, the Ministry of Land, Infrastructure and Transport, the Ministry of Economy, Trade and Industry, and the Cabinet Secretariat, laid down the "Outline of the Policy Framework to Reduce Urban Heat Island Effects" in March 2004. The outline systematizes urban heat island mitigation measures, focusing on four areas: reduction of anthropogenic heat release, improvement of surface cover, improvement of urban structure, and lifestyle reform.

The urban heat island effect has been studied from a physical science and engineering perspective, steadily leading to the development of policy. It is now an interdisciplinary subject that involves meteorology, geography, architecture, civil engineering, and the like. A range of studies is elucidating the effect, developing and implementing mitigation measures, and so on. In recent years, there has also been a growing awareness that the urban heat island effect, which is local warming, and global warming have much in common in terms of resource/energy consumption patterns and mitigation measures.

From an urban planning perspective, urban heat island mitigation measures should be implemented simultaneously on an area-wide basis. In April 2005, the government therefore designated 10 cities and 13 areas as “model areas for measures to mitigate global warming and urban heat islands.” Meanwhile, the Tokyo Metropolitan Government, drew up a “Thermal Environment Map” in April 2005 to promote area-specific heat island mitigation measures. It designates four districts as “heat island mitigation measures promotion areas,” which double as national model areas. They include the area around Osaki Station in Shinagawa ward, Tokyo, where a “wind path” is being developed along the Meguro River as part of efforts to reduce environmental load.

In order to mitigate the urban heat island effect, countermeasures must be incorporated into master plans from the design stage. It is therefore imperative to adopt effective measures based on a clear understanding of the natural surroundings and thermal characteristics of the areas concerned. It is also necessary to develop simulation techniques that can predict the effects of mitigation measures such as wind paths, greenification, rooftop greening, water-retentive pavement, and thermo-shield pavement. An assessment system to prevent urban development from extending or exacerbating the heat island effect is also vital. Furthermore, evaluation to determine which mitigation measures should be given priority is necessary.

(Original Japanese version: published in September 2005)

Nanotechnology and Materials

7 Trend of Research and Development for Magnesium Alloys
— Reducing the Weight of Structural Materials in Motor Vehicles —

p.84

To move towards a sustainable future society, CO_2 emissions must be minimized to prevent global warming. To do so, it is necessary to make effective use of energy saving technologies and recyclable products. These energy saving technologies are required to improve the fuel economy of transport equipment. As a foundation for these technologies, great importance is now attached to reducing the weight of the structural materials used in transport equipment.

For reducing the weight of these structural materials, magnesium (Mg) alloys have begun to attract serious attention thanks to recent progress in basic research on these materials. The use of Mg alloys has been limited because they have been lacking in strength, heat resistance and corrosion resistance, though they have a variety of useful physical properties including lightness.

Recently, however, appreciation of Mg alloys has increased in the U.S.A. and

European countries, where the practical application of Mg alloys in passenger cars is being actively discussed. In Asian countries as well, great efforts have recently begun to be made in developing Mg alloys. Although Japan maintains worldwide leadership in terms of basic research and development of Mg alloys, it is now generally behind the U.S.A. and European countries in terms of the development of Mg alloys for use in passenger cars, which is expected to have a great impact on energy saving through the fuel economy of cars. In these circumstances, the Japanese Government should carefully target its support to ensure that the already developed basic technology of Mg alloys will be applied in the fields where these materials might have the greatest impact. To achieve this, the following two recommendations are made in this article:

(1) It is necessary to integrate all the results of development activities that have been carried out separately on basic Mg technologies, set up a national project to apply these results, and take active measures to make practical and efficient use of them in the fields where they can be expected to have the greatest impact. To do so, it is now necessary to:
  (i) Prepare a road map for each application of Mg alloys and share the knowledge; and
  (ii) Strengthen the fundamentals of our database on Mg alloys in order to perform part design more efficiently.

(2) In the near future, it may be necessary to:
  (i) Improve the performance characteristics of Mg alloys through further R & D efforts, enlarge the range of application of the current technologies, and promote cost reduction by increasing the use of Mg alloys.
  (ii) Establish standard specifications for the quality of materials in cooperation with the U.S.A and European countries and require Mg ore producing countries to meet the specifications in order to ensure reliable quality. To achieve this, industrial, academic and government agencies must work together to establish standards for Mg materials that take into account the entire relevant body of accumulated knowledge and information.
  (iii) If the use of Mg alloys increases in applications such as motor vehicles and the cases for portable electronic devices, it is expected that the recovery of recyclable Mg alloys from the general markets will increase. To respond to the increasing recovery of materials, it is necessary to build up an appropriate recycling system and develop recycling technologies.

(Original Japanese version: published in August 2005)

Energy

8 Measures to Promote Renewable Energy and the Technical Challenges Involved

p.98

The introduction of renewable energy is accelerating at a rapid pace, as industrialized countries step up efforts to reduce greenhouse gas emissions and the world oil market becomes increasingly tight due to Asia's rising demand for oil.

While energy derived from fossil fuels is limited, "renewable energy", produced by ongoing natural phenomena, is inexhaustible. In general, this includes such energy sources as wind, photovoltaic, biomass, hydro, geothermal and ocean energy. Although renewable energy is still more expensive than fossil fuel energy, the two factors mentioned above suggest that its world market could expand rapidly - even if its efficiency and cost-effectiveness still need to be improved significantly.

The introduction of promotional programs holds the key to promoting renewable energy. In relation to this, recent promotional programs around the world are drastically shifting from “technology push” (centered on research and development) to “demand pull” (associated with economic incentives). On the domestic front, the Renewables Portfolio Standard Law (the Law on Special Measures for the Utilization of New Energy, etc.) took effect in 2003 to promote renewable energy. Japan’s RPS law, however, is saddled with problems. For example, too modest a goal for the introduction of renewable energy by 2010 holds little promise for creating fluidity in the market, and the green-power purchasing program initiated by the private sector is not compatible with the RPS law. Under such circumstances, a review of the RPS law started in June 2005, as scheduled at the time of its introduction. It is likely that this review will also take account of comparable achievements abroad.

To promote the use of renewable energy, a greater number of wind, photovoltaic and other distributed power sources need to be connected to commercial power grids. However, wind and photovoltaic power generation systems are hard to control and therefore not always reliable in terms of output stability, and solutions to these problems have yet to be found. It is therefore imperative that the performance and cost-efficiency of each renewable energy power generation system be improved to accelerate the introduction of renewable energy. But even more important is the need to address institutional and technical problems associated with the connection of distributed power sources to commercial power grids.

Through analysis of these pending problems and recent trends in renewable energy use in other countries, this article puts forward recommendations on the following two subjects:

- Review of the RPS system

  More ambitious goals for the use of renewable energy on the part of power producers between 2010 and 2020

- Technologies for connection to commercial power grids

  Development of technologies to ensure the quality of the power produced, including system technologies to control the output of distributed power sources in response to power demand fluctuations and to work in coordination with commercial power grids.

(Original Japanese version: published in August 2005)

Frontier

9 Construction of an Integrated Earth Observation System Driven by Utilization Needs
— Promotion of GEOSS, which was Introduced at the Evian G8 Summit and Endorsed at the Gleneagles Summit —

p.115

At the G8 summit held in Gleneagles (United Kingdom) in July 2005, agreement was reached on the “Gleneagles Plan of Action”. This action plan stipulates that participants should proceed with the construction of the GEOSS, first proposed at the G8 summit in Evian in 2003.

The "GEOSS" referred to in the action plan is a "Global Earth Observation System of Systems". Even in the USA and Europe, the world leaders in Earth observation, the term "Earth observation" has usually only meant the observation of Earth from space using observation satellites. Satellite observation and *in situ* observations on the ground have not usually been well coordinated. As we now face problems such as global warming and major disasters, the time has come to shift the Earth observation strategy from a technical seeds orientation to one driven by utilization needs. In keeping with this approach, GEOSS designates nine societal benefit areas that are shared internationally: disasters, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity. GEOSS aims to combine the development of new technologies with the continuation of observation and analysis in a way that meets diverse needs, supports decision-making at various levels, and helps to solve social problems such as global warming.

With regard to Japan's Earth observation promotion strategy, in December 2004, the Council for Science and Technology Policy (CSTP) decided on the "Promotion Strategy for Earth Observation" that sets out a basic strategy for constructing an integrated Earth observation system driven by utilization needs. To date, with the exception of weather observation, no organization in Japan has integrated satellite observation with *in situ* observation and operated them on an ongoing basis. This new strategy, however, is expected to promote initiatives for integrated Earth observation driven by utilization needs.

In April 2005, the USA published a strategic plan that includes an implementation plan for an "Integrated Earth Observation System"(IEOS). It creates an intergovernmental working group spanning space, weather, and geography agencies and which allocates tasks and lays out future plans. Europe has formulated a 10-year plan on "Global Monitoring for Environment and Security" (GMES), which aims to support decision-making on environmental and security issues, and that also provides related user-oriented services, using data from both satellite and *in situ* observation.

At the Gleneagles Summit, Japan highlighted its own experience with air, water and other types of pollution during its era of high economic growth and its success in overcoming these problems. Japan called on the nations of the world to cooperate in using science and technology to help balance environmental protection with economic development. Not only for its own benefit, but also in order to make an international contribution, Japan should promote the 10-year Implementation Plan for the construction of GEOSS strongly.

This article takes an overview of world trends in Earth observation systems and recommends that Japan takes the following three items in advancing the development of GEOSS: i) establish an institution that leads constant satellite observation, ii) utilize ODA to expand *in situ* observation in developing countries, and iii) develop new satellite observation technology driven by utilization needs.

(Original Japanese version: published in September 2005)

1

Present State and Advances in Personalized Medicine
— Importance of the Development of Information Service Systems for the Public —

YOSHIHIRO SOWA
Affiliated Fellow

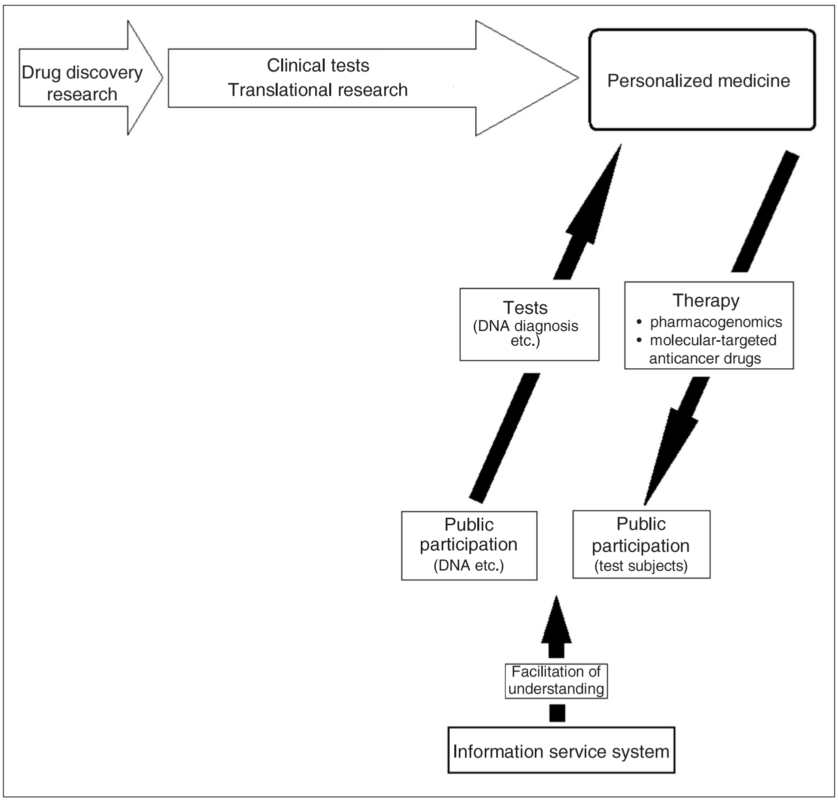
1 Introduction

The International Human Genome Sequencing Consortium, which launched the Human Genome Project in 1990, announced a draft sequence of the human genome in cooperation with Celera Genomics in 2001[1,2]. The consortium released the finished version of the sequence[3] and announced the completion of the project in October 2004.

The complete human genome sequence was obtained using DNA samples taken from only a few people. The completion of the project led to the post-genome era, and the next important task is to apply the genome information of each individual to medicine and promote personalized medicine.

This article discusses advances in pharmacogenomics *1 and molecular-targeted anticancer drugs *2, both of which are rapidly evolving technologies, and suggests future initiatives to achieve social acceptance and public understanding of personalized medicine through the provision of genome-related information to the public (Figure 1). These issues need to be addressed to successfully promote personalized medicine.

Figure 1 : Outline of this article



2 Personalized medicine

2-1 About personalized medicine

In Japan, “personalized medicine” is sometimes called “kobetsuka iryou”, which is a direct translation, or “order-made iryou”, which is a Japanese-English phrase. All of these terms describe the implementation of medicine (prevention, diagnosis and therapy) based on genome information including molecular/genetic data or molecular/genetic aberrations responsible for diseases and symptoms.

In conventional medicine, doctors chose drugs and the method of administration (dosage and frequency) based on their experience and opinions (so-called “doctor’s prescription”). The differences in drug efficacy and side effects among individuals were vaguely explained by the difference in their “constitutions”. However, as the need for evidence-based medicine became more widely acknowledged, doctors began to place emphasis on scientific validity when choosing therapeutic strategies. Scientific validation at a molecular level requires a vast amount of research using the results from the genome project and post-genome research. This implies that we have entered a stage where we now recognize that the difference in “constitutions” is in fact the difference in genes and genome information. (In this paper, the term “molecule” principally refers to a DNA, RNA or protein. The term “genome” originally referred to the entire set of genes, but since many biological phenomena involve DNA regions other than genes, the term “genome” used here refers to an individual’s complete set of DNA. Thus, “molecular data” includes all the information provided by the DNA sequence, mRNA expression, protein expression, etc., and the measurements and analyses of these data are referred to as “molecular diagnoses”.)

In parallel with the progress of the genome project, the concept of “genome-based drug discovery” has attracted attention in drug R&D. This concept aims at the development of drugs that target the molecules responsible for diseases. Pharmaceutical drugs that are developed through genome-based drug discovery potentially show high specificity compared to conventional drugs and are therefore expected to reduce the risk of side effects and increase their therapeutic efficacy. Reduced risk of side effects is an especially important issue, as side effects were found to be the fourth to sixth most common causes of death in the U.S.[4]. According to research reported in 1998, in the U.S., approximately 2.2 million (6.7%) of hospitalized patients suffered from severe side effects, 110,000 (0.32%) of whom died. Thus, the realization of personalized medicine is an extremely urgent task to reduce the side effects of drugs and secure public safety.

Personalized medicine provides appropriate treatment to patients based on the difference in genome information or molecules responsible for diseases (Figure 2).

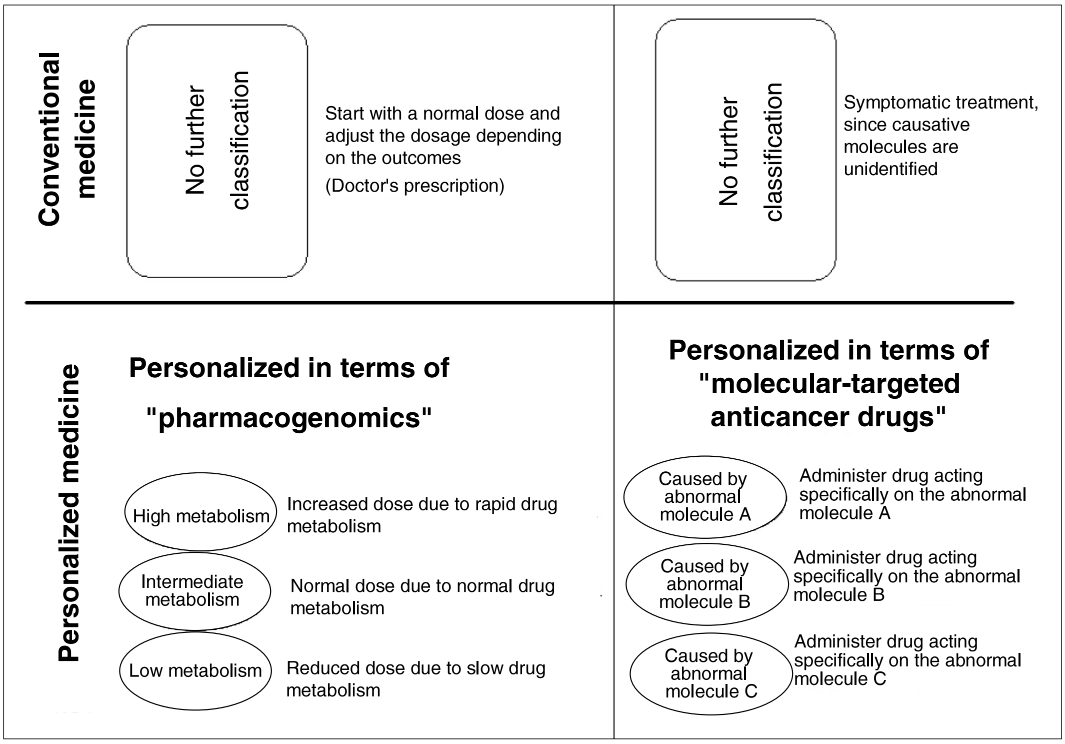
“The five rights” is a slogan originally intended to remind nurses of the points to be confirmed at injection or administration of drugs to patients, but it is also relevant to the concept of personalized medicine.

The minimum standard of practice for medication administration is checking “the five rights” to provide patient safety.

The Five Rights:
- Right Patient
- Right Drug
- Right Dose
- Right Time
- Right Route

“Right patient” and “right drug” imply the use of molecular-targeted drugs developed through genome-based drug discovery, i.e. the recognition of molecular aberrations responsible for diseases or symptoms and the administration of drugs that exclusively act on and remove aberrations. “Right patient” and “right dose” imply the importance of pharmacogenomics in drug-metabolizing enzymes etc., discussed in the next chapter, i.e. prescription of appropriate dosage based on the difference in drug response among individuals. In addition to drug-metabolizing enzymes, steps such as drug absorption, distribution, metabolism and excretion (ADME) all play an important role in drug metabolism. “Right dose”, “right time”

Figure 2 : Personalized medicine



and "right route" are therefore important factors to consider in understanding the difference in ADME among individuals.

2-2 Pharmacogenomics

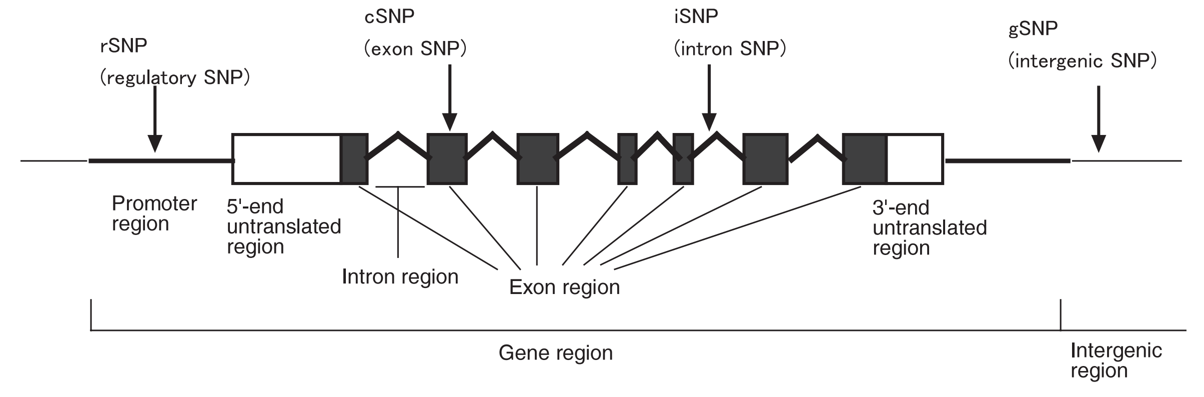
The Food and Drug Administration (FDA) announced a draft plan for "Guidance for Industry, Pharmacogenomic Data Submissions" in November 2003 and its final plan in April 2005. In response to the FDA's action in June 2004, the Evaluation and Licensing Division of the Pharmaceutical and Food Safety Bureau in the Ministry of Health, Labour and Welfare recruited opinions and information from pharmaceutical makers on the current status of clinical trials using genome tests and announced "Submission of information to government agencies for the preparation of guidelines for the application of pharmacogenomics to clinical trials of drugs" (Notification No. 0318001 from the Evaluation and Licensing Division of the Pharmaceutical and Food Safety Bureau) in March 2005. These actions imply that pharmacogenomics has progressed from the research stage to the practical stage, and now requires data submission for application to clinical drug trials.

Pharmacogenomics is defined as the analyses of drug response based on the genetic data of individuals. It is a system to predict and assess the difference in drug efficacy and side effects among individuals (conventionally explained as "constitutions") based on the results of comprehensive and systematic analyses of genome information. The typical research targets of pharmacogenomic studies are the SNPs (single nucleotide polymorphisms) found in the drug-metabolizing enzyme genes CYPs (cytochrome P450). Various molecules involved in *in vivo* kinetics, such as excretion and uptake of drugs (pharmacokinetics), also affect drug efficacy and side effects and are therefore subject to pharmacogenomic studies.

As in the case of Iressa, which will be discussed below, the difference in genes encoding drug target molecules on which the drugs directly act can be correlated with the difference in drug efficacy. Pharmacogenomics of drugs, drug target molecules and the downstream signaling pathway are as important in drug development as that of drug metabolism and dynamics.

A SNP is a single DNA base pair variation shared by a human population greater than a certain size. SNPs occur at a frequency of 1% or higher in the human population and are distinguished from mutations that occur at a lower frequency. In 1999, the SNP Consortium

Figure 3 : SNPs



was established by the Wellcome Trust and approximately ten pharmaceutical and technology companies. Their research work and many other SNP projects have revealed that SNPs are evenly distributed across the genome at a frequency of one SNP per 100-1,000 bp, i.e. there are 3-10 million SNPs in the entire human genome. SNPs found in gene regions that encode proteins or promoter regions that regulate gene expression exert various changes in phenotypes (Figure 3). Thus, SNPs in the above-mentioned CYPs possess considerable clinical significance in terms of drug metabolism. European countries and the U.S. FDA approved DNA chips to identify SNPs in CYPs as ex vivo diagnostic agents in September and December 2004, respectively. Moreover, it is known that the development of side effects of the anticancer agent Camptosar is related to the difference in the activity of its metabolic enzyme (conjugating enzyme UGT1A1). Since the activity of the enzyme is affected by SNPs in the transcriptional region of the gene encoding the enzyme, the FDA revised the labels attached to this anticancer drug in July 2005 and included the list of relevant SNPs and directions for dosage regulation based on the enzyme activity of patients[5]. Regarding the current state of SNP research in Japan, R&D of SNP analysis techniques and research on the involvement of SNPs in diseases are currently being conducted at the SNP Research Center of RIKEN and the Institute of Medical Science of the University of Tokyo[6, 9].

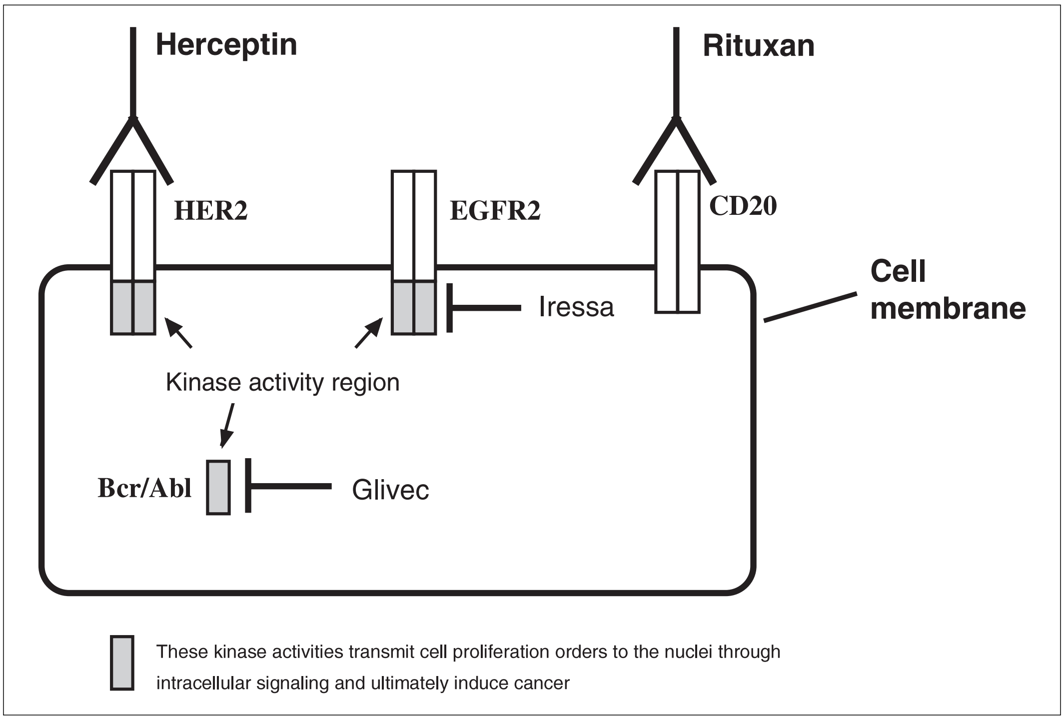
2-3 Molecular-targeted anticancer drugs

Pharmacogenomics uses genome information to analyze the *in vivo* delivery process of drugs, from their ingestion to their arrival at the target molecules. In contrast, “genome-based drug discovery” uses genome information to discover the molecules responsible for diseases and develop drugs (molecular-targeted drugs) targeted at these molecules.

Together with the progress in the Human Genome Project, causative genes of diseases have been vigorously searched for and analyzed. In particular, cancer-related research has advanced rapidly due to the timely integration of clinical research with basic research; for example, research on the mechanism of cancer development was integrated with cell cycle and intracellular signaling mechanism studies, and research on the action mechanism of anticancer agents was integrated with studies on DNA replication, cell division and cell death induction. The results of these studies led to the development of the first anticancer drugs based on molecular mechanisms. To date (as of July 2005), four molecular-targeted anticancer drugs have been approved and used in Japan; Herceptin (breast cancer), Rituxan (B cell non-Hodgkin’s lymphoma), Glivec (chronic myeloid leukemia CML and gastrointestinal stromal tumor GIST) and Iressa (lung cancer), all of which were developed by U.S. or European pharmaceutical companies (Figure 4).

These molecular-targeted anticancer agents act on different target molecules through different mechanisms (Herceptin and Rituxan are antibodies and Glivec and Iressa are kinase inhibitors), but were all developed through a common drug development strategy. Each of

Figure 4 : Molecular-targeted anticancer drugs



these drugs target molecular aberrations that are specific to each disease and act exclusively on patients that possess the aberrations.

Herceptin is an antibody that recognizes HER2, a growth factor receptor that penetrates the cell membrane. After recognizing and binding to HER2, which is located on the surface of cancer cells, Herceptin activates the antibody-dependent cell damage mechanism and specifically exerts an antitumoral activity on HER2-expressing cancer cells. Rituxan is also a specific antibody that recognizes the CD20 antigen, which is specific to some tumors. Glivec exerts antitumoral activity on chronic myeloid leukemia (CML) through the inhibition of Bcr-Abl tyrosine kinase, which is encoded by the Bcr-Abl gene, a causative gene of CML produced through chromosomal translocation. The drug also inhibits KIT tyrosine kinase and therefore exerts an antitumoral activity on KIT-positive gastrointestinal stromal tumor (GIST). Iressa acts through a mechanism similar to Herceptin and inhibits the kinase activity of EGFR, another growth factor receptor that penetrates the cell membrane.

In order to choose the “right drug” and the “right dose”, confirmation of the molecular information of each patient is a prerequisite to implement personalized medicine. Thus, molecular diagnosis is indispensable for the appropriate use of molecular-targeted drugs or drugs whose metabolism depends on SNPs of CYPs.

This is also implied by the indications attached to these drugs; Herceptin “should be used for metastatic breast cancer patients with HER2 overexpression”, Rituxan “should exclusively be used for CD20-positive patients confirmed through immunohistological staining or flow cytometry”, and Glivec “should be used for patients diagnosed chronic myeloid leukemia through chromosomal or genetic screening or KIT-positive gastrointestinal stromal tumor through an immunohistological test”. Before using these molecular-targeted anticancer agents, immunohistological tests or chromosomal or gene screening must be performed to confirm whether their administration is appropriate.

Described below is an episode that demonstrates the importance of pharmacogenomic analysis of target molecules of anticancer agents to confirm the adequacy of anticancer agent administration.

In July 2002, Iressa was approved as a therapeutic agent for lung cancer in Japan before approval in any other country. The drug exerted high anticancer activities including cancer regression in some patients, but often induced severe side effects such as interstitial pneumonia. Later, the drug was concluded to have "no survival advantage" based on the results of the first analysis of a worldwide clinical trial.

However, in April 2004, it was reported that the drug was highly effective in patients that have mutations in EGFR, the target molecule of Iressa[7, 8]. In Japan, extensive research on gene expression and SNP analysis for the prediction of drug response and side effects of Iressa are being performed, with the main initiative carried out by the Institute of Medical Science of the University of Tokyo [9]. Arguments concerning the efficacy and approval of the drug are not relevant to this report and will not be discussed here any further. Nevertheless, the emphasis placed on genetic diagnosis to detect mutations in the target molecule of Iressa demonstrates that personalized medicine has already been implemented in the form of genetic diagnosis in the clinical setting.

2-4 Translational research: clinical studies

Cancer therapy using molecular-targeted anticancer agents and medication regimens based on pharmacogenomics present an excellent opportunity to return the outcomes of scientific research to the public. That is, the results of basic scientific research are utilized for drug discovery and then fed back to clinical practice.

Advances in molecular biology have elucidated development mechanisms of many diseases, and drugs that target these mechanisms or molecules involved in these mechanisms have been intensively researched and developed worldwide. A drug for which the efficacy has been demonstrated *in vitro* will not be approved as a drug until its *in vivo* efficacy has been demonstrated in the human body.

Drug efficacy in the human body was conventionally demonstrated in clinical trials conducted by pharmaceutical companies for commercialization of drugs, but the revision of Pharmaceutical Affairs Law has also enabled researchers to conduct clinical trials. Moreover, systems to facilitate translational research that bridges the gap between basic research and clinical research have been improved[10].

Since drug efficacy ultimately needs to be confirmed in humans, not only clinical trials of drug candidates, but also epidemiological research including genetic analysis must be actively promoted. Furthermore, the high sensitivity to Iressa seems to be associated with "Japanese (Asian)" and "females". In consideration of such "genetic difference among races" and "genetic difference among sexes", we should perform genetic analysis and research locally and avoid the direct application of research results obtained in the U.S. and European countries to the Japanese population. Genetic differences among races must be considered by conducting bridging studies with Japanese subjects to confirm the validity of data obtained from clinical trials conducted overseas. Indeed, a drug has been described that has been demonstrated to be effective only in a particular race (African-American)[11], but was nonetheless approved by the FDA in June 2005.

When predicting drug response in individuals by genetic diagnosis, the current subjects of pharmacogenomic studies are drug-metabolizing enzymes, such as CYPs, the function and clinical significance of which are already evident. In addition, factors involved in pharmacokinetics, drug target molecules (as in the case of Iressa sensitivity) or factors involved in the signaling of target molecules are also potential subjects for pharmacogenomics. Such subjects include genetic variation in EGFR, the molecular mechanism of which is unknown, but has recently been found to contribute to drug efficacy, and many other molecules affecting the effects of drugs that are yet to be discovered.

Prediction of drug response based on molecular information involves many unknown factors and requires further research. In order to translate these research results into medicine, translational research is indispensable for demonstration research in human clinical research.

3 Public understanding for personalized medicine

3-1 Genome information as personal information

"Genetic information" could be regarded as the ultimate form of personal data but differs greatly from other personal data in many ways. With the current state of science and technology, an individual cannot easily access his or her own genetic information. It can never be rewritten and is also transferable among family members, a fact demonstrated by the existence of familial disorders. The biggest problem is "the uncertainty of science" ; the implications of genomic information have not been fully understood but may have a great impact on the life and health of individuals. This indicates that, in the current situation, genetic analysis technology represented by DNA sequencing and SNP analyses goes far ahead of the scientific validation technology required to understand the significance of an individual's genomic information. Basic and applied research for bridging the gap between these technologies should be conducted swiftly but with sensitivity, given the fact that this research is being performed on human subjects. Thus, genome information, where there is still a degree of scientific uncertainty, is more important than ordinary personal data and must be handled with great care. Books written from various standpoints on issues concerning medical science, medicine and personal data should help advance the understanding of these issues[12].

The requirement of making a genetic diagnosis has been stipulated in guidelines for the administration of Iressa and other molecular-targeted anticancer drugs. Genes involved in the development of diseases represented by familial breast cancer, familial adenomatosis coli and hereditary non-polyposis colorectal cancer have been identified. When receiving medical treatment or notification or providing informed consent to the doctor before treatment, each person is required to possess a sufficient knowledge and understanding of genes. The significance of "understanding" is explicitly cited in the ethical guidelines concerning human genome and genetic analysis research[13], which defines "informed consent" (translated as "setsumei ni motozuku doui" — consent based on explanation) as "agreement given voluntarily based on sufficient prior explanation and understanding". In that sense, an open lecture given upon the submission of the FDA's final draft of pharmacogenomics guidelines had the very suggestive title of "Personalizing your Healthcare: The Best Consumer is an Educated Consumer" [14].

3-2 Importance of information provision and public understanding

The handling of genetic information has been stipulated at the policy level through enactment of the above-mentioned Act concerning the Protection of Personal Information and ethical guidelines from individual agencies. The government has proposed measures against bioethical issues, which are inevitably related to genetic information, through the establishment of the Bioethics Committee in the Council for Science and Technology Policy.

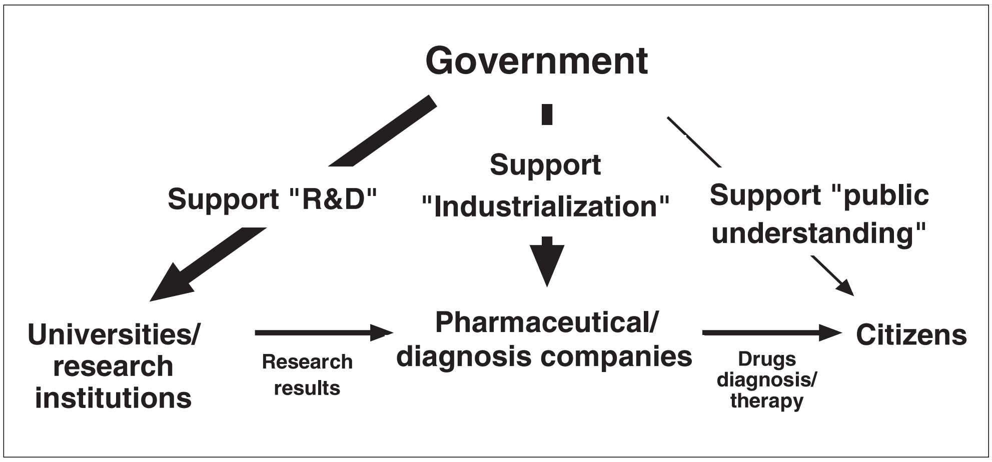
The BT Strategy Council has included "thorough public understanding —establishment of a system enabling appropriate judgment and choice by the public—" as one of the three strategies ("research and development", "industrialization" and "public understanding") in the Biotechnology Strategy Outline[15]. This implies that the well-balanced promotion of these three factors is essential to the development of biotechnology areas including medicine and returning favorable outcomes to the public. Such development cannot be achieved without "public understanding" (Figure 5).

"Strategy 3: thorough public understanding — establishment of a system enabling appropriate judgment and choice by the public". This underlines the fact that "no matter how advanced it is, biotechnology cannot improve people's lives without achieving public understanding and acceptance. It is important to establish a system that enables the public to make appropriate judgments and choices concerning biotechnology and to improve social infrastructure to remove the fear and anxiety against novel technologies". The strategy consists of three factors:

(1) Enrichment of information disclosure and provision systems
(2) Display of a firm government stance on safety and ethics
(3) Enrichment of school education, social education, etc.

These factors correspond to infrastructure

Figure 5 : Diagram describing the three strategies



improvement in the areas of "handling of personal data", "bioethics" and "genetic education", which are vital elements for the implementation of personalized medicine.

"(3) Enrichment of school education, social education, etc." emphasizes that "in order to establish an environment where the public can make appropriate judgments and choices, it is important to increase opportunities in school education that allow children to acquire basic knowledge and acquaint themselves with scientific viewpoints and notions and to increase social education opportunities where people can readily learn about science. Moreover, further enhancement of biological education is required in schools, e.g. efforts to increase the number of students enrolled in biology classes in higher education and to increase the opportunities to take biology exams as part of the university entrance exam. In addition, it is important to support a comprehensive, cross-curriculum approach, such as helping students to acquire a science-based understanding of life in the Period for Integrated Study, and to realize the value of life during childhood." However, Japanese high school students are only provided with a basic knowledge of genetics, and information concerning important terms such as "heredity" and "genes", "genetic mutations" and "SNPs", "mutations in somatic cells" and "mutations in germ cells", which are concepts everyone would have to deal with in personalized medicine, is not provided in sufficient detail[16].

In the "Survey on public awareness of science and technology" conducted in February and March 2001[17], 74% of respondents correctly understood the term "DNA". Then, another question was asked to verify how well the respondents understood this term; "In which part of your body can you find DNA?" (multiple-choice question). Only 33% could answer this question correctly. Furthermore, in a series of questions concerning the probability of developing genetic diseases, which is closely related to personalized medicine, only 39% (55% in the U.S.) could answer correctly for all four questions.

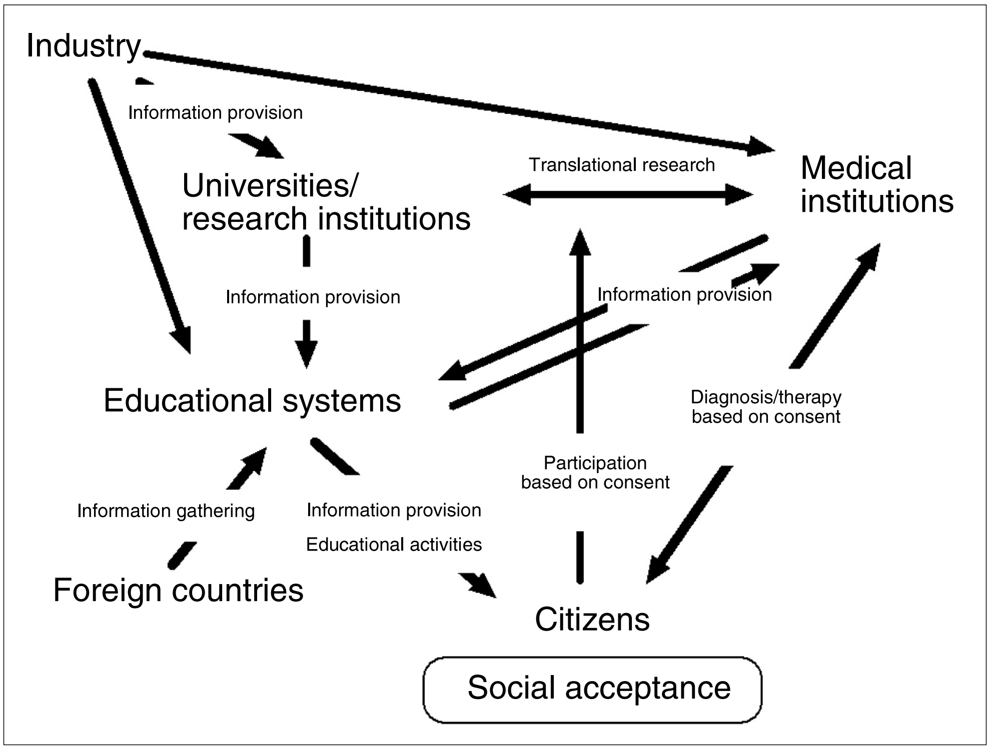
Although the importance of public understanding is advocated in the policy, "genes" are still not sufficiently understood by the public. Such lack of public understanding will become an obstacle to the implementation of personalized medicine based on appropriately informed consent and the promotion of public participation in scientific and genetic research and translational research that is the foundation of personalized medicine.

4 Suggestions

4-1 Current status in Japan

In order to achieve social acceptance of the genetic research that underlies personalized medicine, information services and educational activities which aim at a better public understanding of genes are critical policies that will be required in the areas of science and technology and medicine. Meanwhile, issues concerning genes are not to be left in the hands of doctors or scientists; in personalized medicine, each of us will confront these issues

Figure 6 : Social acceptance of personalized medicine



at the point of "self-determination" of our own medical treatment with "self-responsibility", and a lack of understanding could lead to poor "self-determination". Moreover, the realization of personalized medicine requires participation of the public in translational research, i.e. demonstration research. Thus, it is an urgent task to establish a system that includes personnel and organizations that provide public education on "genetics".

U.S. high school textbooks have richer and more detailed descriptions on "genetics" compared to those found in Japanese textbooks [16]. In addition, the Genetic Alliance (formerly known as the Alliance of Genetic Support Groups, Inc.), which is an organization formed from more than 600 bodies supporting gene-related diseases and patients[18], and the National Council on Patient Information and Education, which was established based on the suggestion of the federal government[19], are involved in various activities to support patients, their families and the public who will eventually become medical service consumers. The activities include counseling, educational activities for providing high-quality information, such as the latest research results and scientific information, mediation between government, company and the public, management and support of patient groups and facilitation of public participation in translational research.

In Japan, we have a clinical geneticist system[20] and a genetic counselor certification system[21] to promote genetic counseling and NPOs to provide genetic education to the public[22], but we still lack an information service system that services the entire nation.

4-2 Establishment of an Internet-based information service system

The above-mentioned survey on public awareness[17] revealed that most people acquire science and technology information "passively" from mass media. In this survey, conducted four years ago, only 12% answered that they actually used the Internet to obtain information, but the Internet was chosen as the most attractive source of information that people would like to use in the future. In consideration of the need to establish a system that services the entire nation, the Internet is one of the most effective routes to provide science and technology information to the public.

Information that needs to be provided to the public is often derived from the latest scientific research results; it is important to immediately add and revise such research results whenever necessary. The system must allow easy updating of the information, and an Internet-based system would be effective in this regard. The system would also need to be accessible to medical institutions, so that the latest information and therapeutic methods can be made available to the suppliers of medical services.

In order to realize personalized medicine based on genome information, where advances in research and applications (drug development and clinical practice) occur in parallel, information must be sufficiently provided to and understood by the public. Considering the above-mentioned advantages, an Internet-based system seems to be the most effective and feasible way of providing such information.

The information can be divided into two types; (i) specialized information (e.g. explanation of molecules involved in disease development and prognosis and significance, risks and benefits) corresponding to each disease is required for understanding and providing consent when receiving personalized medicine or participating in translational research, and (ii) basic information to serve as the basis for understanding such specialized information. The former requires a system to enable one-on-one counseling or answering questions whenever required, while the latter can be integrated into school education or effectively provided through open lectures. Human resources capable of counseling or responding to the public will be necessary, and systems to develop human resources such as genetic counselors will also need to be established. The establishment of an information service system would also be an effective tool to facilitate, support and supplement such counseling.

Since such an information service system involves interactions between areas such as science and technology, medicine, and school education, it would require a cross-ministry linkage led by the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Health, Labour and Welfare. Moreover, since the area of medicine closely involves drugs and diagnostic equipment, the system must include information from private companies working in such areas. Thus, it is necessary to establish an information service organization based on linkages between industry, government and academia.

Personalized medicine is generally considered as an ideal form of medicine, but its implementation requires DNA for molecular diagnoses when using molecular-targeted anticancer drugs and participation of the public in translational research, i.e. demonstration research. Most of all, we must fully understand doctors' explanations when deciding on the therapeutic strategy for ourselves or our families. Thus, the rapid provision of high-quality information to the public is the most important task to secure public safety.

Glossary

*1 Pharmacogenomics
The concept of analyzing the difference in drug response among individuals by utilizing human genome information and genome analysis techniques.

*2 Molecular-targeted anticancer drugs
Anticancer drugs that are developed based on the molecular mechanism of cancer development and target the molecules responsible for cancer development.

References

[1] International Human Genome Sequencing Consortium. Initial sequencing and analysis of the human genome. Nature. 409, 2001, p. 860-921.

[2] Venter, J. C. et al. The sequence of the human genome. Science. 291, 2001, p. 1304-1351

[3] International Human Genome Sequencing Consortium. Finishing the euchromatic sequence of the human genome. Nature. 431, 2004, p. 931-945

[4] Incidence of adverse drug reactions in hospitalized patients. JAMA 279, 1998, p. 1200-1205

[5] http://www.pfizer.com/pfizer/download/uspi_camptosar.pdf

[6] http://www.src.riken.go.jp/index.html

[7] EGFR mutations in lung cancer: correlation with clinical response to gefitinib therapy.

Science. 304, 2004, p. 1497-1500
[8] Activating mutations in the epidermal growth factor receptor underlying responsiveness of non-small-cell lung cancer to gefitinib. N Engl J Med. 350, 2004, p. 2129-2139
[9] Prediction of sensitivity of advanced non-small cell lung cancers to gefitinib (Iressa, ZD1839). Hum Mol Genet. 13, 2004, p. 3029-43.
[10] http://ctrp.tri-kobe.org/
[11] http://www.fda.gov/bbs/topics/NEWS/2005/NEW01190.html
[12] Utsugi, Shin; Sugano, Sumio; Yonemoto, Shouhei. Personal Data on Human Body. Nippon-Hyoron-Sha Co., Ltd., 2004 (Japanese)
[13] http://www.mext.go.jp/a_menu/shinkou/seimei/genome/04122801/007.htm
[14] http://www.cfsan.fda.gov/~frf/forum05/pubsci.html
[15] http://www.kantei.go.jp/jp/singi/bt/kettei/021206/taikou.html
[16] Ikeda, Hiroyuki. Difference in Contents between Japanese and American Genetic Textbooks. Iden. vol.57-1, 2003 (Japanese)
[17] The 2001 Survey of Public Attitudes Toward and Understanding of Science & Technology in Japan. National Institute of Science and Technology Policy, 2001, NISTEP REPORT No.72. (Japanese)
[18] http://geneticalliance.org
[19] http://www.talkaboutrx.org
[20] http://jshg.jp/
[21] http://www.kitasato-u.ac.jp/gene/dept/home.html
[22] NPO Life Bio Plaza 21: http://www.life-bio.or.jp/

Yoshihiro SOWA, Ph.D.
Affiliated Fellow of NISTEP
Assistant Professor of the Kyoto Prefectural University of Medicine, Graduate School of Medical Science, Department of Molecular-targeting Cancer Prevention : http://www2.kpu-m.ac.jp/~pubmed/

Specialized in molecular-targeting therapy and prevention of cancer. Realized the significance of economic activities and public understanding in the promotion of science and technology as a result of his extensive experience at a pharmaceutical company, a venture company, an American research institute, the National Institute of Science and Technology Policy and the university.

(Original Japanese version: published in August 2005)

2

Foresight on Information Society Technologies in Europe

Akihiro Fujii
Information and Communications Research Unit

1 Introduction

This article provides an overview of a recently completed European foresight study on information society technologies. FISTERA (Foresight on Information Society Technologies in the European Research Area) was implemented as part of the action plans called “eEurope 2002” and “eEurope 2005,” which are pillars of the European Commission’s policy.

Europe aims to build a “competitive knowledge-based economy” as stated in the Lisbon Objective, an agenda described below, by means of information society technologies (ISTs). In order to define future visions of ISTs, FISTERA was launched under the leadership of the Institute for Prospective Technology Studies (IPTS), a joint research institute of the European Commission.

In this foresight study, ISTs are clearly distinguished from ICTs, or information communication technologies. While ICTs naturally constitute the major part of the target of the study, the concept of ISTs does not only consist of ICTs and changes therein. Compared with ICTs, which are related to production, information processing and industry, ISTs require discussion on adoption and application of technologies in society. FISTERA set out to consider the ideal form of the information society, taking into account trends in each technology field.

