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Science & Technology Trends

Quarterly Review

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Life Sciences

Food Poisoning and Infectious Disease by Norovirus Situation and Countermeasures in Japan

Information and Communication Technologies

Japan's Critical Issues on IT Human Resource

Environmental Sciences

Contribution of Electric Power Technology to Greenhouse Gases Reduction

Nanotechnology and Materials

R&D Trends in High Efficiency Thermoelectric Conversion Materials for Waste Heat Recovery

Frontier

Japan's Space Development Capabilities for Lunar and Planetary Exploration

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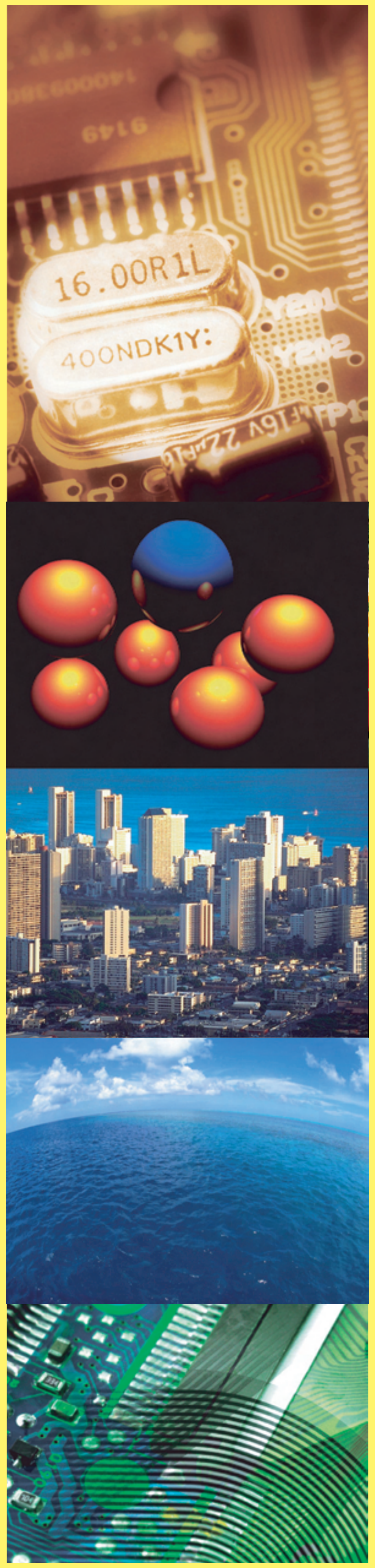

NISTEP

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 2009. 1

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.

Dr. Kumi OKUWADA
Director, Science and Technology Foresight Center
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NISTEP has moved to a new office

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Executive Summary

Life Sciences

1 Food Poisoning and Infectious Disease caused by Norovirus Situation of the Outbreaks and Countermeasures in Japan

p.8

In recent years, norovirus has gained a lot of attention concerning the management of food safety. One reason is that the virus causes not only food poisoning but also infectious disease, resulted in an increased number of the affected persons. The other is that the countermeasures remain unknown against the virus infection, because of no established systems for in vitro replication of the virus. Therefore, the effective antiviral drugs or vaccines against the virus have not been developed yet.

Norovirus can multiply only in the human intestinal tract. The circumstances suitable for the virus are highly populated areas and the water environment which preserves the infectivity of the virus.

In order to prevent the food poisoning and infectious disease caused by norovirus, the virus control in humans, food, sewage, river and seawater should be required. The potential countermeasures for the control include the elimination of the virus from the living environment of human through the strict sanitation management by the individual, and the development of detection and elimination/inactivation methods for the virus which might exist in food and sewage.

For the control of human norovirus, the fundamental researches, such as in vitro replication systems for the virus and animal models of human norovirus infection, are necessary, as well as the cross field studies over microbiology, public health, food hygiene and water supply engineering. Additionally, a comprehensive promotion of the studies is needed by the related administrative institutions, research organizations including universities, medical institutes and the related businesses.

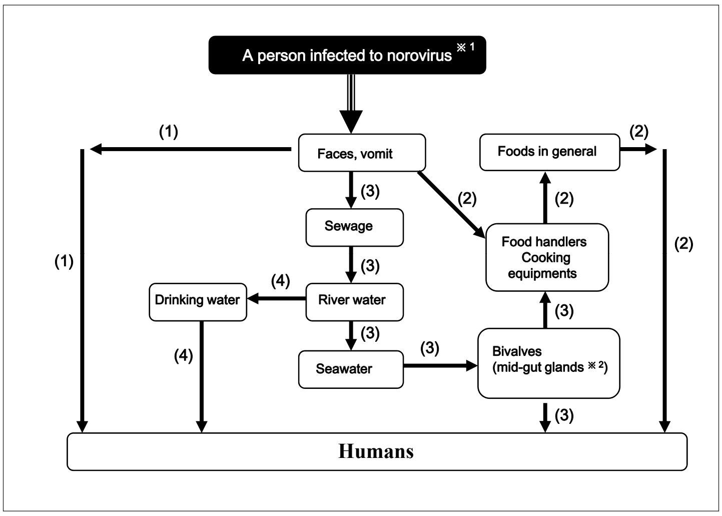

Figure : Route of norovirus infection in humans

Prepared by the STFC based on the documents issued by the Ministry of Health, Labour and Welfare[6] and the National Institute of Infectious Diseases[7]