FISTERA started by reviewing earlier national-level foresight exercises in European Union member states. Then, it analyzed patent data to examine technological competitiveness, conducted Delphi studies on social transition, and constructed scenarios on future ambient environments. A wide range of issues, including human resources development, were discussed. Launched in September 2002, the project was finalized at the international conference held in Seville, Spain, in June 2005, toward the end of the study’s three-year schedule. Results of project activities, such as reports on specialist workshops, summaries of analysis results and trends in ICT fields identified through surveys, are being published on the official Web site (http://fistera.jrc.es/) as they become available. The project has cost approximately 1.5 million euros.

This article introduces key findings from the summary report of FISTERA in order to outline the future of ISTs as envisioned by European experts.

2 Background and goal of FISTERA

2-1 The Lisbon Objective

The European science and technology policy addresses ICTs as an element of ISTs and treats ICTs in connection with system development technologies in interdisciplinary and application areas under a broader and more structured concept. The foundation for such pan-European technology policies is the Lisbon Objective, which is described below.

In March 2000, leaders of the EU member states gathered in Lisbon and set a strategic policy goal called the Lisbon Objective. This declared that by 2010 the EU should become “the most competitive and dynamic knowledge-based economy in the world, capable of sustainable growth with more and better jobs and greater social cohesion.” The EU leaders also agreed that, as a policy goal for the next 10 years, they would seek to enrich the EU and to narrow remaining regional disparities between European nations by carrying out measures to fulfill the above goal. They placed special emphasis on technological innovation in the ICT sector and vitalization of related markets as keys to achieving full employment and strengthening corporate competitiveness.

2-2 FISTERA's goal

FISTERA is a large-scale technological foresight study that was designed to benchmark current ISTs and develop strategies for future ISTs in order to realize the goal stated in the Lisbon Objective.

The study was aimed at bringing together the knowledge of European IST experts. First, it compared results of national foresight exercises in Europe. Then, the project proceeded using a network of existing research institutes across Europe. For example, PREST (Policy Research in Engineering, Science and Technology), a British research organization, undertook implementation of Delphi studies and scenario-building. Participating research institutes were assigned sub-projects, and they prepared individual reports that were integrated into a summary report under the leadership of IPTS.

While there have been a number of technological foresight exercises conducted in individual European nations, many of these have lacked a "pan-European" perspective. FISTERA emphasized this pan-European perspective and was designed to collate knowledge that could contribute to promotion of the European Research Area (ERA) and to construct a network of experts.

Results of FISTERA studies have been summarized by constructing and discussing "Technology Trajectories" (described below) from a pan-European perspective. As an outcome of the FISTERA project, a knowledge base on the future visions of ISTs has been constructed in order to provide a bird's-eye view of the future. Another outcome is deepened mutual understanding among experts in ISTs through the process of project studies, based on which a forum on ISTs was organized to enable research results to be shared.

3 Overview of FISTERA

A large number of reports have already been released from the FISTERA project, including a summary of the discussion on human resource issues and the results of online Delphi studies [4]. To describe the outcomes of FISTERA, this chapter focuses on Reference 1 "Key Factors Driving the Future Information Society in the European Research Area, Synthesis Report on the FISTERA Thematic Network Study (Sep 2002-Sep 2004)," which has been published as a summary report on the entire project.

3-1 Structure of the summary report

Table 1 shows the structure of Reference 1, a document that outlines the FISTERA project.

Table 1 : Contents of the summary report

Key Factors Driving the Future Information Society in the European Research Area — Synthesis Report on the FISTERA Thematic Network Study—	
Executive Summary	
Introduction	
1. Methodology	Analyzing by factors; Combining top-down and bottom-up approaches
2. Social Drivers and Challenges	Changing social relationships; Leisure and recreation; Aging population; Health, Cultural diversity and migration; Transport and mobility; Learning and education; Social welfare; Public services; Government; Security
3. The Human Factor	Skills shortages and skills mismatch; Lifelong learning; Accessing potential labor reserves; Brain drain; Skills outsourcing
4. The Political Environment	Europe's current IST capacity; European Union goals; Foresight studies in EU member states; Commission programs; Member states' activities
5. Technological Drivers	Technology trajectories; Perception of European position; National foresight on technology applications; Technology disruptions

Source: Prepared by STFC based on Reference [1]

Table 2 : Competitiveness (SWOT) analysis tools

	Europe's strengths and weaknesses	Opportunities, threats, and challenges
Technology-related factors	Bibliometric analysis of patents, publications and secondary sources (such as R&D funding), national foresight studies	Analysis of Technology Trajectories and disruptions, assessments included in national foresight studies
Economic and political factors	Information from national foresights and literature	Online Delphi and targeted workshops, information from national foresights and literature
Socio-related factors	Information gathering from literature search and online-Delphi	Scenario-building exercises and workshops, and online-Delphi
S&T-based competitiveness	Interviews, online-Delphi, information gathering through research and analysis	Scenario-building exercises and workshops

SWOT: Analysis of Strength, Weakness, Opportunity and Threat

Source: Prepared by STFC based on Reference [2]

Chapter 1 of the report describes approaches to the foresight studies and the relationships between sub-projects assigned to partner organizations. Chapter 2 explains the scope of ISTs as divided into about 10 categories. In this chapter, ISTs are distinguished from ICTs in respect of being oriented toward social application. Chapter 3 addresses human resources required for technological progress from the viewpoint of pan-European science and technology policies. Chapter 4 assesses Europe's current IST environment and discusses how this foresight project is related to the European Commission's science and technology policy programs. Chapter 5, focusing on elements of ISTs, considers future technological trends, and derives factors necessary for achieving ISTs from these trends.

3-2 Analyzing competitiveness

The FISTERA study started by reviewing the results of national foresight studies from several EU member states. Whereas these studies present results that are beneficial at the national level, FISTERA reconsidered them from the perspective of contribution to the prosperity of Europe as a whole. To do this, FISTERA analyzed the strengths and weaknesses of Europe based on patent statistics, conducted Delphi and other questionnaire surveys of experts, hosted workshops of experts, and developed roadmaps and scenarios. A novel development was online utilization of these well-established foresight tools.

Table 2 summarizes all the tools that FISTERA used for analyzing the technological, economic and political, and social factors as well as science and technology-based competitiveness.

To assess Europe's position relative to the U.S. and Japan, FISTERA carried out bibliometric analysis of patent data. For example, Reference 2 shows the results of bibliometric analysis of the patents filed between 1976 and 2002 in selected fields. The source data consist of the number of patents filed in Japan, the U.S. and Europe, as well as other patent-related statistics. The results indicate that Europe generally lags behind the U.S. and Japan, whereas Europe excels in certain technologies such as trunking in the communications field. FISTERA also reveals that most European patents are held by large companies, suggesting a need to promote ISTs among small- to medium-sized businesses.

In addition, Europe's strengths and weaknesses in about 90 key technologies in the information and communications field were analyzed by specialists in the respective areas. To do this, a database of technological trends was built and offered to specialists, and their opinions were sought. Table 3 shows some of the key technologies in which specialists determined Europe has strengths.

FISTERA defines these technologies as basic elements of "Technology Trajectories" and assumes clusters of these technologies offering functions that contribute to the progress of an information society in given ambient environments. Technology Trajectories and technology clusters are discussed in more detail, below.

Analysis of the selected technologies showed that Europe generally lags behind the U.S. and Japan. FISTERA also notes that the gap between the EU and its key competitors has not

Table 3 : Technologies in which Europe is competitive

Technologies	Leading countries
3D scanner	U.S., Japan / Europe (Italy)
Batteries	U.S., Japan, Korea / Europe (Italy, Germany)
Cell phones	Europe (Finland, Germany, France, Netherlands, Sweden)
e-book reader	U.S., Japan / Europe (Netherlands)
e-ink	U.S., Japan / Europe (Netherlands)
Galileo (satellite-based positioning)	Europe
Mobile processing	Europe (Finland, Germany, France), Japan, U.S.
MPEG	Europe (Italy, Germany, Netherlands)
Printer	Japan, Korea / Europe (Italy)
Radio connectivity	Europe
Trunk	Europe (France, Germany)
Voice synthesis-recognition	U.S., Europe

The technologies in which Europe is leading have been extracted from about 90 technologies listed.
Source: Prepared by STFC based on Reference [2]

diminished since the Lisbon Objective was set in 2000. At the same time, the study suggests that Europe has maintained its leadership in a number of technologies in which it has been traditionally strong, such as communications technology.

3-3 Human resources issues

Human resources issues were discussed extensively in FISTERA workshops [3].

FISTERA mentions that temporary shortages of skilled labor in the information and communications sector in the latter half of 1990s have been mitigated since 2001 due to the bursting of the IT bubble, worldwide. However, the study indicates that, since this mitigation has been brought about primarily by market restructuring, the labor market in the ICT sector will face different types of shortages from those it experienced before the collapse of the bubble.

FISTERA forecasts that the primary change in demand for human resources will be a shift from very specialized technological expertise to broader skills. Firms increasingly seek personnel who combine technical expertise with an understanding of the IST market, business acumen in identifying which products have market potential, and customer-relations skills. The secondary development will be higher demand for people with the ability to acquire new skills in line with changing business operations and the changing role of companies. As to retraining of the existing workforce, FISTERA stresses lifelong learning, which can help reduce skills mismatch. It also emphasizes the growing importance of changing the quality of employment to offer new opportunities for those who hitherto have been undervalued, including women, immigrants and ethnic minorities.

The EU can be characterized by its relationships with surrounding countries, including those that are candidates for membership of the enlarged Union (e.g. East European countries, Turkey), and a close relationship with India, whose former colonial ruler is the U.K. These are essential factors in considering the outsourcing of labor and software development. With regard to outsourcing, while stressing the relationships with India and China, FISTERA draws attention to the emergence of East European countries and suggests the potential benefits to Germany.

3-4 Summary of the foresight study

In conclusion, Reference 1 suggests that investment in research and development needs to be increased in order to realize the Lisbon Objective. According to statistics for 2001, EU investment in IST R&D accounts for almost 2% of GDP, and the average growth rate for 1997-2002 is only 4%. To meet the Lisbon target of "3% of GDP by 2010," an increase in overall R&D expenditure of 8% a year is required, up to 2010.

Particularly in the IST sector, disruptive technologies, or unpredictable extensions of current technologies, may emerge. FISTERA cites examples of areas where such technology disruptions can occur. The study states that if a technology disruption occurs suddenly, it should be given prompt and constant support.

On June 16 and 17, 2005, the conference to finalize the FISTERA project was held in Seville, Spain. The conference theme was "IST at the Service of a Changing Europe by 2020."

It should be noted that FISTERA not only targets 2010, by which date the Lisbon Objective should be realized, but also projects as far ahead as 2020 in discussing future Technology Trajectories and scenarios. Based on experts' opinions, the project also considers setting 2020 as the target year for achieving IST-related goals.

4 Trends in information society technologies

This chapter describes the trends in ISTs as discussed in FISTERA[1], first clarifying application areas for ISTs, and then looking at the concept of "Technology Trajectories." Ten Technology Trajectories were selected for the study. Trends in each of these Technology Trajectories, as identified by FISTERA based on experts' opinions, are shown below. Consequently, FISTERA names the areas whose future trends are worthy of attention as "technology disruptions." In addition, a Web site that provides technology trends identified through the foresight study is mentioned later in this chapter.

4-1 Application areas for ISTs

Application areas for ISTs are expected to expand, especially around healthcare, education, transport and governmental services. FISTERA's summary report discusses, for each of these application areas, which functions will be provided by future technologies in the information and communications sector, and how these functions will benefit individual areas.

For example, given European demographics, healthcare and applications for older people are increasingly high on the political agenda. Health insurance and healthcare systems in many EU member states are faced with cost problems, which ISTs can ease by improving efficiency. FISTERA suggests that ISTs should offer solutions to such challenges. FISTERA also notes the merging of previously separated spheres of daily life, such as work and leisure, and leisure and learning, with the emergence of new concepts such as "infotainment" at the interface between information and entertainment. With respect to the success of teleworking, the report points out that favorable conditions for this style of working are finally emerging on a large scale in this era of increasing economic globalization.

4-2 Technology Trajectories concept

FISTERA uses the concept known as Technology Trajectory (TT) in analyzing future visions for ISTs.

To develop this concept, FISTERA first focuses on the functionality of a technology. For example, when one refers to semiconductor chip technology, there remains ambiguity as to whether this represents a single technology or a group of technologies with dissimilar natures, such as etching, lithography and logic. In other words, whenever the term "technology" is used, it is difficult to define precisely what it means. To avoid this ambiguity in defining technology, FISTERA focuses attention on the "functionality" of technology. By forming clusters of technologies, FISTERA considers what functions each cluster can deliver and what kind of service and ambient environment it can provide. Technology Trajectories are groups of technologies in the information and communications sector, formed from the IST viewpoint.

Over 100 key technologies were discussed by experts and 10 were selected on the basis of the considerable impacts they would have on the information society: Bandwidth, Communications, Data Capturing, Human Interfacing, Info Visual Display, Info Retrieval, Pinpointing, Printing, Processing, and Storage. Section 4-3 below explains the future visions for these Technology Trajectories as analyzed by experts.

4-3 Technological trends

While FISTERA examines current trends (2004), trends toward 2010 and trends toward 2020 for the selected 10 Technology Trajectories, only their outlines are extracted from Reference 1 in this section.

(1) Bandwidth

In the next five years, xDSL at 100 Mbps with a loop length of 4 km and optical fibers will be laid. As a result, connections at speeds close to 100 Mbps will probably satisfy 99% of needs until beyond 2020(Note 1). However, in the wireless and mobile communications environments, securing broadband will continue to be expensive until around 2010.

Research will continue into ways of providing broader bandwidth for specific purposes. With respect to broadband communications in areas such as holographic projection, Grid computing for scientific computations and medical and security applications, the needs are likely to go beyond general infrastructures and applications.

(2) Communications

Easy connectivity with network environments, or "the personalization of connectivity," will emerge in the next 10 years. With the advent of wireless routers and ad hoc networks by 2015, the interference problem will grow in relation to inter-terminal communications with a thousand times greater data rate. The report suggests that this perception should not be "taken for granted" and that an outlook on the direction of progress should be formed through further R&D.

(3) Data Capturing

This area, which has evolved continuously, is facing a major transition. Sensors will become less expensive and more easily available, just as monitoring from satellites, Web cameras and portable playback devices are today. Three-dimensional scanning may also be offered at low cost in the next 10 years. The technologies supporting such trends include electronics, bioelectronics, nanotechnology, MEMS, communications technology and chip manufacturing techniques that allow coexistence between analog and digital technologies.

The need for security in the information-processing environment can accelerate growth in this area. In the next decade, sensors will be embedded in most objects to form autonomous networks via a communication gateway. Broader applicability of sensors will enhance the validity of data, thus further increasing efforts to overcome challenges in information capturing.

(4) Human Interfacing

By the first half of the 2010s, human interfacing technologies that can adapt to personal feelings may emerge. In the latter half of the decade, "shadowing" (monitoring personal exchange of information daily) will become important, possibly evolving into a technology that would complement today's mechanical communications applications.

Communications are likely to depend more on "understanding" than on format. This will lead to issues such as who is responsible for any misinterpretation, which could delay technological progress. Artificial intelligence, interactive agents and other technologies are likely to become "tools" for overcoming such obstacles. While very interesting ideas have already emerged in several areas, they have yet to be solidified.

(5) Info Visual Display

Potential recognition of the significance of new developments in info visual display technology in such sectors as design, drugs and entertainment can bring about new market opportunities. In the next five years, displays in fixed and mobile environments are likely to improve in terms of resolution. Two-dimensional displays will advance over the next 15 years, but their margins will progressively shrink as they become commodities. New display technologies in the mobile environment will emerge to boost services and provide greater profits to those companies that control the advanced technologies. Three-dimensional displays will be confined to niche markets for the next five to eight years but will enable new services in the following decade. Although not inherently disruptive, 3D displays can become a disruptive technology that contributes to a mechanism for creating a new paradigm in the communications environment. Investment in this mechanism is more likely to produce wealth than investment in 3D technology.

(6) Info Retrieval

The quantity of data produced is increasing at extraordinary speed, and production is likely to double every 2 to 3 years over the next two decades. It should be noted that what really doubles is the "data" and not the information. Conversion of data into information and retrieval of that information will be the real technical challenges for the coming decade. Technological innovation regarding information retrieval will be essential for any type of information.

While expectations are high for technological developments in this area, predicting the details is not easy. A major milestone will be reached around 2008. Several fundamental developments will be achieved by this time, enabling more specific predictions. Finding solutions to the basic problems of information retrieval will lead to a critical change that can boost information society development in the future. At the same time, these solutions are likely to generate many challenges such as privacy concerns, intellectual property rights and information protection. In this technology area, improved benefits to citizens could also mean a higher risk of criminal activity.

(7) Pinpointing

By the end of 2010s, services that rely on smart tags, beacons, GPS and satellite-based positioning systems like Galileo will become so widespread that people will take their existence for granted and will no longer talk about them. By 2008, most products will have tags. In the following decade, "soft" products such as content will also be tagged. While concerns over security and privacy will remain high until around 2010, they will wane as new benefits that offset the shortcomings appear.

The information society will become a "tagged society," in which several technologies act in cooperation. From the IST perspective, the emergence of this tagged world is likely to create great opportunities for development in disciplines at the edge of ISTs, such as medicine and biology. It is already possible to tag proteins and viruses. By the end of the next decade, tracking tagged proteins will be much easier. This, in close synergy with ISTs in communications and other areas, will bring about a revolution in the healthcare sector.

(8) Printing

Printing has evolved so remarkably in technical terms as to completely revise business rules, although this fact is not widely recognized. This has opened the door to new services, thus changing business workflows and information exchange methods.

Looking as far ahead as 2015, a "disruptive" situation will arise from technologies that enable the printing function to be embedded in diverse objects and that make printing materials capable of self-printing (e.g. e-ink). Around 2010, printed matter will begin offering some sort of dynamic behavior. For example, printed matter that interacts with the user and automatically updates itself. By 2020, the standard meaning of "printing" will change from transferring a small amount of ink to paper to "reproducing an object."

Copyrights are likely to become physically integrated into printed matter, fundamentally changing users' relations with such materials. Conceivably, a single page of printed text may be able to interact with a user's personal area and negotiate reading rights before actually displaying its information.

(9) Processing

Over the past 30 years, processing power has doubled every 18 months, creating whole new industries and services. Reduced costs have expanded the market from a level of a few computers per country to more than one per household. Even now, in spite of a decrease in demand, the need for greater processing power continues. To meet this demand, it is necessary to reduce fixed costs, increase production and shrink sizes.

By 2020, every conceivable object is likely to have some sort of embedded processing capability. The question is whether industries will accept such an oligopolistic market as exists today if the above embedding becomes widespread, which translates into whether the companies dominating the processing devices field will continue to lead the market. Put another way, processing technology can evolve in either of two directions: toward providing equal opportunities for everyone (and every country) to develop products and services, or toward turning the market in favor of the dominant market players that control processing technology.

(10) Storage

With a new storage medium having been invented every five years and a disruptive innovation emerging every 10 years, storage capacity has doubled every year over the past decade, while storage price has decreased by 10% a year (currently, one euro buys around 300 GB). This trend is demonstrated in the evolution from floppy disks in the 1970s, through smaller diskettes in the 1980s and CD-ROMs in the 1990s, to DVDs in the 2000s. The potential of holographic disks is yet to be realized, while polymer memory is expected early in the next decade.

Such a disruptive technology cycle has had a profound impact on industry, from production through software, content production, information distribution and management to protection. Currently, there are no signs of slowdowns in capacity increase or in price reductions. Capacity is rapidly reaching a point where it can support local storage of huge quantities of information, creating a virtual local "Internet." This may also make everything recordable, enabling new services and creating completely new industries.

Ways of using storage are likely to change in order to enable household and other appliances to access, download and update/synchronize information via data communications infrastructures. By 2020, storage capacity to enable this will become available.

4-4 Technology disruptions

A new methodology or product can disrupt the existing market. When this kind of disruption is caused by technology, FISTERA calls it a "technology disruption." A typical example is seen in the relationship between PCs and mainframes. While their processing power was not as high as that of mainframes in the early days, PCs caused a technology disruption by providing the market with a different value.

The important issue in discussing a potential technology disruption is to analyze why it is assumed possible. Such analysis requires a deep understanding of technology. In other words, better outlooks and parameters worth discussing for R&D investment often derive from a deep understanding of technological trends.

Table 4 lists expected technology disruptions identified through FISTERA's discussion on Technology Trajectories.

Examples of technology disruptions are briefly explained below, based on the descriptions in

Table 4 : Expected technology disruptions as identified by FISTERA

Technology disruptions	From year
Transition from products to services	Already happening; main impact from 2010
Disappearance of the PC	2008-2010
Ubiquitous seamless connectivity	2008-2010
Changing traffic patterns	Already happening; major impact from 2010
Unlimited bandwidth	2015
Disposable products	2009
Autonomous systems	2007
From content to packaging	2010
Virtual infrastructures	2015

Source: Prepared by STFC based on Reference [2] the reference document. Experts predict the first disruption, “transition from products to services,” as follows: Most appliances, including home appliances widely used in people’s daily lives, will have connectivity with networks by 2008. In a broad sense, the functions of these appliances will be provided through software over the network. This implies that the current market, which adopts the model of providing values based on products, will be in transition to a service-based, value-provisioning model. This is what is meant by “transition from products to services.”

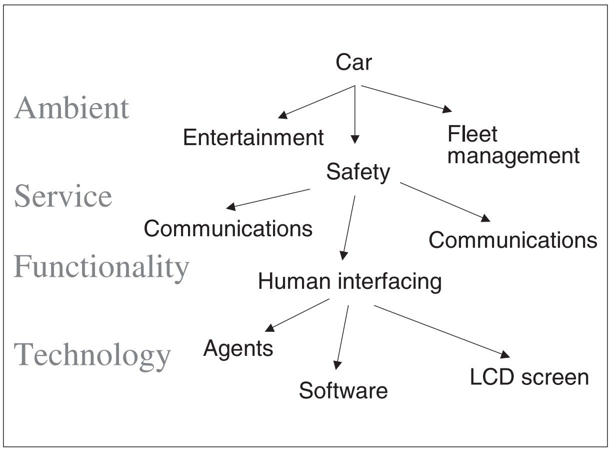
“From content to packaging,” another technology disruption, suggests an attempt to offer meaningful information by retrieving from a large amount of data the combinations and display formats that are valuable to or favored by a specific individual. With production of content such as films and TV programs running at a tremendously high level, the value of each piece of content is steadily declining as oversupply continues. Thus, packaging, or effective presentation of content, is becoming important. The panel of experts draws attention to research into accumulation of personal information, which is conducted by Microsoft and other organizations. This is an example of research that sets out to explore what kind of packaging is valued by individuals.

4-5 Depicting technological trends in a layered structure

FISTERA uses clusters of technologies in the information and communications sector to predict trends in ISTs. The clusters for Technology Trajectories such as bandwidth, data capturing and human interfacing have been identified through the discussion on Technology Trajectories shown in Section 4-2 and adoption of the functionality viewpoint, i.e. what an information and communication technology can provide. Ten representative clusters have been described in the previous section.

How do these clusters interact with application areas as ISTs? What kind of relationship does a cluster have with its constituent technologies? FISTERA examines such relationships between technology and society using a four-layer structure: Ambient, Service, Functionality and Technology. The bottom layer, Technology, consists of 3D scanner, batteries and many other technologies as shown in Table 3. Sitting above this is Functionality, or what a technology does, and then Service, or what a function provides. The top layer is Ambient.

Figure 1 : An example of Technology Trajectory

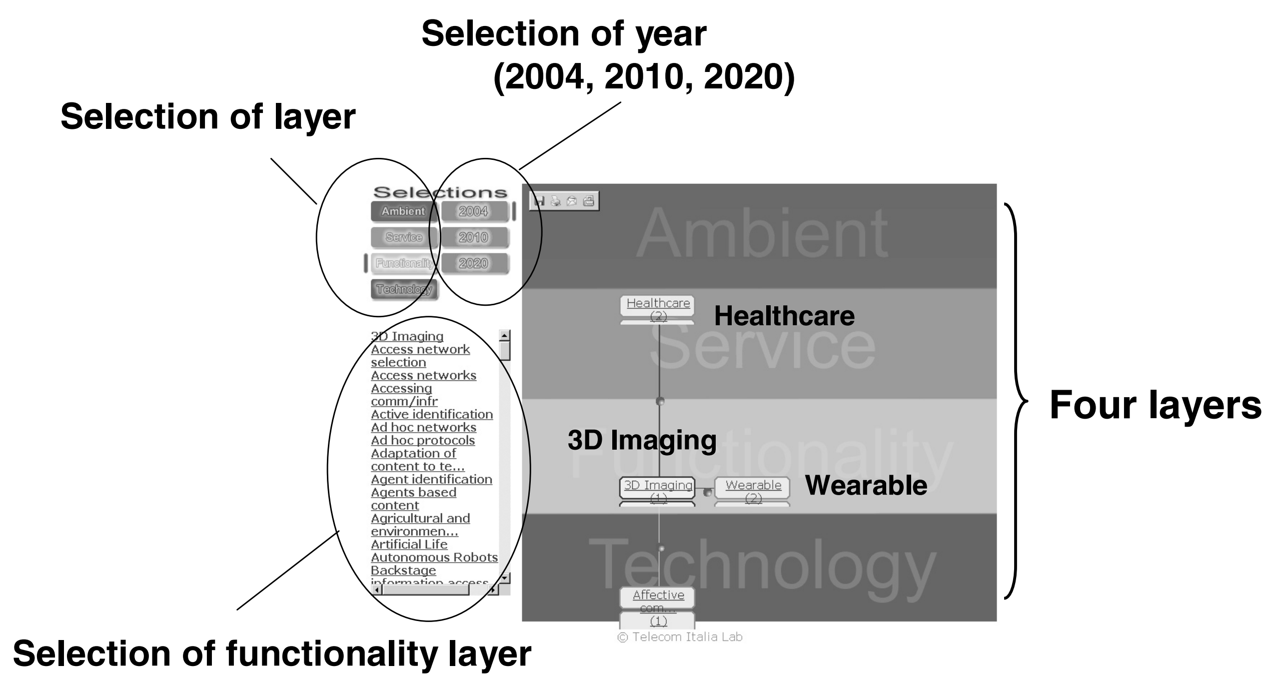


Source: Prepared by STFC based on Reference [1]

We can use the car as an example of Ambient to better explain the relationships between the layers. Figure 1 shows how the car is perceived under the Technology Trajectory concept, or how the given Ambient can be broken down into the underlying layers of Service, Functionality and Technology. The car provides services such as entertainment and fleet management. “Safety” is also a service. The functionalities supporting safety are communications, voice recognition, advanced human interfacing and so forth. These functionalities are enabled by technologies such as agents, software and LCD screens. Although this example is explained using a top-down approach, a reverse approach is also possible. The advancement of a particular technology can be examined from the IST viewpoint using a bottom-up approach - first examining what kind of functionality it is likely to offer in the future, and then, what kind of service it could enable. In FISTERA, experts investigated trends in Technology Trajectory clusters using this layered structure.

Figure 2 shows a Web page depicting a Technology Trajectory cluster, which can be accessed at http://fistera.telecomitalialab.com/. This page visualizes scenarios for 2004,

Figure 2 : Graphical depiction of Technology Trajectories



Source: Prepared by STFC based on Reference [5]

2010, and 2020. The screenshot in Figure 2 indicates that when “2004” and “3D Imaging” are selected as the year and the functionality, “Wearable” (functionality) and “Healthcare” (service) are displayed as areas to which the given functionality contributes. This means that, as of 2004, 3D imaging technology is already boosting technological advances in medical diagnosis, while measuring health conditions through wearable technologies has enabled remote monitoring, contributing to health management.

5 Conclusion

FISTERA can be characterized by two major points. The first and most interesting is that the entire study was designed as part of a process aimed at achievement of a particular agenda. That is, the FISTERA project was designed purely for the purpose of fulfilling the Lisbon Objective by 2010. Thus, the results of its studies and analyses clearly indicate the impact on this goal.

The second point is that multiple perspectives were adopted in performing foresight studies and analyses throughout the three-year project term. Each phase of the project was made widely accessible to the public so that feedback could be used in the next-phase discussions of the working groups. This process was facilitated by using the Internet. Moreover, during foresight studies, the participating experts were provided with a range of basic data such as demographics and other socio-economic indicators. These approaches undoubtedly helped to deepen awareness of the goal among the experts, building a better and more solution-oriented consensus.

FISTERA only targets European ISTs, but there are many things Japan can learn from the project regarding research aimed at formulating national science and technology policies.

Note

1: The discussion here refers to transmission capacity at access level, not that in backbone networks.

References

[1] Key Factors Driving the Future Information Society in the European Research Area, Synthesis Report on the FISTERA Thematic Network Study (September 2002-September 2004)

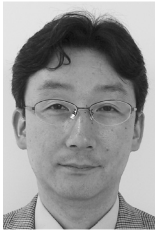
[2] Dachsl, Bernhard; Weber, Matthias; Zahradnik, Georg. Europe’s strengths and weaknesses in Information Society Technologies, a patent analysis. January 2005

[3] "Human Resources in IST: Challenges and Opportunities for Europe - Results of a FISTERA Workshop, Seville, 14-15 June 2004, July 2004"

[4] PREST, The University of Manchester, U.K. The FISTERA DELPHI, Future Challenges, Applications & Priorities for Socially Beneficial Information Society Technologies.

[5] Web site of FISTERA: http://fistera.jrc.es/

[6] Informative Web site on Technology Trajectories: http://fistera.telecomitalialab.com/



Akihiro FUJII, Ph.D.
Information and Communications Research Unit, Science and Technology Foresight Center

D.Eng. After being engaged in research on distributed computing and communications protocols, he implemented a project to construct an electronic commerce system. His current area of interest is the impacts that innovations in information and communications technology can have on business administration and national policies.

(Original Japanese version: published in July 2005)

3

Current Trends in Digital Cameras and Camera-Phones

KIMIO TATSUNO
Information and Communications Research Unit

1 Introduction

Japan's digital camera industry plays a major role in the currently flourishing digital home appliance business[1, 2]. Supported by the business strategy, "manufacture a product that cannot be copied in a way that cannot be imitated", Japanese companies involved in this field have demonstrated their competitive edge by riding the post-1995 sales surge to a position of global market dominance[3]. In contrast, some overseas companies failed to keep abreast of the innovations in camera technology over the last 10 years. DPA GmbH reported, on May 28, 2005, that AgfaPhoto in Germany had gone bankrupt. Agfa used to be one of the so-called "Big Three" established companies in the photographic film business, along with Fujifilm and Kodak.

The digital camera market in Japan is nearing saturation point, with domestic companies now involved in fierce competition. Kyocera, Olympus and Pentax have been reported as having reduced their scale of production. On the other hand, Canon, Casio, Sony, etc. are growing their market shares and are relentlessly competing for unsaturated international market dominance. Nikon and Canon, both established conventional camera manufacturers, are working to develop the market for advanced digital SLR cameras.

Meanwhile, "camera-phones" equipped with miniature digital camera modules have become a rapidly expanding market category since 2001. Of the 500 million mobile phones manufactured up to the end of fiscal 2004, some 180 million were camera-phones. Japanese companies such as Panasonic, Sony, Sharp and Konica Minolta[4], jointly meet 80% of world demand for the imaging devices and optical modules used in camera-phones, which clearly indicates the competitive strength of Japanese industry in this field.

This article discusses the sources of those companies' international strength in both the technology and marketing of digital cameras. It also explores future trends, as represented by the dynamic development of the camera-phone field. Of particular note is a "tunable-focal-length liquid lens" developed by a French university-originated venture company (Varioptic). This lens is expected to lead to major innovations in the digital cameras installed in camera-phones. Varioptic is collaborating with South Korea's Samsung, the third largest company in the mobile phone business after Nokia and Motorola, and is attracting attention as a good example of industry-university collaboration of the type that the Japanese government is currently seeking to promote.

Ministry of Economy, Trade and Industry (METI) reported in May 2005 that 1,099 venture companies had been established by universities in Japan. The target set in 2001 was surpassed through a three-year collaboration between industry, universities and the government. Now, the primary focus has shifted to "the quality of the venture", or success in operating as a viable business. This report proposes a methodology for promoting business quality in venture companies established by universities, based on accumulated intelligence about the French venture company (Varioptic), how it was established, and the role played by the French government.

2 Development and structure of digital cameras

The prototype of the digital camera was developed out of Sony's analog-type "Mavica" electronic camera (1981), with the first truly digital models being produced by Toshiba and Fujifilm in 1989. These products did not gain immediate acceptance in the marketplace due to their high price and the unavailability of sufficiently well-developed peripherals, i.e. PCs. Stimulated by the strong sales of PCs with the Windows95 operating system, the market developed rapidly following Casio's launch of the first consumer digital camera in 1995. The market expanded further in line with the progress of the Internet.

From today's perspective, the 14-year period from 1981 to 1995 can be regarded as the "lift-off" stage of the digital camera's history. With hindsight, R&D managers at that time should have looked to research engineers with innovative ideas, exercised the patience to wait until peripheral technologies were properly developed, and set their sights beyond immediate, limited sales returns.

The digital camera comprises an imaging device, imaging optics, image processor (DSP), LCD, buffer memory (DRAM), card memory (flash memory), electronic drive circuits, and control mechanics, as shown in Figure 1. Its core component, the imaging device, is constructed using a charge-coupled device (CCD) or a complementary metal oxide semiconductor (CMOS), which converts an optical image to analog electric signals. The analog signals are converted to digital form by the image processor and the buffer memory. The digital signals are stored in the card memory, which incorporates rewritable and non-volatile flash memory.

Another core device is the lens optics, which focuses a picture on the imaging device. The lens optics combines several aspheric lenses in order to correct aberration. The optics requires space to incorporate actuators and related mechanics for zooming, through which the focal length and the length between the lens and the imaging device are adjusted.

3 Analysis of global competitiveness of Japanese digital cameras

3-1 Analysis of the global market for digital cameras

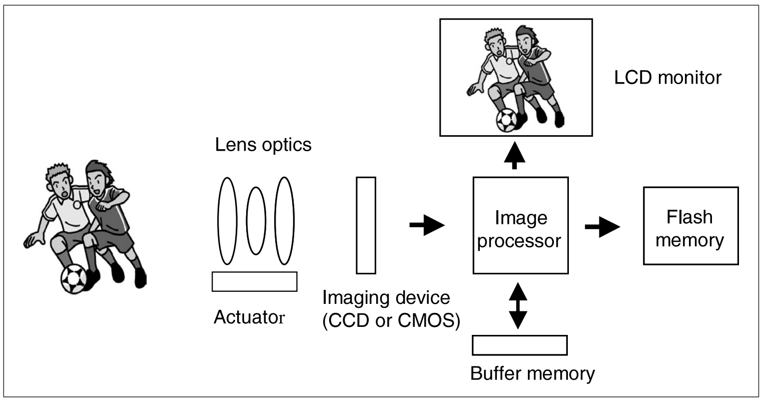
Digital cameras have won widespread acceptance for both business and personal use, due to their usefulness as imaging devices that can be linked with PCs. Sales have grown dynamically (Figure 2), with the ratio of exports to total sales increasing year-on-year (Figure 3)[5].

Digital cameras manufactured in Japan command 80% of the world market (Figure 4), indicating Japanese companies' formidable competitive advantage in this product category.

3-2 Imaging devices

To clarify the source of Japan's global market strength, we show the shipping volume for each pixel number category of imaging devices (CCD or CMOS) in Figure 5[5]. From a baseline of

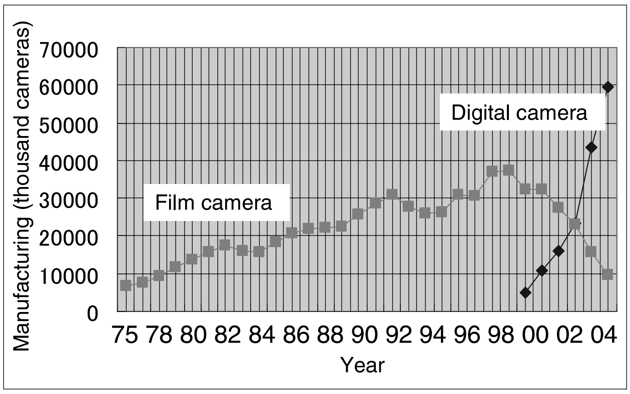
Figure 1 : Basic digital camera construction



imaging devices under 1 M, the pixel number has increased each year, to the stage where the 5-6 M category has dominated the shipping volumes over recent years. The pixel number of the largest sales segment has steadily increased. As digital cameras with larger pixel numbers arrive on the market, consumers tend to select the new models and abandon the smaller pixel number models, which results in increasing price competition in the low-end market. Increases in pixel number lead to expansion of the market, and it is here that Japanese companies driven by advanced R&D manifest their edge over foreign companies. The imaging devices are supplied mainly by Panasonic and Sony, which constantly promote development of the digital camera market, thereby providing an advantage to Japanese camera manufacturers.

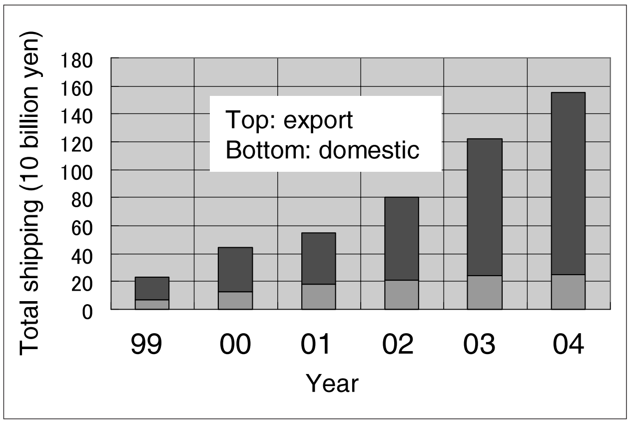
However, when the image is printed up to A4 size, the human eye cannot readily discern the difference between a photograph captured on a 4 M imaging device and one taken by a 7 M camera. It is possible, therefore, that the pixel number for low-end digital cameras will plateau, while professionals and enthusiasts will seek higher resolutions (more than 4 M) in advanced digital SLR cameras, so that they can crop and magnify sections of photographs. It is projected that low-end digital cameras will plunge into cost competition rather than technical competition (i.e. larger pixel numbers), pitting Japanese companies in a fierce price war against South Korean, Taiwanese and Chinese camera manufacturers. Japanese companies will progressively lose their edge in the low-end digital camera market.

Figure 2 : Production of digital and film cameras



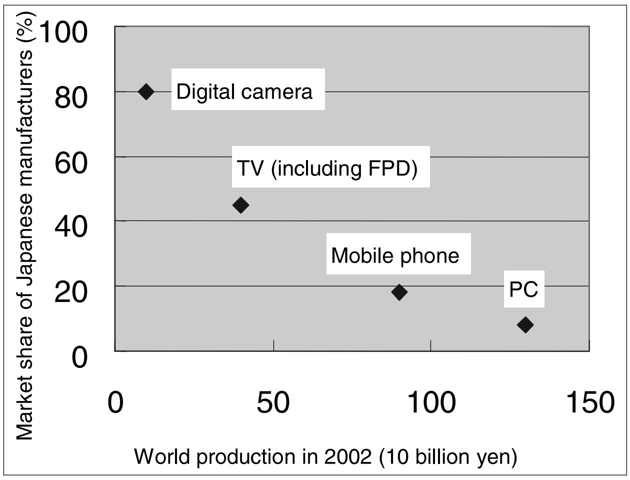
Source: Prepared by STFC based on the Camera & Imaging Products Association report

Figure 3 : Domestic sales and exports of digital cameras



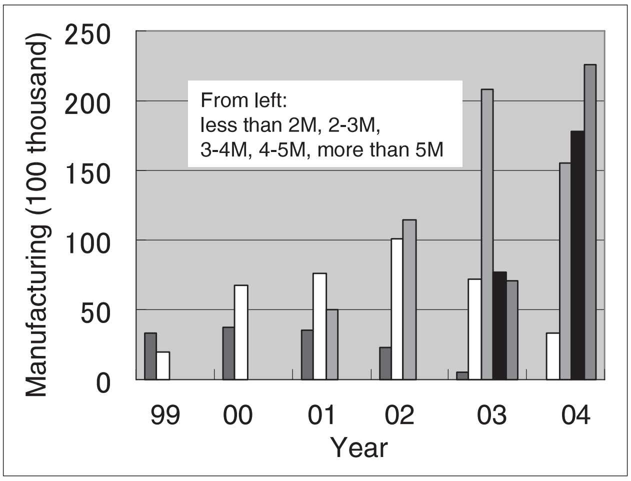
Source: Prepared by STFC based on the Camera & Imaging Products Association report

Figure 4 : World market share of Japanese manufacturers



Source: Prepared by STFC based on reports provided by the Camera & Imaging Products Association [5], Gartner [6], and Japan Electronics and Information Technology Industries Association (JEITA) [7]

Figure 5 : Shipping of imaging devices for each imaging device size (pixels)



Source: Prepared by STFC based on the Camera & Imaging Products Association report

3-3 Optics

Another strength of Japanese companies has been in design and manufacturing of the optics[4]. Many current digital cameras are underpinned by advanced optical design technology, as represented by optical zoom, and advanced manufacturing technology for glass or plastic molded lenses[8] that was developed for optical pick-ups in optical disc drives. The molded lens is designed to be aspheric in order to correct aberration and is manufactured on a large scale using metal molds, which are realized through various types of expertise, including mold-making and lens coating. The business strategy, "manufacture a product that cannot be copied in a way that cannot be imitated", has worked well in this business, helping Japanese companies that are strong in optics and electronics to lead the digital camera market. We considered whether this strength can be maintained in the future, in light of trends in the camera-phone field.

4 Camera-phone trends

4-1 Market trends for camera-phones and technical tasks

The development of the digital camera market is shown schematically in Figure 6. Following the increase in pixels of imaging devices, future progress is projected to diverge along three paths: further increases in pixels; advanced digital SLR cameras equipped with imaging devices of more than 5 million pixels; and camera-phones[9].

The camera-phone has experienced a rapid increase in production, equivalent to that of the digital camera. The past and the future (projected) of the camera-phone market are summarized in Figure 7 [6, 10]. In 2004, 500 million mobile phones had been purchased, including 180 million camera-phones. For 2008, sales of

Figure 6 : Diversifying market for digital cameras

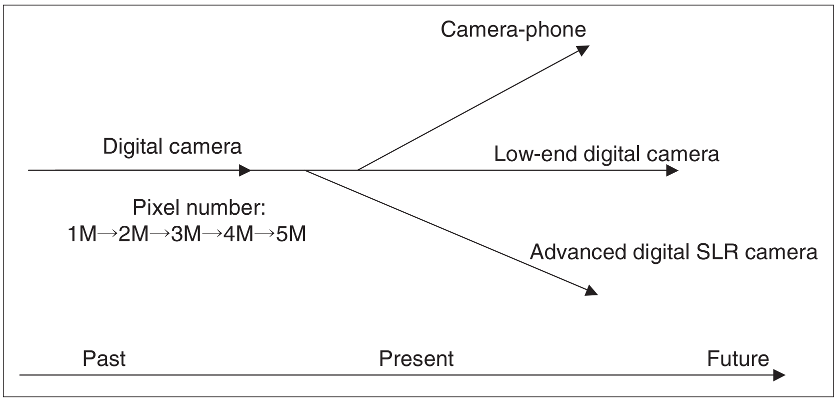
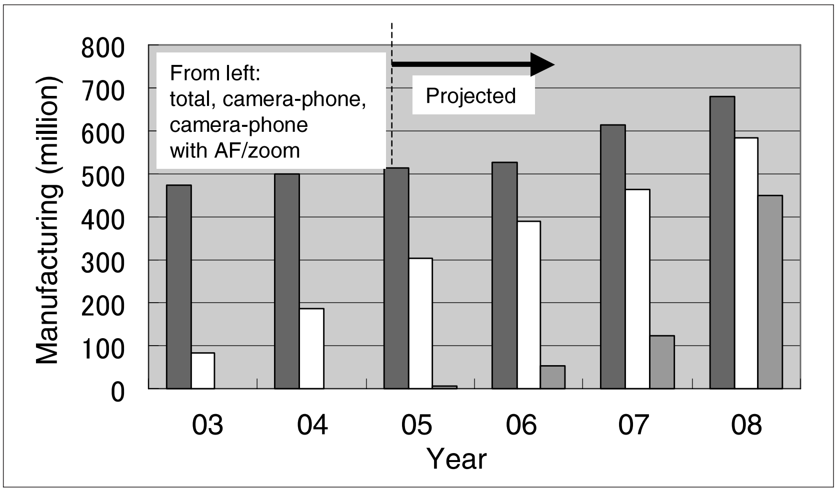


Figure 7 : Past and future of the camera-phone market



Source: Prepared by STFC based on reports provided by Gartner [6] and Varioptic [10]

700 million mobile phones are projected, of which more than 90% will be camera-equipped, and 60% will incorporate zoom functions.

Imaging devices installed in mobile phones have fewer pixels than those in digital cameras. Optical modules with 300,000 pixels are manufactured in China, whereas modules with more than 1 million pixels are made in Japan.

Low-end and low-priced imaging devices, whose prices will decrease further as a result of price competition between digital cameras, will be applied to cameras installed in mobile phones. Regardless of increases in pixels, the number of imaging chips obtained from one wafer does not change, which means that, given adequate production yield, the production cost does not increase as the pixel number increases. Therefore, the pixel numbers for camera-phones are rising rapidly, which is attractive to purchasers. Micron Technology, which enjoyed a price edge over Japanese companies in the DRAM market, is attracting attention due to a steady increase in market share for imaging devices following its entry into production of CMOS imaging devices.

However, the optical modules installed in mobile phones need to be much smaller than those used in digital cameras, incorporating auto-focus or zoom mechanisms. A camera-phone equipped with conventional optical ×3 zoom, which was announced by Samsung in May 2005, is shown in Figure 8. The phone is not convenient to carry due to the larger size of the optical system compared to fixed-focal-length optics. The test criteria for a mobile phone (dropping height: 1.8 m, operation: 50,000 times) are more stringent than those for a digital camera. There is a demand for further reduction in component sizes and power consumption as part of the ongoing integration, and multi-functionalization of mobile phones, such as HDD installation and "Super Urban Intelligent Card" (SUICA) compatibility. Some technological breakthrough is needed to satisfy the growing demand for smaller-sized optics and enhanced shockproofing of the zoom mechanics, or to develop innovative replacements for these modules.

Figure 8 : Prototype of a camera-phone with conventional 3x zoom optics

Source: Prepared by STFC based on photo provided by Samsung

4-2 Emerging technology: Tunable-focal-length liquid lens

Varioptic[10] and Samsung jointly exhibited an innovative optical module at CeBIT 2005 (Hanover, Germany, March 10-16, 2005), to demonstrate their progress in drastically reducing the size of optics for mobile phones.

The CeBIT 2005 organizing committee noted that only one-quarter of this year's exhibits dealt with hardware, reflecting the declining market trend in that sector. Japanese hardware companies are facing fiercer-than-ever price competition with their East Asian rivals (Korean, Taiwanese, Chinese, etc.) in a smaller overall market. In collaboration with Samsung, the French university-originated venture company Varioptic is seeking to enter the market for mobile phone components, which accounts for a significant proportion of today's hardware market.

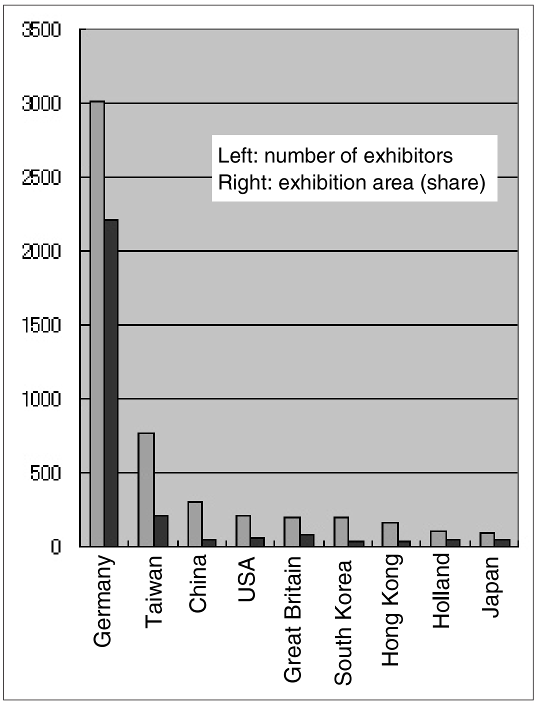
The CeBIT 2005 catchphrase is "Digital Convergence", in which service, software, telecommunications and hardware are integrated around the core of digital technology. The digital technology market is shared equally among the four sectors. As epitomized by the merger of IBM's PC business with Lenovo in China, US companies are moving beyond hardware business into more productive, knowledge-based activities that incorporate IT technology. These moves can be seen as a step toward the post-industrial society.

At CeBIT 2005, 6,270 companies (compared to 6,109 in 2004) occupied exhibition booths, covering 308,881 m^2 (312,539 m2 in 2004) of exhibition space, and 480,000 participants (510,000 in 2004) visited over the 7 days, which indicates the gigantic scale of the convention. Figure 9 summarizes the number of companies from each country that exhibited at CeBIT 2005, and illustrates the expanded representation by East Asian countries.

Panasonic promoted its digital camera equipped with an Optical Image Stabilizer (OIS) in the extensive area dedicated to digital home appliances at CeBIT 2005, although it did not show any new technology. On the other hand, Samsung exhibited a prototype camera-phone equipped with the above-mentioned Varioptic-developed tunable-focal-length liquid lens, which is tuned by applying voltage. An advance on the camera-phone shown in Figure 8, the prototype incorporates a zoom function without any enlargement in overall size. The license fee reportedly is 1.2 million euros.

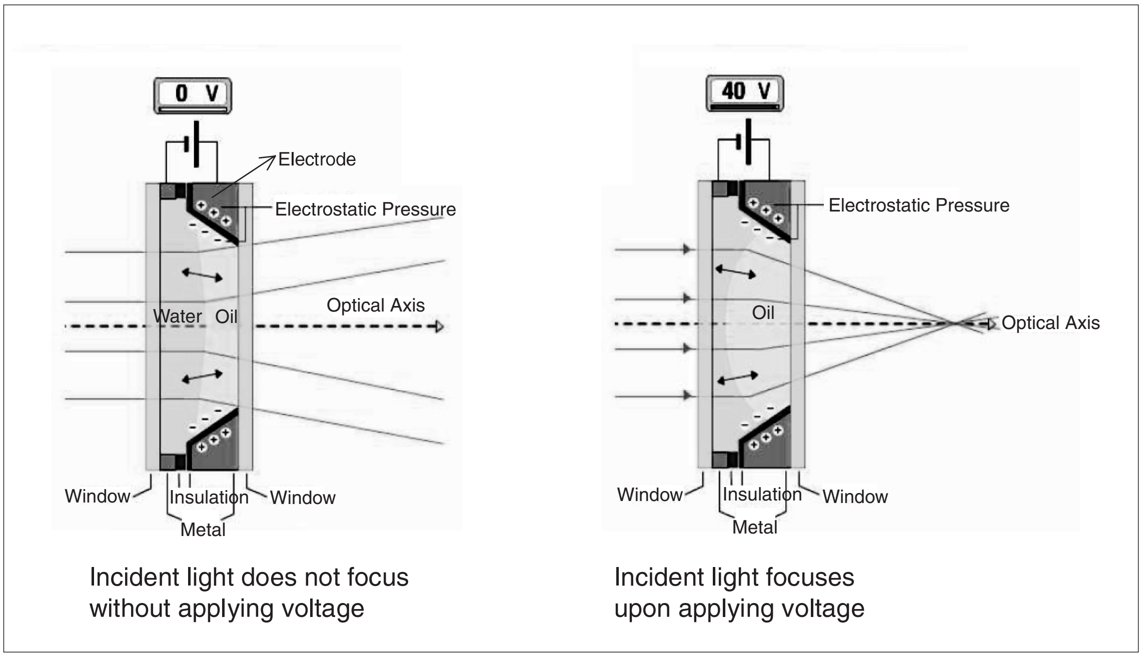
Figure 10 shows the basic design of Varioptic's tunable-focal-length liquid lens, in which the optics is constructed using water and an oil-drop lens. Forming a sphere surface through surface tension, the oil-drop functions as a lens. The lens system is designed to be achromatic, incorporating convex and concave lenses (made of plastic or glass) in order to avoid chromatic or spherical aberration. With no voltage applied, light does not form an image after passing through the lens, as shown in Figure 10 (left figure). When 40 V is applied, the lens curvature increases (diopter, the inverse of focal length, increases) and forms an image after passing through the lens, as shown in Figure 10 (right figure). This system has both focal length tuning and focusing. Further, zooming is realized using two units of this system in place of the mechanics

Figure 9 : Exhibitors from each country at CeBIT 2005



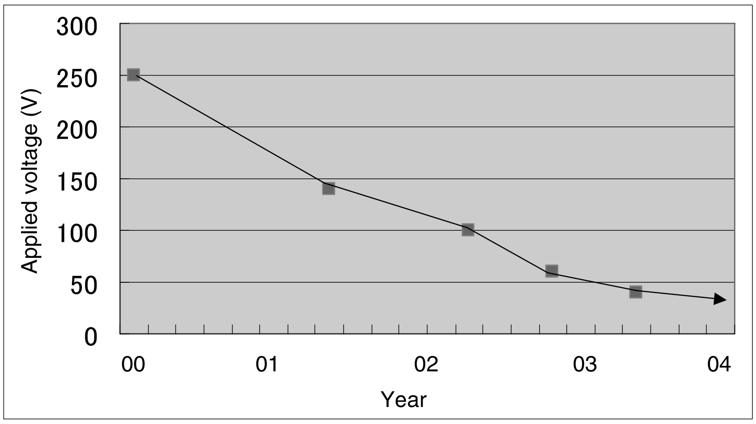
Source: Prepared by STFC based on brochures provided by CeBIT organizers

Figure 10 : Principle of the tunable-focal-length lens



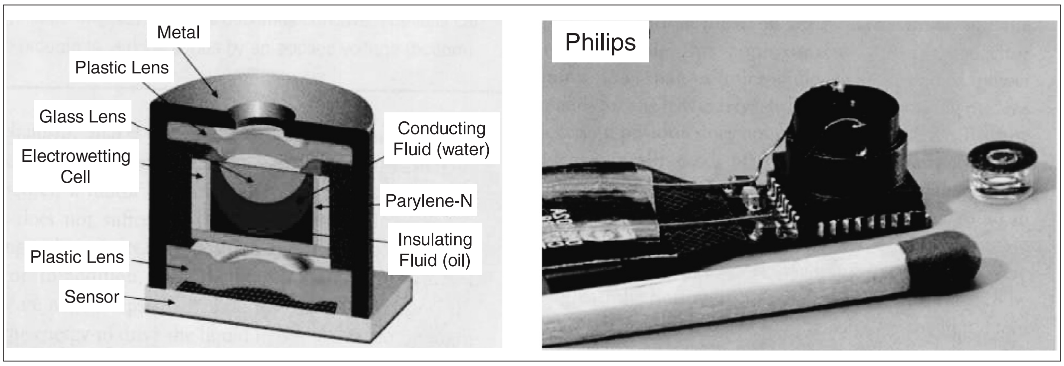
Source: Prepared by STFC based on brochures provided by Varioptic

Figure 11 : History of applied-voltage reduction (25 diopter)



Source: Prepared by STFC based on brochures provided by Varioptic

Figure 12 : Tunable-focal-length liquid lens developed by Philips



Source: Prepared by STFC based on brochures provided by Philips

and the driving motor.

In the initial phase of development, the voltage applied had to be as high as 250 V in order to obtain 25 diopter (focal length: 40 mm), which is the criterion for a camera lens. However, as shown in Figure 11, Varioptic engineers succeeded after 5 years of development in reducing the voltage to lower than 40 V, at which point commercial application of this technology became realistic. Given its advantages in terms of cost, shockproofing, power consumption, rapid response, size, etc., the tunable-focal-length liquid lens is attracting considerable attention as a potential optical module for use in camera-phones.

Philips, the Dutch consumer electronics giant, has been developing a liquid lens for camera-phones[11]. Although Varioptic claims that it obtained its patent ahead of Philips, the latter exhibited a competitive prototype, as shown in Figure 12. Philips is said to be moving toward mass production, although it has not officially announced an application field for its liquid lens.

Venture companies have an edge at start-up, whereas large companies have an advantage at the commercialization stage, namely, reliability/quality control and mass-production. Varioptic is believed to be limiting its activity to development of a prototype, and then licensing the technology to large companies, such as Samsung, for mass-production. Both companies are being watched to see where they move next in this field.

5 History of camera technology innovation in France, and Varioptic

The history of the camera began not with Kodak in the US or Agfa-Gevaert in Germany, but in France with the device invented in 1839 by Louis Daguerre (French painter, 1799-1851)[12]. Gradually, the basic technology proliferated to Germany and the US. In the US, the camera rapidly gained popularity following the invention of the roll-film camera by Kodak in 1888[13].

Today, France has virtually no camera industry. So, although camera technology was originally invented in France, the camera industry actually developed in the US. This is somewhat analogous to the transistor: invented in the US, but then developed industrially by Japanese manufacturers.

This lack of an active camera industry means that French innovation in camera technology takes place only in universities. In the same way, innovation in lithography took place in a US university due to the uncompetitive nature of that country's stepper lithography industry. Researchers at MIT pioneered immersion lithography, coming up with a technological breakthrough that would characterize the next three generations of technology as described in International Technology Road Map for Semiconductors (ITRS) (Source: Science and Technology Trends, May 2004[14]).

Dr. Bruno Berge, who held a teaching position in a university and a research position at the French National Center for Scientific Research, invented the unique tunable-focal-length liquid lens[15], even though the original lens required further development in terms of quality (less thermal dependency) and reduction of fabrication cost. The lens could become competitive through further miniaturization of conventional mechanical optics, or through a high-quality 5 M pixel picture obtained by combining a 15 M pixel imaging device (current device is 5 M pixels) and ×3 digital zoom.

This technology could find specialized applications, such as in the optical head of a gastroscope, even if the liquid lens should fail to enter the mass market of a camera-phone due to complicated mass production or a high manufacturing cost. This implies that Japanese university researchers engaged in applied optics are deprived of the opportunity to demonstrate their potential despite their being better informed as to the development of digital cameras and gastroscopes.

Varioptic was established in 2002 at Lyon-Gerland Technopole[16], Lyon, France, by Dr. Bruno Berge. Supported by the French innovation law[20] enacted in 1999, Varioptic has been funded by the National Agency for the Valuation of Research (ANVAR), Créalys, University of Joseph Fourier, Région Rhône-Alpes, Rhône-Alpes Entreprendre, and the Ministere de la Recherche.

According to Dr. Berge, the tunable-focal-length lens is based on 10 years' research activity at Université Joseph Fourier/Grenoble I and Ecole Normale Supérieure de Lyon. Research began in 1990 and the main patent was filed in 1999 (WIPO: 99018456), even though the camera-phone had not yet been developed. Since 2002, the research has been funded by the government. Dr. Berge could be regarded as a "stubborn researcher", having dedicated himself to basic research on "electrowetting" mainly derived by his scientific interest as a motivation. Incidentally, the first paper published by Dr. Niels Bohr (Nobel Prize Laureate, Danish theoretical physicist) was titled "Surface tension measurement of liquids"[17]. The research on "electrowetting" is considered to be very basic research work. Dr. Berge extended his expertise in and understanding of "electrowetting" during the lead-time, whereby he successfully established a "competitive core of research" by studying the mechanism of "electrowetting".

6 Proposal for industry-university collaboration in Japan

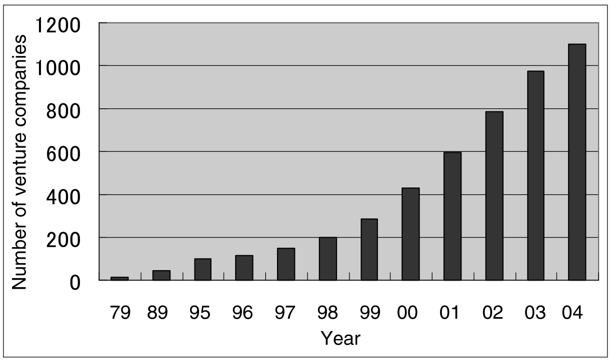
University-originated venture companies are discussed based on the case of Varioptic. Universities in Japan have established 1,099 venture companies, as shown in Figure 13 (Source: METI, May 2005[18]). This is a result of a 3-year program involving industry, universities and the government, which targeted establishment of 1,000 companies. METI commented that, in the process of moving from startup to growth, the venture companies were expected to stimulate the economy by transforming their orientation from one of quantity to one of quality[18].

When Varioptic, a venture company established in France, is reviewed from the viewpoint of quality, it demonstrates that a quality-oriented venture has the potential to evolve from its university base, even in a field dominated by foreign companies, particularly in the current globalized economic environment. This can be applied to industry-university collaboration and is epitomized by immersion lithography, mentioned above, which was a technical breakthrough in steppers for semiconductor manufacturing. That breakthrough was achieved by researchers at MIT[14] in the US, which does not have a competitive industry in this field.

A venture company that obtains patents has the potential to contribute significantly to improving the quality of a university-originated venture, given a "competitive core strength" underpinned by long R&D experience, as shown in the case of Varioptic.

Japanese government institutes that fund research and university institutes that manage research need to take the long view, exercise patience and not raise their expectations too high when promoting core competitiveness. They should manage research in a manner that considers the personalities and independence of researchers, accompanied by assessment of research validity, particularly in the early stages.

Figure 13 : Number of venture companies established by universities



Source: Prepared by STFC based on reports provided by the Ministry of Economy, Trade and Industry

7 Conclusion

As shown in such technological breakthroughs as immersion lithography for steppers[14] and the tunable-focal-length liquid lens, the material used for optics has extended from glass through plastics to liquid. Given the difficulties of handling, manufacturing cost and temperature dependency, it stands to reason that industry would be reluctant to invest in a program to develop the liquid lens, although an idea patent is conceivable whereby the technology is patented at the concept stage. In fact, Hitachi filed a patent related to immersion lithography in the 1980s[14]. Canon also filed a patent related to the liquid lens.

Before the technology could be applied to the advanced aberration-corrected lens, it had to be preceded by a profound understanding of the physics of the system, such as "electrowetting", because an idea without such understanding could not work. Driven by the self-motivated intellectual curiosity of researchers, university research plays an important role, with the researchers expected to spearhead the trend of core research.

The digital camera market has become saturated, while the market for camera-phones is obviously expanding. Business opportunities arise at the intersection of market trends and technological seeds. It should be noted that Philips, an established giant in the Netherlands, is also developing the tunable-focal-length liquid lens, building on the collaboration between Varioptic and Samsung.

Having fostered a number of venture company start-ups over the last few years, industry-university collaboration is now at a stage where it can become productive. Well-trained, experienced engineers state flatly, "Poorly completed research is a joke." Working in an environment that fosters the taking of research risks, university researchers are encouraged to take business risks, to undertake their own core research and to forecast business and technology trends. As demonstrated by Varioptic, a quality-oriented venture company has a chance to emerge, even in a field dominated by foreign companies, in the current globalized economic environment.

Taking into account the personalities and independence of researchers, government institutes that fund research and university institutes that manage research should possess the management expertise to foster impressive, large-scale, but admittedly risky, innovation by adopting a patient approach.

Acknowledgments

The author wishes to acknowledge the valuable viewpoints and information kindly provided by Dr. Hiroshi Ooki (Nikon Corp.), Dr. Hiroshi Miyamae (Konica-Minolta Holdings, Inc.), Dr. Yuji Komatsu (Sony Corp.), Dr. N. Cavasin (Waseda University), Dr. Shingo Hamada (NISTEP, MEXT), Dr. Yukinori Nakano (Kwansei Gakuin University), Dr. Atsushi Ogasawara (AIST), and Dr. Tatemi Ido (Hitachi, Ltd.).

References

[1] Abe, Tadahiko. Growth strategy of digital home appliances. Research Report, Economy Research Institute, Fuji Research Institute Corporation. No. 212, November 2004. (Japanese)

[2] Yamada, Hajime. Technology Management. NTT Publishing Co., Ltd. (Japanese)

[3] Special issue: Future trends and application technology of a digital camera system. Optical and electro-optical engineering contact. Vol. 40, January 2002. (Japanese)

[4] Saito, Tadashi and Yamaguchi, Susumu. Development of 1.3 M micro camera unit with a macro mode. Konica Minolta Technology Report. Vol. 2, pp. 157-160, 2005. (Japanese)

[5] Camera & Imaging Products Association. Camera Industry in Japan - CIPA Report 2005. (Japanese)

[6] http://www.gartner.co.jp/press/index.html (July 5, 2005)

[7] http://www.jeita.or.jp (July 5, 2005)

[8] Ogura,Iwao. Camera development story in Japan. Asahi Sensho 684, Asahi Shimbun Company. (Japanese)

[9] Special issue: Current and future trends in camera phones. Optical and electro-optical engineering contact. Vol. 40, January 2002. (Japanese)

[10] http://www.varioptic.com/en/technology.php (July 5, 2005)

[11] Hendriks, B. et al., Proceedings of ICO 2004, Tokyo, July 12, 2004, pp. 11-12.

[12] Mitsui, Keishi and Tokyo Metropolitan Museum of Photography Ed. Introduction to history of photography. Shinchosha Co. (Japanese)

[13] http://wwwjp.kodak.com/JP/ja/corp/7a140000.shtml (July 5, 2005)

[14] Tatsuno, Kimio. Recent Trends in Semiconductor Microfabrication Equipment Technology - Proposals for Industry-Academy Collaboration on Research and Development in Japan. Science and Technology Trends — Quarterly Review. No. 13, October 2004.

[15] http://www.spm.cnrs-dir.fr/encre/encre_03/CDR/CVs/ (July 5, 2005)

[16] http://www.lyongerland.com (July 5, 2005)

[17] Academia-Industry Cooperation Promotion Division, METI, News Release, April 25, 2005. (Japanese)

[18] Kamefuchi, Susumu. Books. Iwanami Shoten, May 2005. (Japanese)

[19] NISTEP. Survey for evaluating the accomplishment of the master plan. Report No. 83.

[20] http://www.lexpressmagazine.com/reussir/dossier/creation/dossier.asp?ida=430024

Kimio TATSUNO, Ph.D.
Head of Information and Communications Research Unit, Science and Technology Foresight Center

D. Eng. He was formerly involved in the R&D on optical disks, fiber-optic communication, and diode laser-related instruments at the Central Research Laboratory, Hitachi Ltd. Currently, he proposes government policies from the viewpoint of industry-university collaboration, standardization, and technology innovation, and studies science and technology trends at NISTEP.
Membership: JSAP, IEICE, OSA.

(Original Japanese version: published in July 2005)

4

PC Grid Computing
— Using Increasingly Common and Powerful PCs to Supply Society with Ample Computing Resources —

MAKOTO TACHIKAWA
Affiliated Fellow

1 Introduction

While the continued penetration of personal computers and the remarkable improvement of CPU processing speed, 80 to 90 percent of most PCs' processing power is untapped, according to a study[1]. This does not mean that many PCs remain turned off, but that the capacity of the CPU, the brain of the PC, is not fully utilized. In case the CPU is more extensively used when a task requiring an enormous number of operations, such as three-dimensional graphical processing, is assigned, it sits idle most of the time during word processing and Internet browsing because CPU processing speeds are much faster than the speeds of input from the keyboard or the communications line.

This fact led to the idea of virtually gathering the power of idle CPUs to use as a computer resource. In other words, this means networking numerous computers to make them work like a single high performance computer, and assigning complex processing tasks to it. The assigned task will be divided into a myriad of small tasks and allocated to individual computers on the grid-like network. Even with increasingly faster CPUs, the power of PCs are not comparable to those of supercomputers, but in a networked environment where individual PCs simply process complex task in parallel, PCs can deliver surprisingly high performance. This is the core concept of PC grid computing, and it came into a reality several years ago.

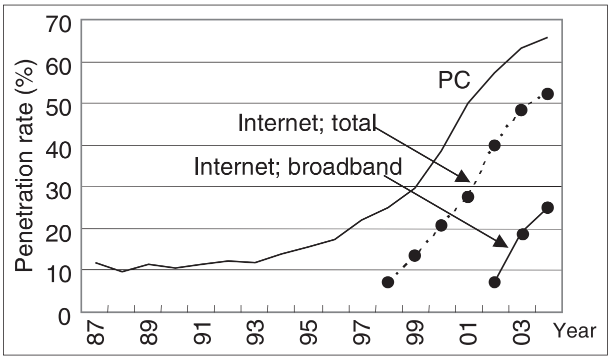
The commoditization and the increased processing speed of PCs leads the growth of idle CPU power. This will facilitate the construction of PC grid computing system along with improvement of communication environment by broadband connectivity. With these trends in mind, this article discusses PC grid computing schemes for supplying society with ample computing resources.

2 Background: Advances in PCs and networks

2-1 Penetration of PCs

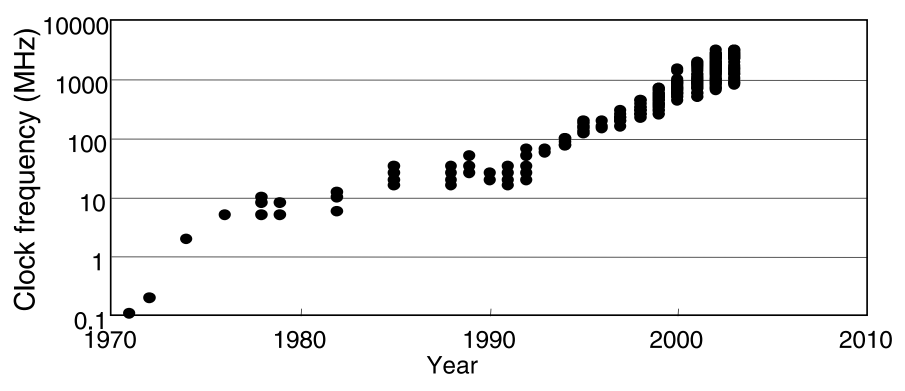
Driven by lower prices and enrich user support, PCs have rapidly come into offices, homes and schools (Figure 1). As mentioned above, growth in the number of PCs means growth in the total CPU idle time across society, because the processors in PCs are most likely under utilized while PCs are running, and many PCs are not even turned on much of the time.

Figure 1 : Penetration rate of PCs and the Internet among Japanese households



Source: Prepared by STFC based on References[2,3]

Figure 2 : Growth in CPU clock frequency (Intel)



Source: Reference[4]

2-2 CPU performance improvement

As Figure 2 shows, the CPU clock frequency has increased explosively, which is another factor of growing idle CPU processing power. Although the increasing of CPU clock frequency is said to be approaching its limit, CPU performance is expected to continue to improve, driven by dual-core CPUs, a technology that includes two logic circuits (cores) in a single processor, and by an increase in the amount of data processed by a CPU per clock cycle (from 32 to 64 bits).

2-3 Diffusion of Broadband Internet

Broadband Internet access has rapidly become widespread in Japan in the last few years (Figure 1). This has enabled PC users to exchange sizable amounts of data over the network, such as modeling data*1 in three-dimensional graphics. The widespread use of broadband access has also allowed running PCs to be remotely monitored in detail because many broadband users keep constant connectivity, facilitating more frequent communications.

3 PC grid computing

3-1 What is grid computing [5,6]?

The concept of the grid is derived from the electric power grid, and the term refers to "an environment in which various information processing resources (computers, storage devices, displays, experimental and observation equipment, etc.) distributed across the network are used as a virtual computer." Grid computing aims to provide the necessary amount of processing resources for its operator, on demand. Its potential benefits are as follows:

- Collection of distributed processing resources for centralized use
- Effective utilization of idle resources
- Load balancing to eliminate the need to maintain the processing capacity to meet the peak load
- Ensured fault tolerance for improved reliability

Grid computing can be divided into the following four types according to configuration.

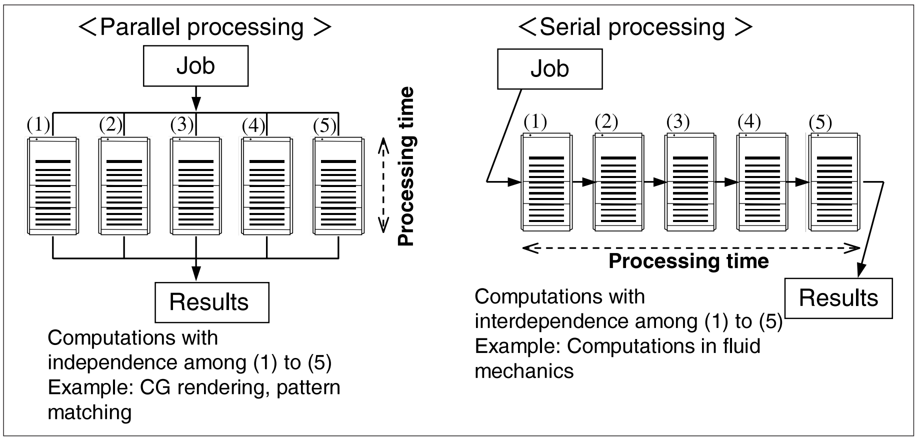
(i) Computing grid: A network of distributed high performance computers (e.g. supercomputers) working like a single huge computer.

(ii) PC grid computing: A concept similar to the computing grid. Collecting the idle CPU power of numerous PCs to perform large-scale processing.

(iii) Data grid computing: Making a grid of disk devices and file systems that is remotely accessible through the network and works like a large external storage device.

(iv) Sensor grid: A group of a myriad of distributed and networked sensors from which data can be collected for specific purposes, such as global environmental monitoring system.

Figure 3 : Parallel and serial processing



Source: Prepared by STFC based on Reference[7]

3-2 Pc grid computing's advantages and constraints

Among the above four types of grid computing schemes, PC grids are constructed PCs, which are inexpensive and widely available, and therefore have the following characteristics:

(1) Easy construction and economical operation

Computing power equivalent to a high performance computer can be achieved at very low cost using a large number of computers connected to a LAN, or the Internet. The ability to make use of the capabilities of a high performance computer with little additional investment can offer a great opportunity as PCs are becoming more commonplace in offices and households.

Since PC grids are comprised of PCs intended for other purposes unrelated to grid computing, operating them as part of a PC grid while their CPUs are idle would have little impact on their operating cost (note 1).

(2) "Automatic" improvement of the total system performance

The performance of the PC and its CPU is steadily improving, and the PCs constituting a PC grid are periodically replaced more powerful ones. This leads to automatically improve the total system performance of PC grid, even while the performance of the constituent PCs varies.

(3) Job independence

PCs are usually linked to external networked PCs via LAN, ADSL or fiber-optic cables, whose data transfer speeds are far slower than CPU processing speeds. Therefore, most PC grid applications are suitable for jobs that can easily be split into small parallel-processing jobs so that each PCs can independently execute them without much communication with other PCs.

Examples of such application areas are bioinformatics for genome information analyses and searches, and CG (Computer Graphics) rendering, which involves creating images from the given numeric data describing an object or graphical figure through computation. In contrast, computations in fluid mechanics require serial processing because of the interdependence of their computational tasks. Such jobs would require supercomputers, which can process a large number of tasks much faster than ordinary PCs. This suggests that the PC grid and the supercomputer are not interchangeable, but are two different solutions to different types of problems (Figure 3).

(4) Expertise, not required to PC owners/users

While the owners or the users of supercomputers are usually computer experts, those of PCs are not. Those who intend to construct and operate a PC grid must take the scarcity of expertise among participating ordinary PC owners and users into account.

4 Mechanisms and technology

4-1 Typical configuration

A typical PC grid consists of a central server and a group of PCs on which special software has been installed, and components that assume the roles shown in Figure 4. A grid in which PCs are connected through the Internet, more project operators are choosing BOINC[8] (Berkeley Open Infrastructure for Network Computing), an open-source platform that was developed at University of California, Berkeley.

4-2 A typical mechanism of operation

A PC grid computing typically works as follows (Figure 5):

(i) Participating PC owners download special software from the Web server and install it on their PCs.

(ii) The special software requests to the central server the application programs and the data that each PC is to process as part of the grid.

(iii) The central server transmits the parallel processing programs and the data to the PCs, divided into packages of appropriate size.

(iv) The PCs run the received programs and data during their CPU idle time as their lowest priority task (note 2).

(v) When the processing is complete, the special software returns the results to the central server and requests new data.

(Steps (iii) to (v) are repeated until the entire project is finished.)

(vi) The central server collects and compiles the results returned from participating PCs into the final results.

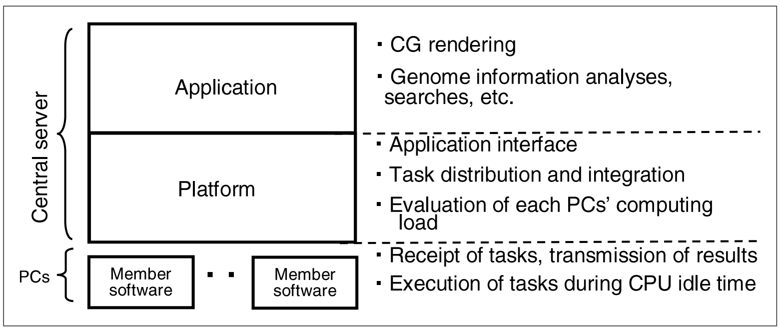
4-3 Technical requirements for implementation

(1) Security protection

Security in PC grid computing must take into account both the participants who offer their PC resources and the member of the project. Major risks for the participants are virus infection and the leakage of personal information. These risks can be significantly reduced by the ensured reliability of the connection destination (the central server in Figure 5) and complete data encryption. A more serious concern is the increased possibility of unauthorized access due to constant connection to the network. However, since this issue is not specific to grid computing, but rather common in the information society, it can be countered by introducing firewalls and frequently checking and patching security holes in software.

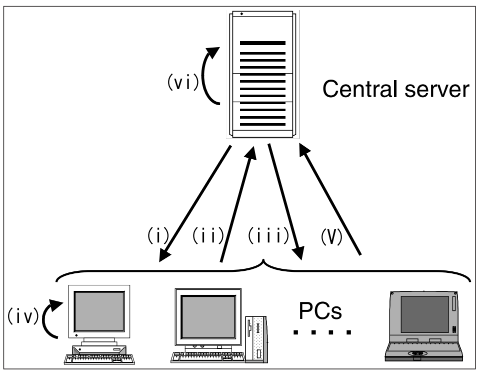
Risks for the project member include data theft and the intentional transfer of incorrect processing results by a malicious participant. Possible measures against these problems are encrypting the data to be stored on the

Figure 4 : Typical configuration of PC grid computing



Source: Prepared by STFC based on Reference[7]

Figure 5 : A typical mechanism for PC grid computing



Source: Prepared by STFC based on Reference[7]

participating PCs' hard disks and recomputing unusual results.

(2) Reliability of computation results

Unlike supercomputers and other special-purpose computers, which are installed in a well-controlled environment in terms of power supply, temperature and so on, PCs usually operate in a less desirable environment, and their performance is somewhat unstable. This raises the need to allow for redundancy depending on the state of participating PCs, on the assumption that the processing results returned from the PCs are not always reliable. This need can be met, for instance, by assigning the same task to multiple PCs so that the results can be checked by matching.

5 Classification by structure

5-1 Open structure

This is the most common type of PC grid computing. This type of grid is connected through the Internet and comprised of PCs owned by individuals who are willing to offer their PCs' idle processing power. Such projects sometimes involve a great many PCs from a broad range of individuals. Since participation is essentially on a voluntary basis, providing an attractive incentive is the key to success. Recognizing that sending goods or real money to individual participants is not practical because of huge delivery costs, project operators are finding other cost-effective ways of rewarding the participants, such as sending electronic money, electronic mileage points or other incentive points over the network, or lottery systems.

Instead of giving such financial incentives, other grid project operators choose to appeal to people's volunteer spirit by emphasizing the contribution to social welfare, the search for truth, and the contribution to human advancement. Such projects are sometimes called volunteer computing because participants offer their PCs' extra power for free. A famous example is SETI@home[9], a project operated by the University of California, Berkeley. It aims to search for extraterrestrial intelligence based on data collected with a radio telescope. More than five million PCs voluntarily participate in this project from around the world. The computing power is said to have reached 100 TFlops*2, which is almost comparable to the performance of IBM's Blue Gene/L (approximately 140[10] TFlops), the world's fastest supercomputer[11]. There are many other open grid projects as shown in Table 1, and many of them focus on social consensus such as searching for new anticancer drug agents.

5-2 Closed structure

PC grids in a closed structure are constructed by business enterprises and other organizations, based on their existing PCs. Organizations can have high computing power at low cost, while effective using existing resources. The benefits

Table 1 : PC grid computing projects in an open structure

Project	Research base	Goal
SETI@home	University of California, Berkeley	Find extraterrestrial intelligence
Folding@home	Stanford University	Predict how proteins fold
ClimatePrediction.net	University of Oxford	Test models of climate change
LHC@home	CERN (European Organization for Nuclear Research)	Model particle orbits in accelerator
Cancer Research Project	NCI (U.S. National Cancer Institute) University of Oxford	Search for candidate drugs against cancer
Lifemapper	University of Kansas	Map global distribution of species
cell computing	NTT Data Corporation Toagosei Co. Ltd.	Elucidation of the sequence of bases on human chromosomes: the genome project

Source: Prepared by STFC based on Reference[12]

of creating this type of PC grid include the following. Once the organization decides to launch a project, there is no need to consider incentives for participants; the state of the participating PCs can be monitored and managed with relative ease; and since the each participant ID is known, security risks are better controlled than open structure. To construct a grid using PCs within a single building, an organization can purchase a software package that easily integrates PCs connected via LAN into a grid[13].

5-3 Semi-open structure

Where multiple organizations that own many PCs, these organizations can build a single network that extends beyond their boundaries to achieve high computing power. Such a grid would have a semi-open structure and allow public organizations (municipal offices, schools, etc.) and local businesses to jointly provide the local community with shared computing resources. This is a PC grid that makes computing resources available at low cost to local small-to-medium companies that hardly afford to use supercomputers. Even large companies can benefit from such a grid because owning expensive supercomputers is not always an option. Universities and research institutes in the region also enjoy this benefit. When many regions are making a variety of efforts to enhance their information infrastructure, regionally based grid computing scheme would strengthen these efforts. This is the scheme of 'of the region, by the region, for the region'.

An example of this type of grid project is a field experiment conducted in Gifu Prefecture in February 2005. Led by Gifu National College of Technology, universities, high schools, education boards, research institutes and other organizations in the prefecture participated in the project, offering over 1,000 PCs. The experiment was designed to solve "the traveling salesman problem" for 80 municipalities in Gifu by using parallel genetic algorithms. After the experiment, the institutions involved expressed their expectations for the future if abundant computing resources were to become easily available, including research projects that would otherwise not be feasible, such as highly complex simulations. On the other hand, the experiment exposed social issues, such as whether each organization's rules permit its PCs to be used for purposes other than the original intent, and how to compensate for the differences in security policy among the participating organizations[14].

6 Future activities

Most existing PC grids are in an open structure, and in semi-open or closed structures have just emerged. In these structures, semi-open PC grids may be expected to have highly public effects. Building a public computing infrastructure by PC grid can lead to provide processing power as some sort of utility services. This is analogous to an environment where water and electricity are supplied as public services so that any entities in need of them can use them at reasonable cost, without having to own their own purification plant or power station. Creating local computing resources and making it accessible as needed to those who require it would bring diverse benefits to the community. This suggests that municipal governments that pursue local revitalization should pay attention to the benefits of semi-open PC grid computing as a public infrastructure. However, practical proposals on how to create semi-open PC grids and how to utilize them effectively have not been establish yet. The first step to moving beyond the status quo would be to conduct feasibility studies from many different perspectives with a view to exploring the potential of PC grid computing. Here are some examples of feasibility study in this direction.

6-1 A proposal for the construction of semi-open grids

• Utilization of PCs in schools

Now that computers are part of the curriculum even in elementary and secondary education, schools in every region own many PCs. A total of about 1.5 million PCs are in use in all elementary, junior and senior high schools in Japan, which works out to an average of about 30,000 PCs per prefecture[15]. If these computers were networked to form a PC grid, the resulting computing power would be huge. PCs produced in 2000 or later are usually expected to perform at 1 GFlops[11]. To consider the older machines among the participating PCs, one tenth of this figure, 100 MFlops, is used as the assumable average performance. Provided that the PCs are in an ideal state, the resulting grid would have a computing power of 3 TFlops (=100 MFlops ×30,000 machines). This result is well beyond 500 GFlops, the minimum performance for a supercomputer, indicating that a prefectural grid of school PCs would provide CPU power comparable to a supercomputer.

Despite this potential, there is a hurdle that such a grid project would have to overcome. Since most PCs in schools are intended for student education, school officials would hesitate to permit their use for purposes unrelated to education and might have trouble deciding how much a school should be involved in a regional PC grid computing project that is operated outside the boundary of ordinary school activities. One solution is that the competent authority of each school issues a policy for promoting PC grids. This should happen after some basic issues have to be solved first: finding ways of coping with increases in electricity and other operational costs; having school PCs constantly connected to the network; and establishing a system to ensure the security of connection.

6-2 Potential applications of the constructed PC grids

(1) Developing virtual learning materials for local use

A PC grid consisting primarily of PCs owned by schools and other educational institutions may be suitable for the development of virtual learning materials. For example, it would help visualize what students cannot directly observe, such as dangerous tests, motions in dynamics, and internal changes in materials. PC grids may also be useful for developing learning materials with simulating a social experiment in the local community that is hardly in the real world, and expressing the results with animation.

(2) Promoting the local content business

There is a national vision that Japan should transform itself into a country built on intellectual property. This goal is being pursued through initiatives such as the "Contents Business Promotion Policy,"s[16] which is being formulated by the government's Intellectual Property Policy Headquarters, and Nippon Keidanren's "Intellectual Property Strategic Program"[17]. One type of intellectual property that is expected to grow in significance is high quality, sophisticated digital content. A key to moving forward in this area is building a development infrastructure, as well as strengthening human resource development and facilitating content distribution. Although Japanese animation content called "Japanimation" is already valued highly across the world, the animation industry will face a growing need for computing power, as more animation produced entirely by Computer Graphics and more TV sets come to support high-definition broadcasts. The Japanese movie industry does not have a solid business base, and in particular, its animation sector is in a weak financial position, which makes supercomputers too expensive to afford to them. Therefore inexpensive and ample computing power is desirable, and PC grid computing is suitable one. Moreover, for Japan to pursue balanced local revitalization, the "Japanimation" development infrastructure should be distributed across nationwide. Regional PC grid computing would be an ideal scheme.

7 Conclusion

As society goes more digitized, it will become replete with networked devices with powerful CPUs, including home information appliances such as HDD (Hard Disk Drive) video recorders, home servers (devices that work as the central controller for all information traffic within a home) and online game consoles. These devices are all potential sources of CPU power. This suggests that future PC grids may go beyond PCs. Such changes in the social environment should be recognized as leverages of PC grid computing and taken into consideration in future discussions.

Acknowledgements

The author would like to thank the following people for their very valuable suggestions and advice, and for the provision of valuable reference materials for this article: Ryoichi Shibata, an associate professor of the Department of Architecture, Gifu National College of Technology; Tetsuhiko Yoshida, Chief Scientist of the Corporate Research and Development Department, Toagosei Co., Ltd.; and Shoji Yarimizu, deputy executive manager of the Cell Computing Business Promotion Office, Business Incubation Sector, NTT Data Corporation.

Glossary

*1 Modeling data
Data that define the shape of a model (object), such as the coordinates of vertices and the parameters of equations expressing contours and faces.

*2 Flops (Floating point number Operations Per Second)
A measure of computer performance, equal to the number of floating-point calculations (real calculations) a machine can perform in a second.

Notes

1: If PCs are to operate only for the PC grid, an electricity and other operating costs will be incurred. But these costs would still be required if the target processing were performed by any other means.

2: PCs usually process multiple tasks in parallel, but they actually divide the CPU processing time into very short cycles and allocate them to the given tasks one by one, according to their priority. By assigning the lowest priority to the PC grid tasks, PCs can only offer their CPU idle time for grid computing with no impact on their other tasks.

References

[1] Miller,Michael. Discovering P2P. SYBEX Inc., 2002.
[2] Supervised by Internet Association Japan. Internet White Paper 2004. Impress Corporation, Jul. 2004. (Japanese)
[3] Economic and Social Research Institute, Cabinet Office. Consumer Confidence Survey., the diffusion rate for 2005 (surveyed in March): http://www.esri.cao.go.jp/jp/stat/menu.html#shohi-z (as of July 26, 2005).
[4] Yamada, Hajime. Management of Technology. NTT Publishing Co. Ltd., 2005. (Japanese)
[5] Watari, Masao. Trends in Grid Technology. Science & Technology Trends — Quarterly Review. No. 6, Feb. 2003.
[6] Grid Technology Research Center, National Institute of Advanced Industrial Science and Technology (edition). Grid. Maruzen, 2004. (Japanese)
[7] Yarimizu, Shoji. The Present and Future of PC Grid. Joho Shori. Vol. 44, No. 6, 2003.
[8] je2bwm. Overview of BOINC: http://boinc.oocp.org/intro.php (as of July 14, 2005).
[9] 2001 SETI@home: http://setiathome2.ssl.berkeley.edu/ (as of July 26, 2005).
[10] TOP500 SUPERCOMPUTER SITES: http://www.top500.org/lists/plists.php?Y=2005&M=06 (as of Aug. 12, 2005).
[11] Contributing to science through @home. Nikkei Science. August 2005. (Japanese)
[12] Grassroots Supercomputing. Science. Vol. 308, May 6, 2005.
[13] DNP trading Co., Ltd., "AD-POWERs Gaiyou" (AD-POWERs Overview), http://www.ad-powers.jp/index_ie.html (as of July 19, 2005).
[14] Shibata, Ryoichi and Koike, Hirotaka. Grid System Development Using Local Computing Resources-A report on the Gifu Grid Project Field Experiment. Transcript of the Symposium on Advanced Computing Systems and Infrastructures (SACSIS) 2005, IPSJ Symposium Series Vol. 2005, No. 5, May 18, 2005. (Japanese)
[15] Ministry of Education, Culture, Sports, Science and Technology, "School Computer Ownership and Internet Connectivity: http://www.mext.go.jp/a_menu/shotou/zyouhou/04120301.htm (as of July 27, 2005).
[16] Intellectual Property Policy Headquarters.

Contents Business Promotion Policy (Draft)-National Strategy in the Soft Power Age:
http://www.kantei.go.jp/jp/singi/titeki2/tyousakai/contents/dai5/5siryou5-1.pdf (as of July 27, 2005).

[17] Nippon Keidanren. Toward the Formulation of 'Intellectual Property Strategic Program 2005' :
http://www.keidanren.or.jp/japanese/policy/2005/013/honbun.html (as of July 27, 2005).

Makoto TACHIKAWA
Affiliated Fellow of NISTEP
Research Institute for System Science, Research and Development Headquarters, NTT Data Corporation
http://www.nttdata.co.jp/rd/riss/index.html

He researches information systems from a broad perspective transcending computers and communications and examines their correlation with society, focusing on topics such as individual-oriented health promotion support systems.

(Original Japanese version: published in September 2005)

5

Air Pollution Monitoring in East Asia
— Japan's Role as an Environmentally Advanced Asian Country —

Hirokazu Fukushima
Environment and Energy Research Unit

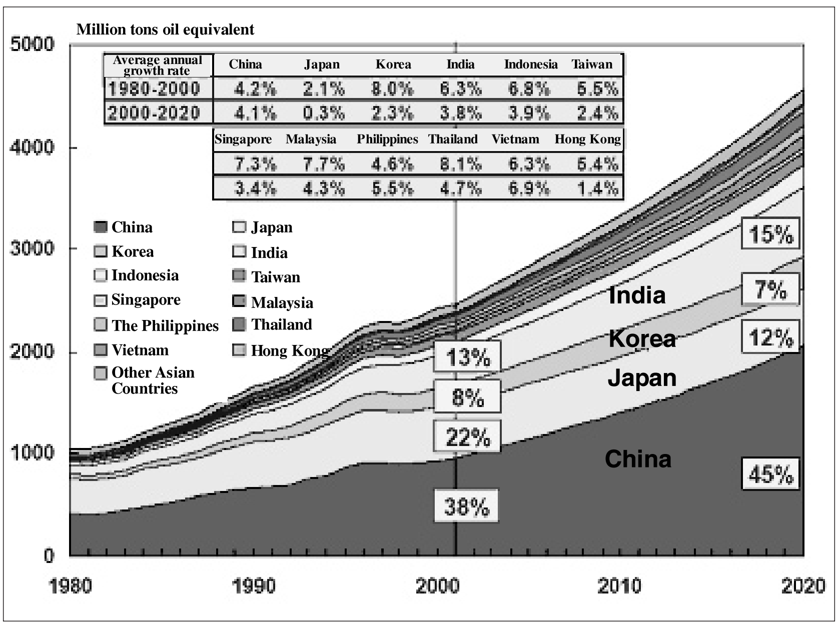
1 Introduction

As shown in Figure 1, primary energy consumption in East Asian countries -more than one third of the world's population live in- is surging with the rapidly growing regional economy. However, oil has yet to replace coal as the primary energy source in these countries, many of which are still dependent on coal with a high sulfur content. Meanwhile, with the rapid motorization in China and in the other emerging economies in the region, the atmospheric concentrations of sulfur oxides (SOx), nitrogen oxides (NOx), suspended particulate matter (SPM) and ozone (O_3) are on the rise, causing serious air pollution.

Air pollutants, once released into the atmosphere, are carried across borders through the general atmospheric circulation (seasonal winds, etc.), and this could have a serious impact on other countries. Given the ever-expanding economic activities in East Asia, transboundary air pollution is expected to pose a serious problem in the near future, necessitating immediate measures.

This article describes the role of monitoring of ambient air quality and pollutant emission sources in solving air pollution problems, while providing an overview of Japan's efforts to significantly reduce air pollutants, primarily through monitoring activities. The development of a regional monitoring network is critical in addressing transboundary air pollution in East Asia, where Japan, as an environmentally advanced country, has a role to play.

Figure 1 : Trends in primary energy consumption in Asian countries



Source: The Institute of Energy Economics, Japan[1]

2 Possible impact on Japan of air pollutants originating in the Asian Continent

2-1 *Acid rain in the region along the Sea of Japan*

According to a nationwide survey on acid rain conducted over the past two decades by the Ministry of the Environment (completed in 2002), the amounts of sulfate and nitrate ion deposits in acid rain vary both seasonally and regionally. Specifically, they peak during the winter months in the central and northern regions along the Sea of Japan and in the San-in region. This observation suggests that SOx and NOx originating in the Asian Continent were carried aloft by the winter winds to reach the region along the Sea of Japan[2].

Meanwhile, the results of a numerical model for the transport of transboundary air pollutants during the high wind period (from January 15 to February 14, 1999) indicate that 62% and 16% of the SOx deposits observed in Japan originate in China and Korea, respectively. The air pollutants released in the Asian Continent could therefore have a significant impact on Japan[3].