(Original Japanese version: published in July 2008)

Information and Communication Technologies

2 Japan’s Critical Issues on IT Human Resource

p.23

The shortage of ‘IT engineers’, often called as ‘IT human resources problem’, is becoming more serious compared to the past. This current crisis is unlike previous ones because it is the real crisis of Japan as the shortage of IT human resources could even weaken the economy and the governance of this country. IT technology that will enable the future is not the ‘conventional technology to substitute the existing manual systems with automated systems’, but an innovative and general technology to create new ‘socio-techno systems for innovation’ to enhance the economic competitiveness of the country with the development of hardware, software and networks. This is because many industrial areas have introduced ‘IT’ and the information systems have become the decisive factor for the competitiveness and the quality of service.

At present, even the most conventional IT human resource development system is not working well in Japan.It is said that the offshore outsourcing of IT jobs has begun and the end of the so-called 'IT national isolation' has started.The trend could further weaken the business of small and weak IT vendors. On the other hand, the governments of the US, India, South Korea, and China are making tremendous efforts to develop IT human resources of the advanced level through the cooperation of industry, government and academia. Japan lags behind, and is currently at the stage where some activities have just begun. Some people argue that it may be impossible for Japan to develop IT industries on par with as those of the United States. However, in order to maintain competitiveness in other industries than information technology, it is necessary to develop and maintain advanced IT human resources.

The development of advanced IT human resources should be promoted as a high-priority issue of the Cabinet to proceed immediately. To oevercome this crisis is the task of the entire Japanese society, not only the task for the government and academic institutions.

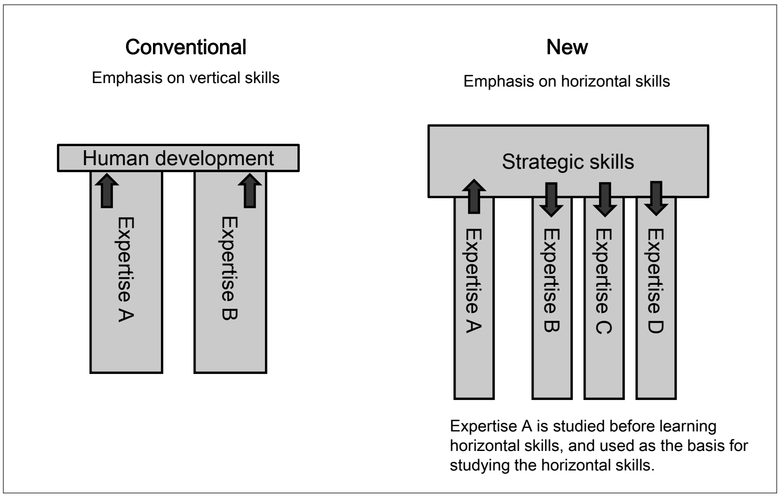

Figure : Conventional and new T-shaped/Π-shaped people

Prepared by the STFC

(Original Japanese version: published in July 2008)

Environmental Sciences

3

Contribution of Electric Power Technology for Greenhouse Gas Reduction

p.41

Recently, Increases in population and demand for energy mainly in developing countries cause environmental problems such as air and water pollution, whereas in developed countries citizen are concerned that increases in CO_2 emissions cause global climate changes affecting their life, health, and living environment. International efforts should be implemented to cope with these problems.

Japan has top level technologies such as high-efficiency power generation and transmission, energy-saving, electric power storage, and environmental technologies etc. The dissemination, establishment, and improvement of these existing technologies in the country are critically important for domestically reducing greenhouse gas emissions. Japan is also required to provide technically less-advanced developing countries not only with its advanced hardware electric power technologies such as high-efficiency equipment but also with its software technologies on operation management, inspection, and maintenance through human, exchange, information exchange, and technical assistance, thus contributing to regional environment conservation and a reduction in global greenhouse gas emissions.

As for the implementation of energy and environment policies, consensus building among industrial, academic, governmental, and private sectors, as well as technology and infrastructure development, is essential. The government, industry, and the general public should work together to enable the implementation. Policies to facilitate consensus building and enhance opportunities for more people to positively participate in related activities are needed. It is therefore desirable for specialists in social science and technology fields to cooperate in scientific research.