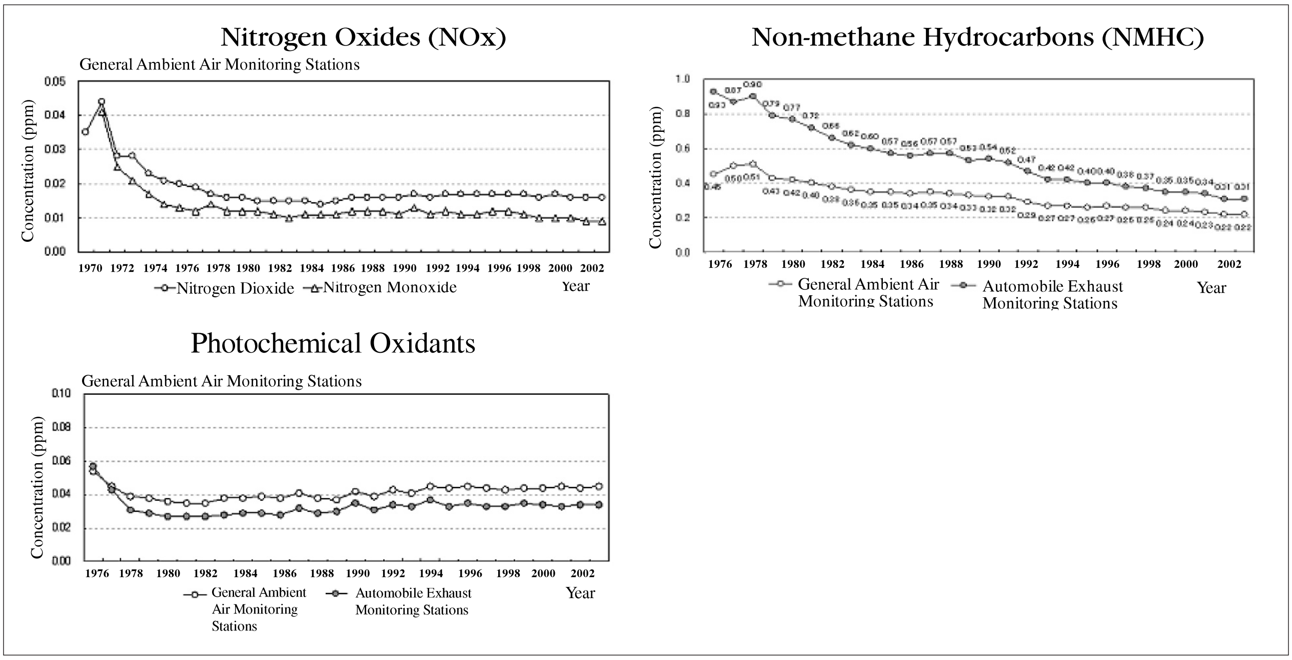
2-2 *Tropospheric ozone concentrations over Japan*

Figure 2 shows the concentrations of NOx, non-methane hydrocarbons (NMHC)*1 and photochemical oxidants*2 in Japan, while Figure 3 shows the number of days when photochemical oxidant warnings were issued in Tokyo. While NOx and NMHC concentrations have been stable or declining in recent years, photochemical oxidant concentrations are increasing across the country. As a result, environmental standards*3 for photochemical oxidant concentrations are not complied with in many areas, and the number of warnings shows no sign of abating in metropolitan areas. The Japan Agency for Marine-Earth Science and Technology analyzed data on tropospheric ozone concentrations using backward trajectory analysis*4 in an effort to explain this phenomenon. The results of this analysis indicate that NOx originating in East Asia contributes to increasing tropospheric ozone concentrations over Japan, which is located in the lee of East Asia, during the spring and summer months when photochemical reactions peak[4].

2-3 *Brown clouds*

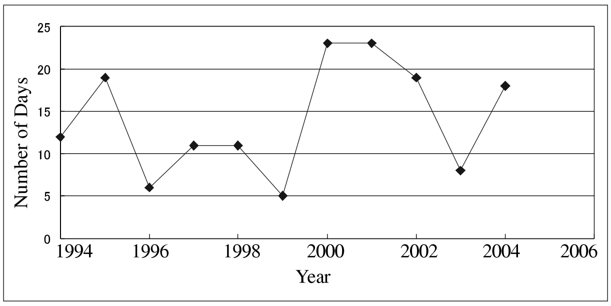
Brown clouds have been observed in recent

Figure 2 : Trends in the average concentrations of nitrogen oxides, non-methane hydrocarbons and photochemical oxidants in Japan



Source: Reference[5]

Figure 3 : Number of days where photochemical oxidant warnings were issued in Tokyo



Source: Reference[6]

years over the Asian region. Brown clouds, averaging about 3 kilometers in thickness, are made up of high concentrations of aerosols*5 and yellow sand. These airborne particulates block the sunlight, resulting in less sunlight reaching the earth's surface — a phenomenon that has a serious impact on crop production and may have been implicated in recent unusual monsoon weather patterns in Asia. The United Nations Environment Programme (UNEP) launched an international research project in 2003 to investigate brown clouds in Asia.

2-4 Transboundary air pollution problems

As mentioned earlier, acid rain, photochemical oxidants and suspended particulate matter have all proved to be transboundary air pollution problems. Keeping track of the atmospheric concentrations of SOx, NOx, ozone and SPM in the whole of East Asia is considered a critical first step towards solving these problems.

3 The role of monitoring in addressing air pollution problems

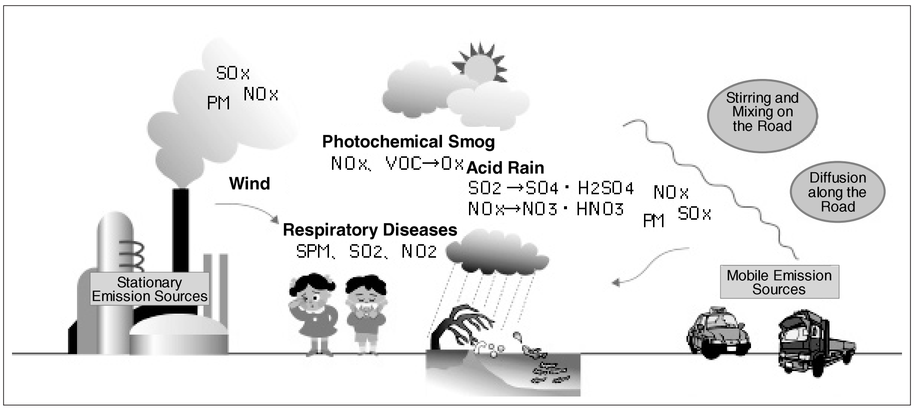
3-1 Mechanisms of air pollution

As shown in Figure 4, emissions from stationary sources (fossil fuel combustion gases) and mobile sources (tailpipe emissions) contain pollutants such as SOx, NOx, particulate matter (PM) and volatile organic compounds (VOCs). SOx and NOx, when inhaled, cause respiratory disease. They are converted to sulfuric acid and nitric acid in the atmosphere, causing acid rain. In addition, NOx and some VOCs (non-methane hydrocarbons), when exposed to strong ultraviolet radiation, are converted to photochemical oxidants, irritating the eyes and respiratory organs. Very fine particulate matter is suspended in the air, and hence is called "suspended particulate matter (SPM)". It is considered to cause respiratory disease and climate change.

3-2 The role of air pollution monitoring

The first step in instituting measures against air pollution is to have a clear picture of the current pollution situation through ambient air monitoring. Such measurement values are a basis for setting emission standards for environmental measures. Ambient air monitoring plays a vital role in assessing and reviewing environmental measures, which are implemented by repeating the cycle of (1) understanding the current situation (through ambient air monitoring), (2)

Figure 4 : Mechanisms of air pollution



Source: 2004 Energy White Paper[7]

formulating and implementing specific measures, and (3) reviewing achievements (through ambient air monitoring), as shown in Figure 5.

(1) Ambient air monitoring

Ambient air monitoring can be broadly categorized into (1) regional monitoring, which keeps track of local pollution, and (2) broad-based monitoring, which is not influenced directly by air pollution sources, and provides background measurements.

Regional monitoring is conducted by monitoring stations around the world, each of which provides representative data for the region in which it operates. In Japan, two types of monitoring stations are in operation: general ambient air monitoring stations (continuous monitoring of general air pollution), and automobile exhaust monitoring stations (continuous monitoring of air pollution caused by automobile exhaust).

Broad-based monitoring, meanwhile, is designed to keep track of the medium to long-range transport of air pollutants (several hundred to several thousand kilometers). It is conducted in locations away from pollution sources such as Oki (Shimane Prefecture) and Hedo Cape (Okinawa Prefecture).

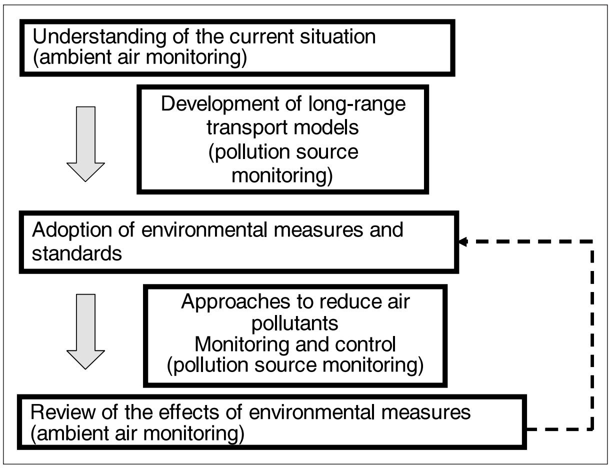
These monitoring systems, both essential in keeping track of air pollution levels, should be integrated to establish a monitoring network.

(2) Pollution source monitoring

Long-range transport models are quite effective in shedding light on how air pollutants are transported over thousands of kilometers.

The development of such accurate transport models involves the identification of pollution sources (factories, facilities, etc.) along with the types and amount of pollutants released into the atmosphere. This can be done by monitoring air pollution sources. In a situation where environmental measures are in place — with factories, facilites, etc. implementing measures to reduce air pollutants — there is a need to monitor pollution sources to ensure that emission standards are observed. Such pollution source monitoring is also needed to measure emissions in real time, as a means of controlling combustion processes and the operation of desulfurization/de nitrification facilities.

Figure 5 : Measures against air pollution



Source: Prepared by STFC

3-3 *Controlling the accuracy of ambient air monitoring*

Measurement values obtained from ambient air monitoring should be accurate in order to keep track of the pollution situation in the region concerned. In other words, certain standards should be set for measuring instruments, and measurements should be conducted in accordance with prescribed procedures. It is therefore essential that operating procedures for the entire monitoring process (including calibration procedures using standard samples) be established and accuracy assurance/control be implemented at each monitoring station. Specific approaches to ensure the accuracy of measurement values include:

(1) Preparation of high accuracy standard samples
(2) Establishment of a calibration system
(3) Regular cross-checking among monitoring networks
(4) Establishment of a data management system
(5) Improvement of technical training for monitoring activities
(6) Development of standard operating procedures (SOPs) for monitoring site selection, sampling, sample preservation, pretreatment and analysis
(7) Establishment of a reference center to put the above approaches into practice

Table 1 : History of air pollution in Japan

Year	Description
Early 1960s	Air pollution in Yokkaichi City became an object of public concern
1968	The Air Pollution Control Law was enforced
1969	SO_2 environmental standards were set
1970	Photochemical smog occurred frequently
1974	Total volume control was introduced for sulfur oxides (SOx)
1978	Automobile emissions control was introduced
1978	NO_2 environmental standards were revised
1981	Total volume control was introduced for nitrogen oxides (NOx)
1992	The Automobile NOx Law was enforced
2001	The Automobile NOx Law was revised to control particulate matter (the Automobile NOx and PM Law)

Source: Reference[10]

Each of these is essential in developing an ambient air monitoring network.

3-4 Japan's ambient air monitoring network

Japan's rapid economic growth in the post-war period took its toll, with serious air pollution in large cities and areas surrounding industrial districts. With the combustion of heavy oil containing about 3% sulfur, for example, a massive amount of SOx was released into the atmosphere in Yokkaichi City (an industrial city in Mie Prefecture) around 1960, causing serious air pollution known as the Yokkaichi Pollution (see Table 1). As a result, local residents suffered bronchial asthma, pulmonary disease and respiratory disease. Against this background, continuous air pollution monitoring was launched in 1962 in large cities (Tokyo, Osaka, etc.) and areas surrounding industrial districts (Yokkaichi, etc.), followed by the enactment of the Air Pollution Control Law in 1968. In the same year, the Osaka Prefecture Government established an online, real-time air pollution monitoring system, connecting 15 local monitoring stations through radio transmission. Other municipalities followed suit, setting up similar systems[8]. As of 2004, sulfur dioxide is monitored at 1,487 stations, nitrogen dioxide at 1,880 stations, photochemical oxidants at 1,193 stations, suspended particulate matter at 1,910 stations, and carbon monoxide at 401 stations. This nationwide monitoring network is designed to keep track of air pollutant concentrations and appropriate measures are taken immediately when these concentrations exceed environmental standards. The Air Pollution Control Law, meanwhile, mandates prefectural governors to monitor the air environment around the clock and report the results. Each governor is authorized to take emergency measures when air pollution is severe enough to damage human health and the living environment.

In 2001, the Atmospheric Environmental Regional Observation System dubbed "Soramame-kun"[9] was introduced, with real-time monitoring results provided by each monitoring station being made public through the Internet. This system is unique in that it allows proactive measures to be taken to counter unusually high atmospheric concentrations of photochemical oxidants. It is expected to contribute to raising public awareness of air pollution. Table 2 outlines Japan's air quality standards and the number of monitoring stations.

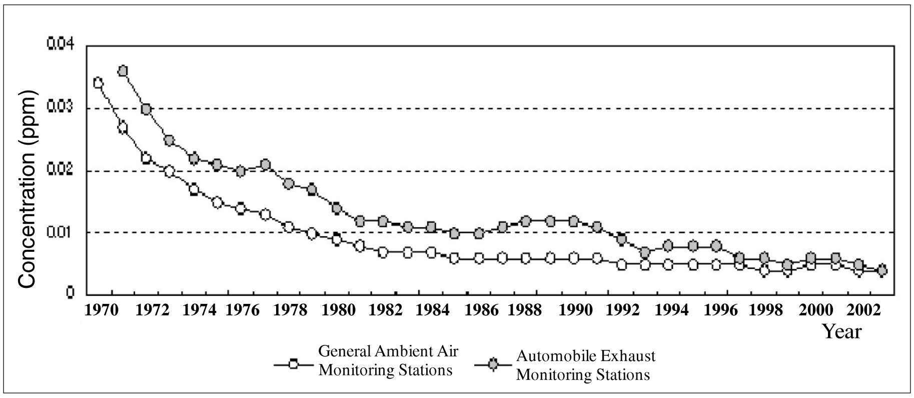
Figure 6 shows the trends in the average SO_2 concentrations measured by general ambient air monitoring stations and automobile exhaust monitoring stations. The annual average decreased dramatically in the fourth and fifth decades of the Showa Era (1965-1984). They have been stable or declining in recent years. As these results suggest, SO_2 emissions (a major cause of acid rain) are now significantly reduced in Japan. This achievement is due, in large part, to a series of environmental measures based on the advanced ambient air monitoring network and pollution source monitoring, which together,

Table 2 : Air quality standards and the number of monitoring stations

Subject	Standards	Number of Monitoring Stations (2004)
Sulfur Dioxide (SO_2)	0.04 ppm (Daily average) 0.1 ppm (Hourly average)	1,487
Carbon Monoxide (CO)	10 ppm (Daily average) 20 ppm (8-hour average)	401
Suspended Particulate Matter (SPM)	0.10 mg/m^3 (Daily average) 0.20 mg/m^3 (Hourly average)	1,910
Nitrogen Dioxide (NO_2)	0.04 ppm - 0.06 ppm (Daily average)	1,880
Photochemical Oxidants (Ox)	0.06 ppm (Hourly average)	1,193

Source: Prepared by STFC based on Reference[11]

Figure 6 : Trends in the average SO_2 concentrations



Source: Reference[6]

encourage factories, facilities, etc. to take emission reduction measures.

4 Approaches to transboundary air pollution in the West and Asia

4-1 Measures in Europe

In the latter half of the 1960s, environmental problems such as lake acidification (resulting in the extinction of fish and aquatic organisms) and the death of forests began to become apparent in the Scandinavian Peninsula and other parts of Northeastern Europe. The cause was considered to be transboundary air pollutants (SO_2, etc.) originating in Western Europe. An international, continent-wide monitoring system was immediately put in place to address these problems. Subsequently, in 1972, 11 OECD member countries jointly launched a monitoring network in compliance with the "OECD Programme on Long-range Transport of Air Pollutants."

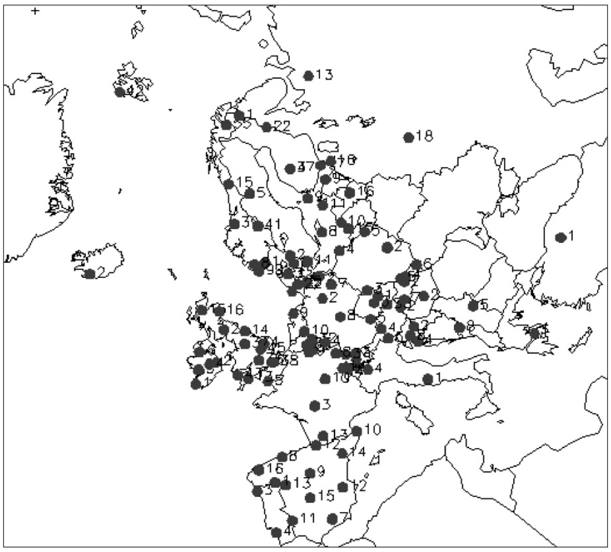
In addition, the OECD conducted a research study between 1973 and 1975 on the long-range transport and deposition of airborne sulfur in Eastern and Western Europe, the results of which showed that acid deposition had spread across Northwestern Europe. The United Nations Economic Commission for Europe (ECE), meanwhile, launched the "European Monitoring and Evaluation Programme" (EMEP) in 1977 to create a long-range transport model for air pollutants. A network of 60 monitoring stations located in 16 countries is now in place. Data collected by each station are fed for analysis to the Chemical Coordination Centre (CCC) of Norwegian Institute for Air Research. Figure 7 shows the locations of the EMEP monitoring stations for acidic substances.

In Europe, the accumulation of scientific data through the monitoring networks shed light as early as the 1970s on the mechanisms of acid deposition - i.e., acid fallout originates not only from domestic sources but also from overseas sources located hundreds to thousands of kilometers away from monitoring stations. As a result, in order to address a broad range of problems, measures against air pollution in Europe evolved further, from the initial stage of using ambient air monitoring and long-range transport modeling, to the next stage which saw the development of international environmental measures.

In 1979, the ECE took the lead in concluding a groundbreaking international treaty on transboundary air pollution, the Convention on Long-range Transboundary Air Pollution (Geneva Convention), in which a total of 35 countries, including the former Soviet Union, the U.S. and Canada, participated. Following the signing of the treaty, the Helsinki Protocol was ratified in 1985 by 25 countries, with the 1993 goal of reducing sulfur emissions and their transboundary fluxes to 30% below their 1980 levels. With these measures in place, Europe has achieved a breakthrough in reducing SO_2 emissions, a major cause of acid rain. Figure 8 shows the trends in SO_2 emissions in Europe (the EMEP member countries). Annual emissions were reduced by 56% between 1980 and 1998.

About 100 monitoring stations are in operation under the EMEP, with each of them monitoring SO_2, NO_2, SPM and ozone. Another network is in place to monitor transboundary air pollutants other than acidic substances. EMEP monitoring stations for SPM and ozone are shown in Figures 9 and 10.

Figure 7 : EMEP monitoring stations for acidic substances (2001)



Source: Reference[12]

4-2 Measures in North America

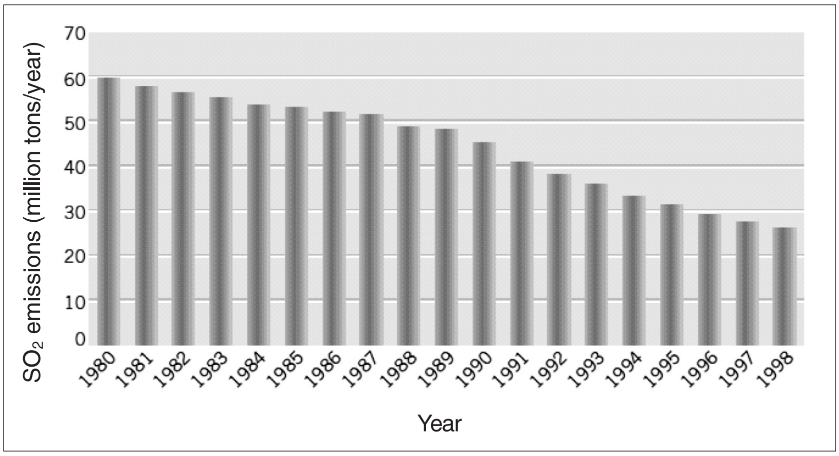
Acid rain and snow, which had begun to cause serious damage to trees (maples, etc.) and freshwater fish in North America, subsequently emerged as public concerns.

The U.S. and Canadian governments launched a bilateral research convention in 1973 on the long-range transport of air pollutants in order to exchange information regarding acid fallout, and signed a memorandum on transboundary air pollution in 1980 to elucidate the mechanisms of acid rain through monitoring networks, etc. In addition, the U.S. government announced a major revision of the Clean Air Act in 1990. As a result, SO_2 emissions in the U.S. were reduced from 20 million tons in 1990 to 15 million tons in 2000[14].

4-3 Measures in Asia

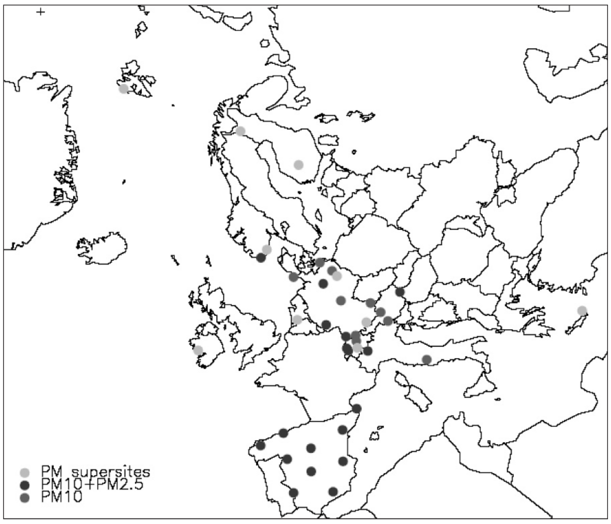
Measures against transboundary air pollution start in the 1990s.

Figure 8 : Trends in SO_2 emissions in Europe (EMEP member countries)



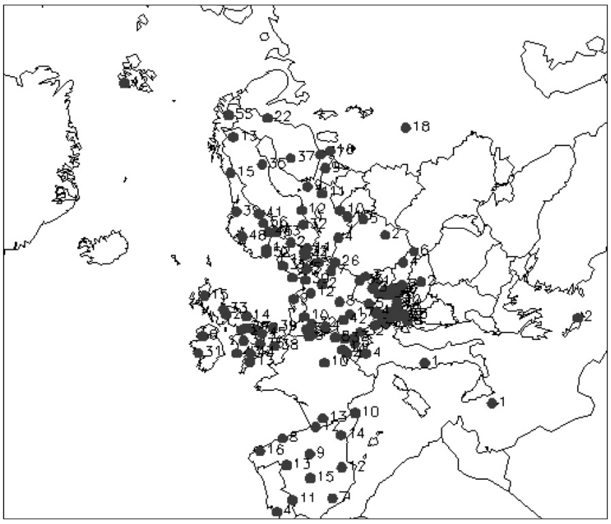
Source: Reference[13]

Figure 9 : EMEP monitoring stations for suspended particulate matter (2001)



Source: Reference[12]

Figure 10 : EMEP monitoring stations for ozone (2001)



Source: Reference[12]

In 1991, the Environment Agency of Japan (now the Ministry of the Environment) proposed the concept of an "Acid Deposition Monitoring Network in East Asia" (EANET), with the aim of preventing the effects of acid rain in the East Asian region. As a result of this initiative, since 1993, Japan has played a leading role in giving expert advice on acid rain monitoring networks in East Asia. The acid rain problem involves a variety of factors such as the acidity of rain, snow, gas and aerosols, as well as their chemical composition, and the tolerance which soil exhibits to them. In monitoring acid rain, therefore, not only should the pH of the rain be monitored, but also its ion concentrations, as well as dry deposition. As mentioned in Section 3-3, monitoring methods and accuracy should be standardized internationally for data comparison purposes. In 1997, consultation by experts highlighted the need to develop a regional monitoring network where each country performs acid rain monitoring using a standardized methodology. In response to this, EANET was test launched in April 1998, and began fully fledged operations in January 2001, based on an intergovernmental agreement. The secretariat of EANET is located at UNEP RRC.AP (Regional Resource Centre for Asia and the Pacific) in Bangkok, while the Acid Deposition and Oxidant Research Center in Niigata Prefecture serves as a network center in which a total of 12 countries (China, Indonesia, Japan, Malaysia, Mongolia, the Philippines, Korea, Russia, Thailand, Vietnam, Cambodia and Laos) participate. Figure 11 shows the locations of the EANET monitoring stations.

Figure 11 : EANET monitoring stations for acidic substances

Source: Reference[15]

A monitoring network is designed primarily to disseminate information that is useful in developing national and regional policies for the prevention of the negative impacts of air pollution on the environment. Both broad-based monitoring of background pollution levels and regional monitoring of local pollution levels need to be improved for this purpose, as mentioned in Section 3-2 (1). EANET monitoring stations, however, are located in areas mainly for background monitoring (broad-based monitoring). More stations are needed to keep track of regional pollution levels. In addition, technical training should be provided for the staff members of new monitoring stations to ensure the reliability of the data they supply.

The existing ambient air monitoring system of EANET, meanwhile, is designed mainly to monitor air pollutants causing acid rain (NO_2 and SO_2). A monitoring network for other transboundary air pollutants such as SPM and ozone - like the one run by EMEP - has yet to be developed in Asia.

5 Conclusion : Japan's role and responsibilities

It was in Europe that acid rain was first recognized as being a manifestation of transboundary pollution. A monitoring network encompassing the entire European continent is in place to keep track of transboundary air pollutants, in line with the European Monitoring and Evaluation Programme (EMEP). In addition, the promotion of international environmental measures has contributed dramatically to reductions in SO_2 emissions (a major cause of acid rain). Under EMEP, a further network is in operation to monitor SPM and ozone in addition to acidic substances.

An immediate improvement in the air pollution monitoring network covering the entire East Asian region should be the first step towards addressing transboundary air pollution involving acid rain, SPM and ozone - each of which poses a great threat to the region. The Acid Deposition Monitoring Network in East Asia (EANET) began fully fledged operations in 2001 based on an intergovernmental agreement, with 12 East Asian countries taking part as of 2005. This network, however, requires more monitoring stations in order to be on a par with EMEP in terms of the scope of monitoring. It should also keep track of air pollutants other than acidic substances.

Japan, as an environmentally advanced Asian country, should take the lead in improving and expanding the scope of EANET. Specifically, the following should be put into practice.

(1) Expansion of the monitoring network

EANET monitoring stations for acid rain are located in areas mainly for the purpose of background monitoring (broad-based monitoring). More stations are needed to keep track of regional pollution levels. The following two issues are critical in expanding the monitoring network:

1) Technical training to ensure the accuracy of monitored values

For data comparison purposes, each monitoring station should perform monitoring in accordance with standard operating procedures. In addition, theoretical training should be complemented with on-the-job training in the use of measuring instruments to ensure the accuracy of data provided by new monitoring stations. In addition, a system should be implemented whereby local technical experts and staff members manage technical training on a continuous basis. As part of its international cooperation, Japan, which has expertise and years of experience in measurement technology, should offer technical support to other East Asian countries to assist them in managing their own technical training independently.

2) Development of low-cost analytical instruments

Budgets should be increased and, in addition, low-cost analytical instruments should be developed to improve the monitoring network. Japan, which has extensive technical expertise in such instrumentation, should therefore strive to lower the cost of ambient air monitoring instruments (continuous monitoring). Increasing the number of monitoring stations by introducing simple measurement methods (batch measurement) would also be effective.

(2) Creation of a monitoring network for suspended particulate matter and ozone

There has been a growing need to create a monitoring network encompassing the East Asian region in order to keep track of SPM (including yellow sand, and particulate matter in automobile exhaust and plant emissions), and ozone (a major cause of photochemical smog) in the regional atmosphere. Such a network could be created quickly by improving the existing EANET monitoring system. In other words, it is recommended that a network be put in place to monitor not only acidic substances such as SO_2 and NO_2, but also SPM and ozone. The issues described above - technical training to ensure the accuracy of monitored values, and development of low-cost analytical instruments - should also be addressed in this instance. As far as technical training to ensure the accuracy of monitored values is concerned, however, standard operating procedures should be tailor-made to meet the needs of East Asian countries.

Acknowledgements

I would like to express my deepest gratitude to Dr. Shiro Hatakeyama (Head of the Atmospheric Chemical Reaction Section, the Atmospheric Environment Division, the National Institute for Environmental Studies), Dr. Hajime Akimoto (Director of the Atmospheric Composition Research Program, the Frontier Research Center for Global Change), Hajime Mikasa (Chief of the Atmospheric Subcommittee, the Japan Environmental Technology Association) and Hu Li (Manager, Horiba, Ltd.) for their support in preparing this article.

Glossary

*1 Non-methane hydrocarbons
Hydrocarbons excluding methane - they are precursors of photochemical oxidants.

*2 Photochemical oxidants
Atmospheric oxidants (powerful oxidants) causing photochemical smog - they are comprised primarily of ozone.

*3 Environmental standards
Administrative objectives that should be complied with in order to protect human health and the living environment - they are based on as many scientific findings as are available.

*4 Backward trajectory analysis
An analytical method that keeps track of the past route of the atmosphere using meteorological models.

*5 Aerosols
Solid or liquid airborne particulates - they diffuse or absorb sunlight and alter the properties of clouds by serving as condensation nuclei, thereby having a complex impact on the climate system.

References

[1] The Institute of Energy Economics, Japan. The Asia/World Energy Outlook - Burgeoning Asian Economies and the Changing Energy Supply-demand Structure. March 2004. (Japanese)

[2] The Ministry of the Environment. Summary Report on Measures Against Acid Rain. June 2004. (Japanese) : http://www.env.go.jp/press/press.php3?serial=5052

[3] Formation/Deposition Matrix of Air Pollutants in East Asia and International Joint Observation Activities (led by Kentaro Murano, the National Institute for Environmental Studies). The FY1999-2001 Global Environment Research Fund Terminal Report, Ministry of the Environment.

[4] The Frontier Research Center for Global Change. A Significant Increase in Tropospheric Ozone Concentrations over Japan in the Last 30 Years.: http://www.jamstec.go.jp/frcgc/jp/press/0406/index.html

[5] The Ministry of the Environment. Air Pollution Situation in 2003.: http://www.env.go.jp/air/osen/jokyo_h15/04_5figs.html#4_1

[6] The Bureau of Environment, the Tokyo Metropolitan Government. Photochemical Smog Warnings Issued in Tokyo.: http://www.kankyo.metro.tokyo.jp/ox/bunpu/smog.htm

[7] 2004 Energy White Paper : http://www.enecho.meti.go.jp/hokoku/html/16011221.html

[8] Global Environment Engineering Handbook. 1991. Ohmsha. p.661. (Japanese)

[9] Ministry of the Environment. Atmospheric Environmental Regional Observation System (AEROS).: http://w-soramame.nies.go.jp/

[10] The Environmental Restoration and Conservation Agency. The History of Air

Pollution in Japan.: http://www.erca.go.jp/taiki/history/
[11] Ministry of the Environment. Environmental Standards for Air Quality.: http://www.env.go.jp/kijun/taiki.html
[12] EMEP Measurement Network.: http://www.nilu.no/projects/ccc/network/index.html
[13] Global Environmental Outlook 3.: http://geo.unep-wcmc.org/geo3/pdfs/Chapter2Atmosphere.pdf
[14] Global Environmental Outlook 2000. :http://www.unep.org/geo2000/english/0048.htm
[15] Acid Deposition Monitoring Network in East Asia.: http://www.eanet.cc/jpn/eanet_f.html

Hirokazu FUKUSHIMA
Environment and Energy Research Unit, Science and Technology Foresight Center

Engaged in the research and development of analytical instruments (for engine emissions, particulate matter, etc.) at Horiba, Ltd. His area of interest includes environmental purification technology and its trends, and environmental policies aimed at the creation of a sustainable society.

(Original Japanese version: published in July 2005)

6

Measures to Mitigate Urban Heat Islands

Yoshika Yamamoto
Environment and Energy Research Unit

1 Introduction

The "Outline of the Policy Framework to Reduce Urban Heat Island Effects", which was laid down in March 2004, stipulates that lifestyles must be reformed as part of measures to mitigate urban heat islands. One of these measures is the promotion of the wearing of light clothing in summer. For instance, with the Kyoto Protocol now taking effect, the Ministry of the Environment encouraged its staff members to participate in the "Cool Biz" dress code campaign by not wearing neckties or jackets in summer beginning in June 2005. This enabled the temperature of its air-conditioned workplaces to be kept at 28°C. In addition, an annual event dubbed the "Grand Water Sprinkling Campaign" was carried out across the country on August 10. Urban heat island mitigation measures are making steady headway. Aside from lifestyle issues, however, another perspective from which to debate urban planning itself is necessary.

Japan's approaches to the urban heat island effect trace their origins to the 1980s, when it became a topic of study in the field of physical science, including meteorology and geography. That is where most early progress was made. In the 1990s, the phenomenon also became a research topic in engineering fields such as architecture and civil engineering, which addressed urban heat and energy problems. Study of the urban heat island effect from an urban planning perspective thus began[1]. Political approaches, meanwhile, have also made significant headway over recent years, playing catch-up with more-established approaches. When the Ministry of the Environment defined "the urban heat island effect as air pollution" in August 2001, mitigation measures suddenly emerged as a political issue. In response, the Cabinet decided in March 2002 to "set up a general task force comprising the ministries concerned and draw up guidelines to implement comprehensive approaches to urban heat island mitigation" in accordance with the "Three-Year Program for Promoting Deregulation (Revised)." The Ministry of the Environment, the Ministry of Land, Infrastructure and Transport, the Ministry of Economy, Trade and Industry, and the Cabinet Secretariat subsequently established the Inter-Ministry Coordination Committee to Mitigate Urban Heat Islands (hereinafter "the Liaison Council") in September 2002. This was followed by the establishment of the "Outline of the Policy Framework to Reduce Urban Heat Island Effects" in March 2004.

The "Guideline of Measures to Prevent Global Warming" was laid down in 2002. It aims to "promote global warming mitigation measures in order to achieve a 6% reduction in greenhouse gas emissions." One of these measures concerns the "promotion of comprehensive approaches to the urban heat island effect."

The "Basic Policies for Urban Renaissance," adopted by the Cabinet in July 2002, frames urban heat island mitigation measures as a means to revitalize urban areas. Heat island mitigation measures have thus become a major political issue from an urban renewal perspective.

The urban heat island effect was thus originally studied in the fields of physical science and engineering, from which various preventive policies gradually developed. It is too complex a problem to be solved by a single ministry, as is acknowledged in the establishment of the Liaison

Council. Furthermore, it is an interdisciplinary subject that involves meteorology, geography, architecture, civil engineering and the like. A range of studies is underway to elucidate the effect, develop and implement mitigation measures, and so on. There is a pressing need to mobilize a wide range of findings from these studies to come up with comprehensive mitigation measures.

This article explores urban heat island mitigation measures primarily from the perspective of urban planning.

2 The Urban heat island effect

Urbanization involves concentration of population, loss of natural surface, and expansion of living space above and below ground. All of these factors alter the balance of radiation, heat, and water, generating a climate typical of urban areas[2].

The urban heat island effect is a phenomenon whereby cities become warmer than the surrounding suburbs. In other words, there is a temperature difference between cities and the areas surrounding them. The effect was first observed in London and other European cities in the 1830s, followed by big cities such as New York and Chicago in the USA. The phenomenon is now becoming a major problem in Asia as well. Indeed, the urban heat island effect exists wherever there are large cities. While elimination of the phenomenon is not feasible, the key issue is how best to mitigate it. A variety of factors, such as surface cover, anthropogenic heat release, and urban characteristics including geographic features and climatic conditions interact with one another to create the effect. Its generating mechanism is complex and yet to be fully elucidated. Currently, therefore, each mitigation measure, such as energy-saving technologies and greenification, is being separately implemented[3].

Under these circumstances, elucidation of each contributing phenomenon to establish a scientific background and development of quantitative assessment techniques are imperative.

2-1 Status and causes of the urban heat island effect

(1) Status of the urban heat island effect

(i) Long-term upward trend in average temperatures

The third Intergovernmental Panel on Climate Change (IPCC) report*1 points out that average global temperature rose by some 0.6°C during the 20th century. Six big cities in Japan (Sapporo, Sendai, Tokyo, Nagoya, Kyoto, and Fukuoka) have seen average temperature rises of 2-3°C. The urban heat island effect has been more pronounced in these cities than have changes due to global warming.

(ii) Sweltering nights and rising daytime temperatures

Temperatures are on the rise, particularly in big cities. In fact, the temperature now stays above 30°C for longer, over a larger area (see the upper and middle color maps on the front cover and Figure 1). Accordingly, the number of sweltering nights is increasing.

(2) Causes of the urban heat island effect

The following four factors are the major causes of the urban heat island effect[5] (see Figure 2).

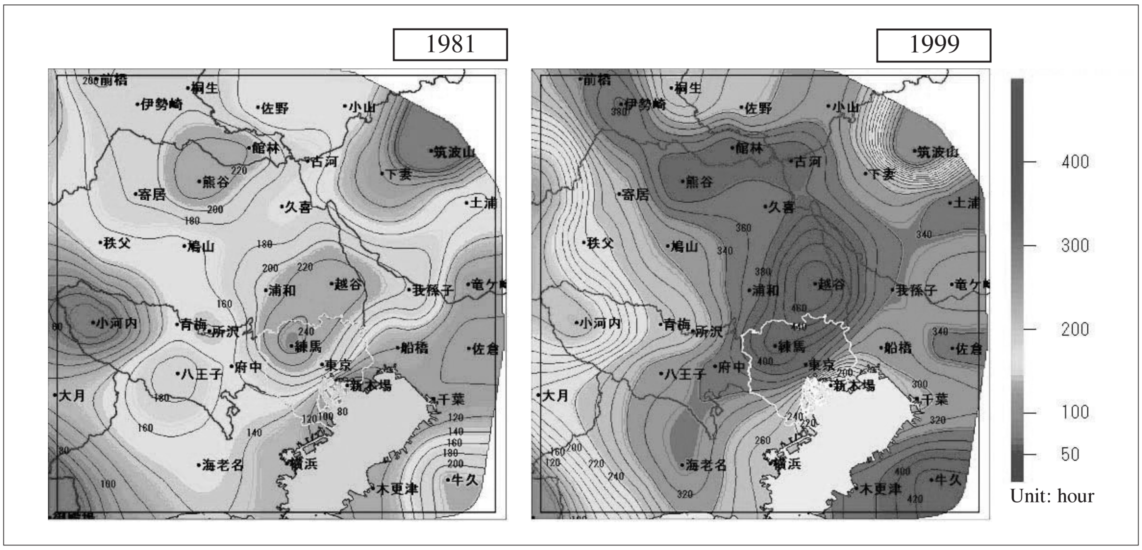
(i) Increased anthropogenic heat release
- Heat release resulting from energy consumption in urban areas

(ii) Changes in surface cover
- Reduced surface evapotranspiration capacity due to less green area
- The heat storage effect of construction materials such as concrete and asphalt

(iii) Urban structure
- Heat stagnation due to densely packed buildings
- Expansion of urban areas

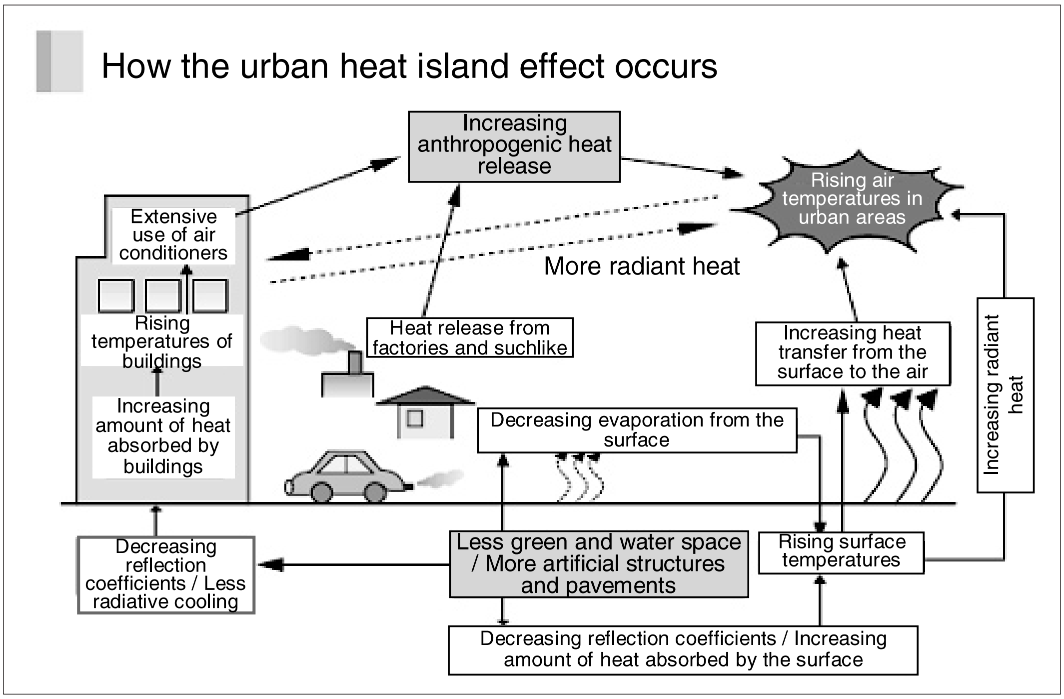
(iv) Other
- The greenhouse effects of fine-particulate air pollution in the urban atmosphere

Figure 1 : Distribution of cumulative hours with temperatures above 30°C (Tokyo) (see the color maps on the front cover)



Based on data provided by AMeDAS (July to September in 1981 and 1999). Cumulative hours with temperatures above 30°C are tabulated, and their distribution is shown by means of an isochrone. Source: Reference[4]

Figure 2 : Causes of the urban heat island effect



Source: Reference[6]

2-2 *Impacts of the urban heat island effect*

(1) Summer impacts

Urban areas are becoming uncomfortable places to live because of higher temperatures during daytime and an increasing number of sweltering nights. Higher temperatures boost demand for air conditioning, resulting in increased energy consumption. They also contribute to localized torrential downpours and the production of photochemical oxidants.

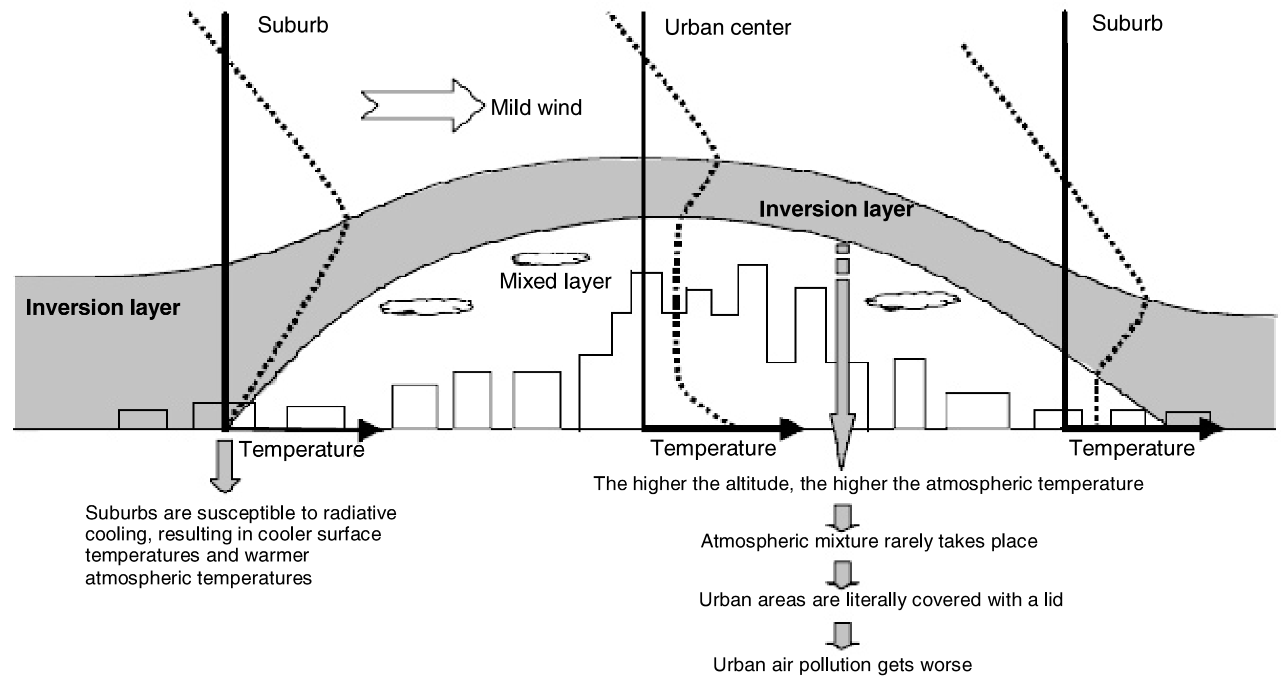
(2) Winter impacts

Inversion layers*3 form by radiative cooling*2 on clear, calm winter nights. Ascending air currents created by warm urban areas are trapped under inversion layers, forming mixed layers (dust domes*4) that exacerbate air pollution (see Figure 3).

(3) Other

Changes in surface cover cause decreased evaporation, making urban areas drier.

Figure 3 : Atmospheric conditions inside and outside urban areas in winter (when inversion layers are formed)



Source: Reference[4]

3 Measures to mitigate urban heat islands

3-1 Status of urban heat island mitigation measures

Since 2000, local governments made remarkable strides in implementing systematic approaches to urban heat island mitigation measures. Typical systems aim primarily to promote the greening of urban areas by mandating the promotion of greening, subsidizing the cost of greening, and incentivizing rooftop greening by granting higher floor-area ratios to buildings that implement it.

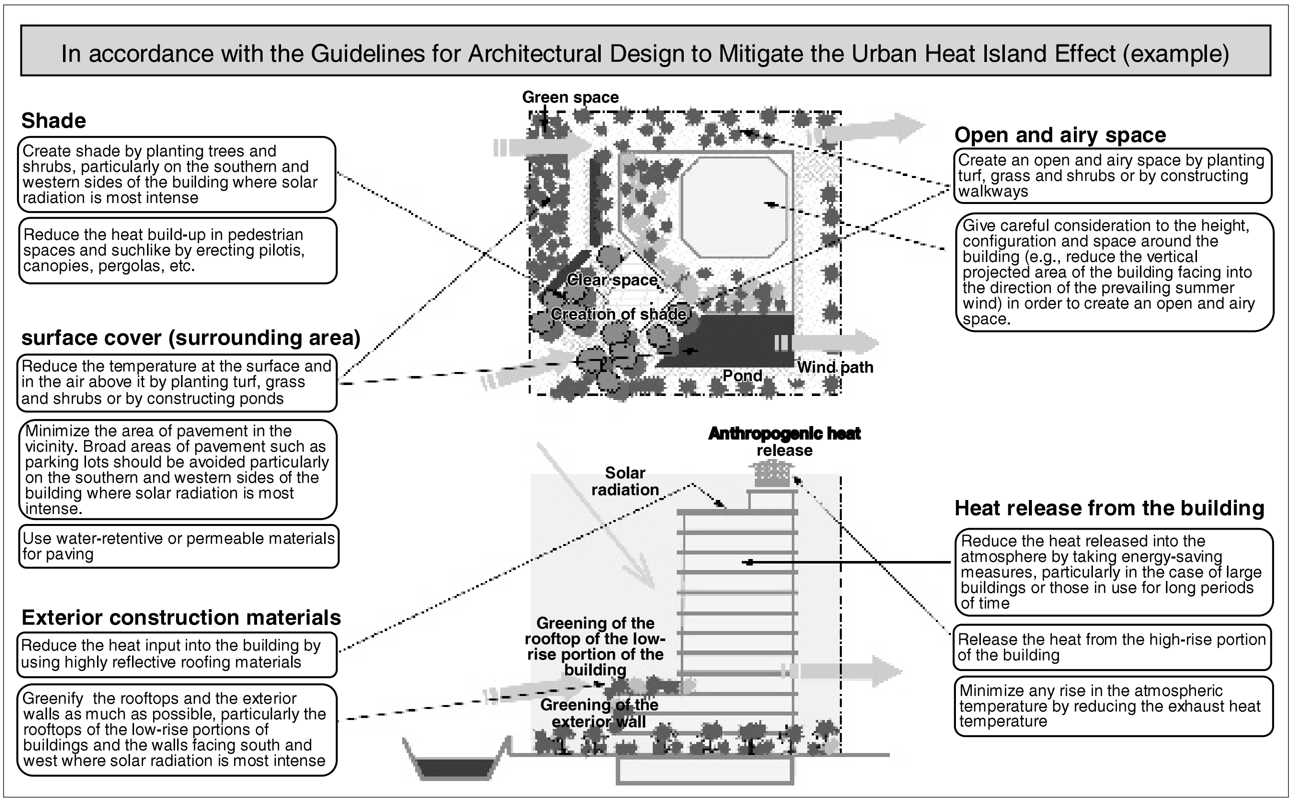
At the government level, in March 2002 the Cabinet decided to create guidelines for urban heat island mitigation measures in accordance with the "Three-Year Program for Promoting Deregulation (Revised)." Establishment of the Liaison Council in September 2002 was followed by the March 2004 adoption of the "Outline of the Policy Framework to Reduce Urban Heat Island Effects."

In line with the policy outline, in July 2004 the Ministry of Land, Infrastructure and Transport laid down "Guidelines for Architectural Design to Mitigate the Urban Heat Island Effect", encouraging building owners to adopt proactive mitigation measures (see Figure 4.). In July 2005, the CASBEE-HI system to assess the overall environmental performance of buildings was completed. CASBEE-HI is a tool for evaluating the effects of mitigation measures. It maintains a comfortable thermal environment in pedestrian spaces and other areas inside buildings. It uses a five-level rating system to assess the environmental performance of buildings by evaluating reduction of thermal impacts on their surroundings.

In December 2004, the Urban Renaissance Headquarters of the Cabinet Secretariat (headed by the Prime Minister) adopted the eighth Urban Renaissance Project: "Development of Measures against Global Warming and Heat Islands through Urban Renaissance Projects". Accordingly, "model areas for measures to mitigate global warming and urban heat islands" (see below) were selected in April 2005.

With the Kyoto Protocol taking effect in February 2005, the "Measures and Policies to Achieve the Goal" stipulated in April 2005 in the "Plan for Meeting Japan's Commitments under the Kyoto Protocol" specifies that "CO_2 emissions must be reduced by improving the thermal environment through urban heat island mitigation

Figure 4 : Issues to be considered when designing buildings



Source: Reference[7]

measures such as greening."

3-2 Major urban heat island mitigation measures

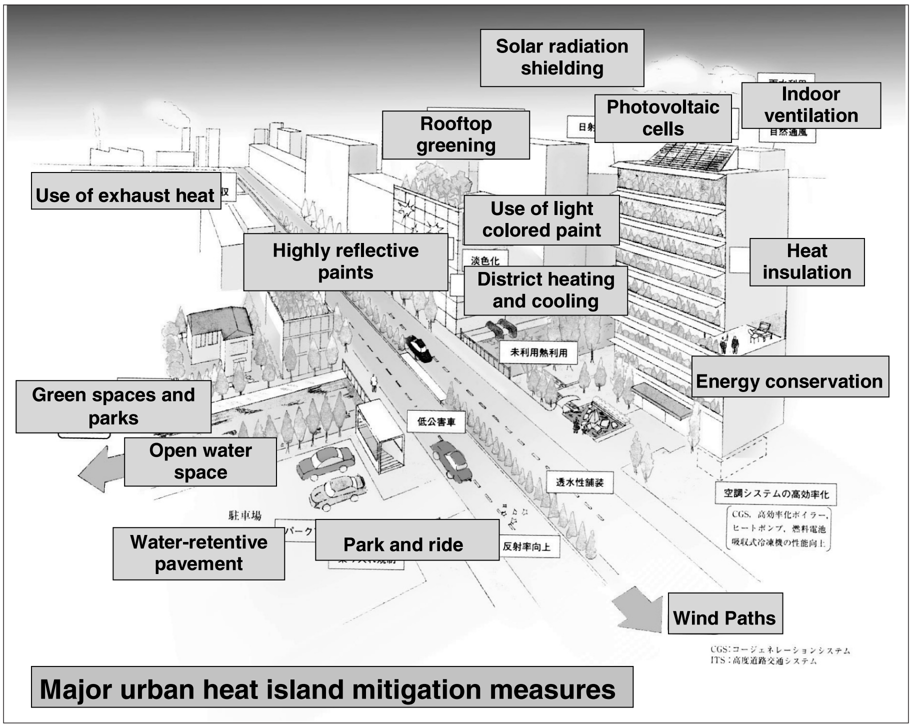
The "Outline of the Policy Framework to Reduce Urban Heat Island Effects" focuses on the following. (i) Reduction of anthropogenic heat release through urban activities, (ii) improvement of artificial urban surface covers, (iii) improvement of urban structure such as the placement and orientation of buildings, and (iv) enhancement of lifestyles. In particular, campaigns to encourage light clothing in summer and to reduce idling of automobile engines are both promoted as lifestyle improvements, i.e., measures closely related to social and economic activities.

The urban heat island effect in summer varies by city according to unique characteristics such as geography. Mitigation measures to be used are therefore left to the discretion of local governments. A variety of organizations and individuals, such as the central government, prefectural governments, municipalities, and business owners, administer the measures, which vary in scale and period (the time needed to produce) results[8]. There are both long-term citywide measures and measures suited for implementation in a relatively short time. Improving surface cover is effective in reducing the amount of heat storage and thus the incidence of sweltering nights. Reduction of exhaust heat contributes to the lowering of maximum daytime temperatures. Given this diversity of factors, the central government should create a framework within which mitigation measures can be tailor-made to suit the needs of each city. Table 1 summarizes the range of mitigation measures that are considered most effective.

These include the greening of building rooftops and walls, adoption of water-retentive construction materials, application of light colored paint to exterior walls, use of reflective roofing materials, central control of building exhaust heat at the regional level, maintenance and improvement of parks and green spaces, construction of large-scale greenbelts, and reorientation of industrial/commercial facilities in light of prevailing wind direction.

These measures grow in scale and scope as

Figure 5 : Urban heat island mitigation measures



Source: Prepared by Toshiaki Ichinose, the National Institute for Environmental Studies, based on Reference[6]

Table 1 : Categories of urban heat island mitigation measures

Description	Scale	Period	Degree of Effect		Administered by
			Sweltering nights	Rise in daytime temperatures	
(1) Reduction in anthropogenic heat release (reduction and substitution)					
(i) Improvement in the efficiency of energy-using products					
Office automation equipment and electric consumer appliances	Individuals	Short term	B	B	Individuals, business institutions, local governments
(ii) Improvement in the efficiency of air conditioning systems					
Refrigerators and heat source equipmen	Buildings	Short term	B	B	Individuals, business institutions, local governments
(iii) Optimal operation of air conditioning systems					
Proper placement of outdoor units	Buildings	Short term	B	B	Individuals, business institutions, local governments
Use of cooling towers	Buildings	Short to medium term	—	A	Individuals, business institutions, local governments
Voluntary restraints on nighttime operations	Buildings	Short term	A	—	Individuals, business institutions, local governments
(iv) Improvement in the heat insulation and thermo-shield of buildings					
High-performance heat insulation materials (interior heat insulating materials)	Buildings	Short to medium term	C	C	Individuals, business institutions, local governments
High-performance heat insulation and thermo-shield materials (exterior heat insulating materials)	Buildings	Short to medium term	A	D	Individuals, business institutions, local governments
(v) Greening of buildings and adoption of water-retentive materials					
Greening of buildings and adoption of water-retentive materials (Exterior heat insulating materials)	Buildings	Short to medium term	A	A	Individuals, business institutions, local governments
(vi) Improvement in the reflectivity of walls and roofing materials					
Light colored walls and highly reflective roofing materials	Buildings	Short term	A	A	Individuals, business institutions, local governments

Description	Scale	Period	Degree of Effect		Administered by
			Sweltering nights	Rise in daytime temperatures	
(vii) Introduction of traffic-control measures					
Traffic demand management and introduction of low emission vehicles	Cities	Medium to long term	B	C	Individuals, business institutions, local governments
Promotion of alternatives such as bicycles	Wards	Short to medium term	B	C	Individuals, business institutions, local governments
(viii) Introduction of district heating and cooling					
Central control of exhaust heat from buildings (at the regional level)	City blocks	Medium term	A	A	Business institutions, local governments
(ix) Use of untapped energy					
Use of sea, river and ground water	Wards	Medium to long term	B	B	Business institutions, local governments
Use of exhaust heat from urban facilities					
Use of exhaust heat from industrial plants, subways, buildings, power plants, substations, etc.	City blocks	Medium term	B	B	Business institutions, local governments
Recovery of energy from waste materials					
Waste power generation and heat supply	Wards	Medium term	B	B	Local governments
(x) Use of natural energy					
Photovoltaic generation	Buildings to cities	Short to medium and long term	B	B	Individuals, business institutions, local governments
Use of solar heat	Buildings to cities	Short to medium and long term	B	B	Individuals, business institutions, local governments
(2) Improvement of artificial surface covers (reduction of sensible heat transfer and expansion of latent heat transfer)					
(i) Improvement in the reflectivity and water-retentivity of paving materials					
Adoption of colored and permeable paving materials	Cities	Short term	B	B	Local governments
(ii) Greening					
Maintenance and improvement of parks and green spaces	Wards to cities	Medium to long term	A	A	Business institutions, local governments
Greening of streets	Wards to cities	Medium term	B	B	Local governments
Greening of dwellings	Individuals	Short term	B	B	Individuals, business institutions, local governments
(iii) Greening of buildings and adoption of water-retentive materials (reduction of sensible heat)					
Greening of buildings and adoption of water-retentive materials	Buildings	Short to medium term	A	A	Individuals, business institutions, local governments
(iv) Open water spaces					
Conversion of small rivers into open channels and construction of ponds in parks	Wards to cities	Medium to long term	B	A	Local governments
(3) Improvement of urban structure (improvement and integration of advection currents)					
(i) Improvement of the orientation of buildings					
Improvement of orientations of buildings and roads, and effective use of wind or water paths	City blocks to cities	Medium to long term	B	B	Local governments
(ii) Improvement of land use					
Construction of large-scale parks and green spaces, and reorientation of industrial or commercial facilities	Cities	Long term	A	A	Local governments
(iii) Creation of eco-energy cities					
Cascade use of energy, and organic integration of energy use in industrial and private sectors	Wards to cities	Medium to long term	B	B	Local governments
(iv) Creation of a recycling-based society					
Effective use of energy and resources, and creation of eco-friendly cities based on recycling	Wards to cities	Long term	B	B	Local governments

Note) Degree of effectiveness: A (very effective), B (effective), C (somewhat effective), D (counter effective) Source: Reference[4] they develop from (1) reduction in anthropogenic heat release to (2) improvement of artificial surface covers and (3) improvement of urban structure. Accordingly, their possible effects grow and so do their costs, with responsibility for their implementation shifting from individuals to government. Urban heat island mitigation measures should therefore be designed within the overall framework of urban planning.

3-3 The potential of "wind paths"

The concept of "wind path" design, a common mitigation measure that deserves further attention, is explained as follows.

(1) A "wind path" along the river

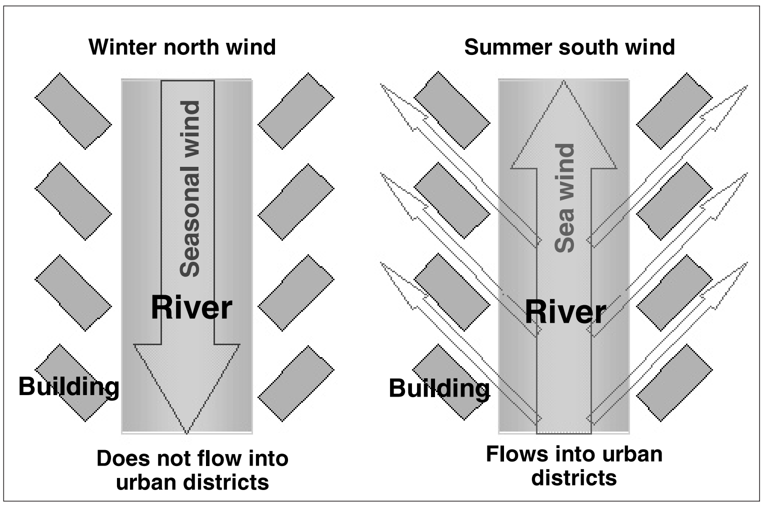
Winds that blow along paths are locally circulating winds such as those blowing from sea to land or from mountains to valleys. "Wind paths" (i) bring in cool air from the sea, lowering daytime urban temperatures, (ii) bring in cool air currents that flow down mountain slopes and valleys, cooling hot urban air at night, and (iii) help alleviate air pollution by bringing in generally cleaner sea winds and cool air currents[9].

Rivers are particularly useful in bringing in sea winds. The fact that a rivers can serve as "wind paths" is now being incorporated into urban design. For example, wind tunnel experiments have been conducted to investigate how effects such as vapor pressure and relative humidity on buildings adjacent to rivers vary when the orientation of the buildings is changed[8].

When buildings are positioned parallel to a river, they interfere with the air flowing along the river, preventing it from finding its way into urban districts. Positioning buildings perpendicular to the river, effectively channels air flow into these districts. When buildings are positioned at a 45°-degree angle to the river, however, they produce two contrasting effects, depending on the direction of wind flow along the river (see Figure 6). If the buildings align with the wind, they channel it in, while if they align against the wind, they deflect its movement. The orientation of buildings shown in Figure 6 channels a cool sea wind from the south into an urban district during the day in summer, while deflecting a cold seasonal wind from the north in winter. These experimental results show that seasonal winds can work in two beneficial ways. A project to put this concept into practice is underway in Tokyo's Shinagawa Ward (see below).

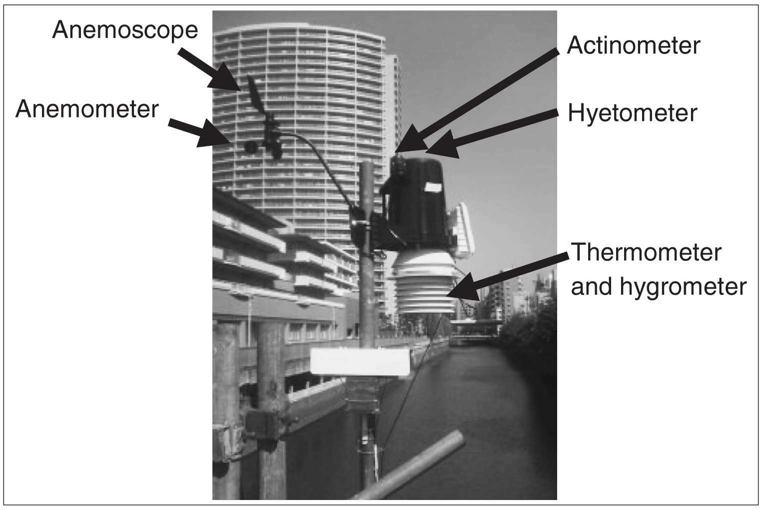
In large oceanfront cities like Tokyo, Nagoya, and Osaka, the wind usually blows from the sea towards the land because the surface of the land is warmer than the surface of the sea. Urban planning for cities, especially major oceanfront cities should therefore take advantage of sea winds flowing in along rivers ("wind paths").

Figure 6 : Illustration of a "wind path" along the river



Source: Prepared by STFC based on Reference[8]

Figure 7 : Meteorological equipment installed along the Meguro River (taken by the author at 14:24 on July 28, 2005)



A shot taken in the direction of Tokyo Bay (The anemoscope shows the direction of the bay)

This option is expected to play a major role in urban heat island mitigation in the future.

(2) Exploration of "wind paths" along the Tokyo waterfront

As described above, most of Japan's big cities are located on waterfronts, where the sea wind that flows from them could lower air temperature in summer. There are, however, no statistical techniques available to forecast this flow and predict its effects. As a result, urban planning does not yet take into account such winds. A group under the Ministry of Land, Infrastructure and Transport led by the National Institute for Land and Infrastructure Management therefore conducted a two-week large-scale survey at the end of July 2005 to explore ways in which "wind paths" can mitigate the urban heat island effect. The survey is part of a three-year general technology development project launched in 2004 by the Ministry of Land, Infrastructure and Transport. Led by Professor Toshio Ojima at the School of Science and Engineering, Waseda University, the project is called the "Development of Management Techniques for Thermal Environments in Urban Space." The project measured wind direction, speed, temperature, and relative humidity at some 200 sites in four areas: near Tokyo Station, the Shiodome/Shinbashi district in Minato Ward, the Shinagawa district, and the Osaki/Meguro River district in Shinagawa Ward. The project also observed changes in wind direction and the effects of altitude on temperature (see Figure 7). The collected data are being compared with those obtained through simulations carried out on supercomputers to analyze the influence of high-rise buildings, streets, parks, and rivers on local wind flow and temperature. One of the key objectives of this analysis is to verify the area of thermal impacts associated with skyscrapers in the Shiodome district, where the so-called "Tokyo Wall[*5]" is located. The survey results are expected to contribute to improvements in urban heat island mitigation measures such as greening and urban development.

4 Urban heat island mitigation measures from the perspective of urban planning

With such a range of accumulated findings and such a variety of developed technologies, many measures to mitigate urban heat islands have now been put into practice. These include rooftop greening, exterior wall greening, water-retentive pavement, and thermo-shield pavement. These sporadic measures, including "water sprinkling," may be effective in temporarily lowering urban temperatures, but they provide no lasting solution to the urban heat island effect. It is imperative that regional mitigation measures be simultaneously implemented in order to produce satisfactory results. Urban redevelopment and renewal, however, involve a complex consensus-building process, both socially and institutionally. In this context, the model-area projects discussed below deserve particular attention.

4-1 Model areas for measures to mitigate global warming and urban heat islands

In April 2005, the government designated 10 cities and 13 areas as model areas in which intensive environmental and energy-saving measures will be implemented to mitigate the urban heat island effect.

These "model areas for measures to mitigate global warming and urban heat islands" (hereinafter, "model areas") were designated based on the following objectives.

(i) Incorporate environmental and

Table 2 : Model areas for measures to mitigate global warming and urban heat islands

Prefecture	Model Areas	Description of Major Approaches
Hokkaido	Sapporo urban area	Creation of an energy network using snow ice cryogenic energy, biomass energy and natural gas cogeneration in addition to the development of old factory sites and the construction of an underpass beneath the Sapporo Station road
	Muroran oceanfront area	Construction of wind power generation facilities on an oceanfront area including a land readjustment project district, and intensive promotion of photovoltaic power generation systems for new residential housing in newly developed residential areas
Tokyo	Tokyo urban center	Introduction of an urban waste heat supply system using untapped energy sources (such as sewage), and implementation of global warming and urban heat island mitigation measures by the public and private sectors (such as rooftop greening, water-retentive pavement, and water sprinkling)
	Shinjuku district	Incorporation of environmental considerations into redevelopment projects (including improved heat insulation of buildings and rooftop greening) and the creation of a thermal environment improvement concept, with Shinjuku Gyoen at its center
	Osaki/Meguro district	Creation of wind paths along the Meguro River, development of environmental consideration guidelines (including the promotion of water-retentive pavement and green spaces), and implementation of district-wide approaches
	Shinagawa Station district	Examination of environmental symbiosis models (including wind paths) in developing the Shinagawa Station district (a priority district for an urban and residential environment development project), and promotion of energy-saving measures and rooftop greening among large-scale condominiums
Kanagawa	Yokohama urban area and Kanazawa district	Application of a multi-level park system to promote large-scale greening, water-retentive pavement, water sprinkling, and production of eco-energy (from natural energy, waste and biomass) to create a network supplying power and heat to businesses and dwellings
Aichi	Nagoya Station, Fushimi and Sakae districts	Introduction of district heating and cooling, and use of untapped energy sources in addition to the implementation of urban renewal projects in urban emergency redevelopment areas in order to roll out global warming and urban heat island mitigation measures
Osaka	Osaka Station, Nakanoshima and Midosuji districts	Introduction of district heating and cooling, and use of untapped energy sources (river water) in addition to the implementation of urban renewal projects in urban emergency redevelopment areas, and construction of parks and green spaces along with expansion of a railroad network to roll out global warming and urban heat island mitigation measures (capitalizing on the characteristics of Osaka, a "capital" of water resources)
	Dainichi district (Moriguchi City)	Construction of photovoltaic power generation facilities and promotion of water-retentive pavement and water sprinkling in addition to the implementation of large-scale development of old factory sites in urban emergency redevelopment areas
	Ibaraki City, Minoh City and Saito district	Promotion of a car-sharing program, new energy sources (such as photovoltaic power generation) and greening in addition to a large-scale community development project
Kochi	Susaki urban area	Construction of photovoltaic and wind power generation facilities in addition to the implementation of projects for tsunami escape routes and land readjustment, intensive construction of photovoltaic power generation facilities at old waste disposal sites and public facilities, and promotion of local lumber for use in housing and public buildings along with reforestation programs
Fukuoka	Kokura (Kitakyushu City), Kurosaki and Dokaiwan oceanfront area	Promotion of environmentally friendly housing, wind paths and district heating and cooling systems, and effective use of energy produced by adjacent factories in parallel with the redevelopment of idle land owned by companies in partnership with operating factories; promotion of global warming measures by taking advantage of existing industrial infrastructure and integrating these measures into a community planning package

* Model areas include 10 cities and 13 areas

Source: Reference[10]

energy-saving measures into urban renewal initiatives and designate urban emergency redevelopment areas and areas of concentrated urban activities as model areas in which pioneering approaches will be adopted

(ii) Systematically concentrate environmental and energy-saving measures that contribute to the alleviation of global warming and to the urban heat island effect as well as community planning measures in model areas within a certain time frame to produce maximum effect, thereby redeveloping an economically and environmentally viable city and helping achieve the Kyoto Protocol target

(iii) Concentrate measures administered by ministries, local governments, and the private sector on "model areas" to make steady progress in mitigating the urban heat island effect

In particular, the model areas must each meet the following three criteria. (i) Systematic and concentrated approaches involving cooperation and partnership among the central government, local governments, and the private sector are underway, (ii) pioneering approaches using underutilized materials/resources and mobilizing advanced technology/expertise are underway, and (iii) the approaches now underway are expected to effectively reduce environmental burdens.

The following section presents an overview of the approaches adopted by the Tokyo Metropolitan Government, including measures taken for Osaki/Meguro River district and other designated model areas (see Table 2).

4-2 Promotion of measures to mitigate urban heat islands in Tokyo

The Tokyo Metropolitan Government produced a "Thermal Environment Map" in April 2005. This map shows the atmospheric impact (thermal loading) of anthropogenic heat release and surface cover conditions. These factors cause the urban heat island effect in Tokyo's 23 wards (see the lower color map on the front cover). Efforts are now underway to implement mitigation measures designed to suit the characteristics of each area. The map categorizes these areas into five types according to thermal environment characteristics such as anthropogenic heat release and surface cover conditions, plotting them on a 500-m ×500-m grid. In particular, Type I (high-density commercial areas) and Type II (high-density residential areas), whose atmospheric impacts are relatively large, are designated by different colors according to their amount of thermal loading. On the basis of this map, four areas are designated as "areas for the implementation of urban heat island effect mitigation measures" (hereinafter, "designated areas") (see Table 3 and Figure 8).

The criteria used in designating these areas are: (i) areas whose atmospheric impact (thermal loading) is relatively large according to the Thermal Environment Map (i.e., high-density commercial and residential areas), (ii) urban emergency redevelopment areas that can attract environmentally friendly development by the private sector, and (iii) areas in which a wide range of development can be expected and where urban planning should be systematically introduced (with urban heat island mitigation measures incorporated in advance). In these designated areas, water-retentive pavement, the greening of exterior walls, and the planting of lawns on school grounds will all be promoted as part of urban renewal. The private sector will also be encouraged to take part in these developments.

In July 2005, the Tokyo Metropolitan Government developed the "Guidelines for Urban Heat Island Mitigation Measures" to encourage private businesses and the Tokyo public to develop mitigation measures according to the thermal environment in which they operate or live. These guidelines comprise (i) the Thermal Environment Map, (ii) an area-specific mitigation measures menu and (iii) a building-specific mitigation measures menu.

With the designated areas adopted as model areas by the central government, the Tokyo Metropolitan Government then set up the "urban Heat Island Mitigation Measures Designated Areas Council" in July 2005 to undertake concerted efforts to implement the program. This involves collaboration with the central government and all parties concerned, including private businesses.

4-3 Approaches to reduce environmental load through use of the Meguro River in the Osaki Station district

In July 2002, the Osaki Station district (60 ha), located in Tokyo's Shinagawa Ward was designated an urban emergency redevelopment area based on the Urban Renaissance Special Measures Law. Community-planning efforts are now underway, with the private sector (local developers, stakeholders, and others) playing a leading role. In April 2005, an area of 1,100 ha, including the Osaki Station district, was designated a national model area (see Table 2, 3 and Figure 8).

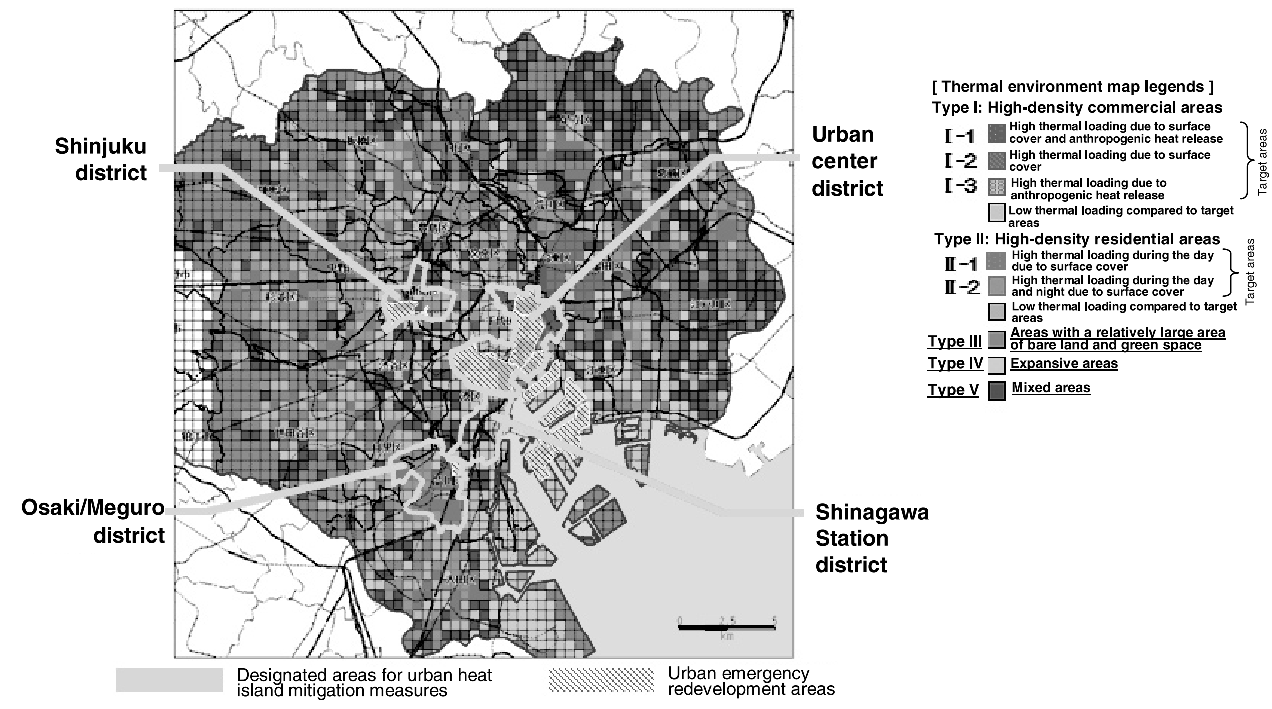
Based on their previous experience with community planning, all parties concerned, including local companies and redevelopment organizations that have development projects in

Table 3 : Overview of designated areas (Tokyo)

District	Characteristics	Description
Urban center (measures for high-density commercial areas), about 1600 ha	A substantial amount of heat is released from office buildings and artificial surface covers such as asphalt, leading to higher temperatures during the day and night	Urban emergency redevelopment areas (districts around Tokyo Station and Yurakucho Station, Akihabara, Kanda, loop road 2-Shinbashi, Akasaka, Roppongi, part of the Tokyo waterfront area), Iidabashi, Jimbocho, Nihonbashi (eastern district), and others
Shinjuku district (measures for high-density commercial areas), about 600 ha	A substantial amount of heat is released from housing, office buildings and artificial surface covers such as asphalt, leading to higher temperatures during the day and night	Urban emergency redevelopment areas (Shinjuku Station district, loop road 4-Shinjuku Tomihisa Street), Kita-shinjuku, Hyakunincho, Takadanobaba, Tomihisacho, and others
Osaki / Meguro District (measures for high-density residential areas), about 1,100 ha	A substantial amount of heat is released from the surface, leading to higher temperatures during the night (sweltering nights); a high-density residential area	Urban emergency redevelopment areas (Osaki Station district), and priority areas for disaster-resistant community planning (Rinshi-no-mori district and Ebara), Ooimachi, and others
Shinagawa Station district (introduction of measures through development projects), about 600 ha	A wide range of development is expected to take place, and systematic urban planning should therefore be adopted, with urban heat island mitigation measures incorporated	Areas designated as "urban and residential development priority areas" through the "general urban renewal project" administered by the Ministry of Land, Infrastructure and Transport

Source: Prepared by STFC based on Reference[11]

Figure 8 : Thermal environment map and designated areas for urban heat island effect mitigation measures. (see the color map on the front cover)



Source: Reference[12]

the Osaki Station district, the Shinagawa City, and elsewhere, jointly established the "Osaki Station District Emergency Redevelopment Area Community Planning Circle" (hereinafter, the "Community Planning Circle"). Established in February 2003, its aims are to formulate a shared vision of a future community and to push ahead with strategic community planning in line with the Urban Renaissance Special Measures Law. The Community Planning Circle developed with the "Osaki Station District Urban Renewal Vision" (hereinafter, the "Urban Renewal Vision") in November 2004. This included a plan to "make use of the Meguro River as an environmental resource" (see Figure 9).

Global warming and urban heat island mitigation measures are key elements of urban renewal in the Osaki Station district. The overall plan is to utilize the Meguro River (one of the main geographical features of the district) as part of the area's environmental resources, with particular emphasis on the following.

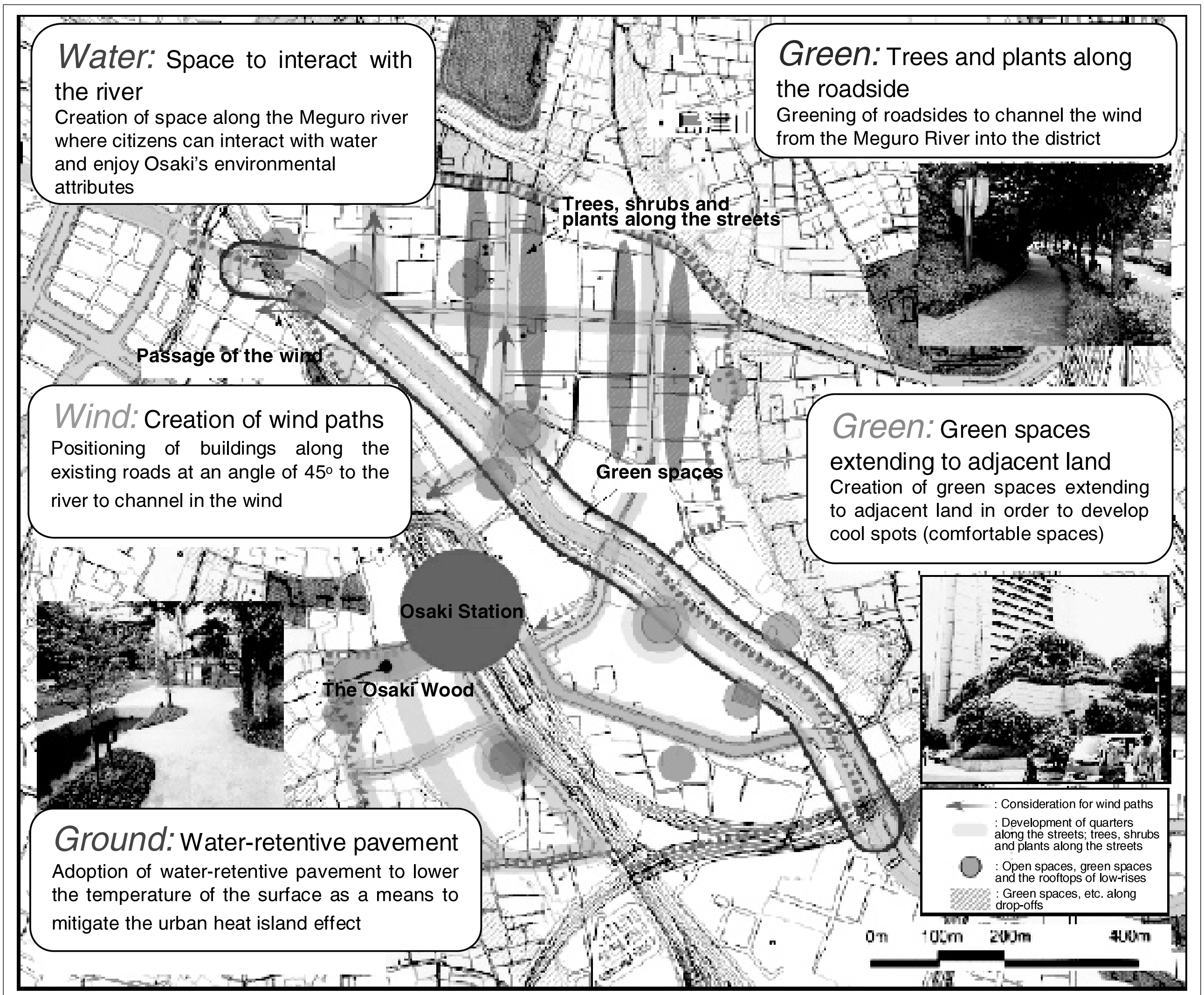
(i) Creation of a community centered on the Meguro River that gives due consideration to urban heat island mitigation measures, including the development of wind paths

(ii) Construction of riverfront parks, etc. along the Meguro River to create a community where citizens can enjoy and interact with the water and construction of river walls, open spaces and bridges to provide citizens with opportunities to interact with the river

(iii) Development of "Environment-conscious guidelines" based on a shared awareness of environmental conservation to support concerted efforts

(iv) Application of the guidelines to development projects in order to reduce

Figure 9 : Network of water, green spaces and wind paths along the Meguro River



Source: Reference[13]

the environmental load of urban heat island effects and to enhance the potential of the district

In response to this agenda, a voluntary proposal called the "Osaki Station District Environmental-conscious Guidelines" was set forth in July 2005 to carry out joint environmental measures, i.e., urban heat island mitigation measures. These guidelines encourage local developers to undertake environmental measures based on a shared awareness of environmental conservation. An "Environment-conscious Manual" was also prepared in order to present examples of the sort of environmentally conscious measures envisaged by the guidelines.

In Shinagawa Ward, the concept of a "wind path" is being put into practice. As part of the Osaki Station district's community planning, a project has been specifically authorized whereby buildings will be constructed along the Meguro River, all facing upstream at an angle of 45°. The project takes advantage of existing ward roads that extend from the river at similar angles (see Figure 9).

5 Urban heat island mitigation measures in other countries

(1) "Wind paths" in Freiburg, Germany

Freiburg is located at the east end of the Rhine River Valley, where a lack of wind often leads to thermal stress (heat impacting human health) in summer and air pollution in winter. In this area, the prevailing wind blows up the valley (behind the city) during the day and down the valley during the night. The nighttime wind, generated by radiative cooling in the mountain forests and pastures, cools as it flows down the streams. When channeled into the city, it is effective in alleviating thermal stress and air pollution. The street pattern has therefore been laid out in order to bring in cool air currents at night and the cool north wind during the day, while blocking the strong southwest wind that prevails in spring and autumn[8].

Although observations show that the temperature has been rising in European cities over recent years, the heat wave that struck the region in 2003 was considered a very unusual phenomenon. Public awareness of the urban heat island effect is thus not as prevalent in Europe as it is in Japan[14].

The creation of "wind paths" in Freiburg and other inland cities in Germany instead is primarily a means to alleviate air pollution in low-wind conditions or when surface inversion layers form*6.

(2) Urban heat island mitigation measures in the U.S.

In 1997, the Environmental Production Agency (EPA) instituted the "Heat Island Reduction Initiative" (HIRI) in the wake of the heat wave that struck Chicago in July 1995, resulting in a death toll of over 700 people[15]. As part of this initiative, the "Urban Heat Island Pilot Project" (UHIPP) was launched in 1998 to investigate the heat island effect, raise public awareness of the issue, and quantify the effects of mitigation measures[16]. Subsequently, five cities have been selected for inclusion: Baton Rouge, Louisiana; Chicago, Illinois; Houston, Texas; Sacramento, California; and Salt Lake City, Utah.

(3) The Cheonggyecheon restoration project in Korea

A large-scale river restoration project underway in the heart of Seoul is attracting worldwide attention[17]. The Cheonggyecheon, an 11 km-long tributary that joins the Han River, was converted into a culvert in the 1950s, with an elevated road constructed on top. Due to its age and increasing environmental concerns, however, the Seoul Metropolitan Government demolished and removed a 5.8-km section of the elevated road in July 2003 to restore the river to its natural state. The project was completed in October 2005. As a river restoration project of this magnitude is unprecedented, the potential environmental benefits, including alleviation of air pollution due to lower traffic volume and decreased summer temperatures in the area alongside the river, will produce valuable data (see the lower color photo on the front cover, and Figures 10 and 11).

Figure 10 : Before restoration (the Tondemun district in June 2003)

Source: Reference[18]

Figure 11 : Westward view from the rooftop of a building adjacent to the Cheonggyecheon near the Tondemun (August 2005) (see the color photo on the front cover)

Source: Taken by Kumi Kataoka, the National Institute for Environmental Studies

6 Recommendations on measures to mitigate urban heat islands

There is growing awareness that the urban heat island effect (local warming) and global warming have much in common in terms of their mitigation measures. In fact, they are both caused by the mass consumption of energy and resources and share some key mitigation measures: (i) energy and resource saving in buildings, (ii) energy-saving traffic systems, (iii) restoration of green spaces, and (iv) improvement of urban airflow.

The Tokyo Metropolitan Government is focusing on energy-saving measures in an effort to create an energy-efficient city. It takes account of both the urban heat island phenomenon and global warming as the "twin warmings" responsible. Underlying this action is the realization that energy-saving measures such as a reduction in energy consumption contribute to alleviating both global warming through reduction of CO_2 emissions and the urban heat island effect through reduction of exhaust heat.

As noted above, the urban heat island effect exists wherever there are large cities. Tokyo and many other major cities in Japan, carried out urban development after World War II in an unsystematic way, giving little consideration given to possible impacts on urban climate. The result is an urban system based on mass production and consumption that causes a variety of problems. For example, the incidence of heat stroke is on the rise due to higher daytime temperatures, and sweltering nights have become so frequent and uncomfortable as to be intolerable. Urban heat island mitigation measures must be adopted when planning further development in these cities.

(1) Approaches from the perspective of urban planning

Urban heat island mitigation measures must involve not only individual measures based on environmental technologies but also specific measures to improve infrastructure such as roads, rivers, parks and green spaces. For example, measures such as the development of "wind paths" that use locally circulating winds for urban ventilation should be incorporated into land use and urban planning in a systematic and comprehensive manner. In this context, the Cheonggyecheon restoration project in Seoul City is noteworthy. In short, urban heat island mitigation measures need to be incorporated into urban planning master plans from the outset.

In cooperation with local residents and corporations, local governments are strongly expected to play a leading role in facilitating mitigation measures and incorporating them into urban renewal projects that are already underway. Local policies should also reflect the policies and measures promoted by central government. In particular, relevant information should be shared with all parties who have a common appreciation of the mitigation measures needed. With large numbers of buildings constructed during Japan's period of high economic growth requiring replacement soon, this time of urban renewal in many cities provides a golden opportunity to implement urban heat island mitigation measures.

(2) Elucidation of the mechanisms of the urban heat island effect and mitigation measures

(i) Enhanced monitoring to elucidate the urban heat island effect

The urban heat island effect is the product of a variety of factors such as changes in land use and anthropogenic heat release. Both the thermal and the natural characteristics of relevant areas concerned should be studied, and area-specific approaches should be adopted to carry out effective mitigation measures within the framework of urban planning.

The coverage provided by the observation and monitoring stations of the Automated Meteorological Data Acquisition System (AMeDAS) of the Japan Meteorological Agency is considered insufficient to keep track of the regional characteristics of large, densely-populated cities and their surroundings. A better monitoring system based on high-density meteorological observation is necessary. AMeDAS monitors precipitation at about 1,300 sites across the country, one for approximately every 17km^2, Some 850 sites, one for approximately every 21km^2, are used to monitor wind direction and speed, temperature, and hours of sunshine as well as precipitation. These monitoring sites, however, are not evenly distributed across the country. In fact, there are only 10 such sites in Tokyo, not including outlying islands, and only 5 in the 23 Tokyo wards. In 2002, therefore, the Tokyo Metropolitan Government began installing monitoring equipment at 120 sites in the 23 wards in order to obtain highly precise, high-density meteorological data, such as temperature and relative humidity. This is a means to elucidate the mechanisms responsible for the urban heat island effect. Other government-designated cities should also create high-density meteorological monitoring systems of this sort.

The type of measurement survey conducted this summer (2005) along the Tokyo waterfront area should also be implemented this winter and again next year, and in other cities as well.

(ii) Development of simulation techniques to assess mitigation measures

Simulation plays a vital role in forecasting the urban heat island effect. The development of techniques to simulate the effects of prospective mitigation measures is therefore imperative so that they can be implemented in a comprehensive and systematic manner.

Efforts are underway to develop simulation techniques for the urban thermal environment. They should be integrated with simulation results obtained from other research areas in order to predict the effects of mitigation measures and to develop effective alternatives. Such techniques would enable the accurate assessment of the effects of mitigation measures such as wind paths, air cooling by green spaces, rooftop greening, water-retentive pavement, and thermo-shield pavement.

(iii) Development of comprehensive techniques to assess urban heat island mitigation measures

A system to assess the effectiveness of urban heat island mitigation measures should be put in place to prevent urban development projects such as urban renewal from exacerbating the heat island effect. This entails the development of techniques to assess the effectiveness of urban heat island mitigation measures.

Urban heat island mitigation measures already in place are assessed with the effects of each individual element of the technology quantified separately. There is still a need for comprehensive techniques to assess the overall effects of mitigation measures on entire cities. For example, buildings are the most important elements of cities and require the development of appropriate mitigation measures in order to reduce the urban heat island effect on a city-wide basis. However, the current assessment system is designed only to assess buildings on an individual basis. As new buildings sprout up in rapid succession, they should instead be assessed on a group, block or district basis. There is thus a need to develop standards for comprehensive assessment.

(3) From research to policy implementation

Priorities for implementing urban heat island mitigation measures must be set. Priority has commonly been given to measures that are readily available, but there is a growing need to adopt long-term, large-scale measures. The short-term, small-scale measures now being implemented are not always delivering the hoped-for results.

The use of “wind paths”, a typical long-term measure designed to channel locally circulating winds into urban areas, is shifting from a research and investigation phase to an implementation phase, both in Japan and abroad. Under these circumstances, the current efforts to apply scientific findings by creating “wind paths” from the Meguro River in the Osaki Station district and to use the orientation of buildings near the river to influence wind flow are unprecedented and praiseworthy contributions to community planning.

A variety of mitigation measures should first be applied to the model areas in order to accumulate data on their effects. These areas can then serve as useful examples to other areas in Japan and to rapidly urbanizing cities throughout Asia.

Acknowledgements

I would like to express my deep gratitude to the following people for their support and assistance in preparing this article: Toshiaki Ichinose, Senior Research Scientist, Center for Global Environmental Research, National Institute for Environmental Studies; Shinji Wakamatsu, Project Leader, PM2.5 · DEP Research Project, National Institute for Environmental Studies; Professor Keisuke Hanaki, Department of Urban Engineering, University of Tokyo; Associate Professor Hikari Fujii, Department of Earth Resources Engineering, Faculty of Engineering, Kyushu University; Tomokazu Okada, assistant manager, Urban and Global Environment Division, Bureau of Environment, Tokyo Metropolitan Government; Yuko Nishida, manager, Natural Environment Division, Bureau of Environment, Tokyo Metropolitan Government; Minoru Kanda, general manager, Department of City Amenity Improvement, Shinagawa City. I would also like to thank Hiroyuki Takahashi (senior researcher, Japan Institute of Construction Engineering) for material concerning the General Technology Development Project for the "Development of Urban Thermal Environment Assessment and Mitigation Technology" (administered by the Ministry of Land, Infrastructure and Transport), and Kumi Kataoka (Center for Global Environmental Research, National Institute for Environmental Studies) kindly providing photographs.

Glossary

*1 IPCC (Intergovernmental Panel on Climate Change)
IPCC is a UN organization jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to provide a scientific basis for global warming mitigation measures by using the latest findings on global climate change.

*2 Radiative cooling
A phenomenon whereby the radiation of infrared rays back into space cools down the air and the surface

*3 Inversion layer
An atmospheric layer in which the usual temperature gradient, with warm air below cold air, is reversed

*4 Dust dome
A phenomenon whereby air pollutants are trapped in a dome-shaped layer near the surface

*5 Tokyo Wall
This refers to a wall of skyscrapers in the Tokyo waterfront area that collectively blocks the sea wind, thereby exacerbating the urban heat island effect.

*6 Surface Inversion Layers
Surface inversion layers are formed when the surface temperature drops due to radiative cooling, cooling the air above it such that the higher the altitude, the higher the air temperature.

References

[1] The Science Council of Japan. Recommendations on the Analysis of the Urban Heat Island Effect from the Viewpoint of Architecture and Urban Environment Study, 2003. (Japanese) :
http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-18-t996-38.pdf

[2] Yamashita, S. "Heat Island". Environment Climatology. Yoshino, M. and Fukuoka, Y., ed. University of Tokyo Press, 2003. (Japanese)

[3] Nemoto, M. and Kobayashi, H. Trends in the Studies of Heat Island Mitigation Technology : Analysis from the Viewpoint of Energy Use. Science & Technology Trends Quarterly Review. No. 17, 2002. (Japanese)

[4] The Ministry of the Environment. Report on the Analysis of the Urban Heat Island Effect and its Mitigation Measures: 2000 (Expanded Edition), 2001. (Japanese) :
http://www.env.go.jp/air/report/h14-01/index.html

[5] Saka, S. Development of Urban Space Forming Technology Contributing to Urban Heat Island Mitigation Measures. The National Institute for Land and Infrastructure Management, 2004. (Japanese):
http://www.nilim.go.jp/japanese/report/lect

ure/kouenkai2004/image/saka1.pdf

[6] The Ministry of the Environment. For the Promotion of Urban Heat Island Mitigation Measures (Brochure), 2000. (Japanese) : http://www.env.go.jp/air/life/heat_island/panf01.pdf

[7] The Ministry of Land, Infrastructure and Transport. (Japanese) : http://www.mlit.go.jp/kisha/kisha05/07/070719_2/05.pdf

[8] Ichinose, T. “Urban Planning and Wind Paths”. Environment Climatology. Yoshino, M. and Fukuoka, Y., ed. University of Tokyo Press, 2003. (Japanese)

[9] The Science Council of Japan. The Paradigm Changeover of Metropolis Policies Emphasizing the Quality of Life (Proclamation), 2005. (Japanese): http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-19-s1025.pdf

[10] Secretariat of the Urban Renaissance Headquarters, Cabinet Secretariat. (Japanese): http://www.kantei.go.jp/jp/singi/tosisaisei/siryou/0411tiiki.pdf

[11] The Tokyo Metropolitan Government. (Japanese): http://www.metro.tokyo.jp/INET/OSHIRASE/2005/04/20f4b100.htm

[12] The Tokyo Metropolitan Government. (Japanese): http://www2.kankyo.metro.tokyo.jp/heat/maperia.html

[13] The Shinagawa City (Tokyo). (Japanese) : http://www2.city.shinagawa.tokyo.jp/jigyo/05/bijyon_s.pdf

[14] Iwamura, K. Case Study: (b) Germany. IBEC. No. 138, 2003. (Japanese)

[15] The Environmental Protection Agency (U.S.) : http://www.epa.gov/heatisland/index.html

[16] Urano, A. and Morikawa, Y. Case Study: (a) The United States. IBEC. No. 138, 2003. (Japanese)

[17] Seoul City: http://japanese.seoul.go.kr/chungaehome/seoul/main.htm

[18] Seoul City: http://japanese.seoul.go.kr/chungaehome/seoul/sub_htm/4sub_03.htm

Yoshika YAMAMOTO
Environment and Energy Research Unit, Science and Technology Foresight Center

She is engaged in a variety of projects for global environmental conservation in both the public and private sectors, and in research on the detection of impacts associated with climate change. She is interested in science and technology policies concerning climate change. She doubles as a member of the Committee for the Promotion of Environmental Practice of Shinagawa City, and is therefore interested in the communication of scientific information on environmental issues.

(Original Japanese version: published in September 2005)

7

Trend of Research and Development for Magnesium Alloys
— Reducing the Weight of Structural Materials in Motor Vehicles —

Hisao Watarai
Materials and Manufacturing Technology Research Unit

1 Introduction

According to information[1] provided by the Agency for Natural Resources and Energy in 2004, passenger transport accounted for about 60% of total energy consumption in the transport sector, and in particular the use of private cars contributed significantly to annual energy consumption, which rose by 64% between 1990 and 2001. To build a sustainable society in the future it will be necessary to reduce the weight of the structural materials used in transport equipment, especially private cars, both to conserve energy and to minimize global warming.

Today, magnesium (Mg) alloys are recognized alternatives to iron and aluminum to reduce the weight of structural materials. In recent years, Mg alloys, previously used only in a limited range of applications, have served as automobile parts and cases for portable electronic devices such as notebook-type personal computers (PCs), as well as portable telephones, thanks to improved corrosion resistance and the development of new technologies to form and work the alloys. In addition, the alloys' improved heat resistance and strength have extended their possible range of application. In particular, given the desirability of minimizing energy consumption and creating and developing a new industry, it is expected that Mg alloys may be used as structural materials for motor vehicles.

This article describes what Mg alloys are, and what applications they are expected to have in automobiles, and indicates where our R & D efforts should be aimed, based on the existing R & D picture both in Japan and other countries.

2 Description of magnesium alloys

2-1 Magnesium as a pure metal

(1) Natural resources and refining methods

Among all the elements, magnesium (Mg) has the 8th highest Clarke number (the amount of an element in the surface layer of the Earth), which is 1/4 that of aluminum, 2/5 that of iron and 190 times higher than those of nickel and copper. The abundance of Mg in the Earth is considered to be the 4th highest, following iron, oxygen and silicon. The raw ores of Mg are dolomite ($MgCO_3$•$CaCO_3$) and magnesite ($MgCO_3$), and Mg is the second most abundant metal in seawater, following sodium. Therefore, it can be said that magnesium is an almost inexhaustible resource, and is distributed all over the world.

The methods for manufacturing Mg can roughly be divided into electrolysis and thermal reduction. Electrolysis method involves extracting magnesium chloride from Mg ores and then reducing the magnesium to the metallic form by electrolysis. Thermal reduction involves extracting magnesium oxide from Mg ores, adding a reducing agent such as ferro-silicon to it, and refining the resulting material by heating it to a high temperature under reduced pressure.

(2) Properties of pure Mg metal

Magnesium is the lightest of all metals in practical use, and has a density (1.74g/cm^3) of about 2/3 that of aluminum and 1/4 that of iron. This material has useful properties such as shielding against electromagnetic waves,

Table 1 : Comparison of physical properties of magnesium and other metals

Metal name	Specific gravity	Melting point (°C)	Boiling point (°C)	Latent heat of melting (kJ/kg, J/cm^3)	Specific heat (kJ/kg·K, J/cm^3·K)	Coefficient of linear expansion x 10^6	Tensile strength (MPa)	Elongation	Hardness HB
Mg	1.74	650	1110	368, 640	1.05, 1.84	25.5	98	5	30
Al	2.74	660	2486	398, 1088	0.88, 2.43	23.9	88	45	23
Fe	7.86	1535	2754	272, 213	0.46, 3.68	11.7	265	45	67

Source: Provided by Prof. Kamado, Nagaoka University of Technology

vibration damping, dent resistance, machinability, and low toxicity in humans.

On the other hand, magnesium has shortcomings such as insufficient strength, elongation and heat resistance, as well as being subject to corrosion. Its readiness to corrode has been found to be due to its trace content of metals such as iron (Fe), nickel (Ni) and copper (Cu). The problem of corrosion has to be solved if the purity of the Mg is improved. However, its electrochemical potential indicates that magnesium will corrode by contact corrosion whenever it is in contact with any other metal. Therefore, magnesium is generally surface-treated before it is used.

2-2 Properties of magnesium improved by alloying

Pure magnesium possesses a variety of excellent properties. To put it to practical use, however, it is necessary to deal with its shortcomings and improve its performance. Alloying may be the answer. Alloying means altering a pure metal by melting it and adding other elements to it. This method is applied to almost all metals.

Alloying magnesium improves its strength, heat resistance and creep resistance (creep is defined as deformation at a high temperature and under load). For example, AZ-based Mg alloys are well known materials produced by adding aluminum (Al) and zinc (Zn) to pure Mg. The appropriate amounts of additives may improve the strength, castability, workability, corrosion resistance and weldability of these alloys in a well-balanced way. AZ91-based Mg alloys have excellent mechanical properties and castability. In particular, AZ91D-based Mg alloys with high purity for high corrosion resistance are used in car parts, notebook PCs, portable telephones and other products. AZ31C-based Mg alloys, which have high formability and weldability, are most often used as elongating materials for plates, pipes, rods and other products. ZK60A-based Mg alloys produced by adding zinc (Zn) and zirconium (Zr) have a higher hot-workability than other materials. Mg alloys produced by adding rare earth elements such as cerium (Ce) and neodymium (Nd) have high strength at 200 to 250°C and excellent creep resistance and heat resistance[2]. The improved performance characteristics realized by recent R & D efforts will be described in Chapter 4.

2-3 Working methods

The use of Mg alloys has recently increased in applications such as cases for notebook PCs and portable electronic devices because the methods for working these materials have improved rapidly. Mg alloys, which have crystal structures different from those of structural materials such as iron, steel, aluminum and copper alloys, are so difficult to roll at ambient temperatures that it is necessary to work at higher temperatures. Mg alloys may be extruded in almost the same way as aluminum alloys because they have almost the same hot deformation resistance. Forging with a hydraulic press is also used to produce parts for transport equipment such as motor vehicles, helicopters and other aircraft. Die casting (forming molten materials in dies) is mainly used to form parts for motor vehicles because it can form any material in near net shape (nearly the final desired shape) as well as thin products, and is therefore well suited to mass production. In addition, the use of injection molding is behind the recent increase in the use of Mg alloys in the cases of portable electronic devices. Thixotropic molding (or thixo-molding), a combination of injection molding and die casting often used to form plastic products, is in practical use as a semi-melt working method.

The surface treatment techniques used to provide highly corrosion resistant Mg alloy products have already advanced to the same level as die casting methods for carbon steel plates and aluminum alloy products. Mg alloys are generally submitted to a chemical conversion treatment using a chemical reaction. If they are used in severe conditions that may cause wear and stray current corrosion, however, they are generally given an anodic oxidation treatment. Mg alloys may be welded with the same techniques as other metals, including fusion welding. Recently, however, friction stir welding (FSW), a technique useful for metals having low melting points, has attracted much attention because it has several advantages.

To put Mg alloy products to practical use, however, it is necessary to solve the critical problem that magnesium has a high activity in the presence of oxygen. To produce or cast alloy composites (alloy metals) by melting, it is necessary to melt and mold the materials at a high temperature. For Mg, it is essential to prevent the materials from reacting with oxygen in the air. Currently, this is mainly accomplished with sulfur hexafluoride (SF6) gas, but this is a potential greenhouse gas so alternatives that do not use SF6 are now under investigation. Chapter 4 provides more detailed information on recent research aimed at improved fire resistance.

2-4 Pricing

Import prices for magnesium are still higher than for aluminum, but they have dropped to less than twice the price of aluminum. At present, import prices are 180 to 190 yen/kg for Mg and about 280 yen/kg for Mg alloys. The prices for Mg and Mg alloy products depend on the type of product, such as billets and plates. Worked material for automobile bodies is now on the order of 1,000 to 3,000 yen/kg. To use Mg alloys in a wider range of applications, it is generally felt that prices need to be lower than about 500 to 1,000 yen/kg for cast parts and 1,000 to 2,000 yen/kg for thin rolled plates. The prices for Mg and Mg alloys are so much higher than those for Al and its alloys because the production of Mg and Mg alloy products, worked and formed, is about 100 times smaller than that of Al metal and alloy products, and because high-efficiency working processes for Mg metals and alloys are still being developed[3].

2-5 Applications and examples

The development of magnesium alloy products for nongovernmental use has a long history that dates from 1945. Research has been conducted on the manufacture of various products such as office goods, agricultural machines and tools, telecommunication equipment and sporting goods. Some products have been commercialized, though few of them saw steady use for very long. Recently, Mg alloys have begun to be used for the cases of notebook PCs and portable electronic devices. At present, there are more active moves toward the future utilization of Mg alloys for transport equipment including motor vehicles, motorcycles and aircraft. The domestic demand for Mg alloys in 2002 was greatest for portable telephone cases, followed by notebook PCs, parts for automobiles and two-wheeled vehicles, and digital video cameras. Very recently, some Mg alloys have been used for the housings of large-sized plasma display panels as well.

The use of Mg alloys is greatest for portable electronic devices because the materials have several advantages: they are light, but being metallic they conduct and radiate heat better than plastic; they maintain a metallic texture, but they are non-magnetic; they can block electromagnetic waves and minimize the influence of noise. Mg alloys have not yet been used as light structural materials for aircraft. However, they have been used for the gearbox housings of helicopters and other aircraft because they are good vibration dampers, a characteristic that has also brought them into use in the steering wheel cores of motor vehicles.

2-6 Recyclability

Generally, metals are more recyclable than plastics because they can be melted and reused. In particular, magnesium has a lower specific heat and a lower melting point than other metals.

This gives the advantage of using less energy in recycling, with recycled Mg requiring as little as about 4% of the energy required to manufacture new material. At present, however, recycling procedures are still not fully developed, and work is underway on the technologies required for recycling wastes from relatively clean factories[10]. In the future, it may be necessary to review the material flow in order to ensure that recycled materials will account for about tens percent of total Mg alloy production.

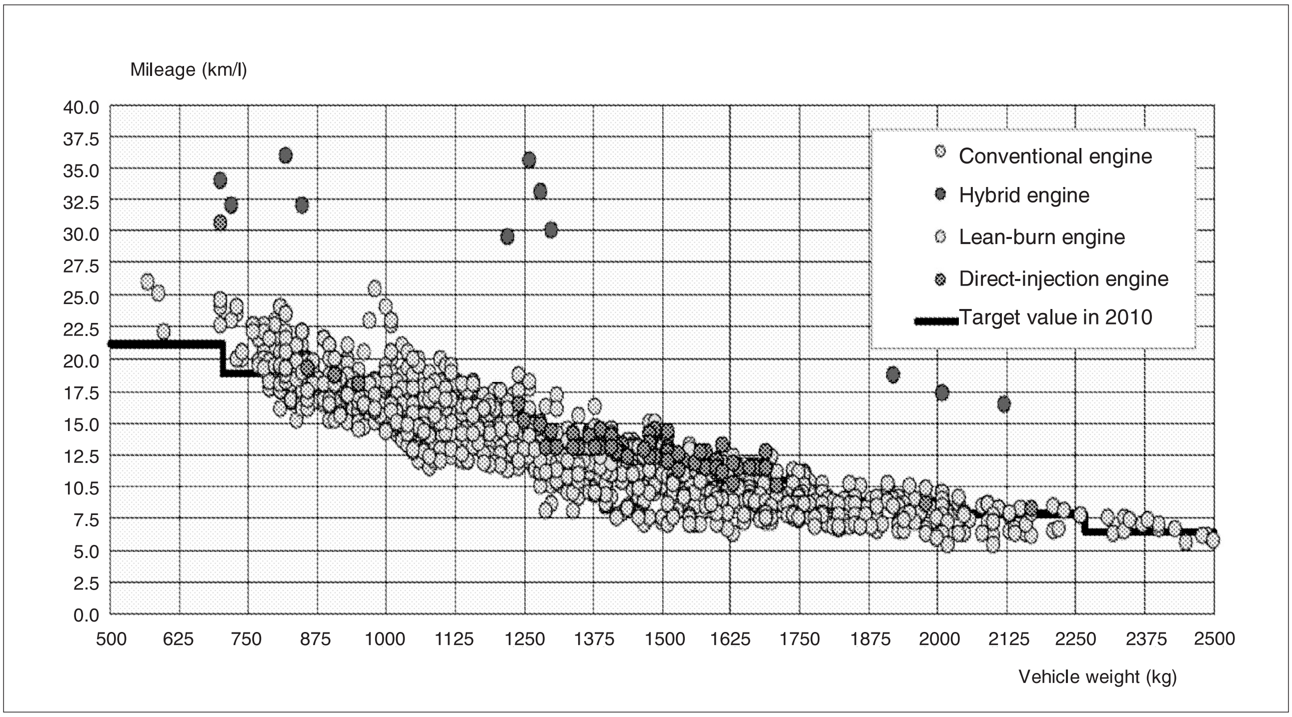
3 Expectations for and problems in the wider application of Mg alloys to motor vehicles

Motor vehicles tend to increase in weight as they are given additional functions such as safety devices and electronic equipment. The challenge for the future is not only to offset weight increases due to performance enhancements, but also to reduce the overall weight of motor vehicles. Conventional weight reduction technologies have reduced the weight of motor vehicles by improving their structural design and thinning steel materials by increasing their strength. For the future, however, it is generally recognized that drastic changes in structural materials should be considered.

For passenger cars, the general rule is that about 86% of their total lifetime energy use (from the time of production to the time of disuse or scrapping) is consumed by carrying their own weight and persons around. It is thought that mileage might be 5 - 10% higher if cars weighed 10% less, as shown in Figure 1. For example, a weight reduction of 1 kg per 1,000 kg of car weight could increase mileage by about 0.016 km/l. For enhanced energy saving in motor vehicles, therefore, weight reduction technology for structural materials is indispensable, so it is necessary to use large quantities of materials having a high specific strength (strength (in kg/cm^2) divided by specific gravity).

In Europe, the regulation governing CO_2 emissions from motor vehicles has been worked out, setting the standard that CO_2 emission shall not exceed 140 g/km in 2012 and 120 g/km in 2014. To meet the standard in 2014, it will be necessary to attain the high mileage of 20 km/l. Figure 2 shows how much improvement will be needed for domestic small passenger cars to meet the mileage standard in 2010. According to this analysis, it will be necessary to reduce the mass of vehicles by about 10% (100 to 150 kg). To attain such a great reduction in mass, it will

Figure 1 : Mileage vs. weight for a gasoline-powered passenger car

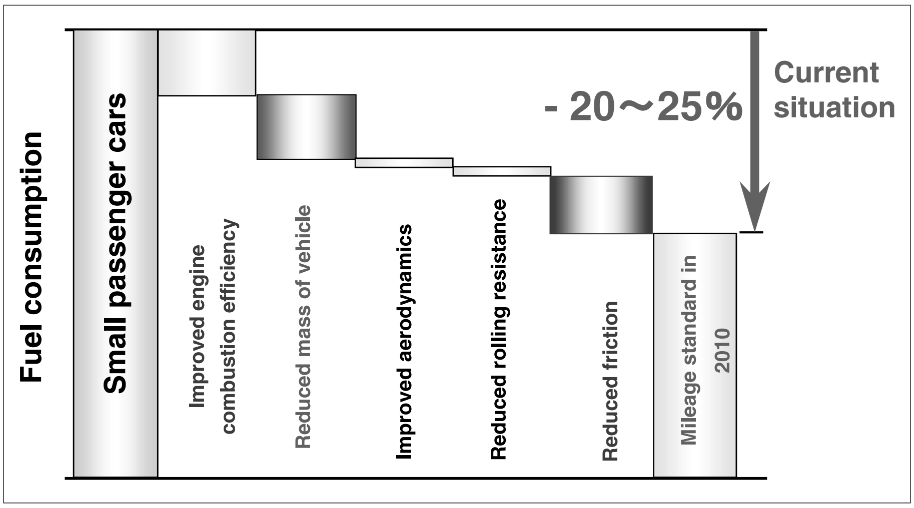


Source: The home page of the Ministry of Land, Infrastructure and Transport[5] probably be necessary to replace steel with Mg alloys as the structural material. For this reason, much attention is now focused on Mg alloys as structural materials or parts for motor vehicles.

Figure 3 shows a car and the places where Mg alloys have been used or where their application continues to be considered.

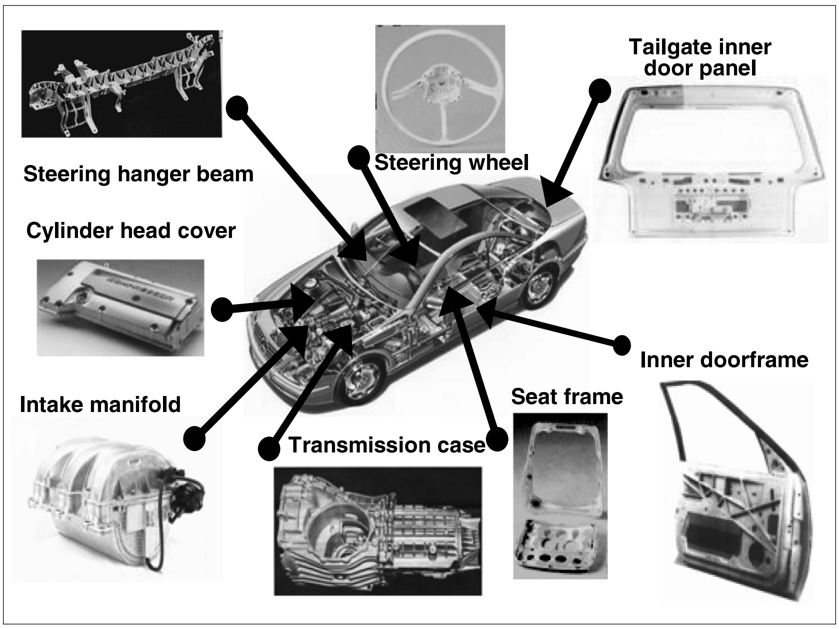
In Germany, Mg alloys have been used as die cast parts, and Volkswagen used 42 thousand tons of Mg alloys in 1971. In the U.S.A., Mg alloy parts have been used in motor vehicles since the 1970s. General Motors and Ford started to use Mg alloys in steering columns in 1973 and 1978, respectively. In Japan recently, the use of Mg alloys has increased incrementally each time a new car is developed. The general-purpose Mg alloy AZ91D is used in various types of covers and cases. Mg alloys AM50 and AM60, with higher ductility and impact resistance, are used for steering wheel cores. Mg alloys that contain additives such as rare earth elements and calcium (Ca) to provide high heat resistance are used for transmission cases and oil pans. Japanese companies have already used Mg alloys in more than 10 types of parts. Other applications include, but are not limited to, steering wheel cores, engine head covers, air bag plates, electronic control part cases, seat frames, and transmission

Figure 2 : Target by function to meet the mileage standard in 2010



Source: Provided by Prof. Kamado, Nagaoka University of Technology

Figure 3 : Applications of Mg alloys in motor vehicles



Source: Provided by Prof. Kamado, Nagaoka University of Technology

Table 2 : Demand for Mg alloys from automobile manufacturers

Formed materials	Metals	• Stable supply and price reduction (including recycling technologies) • Development of low-cost and high-performance alloys (with high heat resistance, strength, toughness, etc.) • Establishment of infrastructure for recycling
	Plates	• Attainment of high formability and good surface quality • Widening and low-cost technologies (for thin plates, continuously cast materials, etc.)
	Extruded materials	• Large-sized materials, irregular sections, low-cost technologies (high-speed extrusion)
Processing technologies	Pressing	• High-speed super-plasticity pressing technologies for large-sized parts
	Forging	• Die casting technologies for large-sized and thin products with decreased defects such as gas and nests
	Welding & joining	• Welding technologies to deal with corrosion protection and resistance to stress corrosion cracking (SCC) • Mechanical joining and solid-phase welding technologies including the joining of different materials
	Surface reforming	• Low-cost surface treatment, easy to recycle products

Source: Prepared by STFC based on a lecture by Prof. Kamado at NISTEP

cases. In particular, steering parts made from Mg alloys are used in many car models because these materials have a good vibration damping effect.

In the U.S.A., three automobile manufacturers (GM, Ford and Daimler-Chrysler), generally called ‘the Big 3’, jointly established the United States Council for Automotive Research (USCAR) in 1992. The Council worked out a plan for strengthening their competitiveness and taking environmental measures, and has since made efforts to implement the plan. As part of this, the Magnesium Powertrain Cast Components Project was started in 2001 under the direction of the United States Automotive Materials Partnership (USAMP). This project aims to increase the use of Mg alloys in a motor vehicle to about 100 kg by 2020[6].

To bring about the extensive use of Mg alloys in motor vehicles, however, it will be necessary to achieve a stable supply of Mg ore, improve the heat resistance of Mg alloys, improve high-speed forming, welding, joining, surface reforming and other technologies for large-sized parts and members, and reduce the cost of these technologies. Table 2 summarizes the technical problems pointed out or requests made by automobile manufacturers as Mg alloy users.

4 Trend of research and development for magnesium alloys in Japan

4-1 Development of high-performance alloys

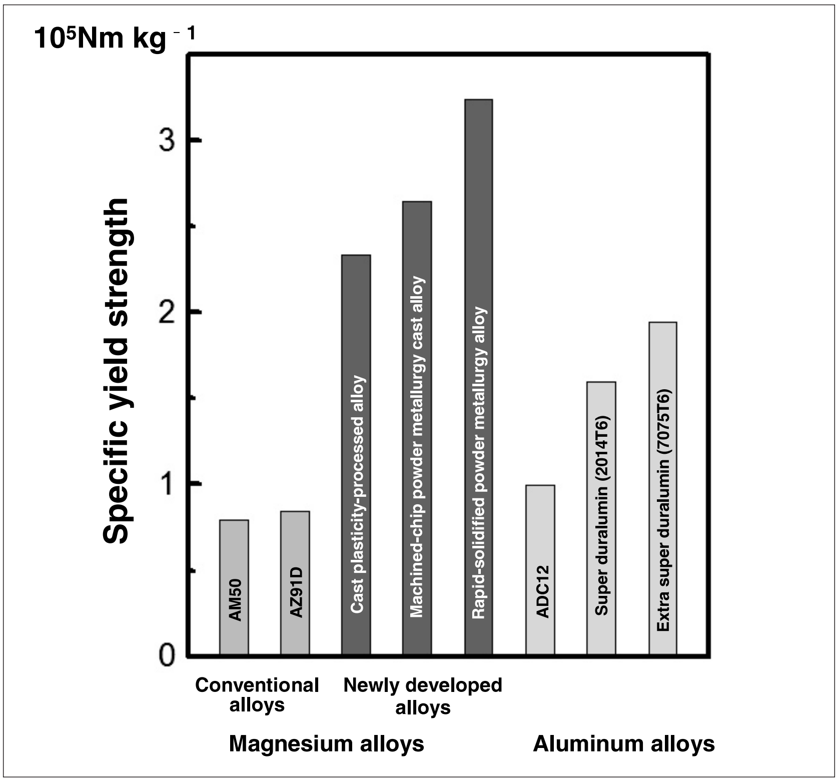
(1) Development of magnesium alloy having the highest strength in the world and a long-period multilayer structure

The development of a new high-performance magnesium alloy as a result of targeted research funded by the Ministry of Education, Culture, Sports, Science and Technology that began in September 1999 is generally considered a breakthrough. This R & D effort produced new Mg-Zn-, Mg-Al-Ca-, and Mg-Y-Zn-based alloys with high strength, creep resistance and heat resistance.

Prof. Yoshihito Kawamura et al. at Kumamoto University succeeded in developing the high-strength and fast-solidifying alloy $Mg_{97}Zn_1Y_2$ using powder metallurgy [7] and showed that this alloy has the special atomic configuration called a long-period multilayer structure. It can also be manufactured by casting, and the substitution of dysprosium (Dy), holmium (Ho) or erbium (Er) as a rare earth element can give almost the same properties as the use of yttrium (Y). In addition, they found ways to process the alloy to improve both its strength and ductility.

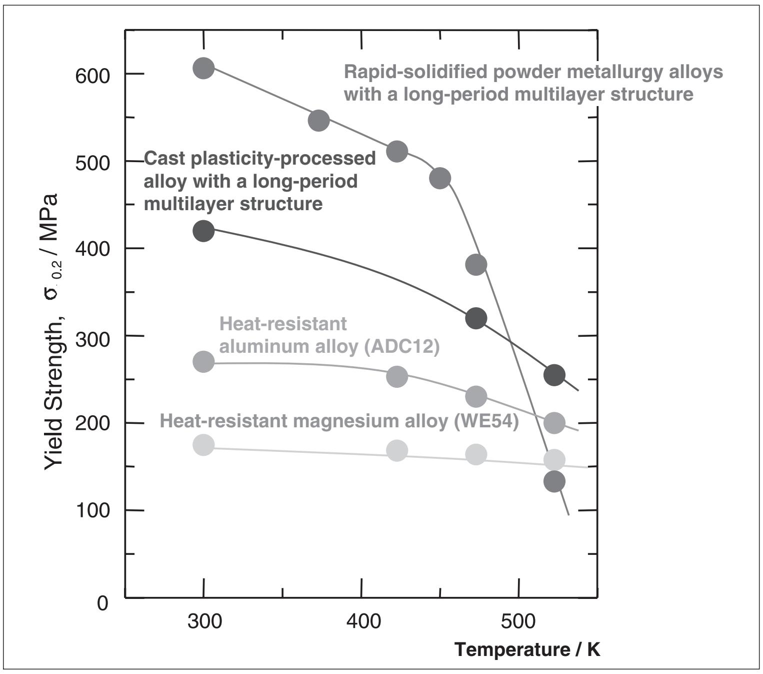
Figures 4 and 5 show the characteristics of the new alloys. The new alloys' specific strength is about 3 times higher than that of commercial high-strength Mg alloys, and higher than commercial titanium alloys and extra super duralumin. Even at high temperatures, they retain high strength and rapid superplasticity (superplasticity is defined as a tensile elongation of 200% or more at a distortion rate of 10-2 to 10-1/sec or more).

Figure 4 : Specific yield strength of Mg alloy with a long-period multilayer structure



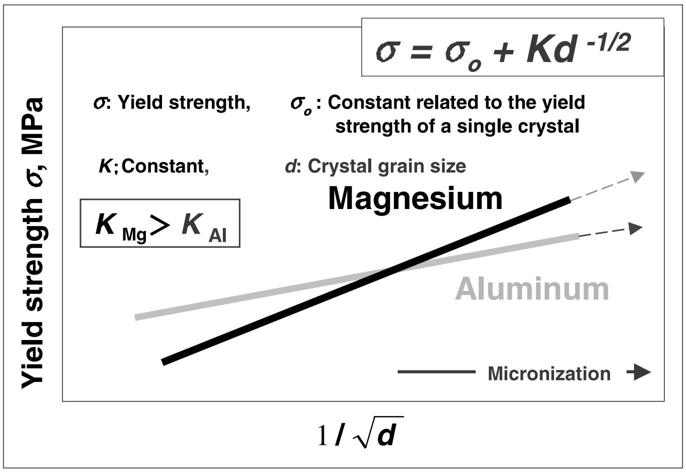
Source: Provided by Prof. Kawamura, Kumamoto University

Figure 5 : Yield strength vs. temperature of new alloys with a long-period multilayer structure



Source: Provided by Prof. Kawamura, Kumamoto University

Figure 6 : Crystal grain size vs. yield strength



Based on these R & D efforts to create new alloys, Development of Next-Generation Powder Metallurgy Magnesium Alloys and Members was started in 2003 as a part of the Project “Civil Aviation Fundamental Technology Program-Advanced Materials & Process Development for Next Generation Aircraft Structures” set up by the Ministry of Economy, Trade and Industry.

(2) Improvement in heat resistance

Prof. Shigeharu Kamado et al. at Nagaoka University of Technology are now developing Mg alloys with high die-castability and high heat resistance, for use in automotive drive systems under a project set up by the NEDO (New Energy and Industrial Technology Development Organization)[7]. These alloys contain aluminum and a rare earth element as additives and show high creep resistance (which should be restrained if they are used at a high temperature). Furthermore, R & D efforts were made to improve Mg-Zn-Al-Ca-RE (RE = rare earth element)-based alloys, with the aim of giving them characteristics comparable to those of heat-resistant aluminum alloy ADC12. To put the improved alloys to practical use, transmission cases were also experimentally manufactured.

(3) Mechanical performance improved by micronization of crystal grains

A metal’s mechanical strength depends on its crystal grain size, as quantified in the Hall-Petch relationship (Figure 6). It is generally known that micronizing their crystal grains improves the strength of Mg alloys more than Al alloys.

(i) Micronization of crystal grains by ECAP method

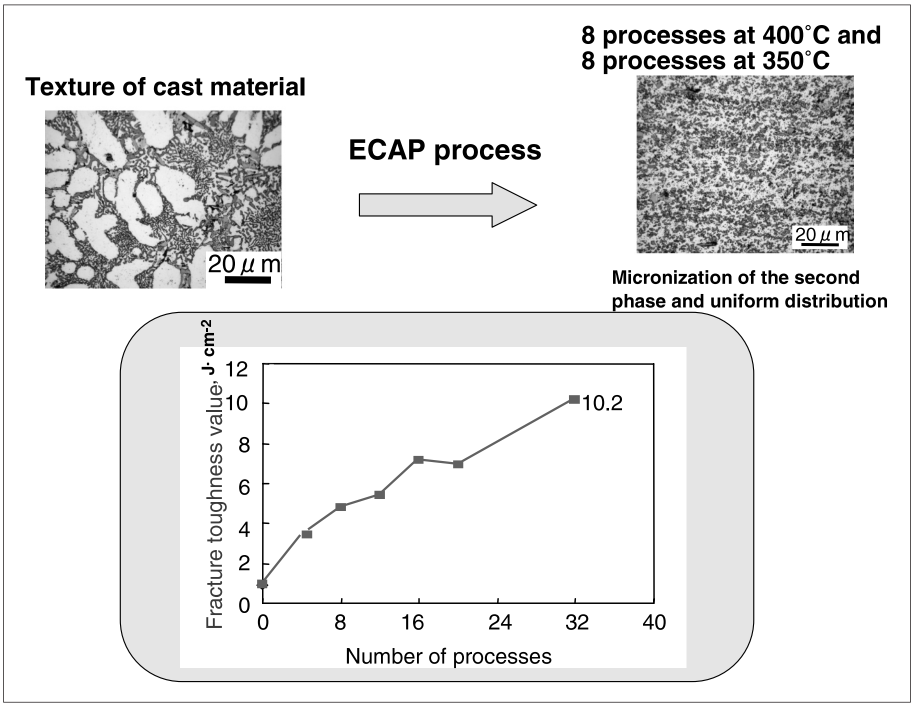
In 1981, Segal et al. in Russia published a method called ECAP or ECAE (Equal-Channel Angular Pressing or Extrusion) for micronizing crystal grains by combining a high working stress (shear distortion) and recrystallization. If this process is repeated several times, the size of crystal grains will be decreased to the level of 2 to 3 μm. Mg alloys subjected to the process repeatedly become excellent materials, with higher strength, higher elongation and an improved fracture toughness value (value expressing the stress that starts to expand cracks in a material). Figure 7 shows a case where the repeated ECAP process decreases the crystal grain size of a material and increases the fracture toughness value of the material.

(ii) Micronization of crystal grains by precipitation

It is considered desirable to form conventional Mg alloys at a high temperature of 200°C or more. To enlarge the range of applications, it will be necessary to reduce the cost of processing[14], and the other method, which can micronize crystal grains at a lower temperature and a higher speed, is preferable.

It was reported that processing Mg alloys around 175°C produced great quantities of fine precipitates on the order of 50 to 100 nm, and that Mg alloys were recrystallized from the precipitates to provide alloys with a crystal

Figure 7 : Fracture toughness improved by rotary ECAP method



Source: Provided by Materials Research Institute for Sustainable Development, National Institute of Advanced Industrial Science and Technology

size of 0.5 μm and both high strength and high elongation. Mg alloys with higher strength and higher extensibility were obtained from the alloys introduced in Section 4-1 (2) with the "Repeated Plastic Working method" developed by Katsuyoshi Kondoh, Associate Professor, Research Center for Advanced Science and Technology, the University of Tokyo[14].

4-2 Development for forming and welding technologies

(1) Forming technologies

Among the different Mg alloy forming methods, a great deal of attention is focused on die-casting, thixo-molding (injection molding) and press forging techniques as described in Section 2-3[8]. These techniques are selected according to the desired application, and continue to be further improved.

In the die casting technique, molten metal is poured into a set of dies; a mobile die and a fixed die. It can be used for mass production, has good dimensional accuracy, and can produce parts that are thin and have complicated shapes. The thixo-molding technique uses thixotropy (the phenomenon of having lower viscosity and higher fluidity when shear force is applied in the semi-molten and granulated solid phase) and injection molding (the conventional plastic molding method in which a heat-melted material is injected into molds and solidified by cooling). This technique, which can be used in an enclosed space, has the great advantage that harmless Ar gas can be used as an alternative to SF6, a gas with adverse environmental effects. This method is used to produce cases for portable electronic devices and production is increasing rapidly. The press forging technique is a method of forging, bending, pressing and finishing thin Mg alloy plates at 300°C to provide thin products of high quality. This method is used in the mass production of cases for electronic devices such as MD players and digital cameras. This method has advantages in that it can be used to manufacture Mg alloy products with a better surface quality than conventional cast Mg alloy products without requiring processing such as polishing, and it improves the rigidity of products.

(2) Welding technologies

It has been felt that it was difficult to weld Mg alloys. However, the use of the friction stir welding (FSW) method will probably attract a great deal of attention. This method is applicable to light metals having a relatively low softening point.

FSW was developed in the United Kingdom about 15 years ago. As shown in Figure 8, it involves simultaneously rotating and pushing a cylindrical tool with a projection on its lower end so as to drive the projection into the parts of base materials to be welded and produce friction heat that softens the base materials; and stirring and mixing the plastic material around the welded parts by the rotation of the tool to weld different base materials together. This welding method has the advantages that it is unlikely to produce deformation, pores and cracks, that no sealing gas is required, and that no harmful radiation such as infrared is produced. The FSW method is now used to manufacture all the Shinkansen trains of Series 700 that use aluminum car bodies. This technology is expected to become very important in the manufacture of large-sized Mg alloy parts.

4-3 Improved fire resistance

One problem with Mg alloys is their high activity in the presence of oxygen. To reduce the hazard, SF6 is used to prevent Mg alloys in the molten state from coming into contact with air, as described in Section 2-3. However, SF6 has a long lifetime in the atmosphere and is 24,000 times more potent than an equal amount of CO_2 in causing global warming. Therefore, it is necessary to minimize the emission of SF6 and urgently necessary to adopt SF6-free Mg alloy manufacturing methods. To take measures against SF6, the NEDO (New Energy and Industrial Technology Development Organization) started the 3-year "Development of Non-SF6 Melting Process and Micro Structural Control for High Performance Magnesium Alloy" in 2004.

The National Institute of Advanced Industrial Science and Technology has already succeeded in raising the ignition point of Mg alloys by 200 to 300°C by adding calcium (Ca), as shown in Figure 9.

4-4 Strengthening databases

The recent research described above indicates that in Japan the basic technologies for using Mg have advanced remarkably in recent years

Figure 8 : Concept of the friction stir welding method

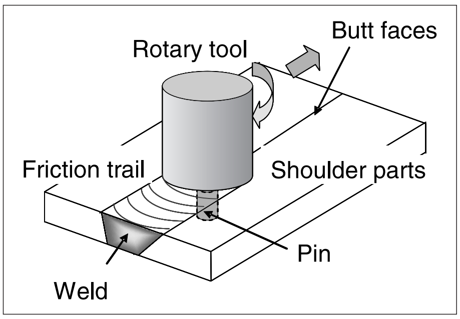
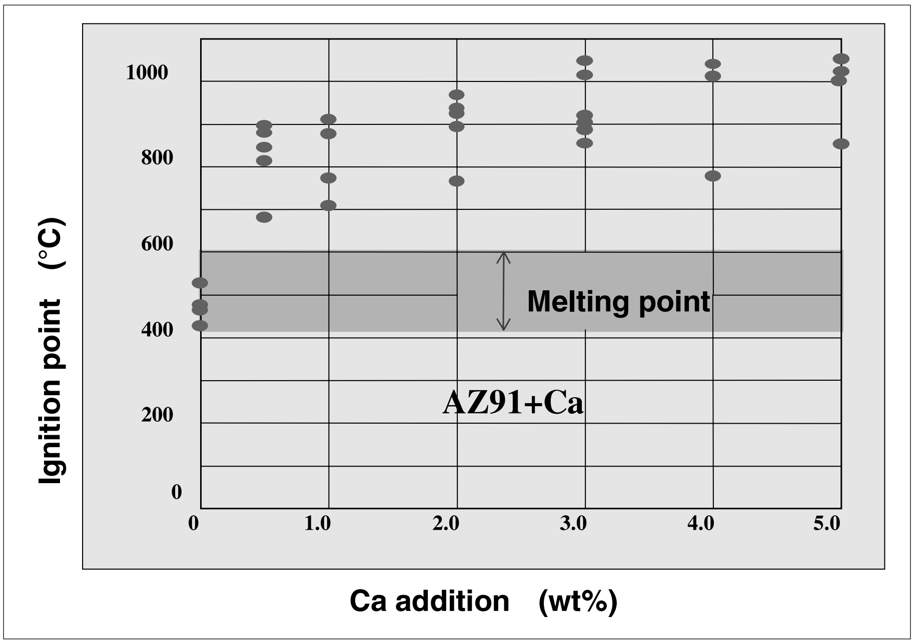


Figure 9 : Ca addition vs. ignition point



Source: Provided by Materials Research Institute for Sustainable Development, National Institute of Advanced Industrial Science and Technology and now rank with the best in the world. In the future, it will be necessary to effectively apply this research, established technologies, and evaluation of the characteristics of Mg alloys to the design of products in order to enlarge the range of applications as soon as possible. One way to promote this is to build up and improve the databases shared by the related organizations. The databases on Mg alloys available in Japan include one prepared by the Japan Magnesium Association[9]. In the future, it will be necessary to further strengthen these databases.

5 Trends of research and development promotion systems in Japan and other countries[4, 6]

5-1 Europe

In Europe, R & D efforts for Mg alloys have been part of the development projects aimed at reducing the weight of motor vehicles for the primary purpose of reducing CO_2 emissions.

The main participant in the EUCAR project being implemented in Europe is the joint research organization established by automobile manufacturers such as Fiat, Volvo, Daimler-Chrysler, Ford, Volkswagen (VW) and BMW; universities, research organizations, and parts suppliers in Europe also participate in this project. For this project, the common themes of research and development are (1) material design guidelines, (2) new welding and joining technologies, (3) the development of new extruded materials, and (4) the development of new heat-resistant Mg alloys.

In Germany, the Federal Ministry of Education and Research has supported the “InMaK-Project” (Innovative Magnesium Compound Structures for Automobile Frames), which is intended to create new material designs by reviewing destruction simulation models. As part of this, research has been conducted on material design methods and welding and joining techniques. Over the period 1996 - 1999, the German government invested about 2 billion yen in research under the MADICA Project (Mg Alloy Die-Casting Project), in which 5 universities and 43 companies including 5 automobile manufacturers participated. This project developed not only die casting technologies, but also mechanical working, welding & joining, and thixo-molding technologies. At present, the Science and Technology Promotion Association, a governmental organization, is implementing the “SFB390 Project” with a total research investment of about 5 billion yen over the 1996 - 2005 period. Under this project, research is being conducted in the areas of metallurgical engineering and microstructure, manufacturing technologies and composite materials.

5-2 United States

The USCAR project, as described in Chapter 3, started in 1992 to develop a 3-liter car with 6 seats. In 1995, the United States Automotive Materials Partnership (USAMP) was established to undertake research and development projects for various materials. As one of these projects, the federal government, research organizations and the Big 3 automobile manufacturers initiated a development program for an environmentally friendly Supercar for the 1993 - 2004 period. Ford is implementing the development program “P2000 Mondeo Contour”, in which 103 kg of Mg alloy parts would be used in an effort to develop a car that gets 29km/l.

Furthermore, the “FreedomCAR Project” in which the federal government, research organizations and the Big 3 automakers participated has been integrated into the huge automobile project called the “FreedomCar and Vehicle Technology Program”. The Department of Energy (DOE) was, is and will be responsible for promoting and managing the implementation of this project from 2002 to 2010. Under this project, magnesium power train parts will be developed to reduce the weight of the trains for which aluminum alloys were and are mainly used, and tests have been conducted on Mg alloys for use as engine parts with the goal of improving creep resistance and corrosion resistance and also improving casting technologies and recyclability while reducing costs. The Argonne National Laboratory is responsible for carrying out the R & D for the project. In 2003, it was expected that a cast Mg alloy developed in this project would be used in a front engine cradle, and the replacement of cast aluminum with this new material reduced the weight of the cradle by 35%, from 15.8 kg to 10.3 kg. The participants in this project have an open working attitude that enables them to actively make use of the results of R & D efforts undertaken in other countries.

5-3 China

At present, China is rapidly emerging as one of the largest magnesium ore producers in the world. It has increased its share of the global production of Mg ore since 1995. In China, abundant coal can be used as a heat source, and many plants using the Pidgeon method have been established. The Pidgeon method is a refining process that uses the reduction of MgO•CaO by silicon. Even relatively small plants can be operated economically, which is why China could easily enter the refining industry.

While material manufacturing technologies improve with the expansion of markets for the base materials, great efforts are also being made in developing new casting and forming technologies to improve the value-added of products. Under China's 10th 5-year Plan, a total investment of about 40 million dollars for 5 - 10 years was initiated in 2001, and R & D projects for magnesium refining and processing technologies began to be implemented in cooperation with foreign automobile manufacturers operating in China as well as Chinese universities and colleges. Academic organizations such as Tsing Hua University, Shanghai Jiao Tong University, and ChongQing University have already started to conduct research on the commercialization of Mg alloy die casting technologies.

5-4 Korea

In the second half of the 1990s, the Korean government started to invest in academic and industrial projects to develop technologies necessary to commercialize large-sized Mg alloy parts and members. These projects have since been implemented. The government intends to participate in the projects until the results of the R & D efforts are transferred to corporations. The projects focus on the improvement of heat resistance and the cost reduction of plate materials. It is reported that R & D efforts are being made to put large-sized parts and members to practical use, for example, to manufacture the systems that can produce rolled materials in 2m widths.

5-5 Japan

As one of the recent projects set up jointly by industrial, academic and government agencies, the "Ibaraki Magnesium Project" started to be implemented on a full scale in July 2005. The prefecture of Ibaraki appropriated 17 million yen for this project in its fiscal year 2005 budget. In this prefecture, companies established a partnership organization to implement joint research and development projects in cooperation with the Ibaraki Industrial Technology Center and Ibaraki University, and to outsource research projects to research organizations such as the National Institute of Advanced Industrial Science and Technology. This project gives priority to three areas: machining, plastic molding and recycling technologies. In the prefecture of Niigata, the Niigata Industrial Creation Organization is launching a development project for next-generation Mg alloy products by outsourcing research to educational institutions such as Nagaoka University of Technology, Niigata Institute of Technology and Nagaoka National College of Technology. However, these projects are not oriented towards the development of automobile materials as described in this article.

6 Conclusions and recommendations

To work towards a sustainable society, it is absolutely necessary for future R & D projects to develop energy saving technologies that contribute to the reduction of CO_2 emissions. It is especially important to reduce the amount of energy that is consumed simply to enable a vehicle to carry its own weight around. Therefore, the weight reduction of transport equipment is one of the most important technical challenges. It is anticipated that R & D activities will be accelerated to develop and commercialize Mg alloys that contribute to the weight reduction of structural materials for transport equipment.

Although Mg alloys possess a variety of

desirable physical properties including lightness, they have had a limited range of application because they also have performance shortcomings such as low strength, low heat resistance and low corrosion resistance. In recent years, however, advanced basic research on Mg alloys has enlarged the range of applications. At present, Japan leads the world in this basic research. However, it is far behind the U.S.A. and Europe in terms of the applications to passenger cars that are expected to have the greatest impact. Recently, the Chinese and Korean governments have also begun programs to develop Mg alloys. It is necessary for the Japanese government to settle the direction of its support so that the basic technologies developed in this country will be of practical use in the fields where they have the greatest impact. From this point of view, two recommendations are made herein as follows:

(1) It is necessary to integrate all the results of development activities that have been carried out separately on basic Mg technologies, set up a national project to apply these results, and take active measures to make practical and efficient use of them in the fields where they can be expected to have the greatest impact. To do so, it is now necessary to:
   - (i) Prepare a road map for each application of Mg alloys and share the knowledge; and
   - (ii) Strengthen the fundamentals of our database on Mg alloys in order to perform part design more efficiently.

(2) In the near future, it may be necessary to:
   - (i) Improve the performance characteristics of Mg alloys through further R & D efforts, enlarge the range of application of the current technologies, and promote cost reduction by increasing the use of Mg alloys.
   - (ii) Establish standard specifications for the quality of materials in cooperation with the U.S.A and European countries and require Mg ore producing countries to meet the specifications in order to ensure reliable quality. To achieve this, industrial, academic and government agencies must work together to establish standards for Mg materials that take into account the entire relevant body of accumulated knowledge and information.
   - (iii) If the use of Mg alloys increases in applications such as motor vehicles and the cases for portable electronic devices, it is expected that the recovery of recyclable Mg alloys from the general markets will increase. To respond to the increasing recovery of materials, it is necessary to build up an appropriate recycling system and develop recycling technologies.

Acknowledgements

Here, I would like to express my sincere gratitude to Professor Yoshihito Kawamura (Kumamoto University), Dr. Motohiro Toriyama (Director of the Materials Research Institute for Sustainable Development, the National Institute of Advanced Industrial Science and Technology), Dr. Toshiji Mukai (Eco-Lightweight Materials Group, Ecomaterials Center, the National Institute for Materials Science), Dr. Kunio Matsuzaki (Leader of the Low-Formability-Materials Processing Group, the Advanced Manufacturing Research Institute, the National Institute of Advanced Industrial Science and Technology), Associate Professor Katsuyoshi Kondoh (the University of Tokyo), Professor Shigeharu Kamado (Nagaoka University of Technology), Mr. Takayuki Tsuzuki (Chief of the Materials Research Section, the Research Division, Nagoya Aerospace System Works, Mitsubishi Heavy Industries., Ltd.), Mr. Hisashi Ohara (Secretary General, the Japan Magnesium Association), Mr. Mikio Sasajima (R & D Institute of Metals and Composites for Future Industries: RIMCOF) and others for their cooperation, including the provision of comments and materials necessary for me to prepare this article.

References

[1] Energy Consumption Trend in Transport Sector: 2-2-1. Analysis on private passenger cars' contribution to the total energy consumption. Home page provided by the

Energy Conservation Center, Japan.: http://www.eccj.or.jp/transportation/2-1-1-1.html
[2] Nemoto,Shigeru. Introduction to Magnesium - The lightest structural metal material. Kogyo Chosakai Publishing Inc., July 2002 (Japanese)
[3] Fujii,Tsuneya. “Magnesium Alloy Die Casting Technologies” for designing and manufacturing engineers. Nikkan Kogyo Shimbun, Ltd. (Japanese)
[4] Report of Investigation on the Technical Trend of Patent Applications in 2004: Automobile Weight Reduction Technologies. Japan Patent Office. March 2005
[5] Home page provided by Ministry of Land, Infrastructure and Transport: http://www.mlit.go.jp/jidosha/nenpi/nenpilist/05-1.pdf
[6] The Japan Magnesium Association, “The Main Projects for Development of Motor Vehicles Using Magnesium”; Hisashi Ohara, “Actual Situation of Mg alloy Applications to Motor Vehicles”; The Japan Magnesium Association, Report of “Investigation on the Practical Uses of Magnesium for Motor Vehicles”, February 2005
[7] Fly Out!! Magnesium - Now, It Has a Potentiality as Structural Material After It Has Carried a R & D History for 100 Years. Nano Tech Weekly, Focus 2, Sangyo Times, Inc. 1173, August 16, 2004 (Japanese)
[8] Feature article: Magnesium Alloys - the Growing Demand Due to New Materials and Processing Technologies. Industrial Materials, Nikkan Kogyo Shimbun, Ltd. Vol. 50, No.8, August 2002.
[9] Database provided by the Japan Magnesium Association: http://www.kt.rim.or.jp/~ho01-mag/
[10] Small feature article: To Develop Low-Loaded Structural Materials - Magnesium Alloy Surface Treatment and Solid-Phase Recycling Technologies Friendly to the Environment. Materia. Vol. 43, No. 4, 2004. (Japanese)
[11] Special edition (2) on magnesium. Light Metals. vol. 51, no. 11, November 2001. (Japanese)
[12] Feature article: Pressing of Titanium and Magnesium. Pressing Technology. vol.42, no. 2, February 2004. (Japanese)
[13] “Report of Investigation on the Trends and Recycling of Magnesium Products for Motor Vehicles, IT Equipment and Consumer Electronics”, investigation on technological measures taken by the materials industry in 2002 (investigation on measures taken to build up the recycling type basic-materials industry), Nonferrous Metals Division, Manufacturing Industries Bureau, the Ministry of Economy, Trade and Industry (outsourced to Shinko Research Co., Ltd.)
[14] Special edition on magnesium plasticity processing. Light Metals. vol. 54, no. 11, November 2004.
[15] Small feature article: Automobile Material Technologies. Materia. vol. 43, no. 10, 2004.

Hisao WATARAI
Head of Materials and Manufacturing Research Unit, Science and Technology Foresight Center

He was involved in research and development activities for electronic and ceramic materials and parts in the Advanced Technology R&D Center, Mitsubishi Electric Corporation. He is currently engaged in investigation and research activities regarding trends in science and technology and science and technology policies.

(Original Japanese version: published in August 2005)

8

Measures to Promote Renewable Energy and the Technical Challenges Involved

TATSUYA OHIRA
Environment and Energy Research Unit

1 Introduction

With the Kyoto Protocol taking effect in February 2005, industrialized countries are stepping up efforts to reduce greenhouse gas emissions. In Japan, for example, the drive for renewable energy use is gaining momentum, with the Ministerial Meeting on Promotion of Comprehensive Energy Measures deciding in April 2005 to promote renewable energy sources that emit less carbon dioxide (CO_2). A tightening world oil market - due to rising oil demand in China, India and other Asian countries, and growing oil consumption in the U.S. - is another factor accelerating the introduction of these alternatives.

Under such circumstances, efforts to develop and promote various types of renewable energy source (e.g., wind, photovoltaic and biomass power) are growing both at home and abroad. Although renewable energy is still more expensive than fossil fuel energy, the factors described above suggest that its world market could expand rapidly in the years ahead.

This article points out that the key to developing renewable energy sources is the introduction of promotional programs, along with the improvement of the efficiency and the cost effectiveness of the power generation systems involved. It also describes how such promotional programs are drastically shifting from “technology push” (centered on research and development) to “demand pull” (associated with economic incentives) and sheds light on the problems associated with Japan's relevant laws and systems. The article finally focuses on the immediate challenge posed by the connection of distributed power sources to commercial power grids.

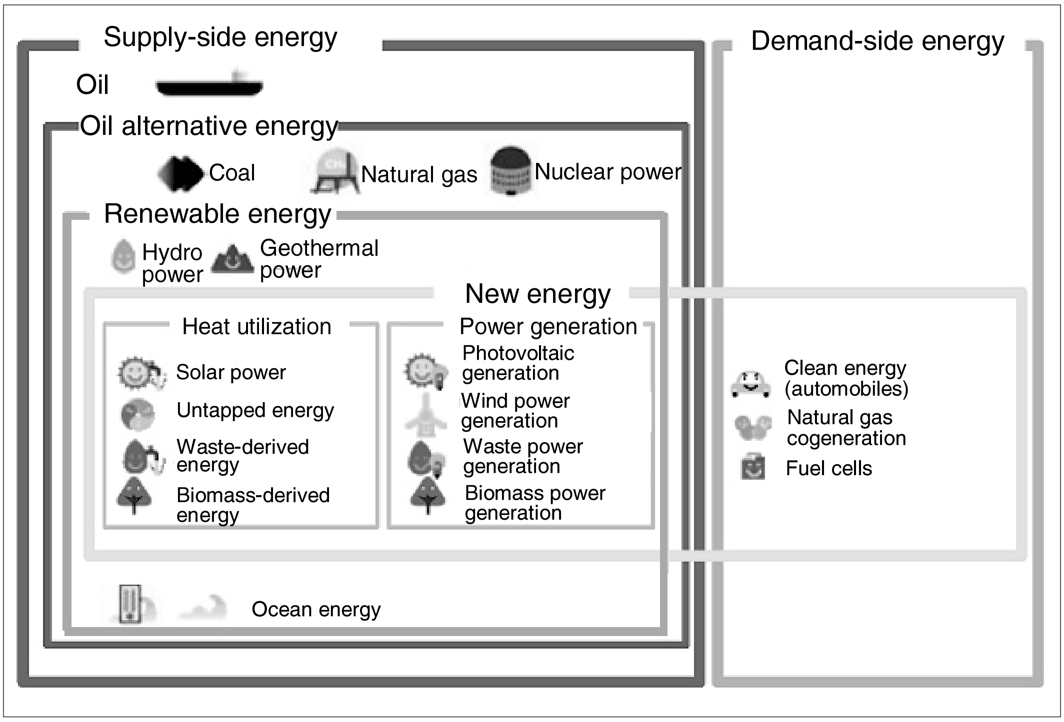
2 Approaches to promote renewable energy

This chapter addresses 1) the definition of renewable energy, 2) factors promoting the introduction of renewable energy, 3) various approaches to promoting renewable energy, and 4) the current status of and problems with the relevant domestic laws and programs already in place, such as the Renewables Portfolio Standard Law, surplus-power purchase contracts and green power programs.

2-1 Definition of renewable energy

As opposed to the energy derived from depletable fossil fuel, “renewable energy” is inexhaustible because it is produced from ever present natural phenomena. Figure 1 shows various types of renewable energy sources. The New Energy Law (1997) defines “new energy” as “a type of energy that is becoming technologically viable and essential as an alternative to oil (oil alternative energy), but has yet to become widespread due to its economic constraints”. The term “new energy”, however, is rarely used in other countries. Instead, it is commonly referred to as “renewable energy”, which includes hydro, geothermal and ocean energy. This international definition is also adopted in this article.

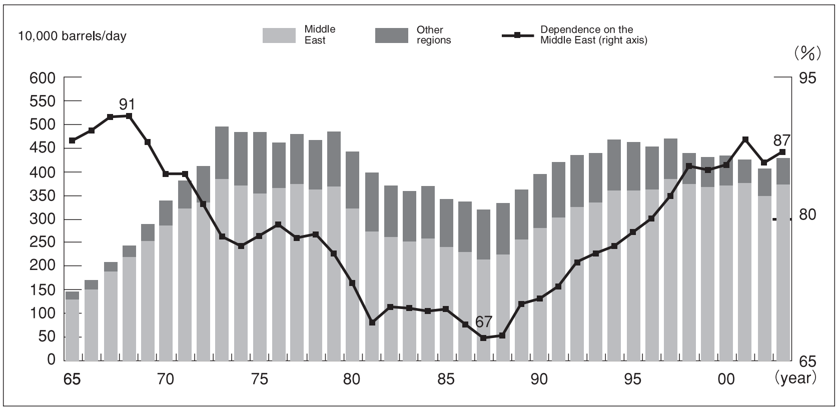
Figure 1 : Renewable energy and new energy



* Biomass includes black liquor and scrap wood. Untapped energy includes snow ice cryogenic energy but excludes waste-derived energy.

Source: Prepared by STFC based on References[2, 3]

Figure 2 : Japan's dependence on Middle Eastern oil



Reference: "Energy Production, Supply and Demand Statistics", the Ministry of Economy, Trade and Industry

Note: the 2003 figures are preliminary estimates.

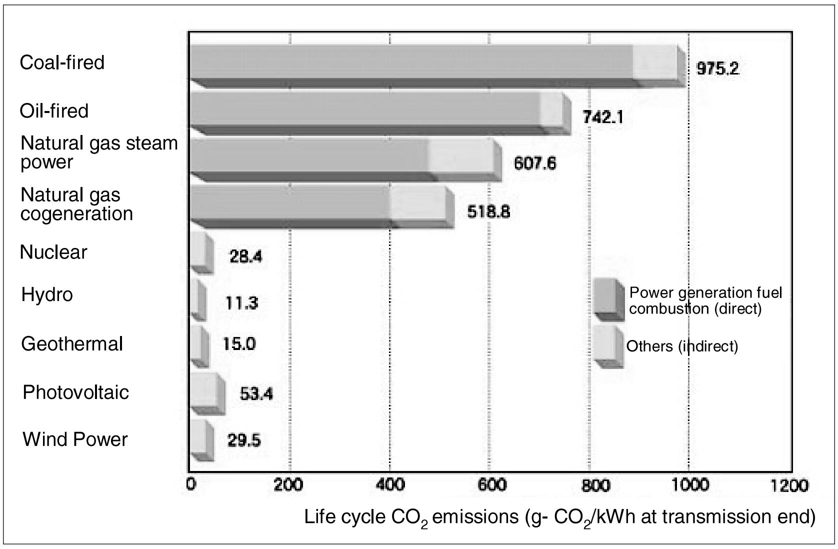
Source: Reference[4]

2-2 Factors promoting the introduction of renewable energy

Two major factors promoting the introduction of renewable energy are 1) stabilization, diversification and decentralization of energy supply and 2) global warming countermeasures.

Oil prices began to surge in the latter half of 2004 due to rising oil demand in China, India and other Asian countries, and growing oil consumption in the U.S. Prices are now hovering between US$40-55 per barrel. With this in mind, it is now widely accepted that the introduction of renewable energy to diversify and decentralize energy sources contributes to shoring up the energy supply structure. Japan's dependence on oil as its primary energy supply dropped from over 70% in the 1970s to 49.4% in 2001. By contrast, its dependence on Middle Eastern oil has been on the rise since the latter half of the 1980s, as shown in Figure 2. Japan's energy supply structure is heavily dependent on

Figure 3 : Life cycle CO_2 emissions of power generation systems



The amount of CO_2 emitted is calculated by taking into account all energy consumed by a series of operations such as mining, construction work, transportation, refining, power generation and maintenance work. For example, coal-fired power generation includes mining, coal dressing, transportation, power generation and ash discharge. In the case of nuclear power generation, the calculation is based on the gas diffusion method (once-through type). Natural gas steam power generation is a system in which natural gas-fired boilers produce the steam which drives the power generation turbines. Natural gas cogeneration uses high-temperature gas produced by the combustion of natural gas to drive gas turbines and produce steam, which in turn drives steam turbines.

Source: Reference[5]

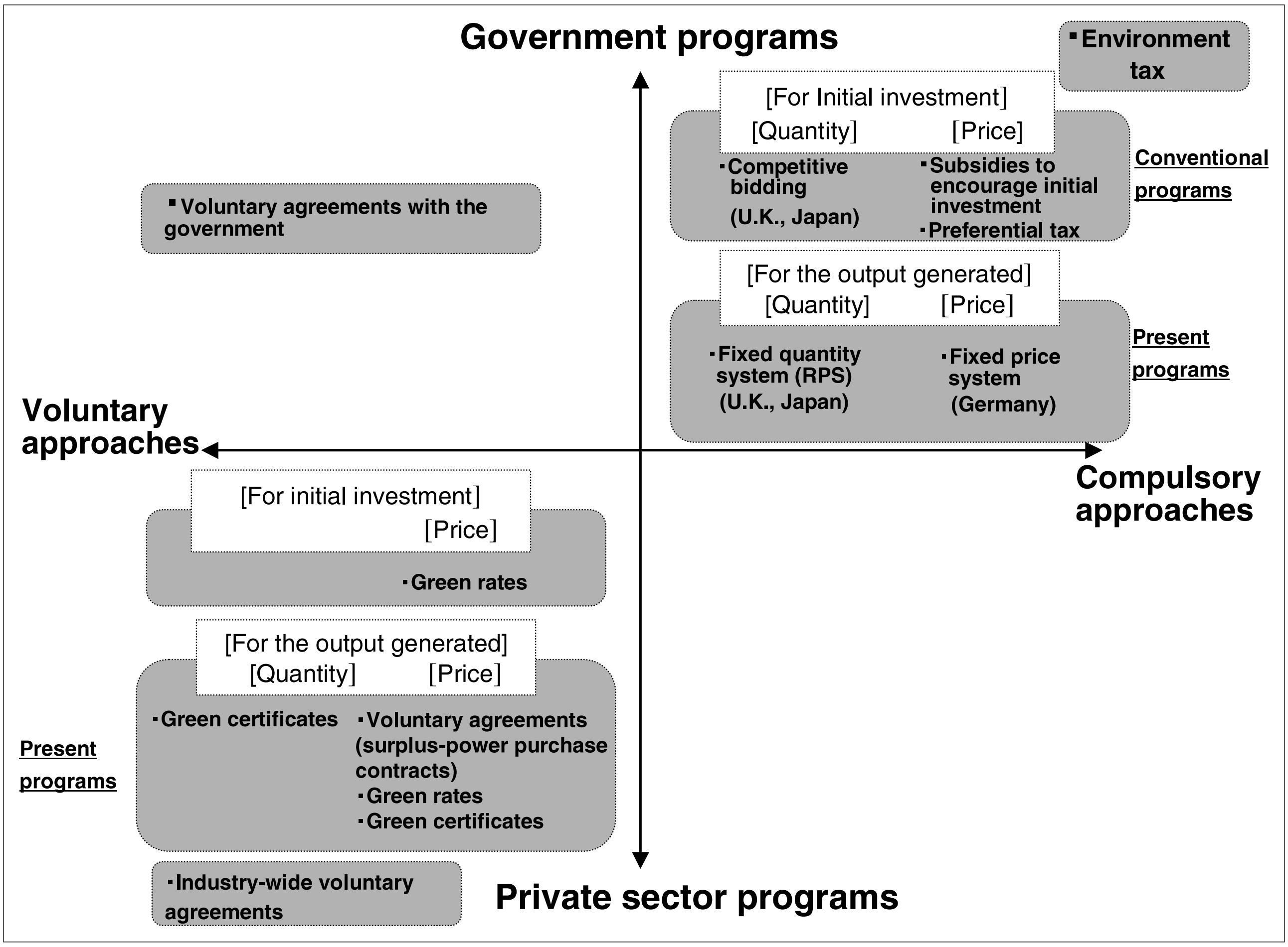
imported energy, especially on Middle Eastern oil, which makes its energy supply security fragile. On the other hand, all renewable energy is being produced domestically, as described below.

The other major factor involves a political issue: global warming countermeasures, or the Kyoto Protocol target. The 3rd session of the Conference of Parties to the United Nations Framework Convention on Climate Change (COP3), which was held in December 1997 in Kyoto, adopted a protocol that mandates industrialized countries to reduce their CO_2 and other greenhouse gas emissions by at least 5% below 1990 levels between 2008 and 2012. Specifically, Japan, the U.S. and the EU are obliged to achieve 6%, 7% and 8% reductions, respectively. With the Kyoto Protocol taking effect in February 2005, industrialized countries are stepping up efforts to reduce greenhouse gas emissions, although the U.S. has seceded from the Protocol. As shown in Figure 3, renewable energy is far more environmentally friendly than fossil fuel in terms of CO_2 emissions. This is a major incentive to promote its adoption.

2-3 Promotional programs

Because of the factors described above, promotional programs for renewable energy around the world are drastically shifting from "technology push" (centered on research and development) to "demand pull" (associated with economic incentives). These promotional programs, coupled with technological development, hold the key to promoting renewable energy. Figure 4 shows a variety of promotional programs as categorized by two measures: whether they are "compulsory" or "voluntary," and "public" or "private." For example, conventional programs that encourage initial investment through government subsidies and special tax cuts for renewable energy facilities are giving way to economic incentives that increase in proportion to the amount of "green power" generated. Typical economic incentives include the fixed price system introduced in Germany in 1990, in which power companies purchase the electricity generated from renewable energy at fixed prices, and a competitive bidding system adopted in the

Figure 4 : Promotional programs for renewable energy



Source: Prepared by STFC based on Reference[6]

U.K. at about the same time. In addition, fixed quantity systems such as RPS were developed in the latter half of the 1990s, followed by various programs adopted in Japan, Europe and the U.S. For example, power companies' voluntary programs to purchase surplus power, and green power programs on the part of consumers (green rates, tradable green certificates, etc.). The current status of and problems with Japan's RPS law, surplus-power purchase contracts and green power programs are discussed below.

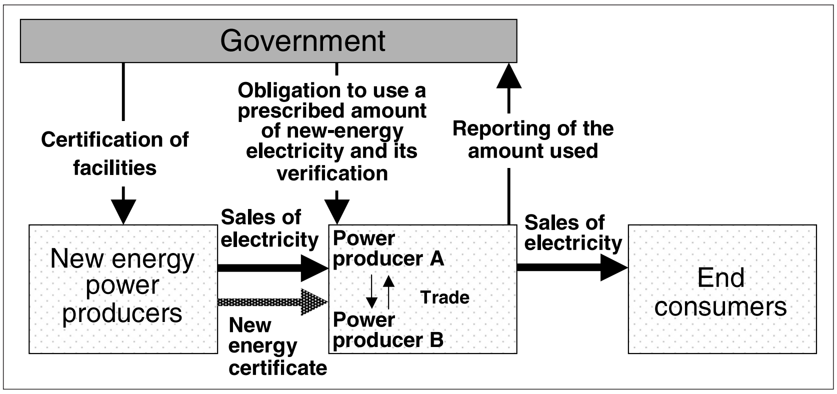
(1) The Renewables Portfolio Standard Law

The fixed quantity system, or the RPS system, is a system that obliges power producers to use a prescribed amount of new energy. It was fully adopted in Japan in 2003 as part of the Law on Special Measures for the Utilization of New Energy, etc. This system is designed to ensure the security of energy supply through the promotion of new energy and mandates power producers to use new energy electricity in proportion to the amount of electricity they sell each year. New energy, in this particular case, refers to those categories described in Section 2-1 (wind, photovoltaic and biomass power generation), run-of-river type hydro power generation (with an output of less than 1,000 kW) and binary geothermal power generation*1, but does not include large-scale hydro power generation.

Figure 5 outlines Japan's RPS system through which power producers are obliged to use new energy electricity in proportion to the amount of electricity they sell each year. This includes general power producers (a total of 10 power producers including Hokkaido Electric Power and Okinawa Electric Power), special power producers*2 and PPS (power producer and supplier) operators*2. These three types of power producer are hereinafter referred to collectively as "power producers".

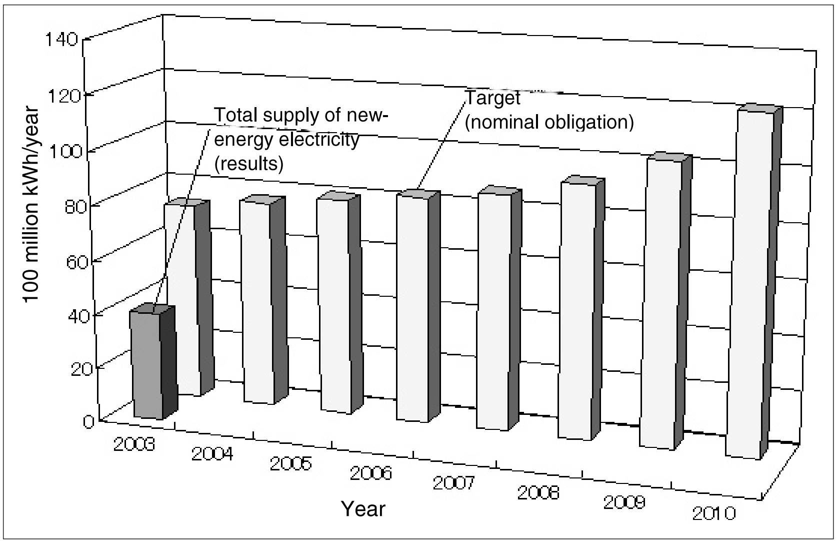
Power producers are expected to promote new energy electricity use through each of the following three alternatives:

Figure 5 : Overview of Japan's RPS system



Source: Reference[10]

Figure 6 : Targets for the use of new-energy electricity



Source: Prepared by STFC based on Reference[10]

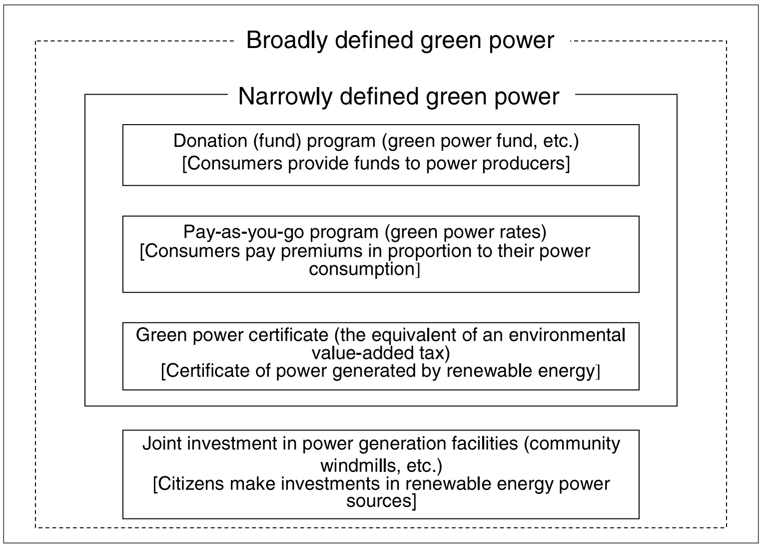
(i) Generate "new energy electricity" independently
(ii) Purchase "new energy electricity" from others
(iii) Obtain "new energy certificates" from others

A "new energy certificate" is a type of "credit" which power producers can purchase from others in order to achieve their targets for the use of a prescribed amount of new energy electricity.

Those who fail to fulfill this obligation without reasonable cause are fined up to one million yen. This kind of penalty, however, is unlikely to provide a good incentive for the adoption of new energy. A more efficient approach would be to impose a surcharge on power producers, based on the proportion of "non-fulfillment" of the obligation in terms of kWh (Penalty program)[7]. Power producers, by definition, do not include self-generation plants mostly dependent on fossil fuels (i.e., those who generate power primarily for captive consumption). Greenhouse gas emissions from such self-generation plants account for some 15% of the total emissions from the energy conversion sector[8]. Self-generation plants should therefore be regulated in the future[9].

The government consults with the Advisory Committee for Natural Resources and Energy every four years to set a target for the use of new energy electricity over the next eight years. The current target, as shown in Figure 6, is set for 2010: 12.2 billion kWh/year or 1.35% of the total power supply, which is too small an amount to create fluidity in the market. With only this target, power producers and power plant builders

Figure 7 : Four categories of green power programs



Source: Reference[6]

cannot formulate adequate long-term financing plans. A more ambitious target should therefore be set, looking towards 2020 and beyond.

The review of the RPS law started in June 2005, as scheduled at the time of its introduction. This review is likely to take account of comparable systems abroad, which are later described in Chapter 3.

The obligation to introduce new energy inevitably results in connecting diverse distributed power sources (wind/photovoltaic power generation, etc.) to commercial power grids, regardless of the size of their output. As discussed in Chapter 4, however, there are some challenges to be addressed in achieving this - e.g., development of more advanced power generation systems and cost reduction technologies, and institutional/technical problems associated with the connection of many distributed power sources to commercial power grids.

As defined in Section 2-1, “renewable energy” in this article also includes hydro power generation. If large-scale hydro power generation, which is not covered by the RPS law, is taken into account, Japan’s target for the use of renewable energy accounts for some 6% of total primary energy consumption.

(2) Surplus-power purchase contracts

As part of their voluntary initiatives to promote new energy, general power producers have been purchasing surplus power generated by wind and photovoltaic power plants since 1992. This program was expanded to include cogeneration and other self-generation plants in 1993, and commercial wind power plants with an output of less than 2,000 kW in 1998. Under this program, the unit purchase price of surplus power is fixed for each new energy source, and a purchase menu is made public. In particular, surplus power generated by wind power plants (excluding commercial plants) and photovoltaic power plants is purchased at the same price as that of the general power producers: about ¥27/kWh for ordinary households (the time-of-day electric rate). With regard to commercial wind power plants, a commercial wind power generation menu is in place to ensure a long-term, stable purchase program. Tokyo Electric Power Company (TEPCO) sets the price at about ¥11/kWh for plants contracted for 15 years, which is much higher than the fuel equivalent of thermal power generation (¥4-6/kWh).

(3) Green power programs

Green power programs offer several types of power to consumers. While the RPS system involves obligations and offers incentives to power producers, this program is designed to encourage consumers to take voluntary initiatives to promote the use of renewable energy. Green power programs, as shown in Figure 7, can be broadly classified into four categories.

The green power market has grown to a

significant size. For example, the total contract amount of green power certificates reached ¥2.5 billion within four years of their introduction[6]. However, there are some problems in developing this market further. For one thing, the costs of purchasing the certificates are generally treated as donations under the current tax system and hence are levied along with corporate tax. This is the biggest problem because it makes their purchase more expensive than other environmental measures and therefore hampers the introduction of renewable energy. Measures should be taken to permit these costs to be treated as expenses.

Meanwhile, in line with these green power programs, the private power producers have launched consumer-oriented voluntary initiatives to develop products and services focused on the "environmental value" of renewable energy. This raises the need for a new system to ensure compatibility between these consumer-oriented approaches and the supply-oriented RPS system. One of the incompatibilities in the current system is that it has no mechanism for avoiding the double counting (double selling) of green power certificates and RPS-based new energy certificates.

3 Developments in major countries where Renewable energy is being introduced

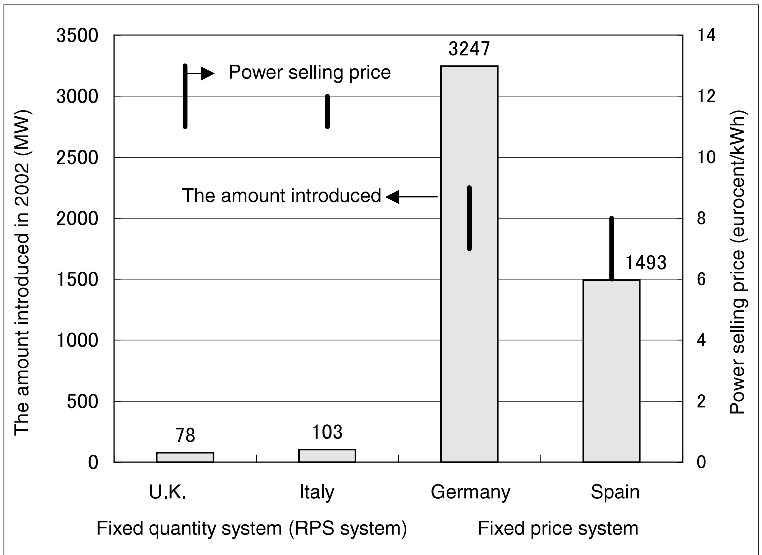
This chapter provides an overview of recent developments in Europe, North America and other parts of the world where renewable energy is being introduced, and compares them with Japan's fixed quantity system (the RPS system) in order to make recommendations for further improvements in Japan.

3-1 Europe

As part of its measures to curb global warming, in October 2001 the European Union (EU) issued the "Renewables Directive"[11], which set the target of doubling the proportion of renewable energy in primary energy use from 6% in 1998 to 12% in 2010 (or 21% in terms of total power consumption)[1]. Specifically, Germany, France and the U.K. are expected to meet targets of 12.5%, 21% and 10%, respectively[1].

The fixed price system is in place in Germany, Spain and Portugal, and the fixed quantity system (the RPS system) is in place in the U.K., Sweden and Italy. As shown in Figure 8, wind power generation has expanded dramatically in

Figure 8 : Development of wind power generation through the use of the fixed quantity system (RPS system) and fixed price system



Fixed quantity system, adopted by U.K. and Italy, and the fixed price system, adopted by Germany and Spain

Source: Prepared by STFC based on Reference[6]

Germany and Spain through the use of the fixed price system. In Germany, the proportion of renewable energy in total power consumption increased from 4.6% in 1998 to 10% in the first half of 2004, thanks in part to the Renewable Energy Law based on the fixed price system. The advantage of the fixed price system is that the purchase price of renewable energy power is secured over the long term, which in turn reduces the business risks that power producers and suppliers are exposed to. This suggests that if Japan fails to achieve its target for the introduction of renewable energy, it should consider adopting similar follow-up measures such as setting a minimum purchase price for a certain period of time.

The EU Renewables Directive described above stipulates that priority should be given to connecting renewable energy power sources to commercial power grids. The EU also actively encourages the development of technologies, such as an innovative control technology for stand-alone power generation systems to meet a potential increase in renewable energy sources and their storage[12].

3-2 North America

The U.S. has a preferential tax system to promote renewable energy. In addition, the RPS law is in force in 17 states including California, New York and Arizona, and these states have their own targets for the introduction of renewable energy. The RPS system works well in some states, while it has been suspended in others. Although the federal RPS law has yet to be enacted, President Bush announced in April 2005 that a budget of about US$1.9 billion was earmarked for the promotion of renewable energy over the next decade[13]. Moreover, the "Renewable Energy Bill" is under consideration by the Committee on Environment and Natural Resources. The bill aims to increase the use of renewable energy as a proportion of total energy supply to at least 3% between 2007 and 2009, 5% in 2012 and 7.5% in and after 2013[1].

With respect to grid connection, the U.S. has promoted since the 1990s efforts to enable stand-alone power sources - including those using renewable energy - to connect to commercial power grids. As part of these efforts, a group led by the Federal Energy Regulation Commission (FERC) is setting standards for the connection of small-scale power generation systems with an output of 20 MW or less, the category to which the majority of stand-alone renewable energy power sources belong[14].

In Canada, hydro power generation has long played a major role in the country's energy supply and now meets some 60% of the domestic power requirement. The State of Ontario plans to introduce "Green Power Standard" in 2006 as a renewable energy promotional program[1]. However, there have been no national-level initiatives so far in Canada.

3-3 China and Brazil

In February 2005, the Chinese government promulgated the Renewable Energy Law, which is scheduled for introduction on January 1, 2006. With the aim of promoting the development and use of renewable energy, this law provides preferential tax, finance and price treatment to renewable energy sources, and mandates power companies with commercial power grids to purchase renewable energy power. Its medium- to long-term objective is to raise renewable energy as a proportion of total primary energy consumption to 10% by 2010 (a total of 60.45 GW, comprising 50 GW from small-scale hydro power, 4 GW from wind power, 6 GW from biomass power and 450 MW from photovoltaic power). When this law takes effect, renewable energy power producers are expected to have more opportunities for connection to commercial power grids. The interconnection price to the grids is fixed for the first 30,000 hours (about 3.4 years) and will thereafter be pegged to market rates. In this Chinese system, the price varies depending on the type of renewable energy source.

In Brazil, about 40% of the country's primary energy consumption is supplied by hydro power, biomass power and other renewable energy sources. The government is implementing a program to guarantee the purchase of renewable energy power over the next two decades. In particular, Rio de Janeiro City is poised to promote wind, photovoltaic and small- to

Table 1 : Renewable energy promotional programs in major industrialized countries

Country	Japan	U.K.	Italy	Sweden	Germany	Spain
System	Fixed quantity (RPS) system				Fixed price system	
Year of introduction	2003	2002	2002	2003	2000	2002
Description	Obligation to obtain certificates (credits) in proportion to part of the power sold	Same as on the left	Same as on the left	Same as on the left	Obligation to purchase all renewable energy power generated	Same as on the left
Target	Power producers and suppliers	Power producers and suppliers	Power producers (including private power producers), power importers	End users (excluding the manufacturing industry)	Power producers and suppliers	Power producers and suppliers
2010 introduction target	1.35% of total power supply (obligatory amount)	10.4% of total power supply (obligatory amount)	3.05% of total power supply (2006); target for 2007 and beyond still to be set	16.9% of total power supply (obligatory amount) (or 60% with large-scale hydro power generation included)	12.5% of total power supply	29.4% of total power supply (including large-scale hydro power generation)
Incentives for power producers	• Banking of certificates *1 for the benefit of targets and power producers	• Guarantee for the continuation of the system until 2027	• Guarantee for the minimum purchase price by commercial grid companies • Priority given to renewable energy power for the connection to commercial power grids	• Guarantee for the minimum purchase price until 2008	• Guarantee for the fixed purchase price over 20 years from the start-up of facilities; 8.7 eurocents/kWh (about 11.3yen) for newly-built on-shore wind power stations	• Guarantee for the fixed purchase price without restriction on terms; 6.5 eurocents/kWh (about 8.4yen) for newly-built on-shore wind power stations • The period for which the purchase price is guaranteed varies for each energy source (e.g., 15 years)
Target energy	Photovoltaic Wind Geothermal Hydro (conduit types with an output of less than 1,000 kW) Biomass	Photovoltaic Wind Hydro (small-scale plants inaugurated in and after 1990) Geothermal Biomass Wave Tidal Waste (originating from non-fossil fuels) Landfill/Sewage Sludge	Photovoltaic Wind Hydro Geothermal Wave Tidal Biomass Waste (originating from non-fossil fuels) Mixed combustion	Photovoltaic Wind Hydro (existing plants with an output of less than 1.5 MW or those inaugurated in and after July 2002) Geothermal Biomass Wave Tidal Waste (originating from non-fossil fuels)	Photovoltaic Wind Hydro (with an output of less than 5 MW) Geothermal Biomass (with an output of less than 20 MW) Landfill/Sewer gas (with an output of less than 5 MW) Mine gas	Photovoltaic Wind Hydro Geothermal Wave Tidal Biomass (including mixed combustion) Waste (including non-biomass resources) *all with an output of less than 50 MW

*1 A system where a surplus of new energy electricity in a given year can be carried forward to the following year in order to be counted as an achievement.

medium-scale hydro power generation[15].

3-4 Promotional programs around the world

Current promotional programs for renewable energy around the world can be broadly classified into either the fixed quantity system (the RPS system) or the fixed price system. Table 1 summarizes typical promotional programs in major countries so that they can be compared with Japan's programs. As explained in Section 3-1, countries adopting the fixed price system have taken the lead in introducing wind power generation. Since the fixed price system secures the purchase price of renewable energy power over the long term, it has served as a powerful incentive to power producers. This proves the effectiveness of approaches that provide long-term assurance of the power purchase price.

Overseas RPS systems could be useful models when Japan reviews its own system. The candidates include a medium- to long-term assurance program in the U.K., guaranteed minimum purchase price programs in Italy and Sweden, and a program in Italy that gives priority to renewable energy power for connection to commercial power grids. As pointed out in Chapter 2, Japan's target of increasing the use of new energy power to 1.35% of the total power supply by 2010 is too modest compared with those of other countries. With such a small size, Japan's renewable energy market will have little fluidity. For better results, Japan should, while still maintaining the current framework of the RPS law, set a more ambitious target and introduce schemes for guaranteed purchase prices and long-term assurance to minimize the business risks of power producers and suppliers[16].

4 Problems associated with the connection of renewable energy power sources to commercial power grids

To increase the amount of renewable energy being introduced on the market, a greater number of distributed power sources, such as wind and photovoltaic power generation systems, need to be connected to commercial power grids. These power generation systems are, however, still in the development phase and hence their connection to the grids poses some immediate and critical problems. This chapter outlines these problems and their possible solutions.

4-1 Renewable energy as a distributed power source

A renewable energy system functions as a distributed energy system in which the electricity produced from specific resources is stored locally or supplied to commercial power grids as needed. Table 2 outlines how each renewable energy system acts as a distributed power source.

When large amounts of renewable energy are introduced as distributed power sources, a system that coordinates their operations with those of grid power is essential for ensuring effective utilization and maintaining supply reliability and quality. Such a system should be able to work with the existing power grid system to regulate the output of distributed power sources and the facilities connected to the grid in response to fluctuations in power demand.

Table 3 shows the output stability and controllability of each renewable energy system when used as a distributed power source. Wind and photovoltaic power generation systems are inferior to small-scale hydro and biomass power generation in both output stability and controllability because they are subject to weather conditions, and there is little chance that the former technologies will develop dramatically in five years' time or so. Despite these drawbacks, however, the targets for the introduction of wind and photovoltaic power generation are set at 3,000 MW and 4,820 MW, respectively, for 2010 (see Figure 9).

With such targets already in place, a lot of distributed power sources with unstable output and poor controllability will have to be connected to commercial power grids, necessitating a variety of measures to coordinate the connection between the two. The next section explains in detail the issues to be addressed and the countermeasures to be adopted.

Table 2 : Renewable energy systems as a distributed power source

Renewable energy	Solar light	Solar heat	Wind	Biomass	Geothermal	Small-to-medium sized hydro
Resources	Solar light energy (about 1 kW/m^2)	Solar heat energy (about 1 kW/m^3)	Wind power energy (proportionate to the third power of the area of blades, the air density and the wind speed)	Wood biomass, livestock waste, construction waste, food waste, etc.	Geothermal energy (hot high-pressure water and steam)	The potential energy of water
Conversion technology	Solar energy is converted directly into electricity through the photoelectric effect of semiconductors	Solar energy is converted into heat through solar energy collectors	The rotational energy of windmills is converted into electricity through generators	Biomass is converted into heat energy through direct combustion, chemical gasification processes, etc; it can be converted into electricity through motors and generators	Heat energy is used directly; geothermal energy can be converted into electricity through motors and generators	The potential energy of water is converted into the rotational energy of water turbines, which produce electricity through generators
Storing technology	Essential in controlling output	Thermal storage tanks are necessary	Essential in controlling output	Wood biomass is processed into chips, pellets, liquid fuels, etc. for storage purposes	Thermal storage tanks and power storage technology are necessary for controlling output	Power storage technology is necessary for controlling output
Network	Connectable to a power network through AC/DC converters	Supplied to some areas through a heat supply network	Connected to a power network in most cases	Connected to a local heat supply network or a power network	Connected to a power network in most cases	Connected to a power network in most cases
System	Residential rooftop systems are becoming widespread	Residential rooftop systems are becoming widespread, with applications extending to hot-water supply and air conditioning, etc.	Connected to commercial power grids in most cases	Used to supply heat and surplus electricity to adjacent areas	Connected to commercial power grids in most cases, with heat used for heating systems, greenhouses, snow-melting systems, etc.	Used to power irrigation systems

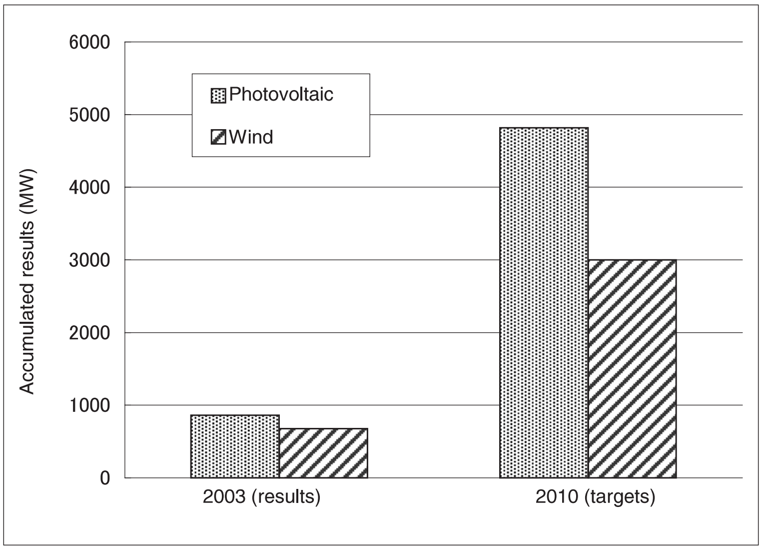
Source: Prepared by STFC based on Reference[17]

Table 3 : Output stability and controllability as a distributed power source

Energy source	Distributed power source	Output characteristics	
		Stability	Controllability
Renewable energy	Photovoltaic	×	×
	Wind	×	×
	Small-scale Hydro	○	×
	Biomass	○	△

" ○ ", " △ " and "x" mean "good", "fair" and "poor" characteristics, respectively.
Source: Reference[17]

Figure 9 : Wind and photovoltaic power generation in Japan; results and targets



Source: Prepared by STFC based on References [18, 19]

4-2 Problems associated with the connection to commercial power grids and their possible solutions

A "power grid" is a general term for a system in which electricity generated by power plants (hydro, thermal, nuclear, etc.) is supplied to users via transmission lines, transformer stations and distribution lines. In most cases, those distributed power sources currently in operation are connected to the power grids of general power producers. Distributed power sources, when connected to commercial power grids, need not be equipped with backup power sources for use in an emergency or during regular maintenance because the grids accommodate fluctuations in power demand. Wind power plants also benefit from the connection as the grids supply an exciting current to the rotor windings of induction generators. Distributed power sources are thus absolutely dependent on the connection to commercial power grids for their stable operation and performance. However, various problems are expected when a large number of distributed power sources, including renewable energy power sources, are connected to these grids. Table 4 summarizes the issues affecting commercial power grids (power source planning and assurance of safety, supply reliability and quality) and those affecting distributed power sources (assurance of safe operation).

In the area of power supply planning, there is a need for techniques to more accurately predict the output of distributed power sources based on weather forecasts. Such techniques will enable the creation of more reliable operating schedules incorporating expected daily demand. On the safety and supply reliability front, failures in commercial power grids may develop into full-blown accidents and result in power disruptions in adjacent areas when they are connected to distributed power sources. Key technologies to prevent such accidents and disruptions include: a system where failures in commercial power grids or distributed power sources are detected immediately so that the latter can be disconnected from the distribution lines, and a system that prevents interference between individual operation detectors installed in distributed power sources. On the quality side, potential difficulty in controlling the voltage and frequency of power requires several types of new technologies. For example, there should be technologies to simultaneously control multiple distributed power sources, those to transmit grid information for control purposes, and those to control supply and demand in order to alleviate any adverse impacts on the voltage and frequency through a network of distributed power sources equipped with power storage systems.

Since the start of 2005, general power producers have begun to put a ceiling on the amount of wind power electricity they receive on the grounds of "constraints on the part of

Table 4 : Problems associated with the connection of distributed power sources to commercial power grids and possible countermeasures

Target	Category	Problems	Countermeasures
Power grids, and users without distributed power sources	Power source planning	• Difficulties in predicting the introduction and location of distributed power sources increase the uncertainty associated with medium- to long-term plans for commercial power supply facilities. • Difficulties in predicting the output of distributed power sources for the next week (or, for that matter, the next day) increase the uncertainty associated with operating schedules forecasting daily power demand.	• Techniques to predict the introduction, location and demand for distributed power sources • Advanced techniques to predict the output of distributed power sources, based on weather forecasts
	Assurance of safety and supply reliability (Protection coordination)	• Failures in commercial power grids may develop into full-blown accidents and result in power disruptions in adjacent areas when they are connected to distributed power sources. • Accidents and failures in distributed power sources may have adverse impacts on commercial power grids. • Distributed power sources may end up operating individually or being reverse-charged when commercial power grids fail.	• A system where failures in commercial power grids or distributed power sources are detected immediately in order to disconnect the latter from distribution lines • Short-circuit current control techniques • A system to prevent interference between individual operation detectors when multiple distributed power sources are connected to one another
	Quality assurance	• The voltage fluctuates significantly in distribution lines when they are connected to distributed power sources. • The more distributed power sources there are connected, the harder it will be to control the frequency of power. • Distributed power sources may generate harmonic current.	• Techniques to optimize the locations of in-line voltage regulators that work in concert with distributed power sources, or techniques to regulate and adjust the voltage in distributed power sources • Load frequency control for the mass introduction of distributed power sources*1 • Simultaneous control of multiple distributed power sources • Power supply technology that controls harmonic current generated by distributed power sources • A system to transmit grid information for control purposes •A network of distributed power sources — each quipped with a power storage system — to alleviate any adverse impacts on the voltage and frequency of power
Distributed power sources	Assurance of safe operation	• Accidents in commercial power grids, grid switches, momentary drops in voltage, sudden load changes, etc. may result in shutdowns.	• A system where failures in commercial power grids or distributed power sources are detected immediately in order to disconnect the latter from distribution lines.

*1 Continuous fluctuations in power demand can be classified into long-term, short-term and minute fluctuations. In particular, the control of short-term fluctuations is referred to as "Load Frequency Control". With an increasing number of distributed power sources (each operating at a load of 100% around the clock) connected to commercial power grids, the power source capacity to control short-term fluctuations decreases, which makes frequency control difficult.

Source: Prepared by STFC based on References[17, 20]

commercial power grids". Underlying this trend is the fundamental issue of who should shoulder the cost of connecting distributed power sources to the grids. The need is arising to reconsider from the perspectives of cost and procedures what the fair and equitable rules for the connection of wind, photovoltaic and other unstable renewable energy power sources should be. This reconsideration should also take account of the public interest in promoting renewable energy, along with the aforementioned technical aspects. In particular, a compromise should be sought between "fairness" and "preference"[6].

5 Conclusion and Suggestions

The pressing need to reduce greenhouse gas emissions and the increasingly tight oil market are spurring countries around the world to promote renewable energy. Although the world market for renewable energy has developed to a certain extent, its costs are still higher than those of conventional energy sources such as fossil fuels. Thus, a variety of programs are underway to promote renewable energy. For example, Germany has introduced the fixed price system that guarantees the purchase price of renewable energy power over the long term, while Italy and Sweden have adopted the fixed quantity system (the RPS system) that guarantees the minimum purchase price. A variety of green power programs are also being implemented by the private sector. Although basic factors such as the type of social system, economic conditions and electric power infrastructures vary from country to country, the achievements of the countries described above suggest that Japan should consider a further package of programs to promote renewable energy.

An increase in the amount of renewable energy on the market means the connection of a greater number of distributed power sources - such as wind and photovoltaic power generation systems - to commercial power grids. However, these power generation systems perform poorly in terms of output stability and controllability. The immediate challenges, therefore, are to develop more advanced power generation systems and cost reduction technologies, and to solve the institutional/technical problems associated with the connection of many distributed power sources to commercial power grids.

Based on the viewpoints described above, the following approaches are recommended as a way to promote the use of renewable energy in Japan and to develop technologies for its connection to commercial power grids.

(1) Promotional programs

(i) From the viewpoint of suppliers

— Review of the fixed quantity system (the RPS system) —

It is recommended that the government guarantees the purchase price of renewable energy power over the long term, while maintaining the framework of the current RPS system. This will help renewable energy power producers continue operating and other power producers avoid the risks of purchasing expensive renewable energy power. Specifically, the RPS system should be reviewed to set more ambitious targets for the use of renewable energy power between 2010 and 2020. At the same time, a minimum purchase price should be guaranteed for each power source to stabilize the price of renewable energy power. Both these measures will contribute to creating fluidity in the semi-public renewable energy market. In addition, penalties should be imposed on power producers in proportion to any failure to fulfill quotas (kWh) to provide a kind of “reverse incentive”.

It is also recommended that the targets set for the next 15, or preferably 20, years should aim to ensure the continuity of the system over the long term. A program could also be considered where power producers bear the prime cost of power while the government contributes the “guaranteed minimum purchase price” of the “new energy certificate price” out of the special account of its energy budget or the revenue from the environment tax. Other costs should be shouldered by power consumers in the form of surcharges.

Meanwhile, regarding the improvement and the operation of commercial power grids, priority should be given to the promotion of renewable energy. All renewable energy power should be purchased, as a general rule, following the European and American approaches that combine an open-access policy and the idea of giving renewable energy power sources greater opportunities for connection to commercial power grids. Prerequisites for these arrangements are transparency in the cost of connecting renewable energy power sources to the grids, thorough discussions about how the cost should be shared, and the preparation and implementation of guidelines for the “public use” of renewable energy.

(ii) From the viewpoint of consumers

— Review of green power programs —

Private-sector green power programs offer opportunities for renewable energy power producers who are not certified under the national RPS system to have their own market. This also allows users such as citizens and companies to participate directly in various programs to promote renewable energy. These programs should, however, be coordinated with the national RPS system. Specifically, there should be explicit rules that stop green power certificates and new energy certificates (based on the RPS system) from being double-counted, or "double-sold."

Currently, the costs of purchasing green power certificates are levied along with corporate tax, which makes green power programs more expensive than other environmental measures and hampers the introduction of renewable energy. Instead, they should be treated as expenses for the benefit of those who purchase the certificates.

(2) Technology development for the connection to commercial power grids

If a large number of distributed power sources that use renewable energy are connected to commercial power grids, the operators of either system can face several problems. Technologies should therefore be developed to address these problems. In particular, the following issues should be addressed immediately to ensure the reliable supply of electricity.

(i) Techniques that contribute to mapping out plans for power sources and their operations

Techniques to predict the introduction, locations and demand for distributed power sources should be developed to support medium- to long-term power source planning. At the same time, simulation techniques to quickly predict the output of distributed power sources based on weather forecasts should be improved to adjust supply to demand on a daily basis.

(ii) Techniques to ensure supply reliability and stable operations

Failures in commercial power grids may develop into full-blown accidents and result in power disruptions in adjacent areas when they are connected to unstable distributed power sources. Another potential risk is the interference between the operation detectors installed in individual distributed power sources connected to the grids, which can result in a decrease in detection sensitivity. These risks raise the need for a failure detection system which immediately disconnects distributed power sources from distribution lines, and a system that prevents interference between individual operation detectors.

(iii) Techniques to ensure the quality of power

The mass introduction of distributed power sources makes it difficult to maintain the quality of the power produced. There are mainly three technical areas that should develop to ensure power quality as measured by voltage and frequency: (1) the simultaneous control of multiple distributed power sources, (2) a system to transmit grid information for control purposes, and (3) supply and demand control to alleviate any adverse impacts on the voltage and frequency through a network of distributed power sources equipped with power storage systems or internal combustion power sources. By establishing a development structure, Japan should seek to incorporate these techniques and those mentioned in (ii) into a system that can control the output of distributed power sources in coordination with the operation of commercial power grids, according to the fluctuation in power demand.

Acknowledgements

I would like to express my deepest gratitude to the following people for their support and assistance in preparing this article: Professor Kenji Yamaji, Department of Electrical Engineering, School of Engineering, the University of Tokyo; Professor Hiroshi Asano, Department of Mechanical Engineering, School of Engineering, the University of Tokyo; Kenichiro Nishio, the Socio-economic Research Center, the Central Research Institute of Electric Power Industry.

Glossary

*1 Binary geothermal power generation

A system where hot water and steam are used to boil pentane (a substance with a low boiling point) to produce steam, which is then used to drive power generation turbines.

*2 Special power producer and PPS (power supplier and producer)

Special power producers are those who supply power to specific areas using their own power generation facilities and transmission lines. PPS refers to those producers who supply power to commercial-scale customers (with a contract demand of more than 50 kW) via the transmission lines of general power producers (i.e., new entrants to the liberalized retail market).

References

[1] NEDO Overseas Reports: Renewable Energy Power Generation: Green Power Promotion in Europe (1/2) (No.953, Apr. 6, 2005), Call for the Integrity of the Renewable Energy Policy in Ontario (No.920, Nov. 26, 2003), Status and Prospects for the US Energy Bill (No.956, Jun. 1, 2005), Trends in EU's New Energy, Environment and R&D (Vol.3, 1/2) (No.904, Apr. 7, 2003) (Japanese)

[2] New Energy and Industrial Technology Development Organization. New Energy Guidebook (Introduction) (Japanese) : http://www.nedo.go.jp/kankobutsu/pamphlets/dounyuu/gairon/

[3] Nuclear Power Encyclopedia ATOMICA (Introduction of New Energy and Its Trends) (Japanese): http://mext-atm.jst.go.jp/atomica/pict/01/01050109/07.gif

[4] Website of the Agency for Natural Resources and Energy: The Energy and Resources Today :www.enecho.meti.go.jp/energy/japan/japan02.htm

[5] The Central Research Institute of Electric Power Industry. Evaluation of Power Generation Technologies Based on Their Life Cycle CO_2 Emissions. Mar. 2000.: http://www.pref.ibaraki.jp/bukyoku/seikan/gentai/chisiki/02ima/c.htm

[6] Iida, Tetsunari. The New Energy Market. Tsukiji-Shokan, 2005.: Factors Hampering the Promotion of Wind Power Generation. Resource and Environmental Measures. vol.41, no.6, 2005. (Japanese)

[7] The Institute of Energy Economics, Japan. Panel Discussion: The Points at Issue in Promoting Renewable Energy in Japan. Aug. 2003. (Japanese)

[8] Website of Ministry of the Environment: The Global Environment and International Environmental Cooperation. : http://www.env.go.jp/earth/report/h12-03/3-4.pdf

[9] The Institute of Energy Economics, Japan. The Points at Issue in the Measures to Promote Renewable Energy in Japan. Jun. 2003. (Japanese)

[10] Website of the RPS Law: New Energy Computerized Management System : http://www.rps.go.jp/RPS/new-contents/top/toplink-sitemap.html http://www.rps.go.jp/RPS/new-contents/top/toplink-1.html

[11] 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

[12] Hashimoto, Yukihiko. Creation of Power Supply Systems Incorporating Distributed Power Sources. Science and Technology Trends - Quarterly Review. No.9, Oct. 2003.

[13] Website of the White House : http://www.whitehouse.gov/news/releases/2005/04/print/20050427-3.html

[14] Iinuma,Yoshiki et al. Recent Trends in the US Power Industry. The Japan Electric Power Information Center, Feb. 2005. (Japanese)

[15] Victer, W. and Marques, V. S. Renewable Energy in Brazil. Proceedings of World Renewable Energy Congress. 2005: P5-9.

[16] Website of the councils of the Ministry of the Environment. : http://www.env.go.jp/council/06earth/y060-27/ref03-3.pdf

[17] Yamaji, Kenji. Distributed Energy System. The Japan Society of Energy and Resources, May 2004. (Japanese)

[18] Website of NEDO: Facilities and Achievements of Wind Power Generation Facilities in Japan :

http://www.nedo.go.jp/intro/pamph/fuuryoku/graphs.pdf
[19] New Energy Business Vision. The New Energy Business Vision Investigative Commission, Jun. 2004. : http://www.meti.go.jp/press/0005361/
[20] Komahashi, Shizuka. New Energy: From Production to Promotion. The Nikkankogyo Shimbun Ltd., Mar. 2004. (Japanese)

Tatsuya OHIRA, Ph.D.
Environment and Energy Research Unit, Science and Technology Foresight Center

Doctor of Engineering. He was engaged in research and development of energy equipment in the private sector. He specializes in mechanical engineering, energy technology, and nuclear engineering. His current subjects of interest include science and technology policies in the fields of energy and the environment, and policies and corporate management that contribute to solving the 3E (Energy, Environment and Economy) problem.

(Original Japanese version: published in August 2005)

9

Construction of an Integrated Earth Observation System Driven by Utilization Needs
— Promotion of GEOSS, which was Introduced at the Evian G8 Summit and Endorsed at the Gleneagles Summit —

TERUHISA TSUJINO
General Unit

1 Introduction

The recent Delphi analysis[1] of important science and technology themes for Japan demonstrated that researcher interest in "Earth observation" is extremely high. Out of the 858 themes listed, 14 of the top 20 themes considered most important involved areas where Earth observation can make useful contributions including global warming, climate change, and disaster management. Despite this, the promotion of Earth observation in Japan has not necessarily been driven by utilization needs. In addition, remote sensing from space and *in situ* observations has not usually been well coordinated. These tendencies are also common in the USA and Europe, which lead the world in Earth observation.

In Japan, however, in December 2004, the Council for Science and Technology Policy (CSTP) called for "construction of an integrated Earth observation system driven by utilization needs" in its "Promotion Strategy for Earth Observation"[2]. In addition, the February 2005 Third Earth Observation Summit approved a 10-year Implementation Plan for the Global Earth Observation System of Systems (GEOSS), beginning a new initiative in international Earth observation. In other words, the strategy is now shifting away from the development of individual systems driven by technological seeds towards the construction of an integrated Earth observation system driven by utilization needs. Furthermore, in an action plan[3] agreed upon at the July 2005 Gleneagles (UK) summit of developed nations, the G8 countries agreed to promote the GEOSS 10-year Implementation Plan.

In GEOSS, the "Earth observation systems" is an integrated concept of *in situ* observation and satellite observation. The elements comprising these multiple "systems" include systems for *in situ* observation of climate, the atmosphere, oceans, disasters, ecosystems, coasts, and so on, as well as satellite observation systems carried out by Earth observation satellites equipped with various instruments. Satellite observation enables the continuous acquisition of a broad range of data, but correction of that data through comparison with *in situ* observation further increases their accuracy. Integration of data from *in situ* observation and satellite observation of a single phenomenon is the technical issue.

With the exception of weather observation, there have been no organizations that operate integrated satellite and *in situ* observation on an ongoing basis in Japan. This has been a weak point in the promotion of international Earth observation initiatives for Japan. As a result of international cooperation, the Integrated Global Observing Strategy Partnership (IGOS-P) was therefore established in 1998 as an experiment in integrated Earth observation. In IGOS-P, Japan works jointly with the USA, Europe, and others, taking the lead in such areas as climate change and the water cycle. The results of IGOS-P will serve as input for the GEOSS 10-year Implementation Plan. As data collection should continue into the future, new observation technology should be incorporated and an Earth observation system, driven by utilization needs, should be constructed. This report provides an overview of *in situ* and satellite observation and, based on the integration of these techniques now occurring in the USA and Europe and recent trends in the development of new observation technology, offers proposals on 1) the establishment of an institution to carry out ongoing satellite observation, 2) expansion of *in situ* observation through the increased utilization of ODA, and 3) the development of new satellite observation technology, driven by utilization needs.

2 Global Earth Observation System of Systems (GEOSS)

2-1 Circumstances from warnings of an Earth in crisis to GEOSS

In 1972, the Club of Rome published a research report entitled *The Limits to Growth*, predicting and warning the world of the dangers of resource depletion, food shortages, and so on that would accompany with rapid population growth on a global scale. Subsequently, with the steadily growing economy constrained by factors such as energy-conservation technology developed in response to oil crises and by the collapse of the bubble economy, the sense of crisis regarding global limits receded somewhat. The economic growth of China and India, however, has brought actualized problems such as resource use and air pollution, while the impact of greenhouse gas emissions on global warming has also become clearer. This has once again shone a spotlight on the global scale of these social problems. Table 1 depicts the course of international progress related to Earth observation since the beginning of the 21st century.

During this period, the Integrated Global Observing Strategy Partnership (IGOS-P) was implemented, beginning in 1998. By means of international cooperation, various types of existing data on eight global themes such as marine, atmospheric chemistry, the carbon cycle, and the water cycle are being integrated into an experimental database while the equipment necessary for constant observation is prepared.

2-2 GEOSS 10-year Implementation Plan

The GEOSS 10-year Implementation Plan approved at the Third Earth Observation Summit was advanced by the “ad hoc intergovernmental Group on Earth Observations” (ad hoc GEO). At the Third Earth Observation Summit in 2005, the ad hoc GEO was succeeded by the “intergovernmental Group on Earth Observations” (GEO) in order to carry out the 10-year Implementation Plan. This plan includes nine goals and objectives for an Earth observation

Table 1 : International progress related to Earth observation in the 21st century

Month & year held	Meeting name	Location held	Major purposes, documents, etc.
October 2002	World Summit on Sustainable Development	Johannesburg (Republic of South Africa)	Take international action on bridging the gaps between developed and developing countries, threats to the global environment, etc.
June 2003	Summit of developed nations	Evian (France)	Agreement on “Science and Technology for Sustainable Development: G8 Action Plan” [4]
July 2003	First Earth Observation Summit	Washington, DC (USA)	Aimed to construct a framework for international cooperation on Earth observation initiatives
April 2004	Second Earth Observation Summit	Tokyo (Japan)	Adopted framework documents for the GEOSS 10-year Implementation Plan
February 2005	Third Earth Observation Summit	Brussels (Belgium)	Approved the GEOSS 10-year Implementation Plan
July 2005	Summit of developed nations	Gleneagles (UK)	Major themes were climate change and African issues. GEOSS promotion was stipulated in the action plan.

system and five common methods by which to achieve them.

(1) The nine goals and objectives of the Earth observation system

The nine goals and objectives of GEOSS are grouped into "societal benefit areas". The observation technology developed and the data accumulated to date will probably be utilized in multiple areas. The nine areas are 1) "Disasters": reducing loss of life and property from natural and human-induced disasters, 2) "Health": understanding environmental factors affecting human health and well-being, 3) "Energy": Improving management of energy resources, 4) "Climate": Understanding, assessing, predicting, mitigating, and adapting to climate variability and change, 5) "Water": improving water-resource management through better understanding of the water cycle, 6) "Weather": improving weather information, forecasting, and warning, 7) "Ecosystems": improving the management and protection of terrestrial, coastal, and marine ecosystems, 8) "Agriculture": supporting sustainable agriculture and combating desertification, 9) "Biodiversity": understanding, monitoring, and conserving biodiversity (abbreviated titles are in quotation marks).

The USA has analyzed the importance of past observation data to each societal benefit area[5]. Table 2 shows some excerpts from this analysis. Because the observation data are roughly

Table 2 : Relationship between observation data and GEOSS's societal benefit areas

Observation data \ GEOSS's societal benefit areas	Disasters	Health	Energy	Climate	Water	Weather	Eco-systems	Agri-culture	Oceans*
Land use	Moderate	High	Moderate	Moderate	Moderate	Moderate	High	High	Low
Ecosystem parameters	Low	Moderate	Low	High	Moderate	Low	High	High	High
Fires	High	High	Low	Low	Low	Low	High	High	Low
Snow and ice	Moderate	Moderate	Moderate	High	High	Moderate	Moderate	Moderate	Moderate
Temperature / ocean surface temperature	High	High	High	High	Moderate	High	High	High	High
Water quality	High	High	Low	Low	Moderate	Low	High	High	High
Ocean circulation	Low	Low	Low	High	Low	Moderate	High	Low	High
Ocean color (chlorophyll)	Low	High	Low	Low	Low	Low	High	Low	High
Atmospheric components	High	High	High	High	High	Low	Low	Low	Moderate
Wind speed and direction	High	High	Low	High	Low	High	Moderate	Moderate	High
Cloud volume	Moderate	Low	Low	High	Low	High	Low	Moderate	Moderate
Space atmosphere	High	Moderate	High	Low	Low	Low	Low	Low	Low
Earthquakes and volcanoes	High	Low	Low	Moderate	Low	Low	Low	Low	Low

High: High importance; Moderate: Moderate importance; Low: Low importance

* GEOSS includes the area of "Biodiversity" rather than "Oceans".

Source: USA materials[5]

equivalent to the eight IGOS-P themes of oceans, atmospheric chemistry, terrestrial, terrestrial disasters, and snow/ice etc., Table 2 also shows the degree of connection between IGOS-P and GEOSS.

(2) Common methods

In order to realize goals in the above societal benefit areas, GEOSS includes the following five common methods: 1) adoption of new means of observation and the improvement and linkage of existing observation systems, 2) appropriate data sharing, 3) ensuring interoperability, 4) facilitation of research and development, and 5) capacity-building in developing countries.

3 Trends in *in situ* observation systems

In situ observation systems are systems that measure terrestrial weather, ocean temperature and pressure, and so on, and integrate global data. This section provides an overview of weather, ocean, and terrestrial observation systems implemented mainly by the United Nations.

3-1 Weather observation systems

In 1992, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) established the Global Climate Observing System (GCOS)[6] in order to strengthen various forms of terrestrial, ocean, and space monitoring and scientific observation. Signatory countries to the framework agreement on climate change have a duty not only to strictly abide by the Kyoto Protocol, but also to scientifically evaluate the results and to work to further advance climate change prediction. In order to distinguish changes related to global warming from changes in the natural environment such as solar activity, volcanic eruptions, and El Niño, long-term and highly accurate observation is necessary. In addition, in order to carry out research that compares various types of data, measurements collected from each country during each observation period must be standardized and checked. This sort of long-term, “systematic climate change observation” on a global scale is vital for research on global environmental change.

In Japan, the Japan Meteorological Agency (JMA), which uses the observations of weather satellites and oceanographic observation vessels to forecast the weather, cooperates with GCOS.

3-2 Ocean observation systems

Along with the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), institutions such as the World Meteorological Organization and the United Nations Environment Program promote and sponsor the Global Ocean Observing System (GOOS)[7] in order to gather scientific data through the use and improvement of existing ocean observation systems and to disseminate them widely throughout society in order to contribute to sustainable development. Japanese activities carried out in conjunction with GOOS include the establishment of a subcommittee on GOOS by the Science Council of Japan’s Liaison Committee on Marine Science. Several oceanographic research institutions, such as the University of Tokyo’s Ocean Research Institute and Hokkaido University’s Division of Earth and Planetary Sciences, participate in research on individual themes within GOOS.

Since 1983, the Hydrographic and Oceanographic Department of the Japan Coast Guard has been accumulating observation data for research on the western Pacific. The Coast Guard’s Japan Oceanographic Data Center (JODC) makes this data widely available.

Oceangoing robots called Argo floats, which form a floating observation network around the world, are an example of new *in situ* observation equipment for oceans. Argo floats usually drift at a depth of 1,000 m, but about every 10 days they descend to 2,000 m and then rise to the surface, measuring pressure, temperature, and salinity along the way. After reaching the surface, they transmit their observation data to satellites. To date, over 3,000 Argo floats have been released by various ships. Of these, communications from about 1,000 have failed, so plans call for more to be added until the goal of 3,000 operating units is reached. The oceanographic data obtained by each country’s floats are transmitted to the Argo

Information Center in France. In Japan, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) releases Argo floats and collects and analyzes the data.

One of GOOS's pilot projects is the Global Ocean Data Assimilation Experiment, which can predict the occurrence of the El Niño effect by measuring both surface and underwater temperatures[8]. Ships traveling the world's oceans have, for many years, measured the underwater temperatures of the seas they traverse. Oceanographers have analyzed those records and collated the past 150 years of ocean temperature data (Data assimilation). With the addition of satellite observation of surface temperature and precipitation to existing *in situ* observations of underwater temperature and salinity, it is hoped that it will be easier to predict the occurrence of the El Niño effect in the future.

3-3 Terrestrial observation systems

The United Nations Food and Agriculture Organization (FAO), the International Council of Scientific Unions (ICSU), the United Nations Educational, Scientific and Cultural Organization, the United Nations Environment Program, and the World Meteorological Organization sponsor the Global Terrestrial Observing System (GTOS)[9]. GTOS is a system for gathering data related to terrestrial ecosystems, including food, water, living things, and so on, and transmitting them to users. GTOS is concerned with 1) the possibility of producing sufficient food for an expanding population, 2) supply and demand relationships regarding water resources, 3) threats to human beings and ecosystems from hazardous waste, 4) biodiversity, and 5) the impact of climate change on terrestrial ecosystems. GTOS is aiming for expanded observation of these areas, sustained data collection, and the successful implementation of systems for analysis and forecasting. Observations currently carried out by GTOS include the monitoring of terrestrial ecosystems, primary productivity, terrestrial carbon, forests, land cover, and land-based and freshwater ecosystems along coastlines.

4 Trends in satellite observation systems

4-1 Trends in U.S. Earth observation satellite technology

(1) The history of NASA's development and operation of Earth observation satellites

The National Aeronautics and Space Administration (NASA) has carried out the development of satellite Earth observation technology since the earliest days of space development. It launched its first weather satellite, TIROS, in 1960 and the terrestrial observation satellite LANDSAT 1 in 1972. In 1983, jurisdiction over LANDSAT shifted to the National Oceanic and Atmospheric Administration (NOAA) and NOAA transferred the operation and ongoing development of LANDSAT to the EOSAT company. This means that monitoring was then carried out by the private sector. EOSAT, however, was unable to successfully compete with French commercial Earth observation satellite "Satellite Probatoire d'Observation de la Terre (SPOT)" and did not achieve the expected sales of satellite images. In 1992, therefore, NASA and the Department of Defense (DoD) took over management of LANDSAT operations. However, NASA's budget for Earth observation was cut sharply, so the observation system was reconfigured using mid-sized satellites such as Terra and Aqua[10]. In addition, NASA has launched further satellites for the observation of oceans, the ozone layer, and so on.

Following recent policy shifts, NASA is now giving priority to manned Moon exploration and Mars exploration, so funds for Earth observation and other fields are decreasing, but NASA is still developing new Earth observation satellites. The Earth observation satellite on which NASA is currently concentrating its efforts is the Orbiting Carbon Observatory (OCO)[11], which will be used for research on the carbon cycle.

(2) NOAA's weather satellites

The National Oceanic and Atmospheric Administration (NOAA) operates the Geostationary Operation Environment Satellites

Table 3 : Earth observation satellite instruments under development in Japan

Satellite name	Instrument name		Developing organization	Observation band
ALOS	Phased array type L-band synthetic aperture radar	PALSAR	JAROS / JAXA	Microwaves
	Panchromatic remote-sensing instrument for stereo mapping	PRISM	JAXA	Visible and near infrared light
	Advanced visible and near infrared radiometer-2	AVNIR-2		Visible and near infrared light
GOSAT	Greenhouse gas observation sensor		Ministry of the Environment / NIES / JAXA	Near infrared to far infrared
	Cloud/aerosol observation sensor			Visible to short wavelength infrared light
GPM	Dual precipitation radar	DPR	NiCT/JAXA	Microwaves

(GOES) and Polar Orbiting Weather Satellites (NOAA satellites). The NOAA-18 satellite, launched by NASA on May 20, 2005, was transferred to NOAA once it reached regular operational status. This satellite carries six kinds of observation sensors, including an advanced very high-resolution radiometer (AVHRR). The United States Air Force (USAF) also operates Defense Meteorological Satellites (DMSP) which carry various Special Sensor Microwave (SSM) equipments and are in continuous use. The final satellite in the DMSP program, DMSP-F20, is due to be launched in 2011. The program will then be integrated with NOAA's polar orbiting satellites.

(3) Private-sector commercial Earth observation satellites

U.S. commercial Earth observation satellites include OrbView, QuickBird, and IKONOS. Space Imaging, Inc., a subsidiary of Lockheed Martin Corp., uses its compact IKONOS satellite to acquire images with a resolution of 1 m from an altitude of 700 km, and sells them. This satellite can also take images of designated locations according to the requirements of customers and has a much higher resolution than that of France's SPOT, which had previously been considered "high-resolution".

4-2 Trends in European Earth observation satellite technology

In 1995, the European Space Agency (ESA) launched the second European Remote Sensing Satellite (ERS-2), the successor to 1991's ERS-1, and in 2002 it launched the environmental monitoring satellite Envisat with improved observation instruments. Because observation data were acquired continuously throughout this time, Europe's satellite observation program can be considered mature.

For weather observation, the European Meteorological Satellite Organization (EUMETSAT) launched seven Meteosat geostationary environmental satellites over a period of 20 years, and then began operating the next-generation Geostationary Operation Environment Satellite (Meteosat Second Generation: MSG) in 2002. It is currently developing the polar orbiting weather satellite (MetOp) for launch in 2006.

As noted above, France's commercial Earth observation satellite SPOT has lost its superiority due to its low image resolution compared to IKONOS, but it remains competitive internationally because of its applications in agriculture for observing vegetation distribution, and its use in compiling topographical maps.

4-3 Trends in Japanese Earth observation satellite technology

In the field of Japanese satellite observation, led by the Japan Aerospace Exploration Agency (JAXA), the Japan Resources Observation System Organization (JAROS), a foundation formed under the jurisdiction of the Ministry of the Economy, Trade and Industry (METI), the Ministry of the Environment (MOE) and the National Institute for Environmental Studies (NIES); the National Institute of Information and Communication Technology (NiCT) under the Ministry of Internal Affairs and Communications (MIAC); and so on, developed observation sensors in accordance with utilization needs, enabling Japan to accumulate technology that now leads the world in satellite observation.

JAXA has continued development of Earth observation satellites and analysis programs and the work of promoting data usage formerly carried out by the National Space Development Agency of Japan (NASDA). An Advanced Land Observing Satellite (ALOS) is scheduled for launch via H-II A launch vehicle during fiscal 2005. In addition, JAXA is developing the Greenhouse Gases Observing Satellite (GOSAT)[12] in conjunction with the Ministry of the Environment and the National Institute for Environmental Studies as a GEOSS-centered initiative on global warming. The Japan Resources Observation System Organization has completed development of the Phased Array type L-band Synthetic Aperture Radar (PALSAR) that will be carried by ALOS, and it is now ready for launch. Following the successful development of Precipitation Radar (PR) for the Tropical Rainfall Measuring Mission (TRMM), the National Institute of Information and Communication Technology is now carrying out research and development into leading-edge information and communications technology such as Dual Precipitation Radar (DPR) for the main Global Precipitation Measurement (GPM)[13] satellite and disaster monitoring through the use of aircraft radar. Table 3 shows the observation instruments being developed by these institutions.

4-4 Progress in satellite observation by countries in Asia and Africa

In Asia, China, India, and South Korea give priority to the development and operation of Earth observation satellites as tools for their own economic development and as contributions to neighboring countries. China operates weather satellites (in both geostationary and polar orbits), resource exploration satellites, marine observation satellites, space environment observation satellites, and so on, carrying out its Dragon Program with the assistance of European Envisat satellites[14]. India also develops and operates geostationary environmental satellites, terrestrial observation satellites, marine observation satellites, cartographical satellites[15], and so on, and has reached the level of selling images commercially. South Korea already operates the camera-equipped Arirang 1 satellite (KOMPSAT-1), and will launch Arirang 2 (KOMPSAT-2) during 2005. It aims to achieve a resolution of 1 m or less. South Korea's activities are attracting attention because they are an attempt to use satellites to carry out joint government-private commercial activities. The South Korean government will launch Arirang 2, but the South Korean venture company Satrec Initiative[16] will sell receiving stations to users in Korea and abroad. In addition, Israel and Taiwan have multiple Earth observation satellites.

As for Earth observation satellites in Africa, the Republic of South Africa launched a Sunsat satellite in 1999, and Morocco launched the MAROC-TUBSAT satellite, with help from the Technical University of Berlin, in 2001. In addition, Algeria launched the Alsat-1 satellite in 2002, and Nigeria launched the Nigeriasat-1 satellite in 2003, and they are now both in operation. However, these countries are not yet very advanced in the technical development of Earth observation satellites and, right from the beginning, their policies have been driven by such needs as disaster monitoring. They therefore participate in international cooperative groups that simultaneously operate multiple Earth observation satellites in order to realize societal benefits for their own countries.

4-5 Committee on Earth Observation Satellites (CEOS)

A major partner in IGOS-P is the Committee on Earth Observation Satellites (CEOS)[17], which consists mainly of the various space agencies that develop and operate Earth observation satellites. CEOS was established in 1984 in response to a recommendation from the 1982 Economic Summit of Industrialized Nations' Panel of Experts on Satellite Remote Sensing, which held in Paris. To date, it has cooperated on areas of fundamental research related to the acquisition, processing, and utilization of Earth observation data, such as data format standards and catalog interoperability. As shown in Table 4, CEOS members (including associates) include space agencies, meteorological agencies, remote sensing agencies, support institutions, and related programs. Major participants include 21 institutions from 17 individual countries, including 3 from Europe. Associate members comprise 21 institutions, mainly government support institutions that propose policies on Earth observation, UN agencies, and related programs. Relevant institutions can participate in the observation program regardless of their CEOS membership status.

In Japan's case, the Japan Meteorological Agency, the Remote Sensing Technology Center of Japan (RESTEC), and so on are not yet CEOS members. In the future, however, it is hoped that institutions that are driven by utilization needs (a position different from that of Ministry of Education, Culture, Sports, Science and Technology (MEXT)/JAXA, which develops technological seeds) will participate in CEOS.

Table 4 : CEOS member institutions (including associates)

Space agencies	16, including NASA and MEXT/JAXA
Weather agencies	3, NOAA (USA), Russia, Europe
Remote sensing agencies	3, Canada, China, Thailand
Government support institutions	8, including the EC
UN support agencies	8, including UNESCO
Programs	7, including GCOS

5 Trends in the construction of integrated earth observation systems in the USA and Europe

5-1 The USA's Integrated Earth Observing System (IEOS)

In April 2004, NASA, NOAA, DoD, the Department of Energy (DOE) and other agencies published the "Strategic Plan for the U.S. Integrated Earth Observation System" compiled by the Interagency Working Group on Earth Observations, a part of the National Science and Technology Council's Committee on Environment and Natural Resources. The USA's GEOSS 10-year Implementation Plan will proceed in accordance with this document. It sets out a policy of putting effort into warning of natural disasters as a short-term goal for IEOS for the fiscal 2007 budget[18].

The USA utilizes the shared societal benefit areas in international action on GEOSS, but in domestic plans it replaces "biodiversity" with "oceans" (See Table 2). Conservation of biodiversity can be seen as a facet of ocean resource issues but, from the perspective of biodiversity, ocean biodiversity is only one component. In light of the importance of terrestrial biodiversity, this strained definition of a societal benefit area by the USA may have a negative impact on international cooperation.

NASA's Goddard Space Flight Center (GSFC) researches the most advanced systems related to Earth observation and collects much of the world's Earth observation data in its GCMD server[19]. By use of this resource, one can determine where different types of observation data are located. The server acts as the U.S. contact point for the Committee on Earth Observation Satellites' International Direct Network (CEOS/IDN).

The U.S. Environmental Protection Agency (EPA) provides 45 types of real-time observation data, 37 databases, 50 kinds of models, 34 decision-making tools, and 33 programs encompassing observation targets such as air, water, land, and ecosystems, all laid out in a graphical interface[20]. General users can access real-time data from observations of air, soil, and so on made by organizations under its umbrella. For example, if one wants information on ultraviolet rays, one need only enter a zip (postal) code or city name to see a display of the current UV index and any warnings about exposure.

Despite such efforts to disseminate user-oriented Earth observation systems in the USA, they still do not reach the level of the "integrated observation system" envisioned for GEOSS.

5-2 Europe's Global Monitoring for Environment and Security (GMES)

In February 2004, the European Commission (EC) adopted an action plan on GMES. The purpose of this plan is to utilize satellite and *in situ* observation data to support decision-making on the environment and security and to provide user-oriented services. For example, GMES is intended to be useful in the management of disasters such as forest fires and floods and in addressing various environmental issues. The action plan for GMES even includes aspects such as supervising institutions and procuring funds, and it specifies the functions to be established by 2008. Target dates differ by category but functions include 1) an organizational framework for GMES, 2) a framework for dialog with users, 3) implementation of high-priority services, 4) strategies for data and information, 5) development of capacity and interfaces to improve data and information access, traffic, and sharing, 6) elemental development of space capability, 7) supplemental utilization of existing in situ observation, evaluation of its capabilities, and implementation plans for new developments, 8) surveys and practical actions (including provision of adequate funding) to support service quality and progress, 9) the GMES international partnership policy, and 10) ensuring the sustainability of GMES services through the adoption of financing mechanisms. Even in Europe, however, data obtained from many different information sources are still not fully integrated.

6 New research examples and ideas on earth observation methods which Japan should note

6-1 Broad observation of the water cycle by satellites equipped with laser interferometers

Japan has led the world in research on the water cycle. Research in this field, on the "establishment of water cycle informatics", has been underway since fiscal 2003, facilitated by the Special Coordination Funds for Promoting Science and Technology. As part of this program, the assimilation of terrestrial observation data and construction of a database integrating them with satellite observation is now underway. Based on such successes, Japan views the water cycle as a high-priority area. However, terrestrial observation and conventional satellite observation may explain only part of the behavior of the water cycle. One possible method of effecting a deeper understanding the water cycle is to utilize laser interferometers to measure gravitational anomalies between pairs of satellites. The USA and Germany launched the gravitational observation satellite GRACE for just such a purpose and are now analyzing its data, demonstrating the effectiveness of this method for water cycle research[21]. In Japan as well, in November 2004, the Earthquake Research Institute of the University of Tokyo, the Kyoto University Faculty of Science, and the National Institute of Information and Communications Technology led a research conference to consider a satellite gravity mission to view the Earth's "flow". Researchers who participated in the conference recommended the development of laser interferometers with even higher resolution than GRACE. Unfortunately, however, this new research trend is not yet included in the GEOSS 10-year Implementation Plan. Utilization of satellite gravity missions to advance research on the water cycle should be considered.

6-2 Earthquake detection by observation of electromagnetic waves

Among those societal benefit areas mentioned above, earthquake countermeasures are considered the policy area most important for Japan's national safety and security. Numerous seismometers have been placed in underground and on the bottom of sea, establishing a system for the early detection of earthquakes. In the field of earthquake detection, while *in situ* observation with seismometers and so on has comprised the mainstream approach, but another research has also begun on radically different methods of observation technology.

For example, the French electromagnetic wave observation satellite DEMETER was launched in June 2004 and is collecting research data on the relationship between electromagnetic wave anomalies and the occurrence of earthquakes[22]. In the USA, the Quakesat satellite, launched by a private-sector company, detected electromagnetic waves believed to have been generated by an earthquake.

In Japan, since 2003, the Japan Aerospace Exploration Agency has analyzed the correlation between earthquake occurrence and the plasma parameter data obtained by the solar observation satellite Hinotori (orbit inclination 30°, altitude 600 km) launched by the Institute of Space and

Astronautical Science (ISAS) in 1981. Research in this area should be encouraged in order to carry out more of this type of analysis.

6-3 Weather observation from quasi-zenith orbits

Improving the accuracy of weather forecasts is another goal of GEOSS. In Japan, the Ministry of Land, Infrastructure and Transport (MLIT) operates the Multi-functional Transport Satellite Himawari 6 (MTSAT-1R), which includes weather observation functions. It carries out observations every 30 minutes across a broad swath of the Pacific Rim from its position above the equator at 140° east longitude, enhancing the accuracy of weather forecasts.

If at least three satellites with weather observation sensors equivalent to those aboard the Himawari 6 were to be placed in orbits of Quasi-Zenith Satellite System (QZSS)[23], they could carry out continuous observation of the Arctic and Antarctic, which cannot be covered by a geostationary satellite. Japan currently has no polar orbiting weather satellites and is dependent on observation data from the USA's NOAA satellites. Because quasi-zenith weather satellites have a lower resolution than NOAA satellites, they could not immediately replace them but, by constantly observing the Arctic region, which has a strong influence on weather in the northern hemisphere, they could play an important role in supplementing NOAA satellites and geostationary meteorological satellites.

6-4 Research on relationships between solar activity and Earth systems

We know that the Sun's activity directly affects the Earth's biosphere. For example, in an international workshop on space weather held in Tokyo in April 2005, new research was announced showing that when "flux ropes", generated as helical extensions of the Sun's magnetic field by solar flares, penetrate the Earth's magnetosphere they create magnetic storms. Of further note was the report that when the interplanetary space magnetic fields of these helixes are oriented towards the Earth's South Pole, they have a stronger influence on Earth's radioactive and electromagnetic plasma environments than when they are oriented towards the North Pole. When carrying out Earth observation, observing changes in the space environment such as solar activity and changes in the magnetic fields of solar winds and understanding their long-term relationships with the Earth's weather have now become important[24]. In the Council for Science and Technology Policy's "Promotion Strategy for Earth Observation", "Earth science" is also among the 15 promotion strategies listed. Through observations not only of solar activity, but also of geospace, the upper atmosphere, ocean and lake sediments, and ultradeep drilling, we can gain a more complete understanding of the relationships between Earth systems and the expanding humanosphere.

7 Improving data processing environments

Because Earth observation systems add to their vast amounts of accumulated data, day by day, proper data processing is a serious issue. A number of methods have been developed in order to process the huge amounts of Earth observation data collected and to extract meaningful information from them. Advanced supercomputer systems play a large role in this data processing. Japan's representative supercomputer system is the Earth Simulator at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). According to the Linpack benchmark, some US supercomputers have already exceeded its performance, but it remains among the world leaders in actual speed of large-scale numerical simulation.

The technologies cultivated through the development and operation of the Earth Simulator should be applied to the processing and analysis of satellite data, and a data processing environment should be developed that meets diverse needs. In particular, maximizing the use of networks would greatly increase convenience. In 2005, remote use of the Earth Simulator, which had previously only been available within its own building, became possible through Super SINET.

From the point of view of the data processing environment, development and use of a supercomputer system that can outperform the

Earth Simulator should contribute to expanded science and technology successes for Japan. The Earth Simulator works around the clock, but it still cannot meet the widespread demand for its calculations, so only users in selected fields can utilize it. In order to create a data processing environment that would give its many users easy access, for example, the Remote Sensing Technology Center of Japan (which has ability to analyze various Earth observation data) could be further developed to implement the operation of a multi-supercomputer system that provides easy access for a broad range of researchers.

8 Conclusion — Proposals for an optimal Japanese integrated earth observation system —

"U.S.-Japan Space Policy: A Framework for 21st Century Cooperation"[25], published by the USA's Center for Strategic and International Studies (CSIS) in 2003, offers three scenarios for future Japan-U.S. relations regarding Earth observation:

A: "U.S.-dominant". At this point, the USA has little use for Japanese capabilities, but Japan is still reliant on the USA, and this inequality continues.

B: "Autonomy". Japan develops fully autonomous capabilities, its reliance on the USA declines, and there is little real value created by any cooperation.

C: "Partnership". Japan develops a strong capability of its own while also increasing its collaboration with the USA. The two countries allocate resources and costs and create joint frameworks to share imagery on a real-time basis.

The Center for Strategic and International Studies argues that there is sufficient value in cooperation between Japan and the U.S. on space issues to overcome the disincentives but, in order to obtain these benefits, frameworks must first be established to allocate appropriate areas of responsibility and provide incentives to the institutions involved.

It is my opinion that given this U.S. view, Japan is likely to proceed with a Japan-U.S. partnership by promoting GEOSS, as described above. At the same time, Japan must also turn its attention to seeking partnerships not only with the USA, but also with Europe and Asia, especially China.

Outlined below are some proposals for points that Japan should bear in mind as it moves forward with GEOSS.

(1) Proposal 1: Establishment of an institution to carry out constant satellite observation

The biggest problem when attempting to integrate *in situ* and satellite observation is the question of whether a workable system for constant satellite observation can be established. At present, this is considered a structural issue within the Japanese system. JAXA is a research and development institution, so it is limited to the development of new types of satellites and cannot provide satellites with constant performance for continuous use. If satellite specifications are broadened and opened up for international tender, inexpensive foreign-made Earth observation satellites might be purchased. Compared with commercial communications satellites, where there was an obvious capability gap with the USA and Europe, Earth observation satellites, with their more complex specifications requiring advanced robotic technologies, might well become a Japanese specialty. In order to accomplish this, however, an institution is needed that can procure and operate Earth observation satellites on a continuous basis. One possibility is to establish a Japan Remote Sensing Center as an affiliate of the Remote Sensing Technology Center of Japan under the jurisdiction of the government, and for it to become a member of CEOS along with JAXA. In order to promote integrated Earth observation in Japan, the Subdivision on R&D Planning and Evaluation of the Council for Science and Technology established a subcommittee on the promotion of Earth observation. Without an organization to lead the implementation of integrated observation, however, no matter how often the importance of integration is touted, there is a danger that 10 years will pass without any real progress being made in implementing the plan. The reason that the situation has stagnated in this way is because of the inflexibility of Japan's budget system, which makes it difficult, from a funding perspective, to induce policies in fields where change is swift. An institution must be established with the ability to lead the construction of an Earth observation system that transcends agency boundaries and meets user needs. Currently, there are large organizations such as JAXA and the Japan Meteorological Agency that have advanced technical capabilities, but neither is in a position to take a broad view of GEOSS as a whole.

(2) Proposal 2: Measures to expand *in situ* observation by using ODA

Already, the invitation of representatives from developing countries such as the Republic of South Africa to attend the summits of industrialized nations is paving the way for international cooperation on Earth observation and measures against global warming. Japan could quantitatively express its international contribution to Earth observation by dedicating a set percentage of ODA, say 10%, for GEOSS use. When given a choice between aid for economic development and aid for the protection of the global environment, ODA recipients will tend to prefer the economic development option but Japan should devise means to distribute GEOSS ODA to developing countries that want to share the benefits of IGOS-P and have the ability to do so. This kind of financial assistance, clearly defining the role of contributions made to GEOSS through ODA, could be expected to help create a commitment to balancing economic growth with the protection of the environment in developing countries. If this kind of measure can fill in some gaps in current observation, it would also bring about the global benefit of improving the accuracy of Earth observation systems.

(3) Proposal 3: Development of new satellite observation technology driven by utilization needs

Japan is already working on the development of the Greenhouse Gases Observing Satellite (GOSAT), which will contribute at the forefront of international research by observing the distribution of greenhouse gases and their sources. Japan's efforts on IGOS-P in societal benefit areas such as disaster mitigation, weather, and the water cycle while moving towards GEOSS have been well received. In the future, an integrated observation system should be further developed to incorporate important observed phenomena for which data is currently lacking, and to make better use of existing data where important relationships have yet to be recognized. New observation methods that should be developed are likely to center on satellite observation, and the question of how to raise the necessary funding for obtaining data for use in societal benefit areas must be addressed. I believe that only when Japan has unique technologies, Japan can build equal partnerships not only with the USA, but with Europe and Asia as well. However, institutions developing new observation technology should not give priority only to seeds-oriented technologies, but instead should always emphasize on utilization needs-oriented technology.

Acknowledgements

I would like to express deep gratitude to all those in the Earth Observation Research and Application Center (EORC) of the Japan Aerospace Exploration Agency's Office of Space Applications, the agency's Institute of Space and Astronautical Science, the National Institute for Environmental Studies, the Japan Agency for Marine-Earth Science and Technology, the Remote Sensing Technology Center of Japan, the University of Tokyo, Hokkaido University, Kyoto University, and Kyushu University who assisted with the writing of this article by providing materials and with whom this article was discussed.

References

[1] National Institute of Science and Technology policy. The 8th Science and Technology Foresight Survey, Delphi Analysis. May 2005, NISTEP Report No. 97: http://www.nistep.go.jp/achiev/ftx/jpn/rep097j/idx097j.html (Japanese)

[2] Council for Science and Technology Policy.

Promotion strategy for Earth observation. December 27, 2004: (Japanese)

[3] Climate Change, Clean Energy, and Sustainable Development (Gleneagles Plan of Action). Ministry of Foreign Affairs website, 2005: http://www.number-10.gov.uk/output/Page7882.asp

[4] Science and Technology for Sustainable Development: G8 Action Plan. Ministry of Foreign Affairs website, 2003: http://www.g8.fr/evian/english/navigation/2003_g8_summit/summit_documents/science_and_technology_for_sustainable_development_-_a_g8_action_plan.html

[5] National Science and Technology Council (NSTC). Strategic Plan for the U.S. Integrated Earth Observation System, April 2005.

[6] GCOS website: http://www.wmo.ch/web/gcos/gcoshome.html

[7] GOOS website: http://ioc.unesco.org/goos/

[8] Verification of the possibility of predicting El Niño through 148 years of ocean surface temperature data. Science and Technology Trends. July 2004. (Japanese)

[9] GTOS website: http://www.fao.org/GTOS/

[10] Kobayashi, Hirokazu and Urashima, Kuniko. Trends in Earth Monitoring and Observation Satellites. Science and Technology Trends - Quarterly Review. no. 11, April 2004.

[11] NASA OCO project website: http://oco.jpl.nasa.gov/

[12] JAXA GOSAT project website: http://www.jaxa.jp/missions/projects/sat/eos/gosat/index_e.html

[13] JAXA Global Precipitation Measurement (GPM) website: http://www.eorc.jaxa.jp/GPM/index_e.htm

[14] Tsujino, Teruhisa. The Rapid Progress of China's Space Development. Science and Technology Trends— Quarterly Review. no.14, January 2005

[15] India successfully launched a cartographical satellite, Science and Technology Trends. July 2005: (Japanese)

[16] South Korea Satrec Initiative website: http://www.satreci.com/eng/index.htm

[17] Committee on Earth Observation Satellites (CEOS) website: http://www.ceos.org/

[18] Executive Office of the President, Office of Science and Technology Policy. FY 2007 Administration Research and Development Budget Priorities. July 8, 2005.

[19] NASA/GSFC GCMD website on U.S. Earth observation activities: http://gcmd.nasa.gov/records/GEOSS_Tools.html

[20] U.S. Environmental Protection Agency GEOSS tools (graphical interface): http://www.epa.gov/geoss/eos/epa_eos.html

[21] Broad mobile observation of water with the GRACE gravitational observation satellite. Science and Technology Trends. October 2004: (Japanese)

[22] France launched an electromagnetic field observation satellite. Science and Technology Trends. August 2004: (Japanese)

[23] Tsujino,Teruhisa. Effectiveness of the Quasi-Zenith Satellite System in Ubiquitous Positioning. Science and Technology Trends - Quarterly Review. no. 16, July 2005

[24] Tsujino, Teruhisa. Research Trends in Space Environment Observation and Fluctuation Monitoring. Science and Technology Trend - Quarterly Review. no.15, April 2005

[25] Kurt M. Campbell, et al. U.S.-Japan Space Policy: A Framework for 21st Century Cooperation. ISCS, July 2003.

Teruhisa TSUJINO
General Unit, Science and Technology Foresight Center

Specialist in electrical engineering. After managing the operation of the Shinkansen (bullet train) for Japan National Railways, he worked at the National Space Development Agency of Japan in areas related to space technology in general and its contact points with society, including information systems, research on space development around the world, and the management of intellectual property. At the Science and Technology Foresight Center, he is in charge of "frontier fields".

(Original Japanese version: published in September 2005)

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 2000 experts of various science and technology fields in the industrial, academic and government sectors. They are in the front line or have advanced knowledge in their fields.

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

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

2. Research into trends in major science and technology fields

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

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

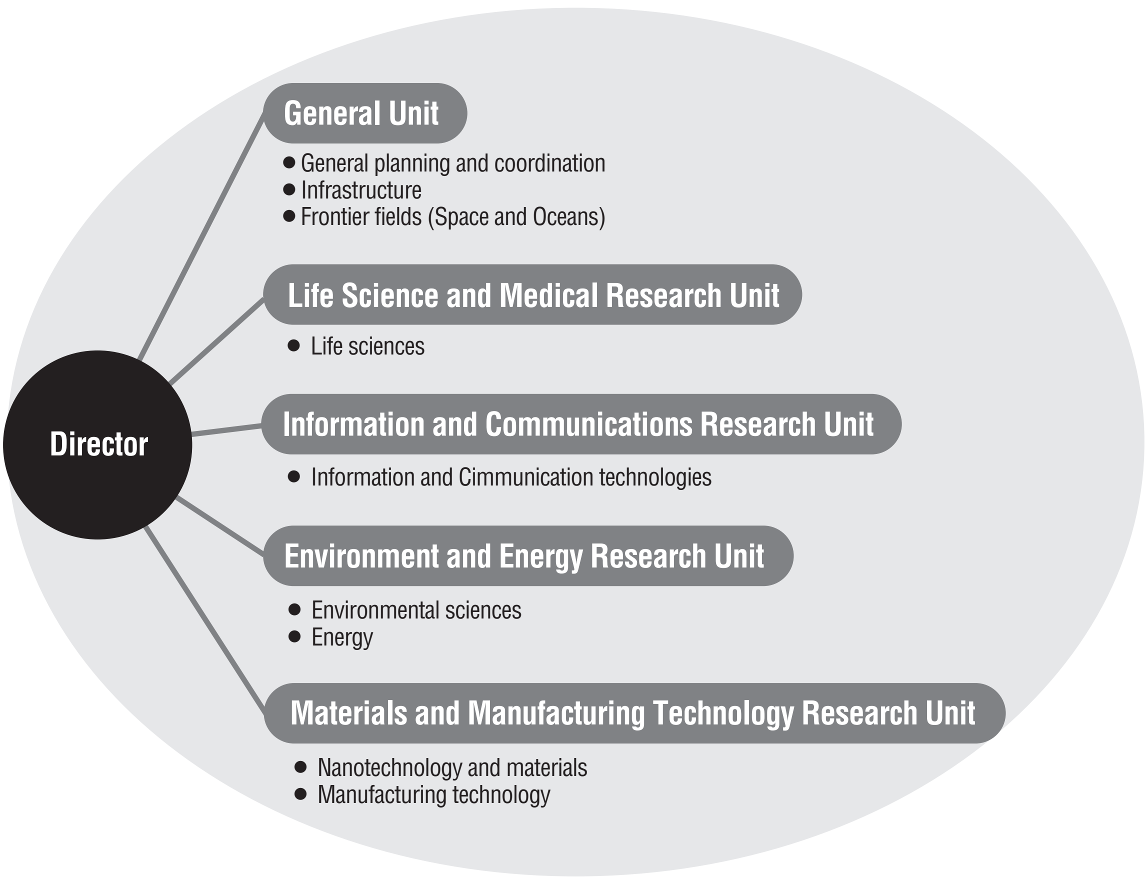
3. S&T foresight and benchmarking

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

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

— The research results are published as NISTEP report.

Organization of the Science and Technology Foresight Center



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

NISTEP

Science & Technology Foresight Center

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

Science and Technology Trends —Quarterly Review 2006.1