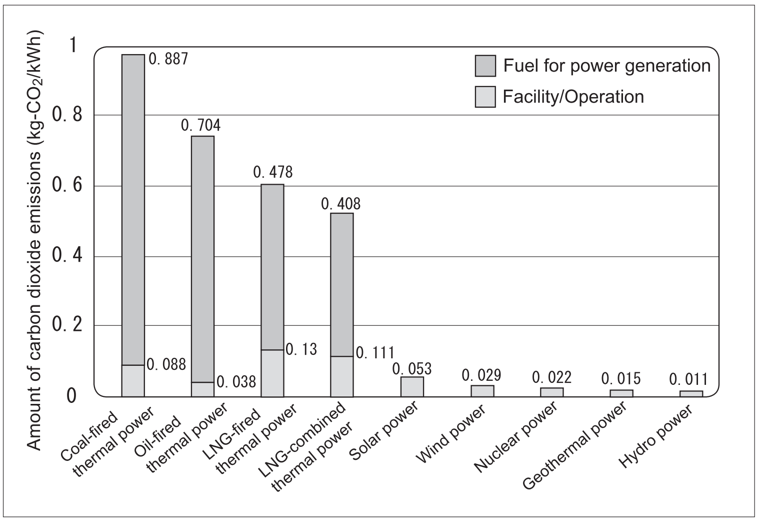

Figure :Comparison of the amounts of CO_2 emissions as a function of power source type based on life cycle assessment

Prepared by the STFC based on Reference[19]

(Original Japanese version: published in September 2008)

Nanotechnology and Materials

4 R&D Trends in High Efficiency Thermoelectric Conversion Materials for Waste Heat Recovery

p.54

Although continuing progress is being achieved in waste heat energy recovery in large-scale power generating systems, steel industry furnaces, waste incinerators, and other facilities which generate high temperature waste heat, the level of recovery still cannot be considered adequate. The establishment of technologies, which recover waste heat as effective energy, is expected to result in reduced energy consumption in social systems as a whole, and therefore can make an important contribution to solving energy problems and environmental problems such as global warming.

Thermoelectric power generating systems, which convert thermal energy to electric energy, have attracted attention from the viewpoint of recycling of waste heat energy. However, for a variety of reasons, little progress has been made in full-scale diffusion of thermoelectric generating systems. Among other problems, because the main constituents of the thermoelectric conversion materials now in use are Bi, Sb, Te, Pb, etc., limited resources and the environmental impact of the substances themselves are concerns. Moreover, the generating efficiency of devices using these materials is considerably lower than that of solar cells and other technologies. In Japan, projects which support research on various thermoelectric conversion materials and generating systems has been promoted mainly by the New Energy and Industrial Technology Development Agency (NEDO). However, the results of the material technologies and system technologies developed to date, including their cost competitiveness with other generating systems, have not reached a level that can support a thermoelectric power generation market.

In the future, concrete measures should be adopted with the aim of promoting R&D projects related to material technologies, device technologies, and application technologies in parallel, based on further clarification of the roadmap from research and development on basic/infrastructural technologies to practical application and the issues that should be addressed on a priority basis, and division of those issues into short-term and long-term issues. In particular, long-term issues include research and development on new nanomaterial systems comprising superlattices, quantum structures, etc. created by nanostructural control and related manufacturing processes, low environmental impact metal oxides, for which abundant reserves of raw material resources exist, and other new technologies. Priority should be placed on research and development of low environmental impact thermoelectric conversion materials, etc., based on a total scenario from the development of basic/infrastructural technologies to practical application or wider popularization.

If it is possible to develop modules and systems with competitive cost performance using these materials, a large expansion of the energy saving/low environmental impact technology industry can be expected, with thermal functional devices, heat recovery devices, etc. as its object. In the future, Japan should take a leadership role in this field at the global level, and secure its technical superiority over other nations.

(Original Japanese version: published in September 2008)

Frontier

5 Japan's Space Development Capabilities for Lunar and Planetary Exploration

p.70

The National Aeronautics and Space Administration (NASA)of the United States of America not only initiated a manned lunar and Mars exploration program since the Apollo program of the 1960-1970s, but is also promoting unmanned scientific missions based on the recommendations contained in a report on scientific exploration of the solar system published by the National Research Council (NRC) in July 2002. Similarly, the European Space Agency (ESA) is planning a Martian mission by an unmanned over, and China and India have begun unmanned lunar exploration programs in order to acquire new space development capabilities.

As to Japan, asteroid explorer "HAYABUSA(Muses-c)" challenged detailed scientific observation and sampling of the surface of asteroid Itokawa, achieving scientific results and has substantially established Japan's ingenious sample return capability with an ion engine and other unique space technologies. Japan's lunar orbiter "KAGUYA(Selene)" is conducting the first full-scale scientific exploration of the moon since the Apollo program to study the origin and evolution of the Moon.

Japan's such performances are due to this country's outstanding researchers and engineers. Because of the researchers and engineers of the Institute of Space and Astronautical Science (ISAS), which is part of the Japan Aerospace Exploration Agency (JAXA), it became possible for "HAYABUSA" to a successfully touchdown on the asteroid, and then to recover from a near-fatal accident due to a propellant leak which occurred after the touchdown. For Japan, being an export-dependent nation with few natural resources and a low food self-sufficiency ratio, human resources are the source of the nation's strength. Thus, the training of next generation students by researchers and engineers like those of ISIS is a critical function.

It is expected that Japan will further continue development of its ingenious technologies like the sample return with an iron engine, and promote international cooperation with its friendly nations to maintain and strengthen its bonds of trust with those nations. Also, Outreach activities based on the scientific results obtained from new lunar and planetary exploration should be continued and strengthened to secure next-generation science and engineering human resources.

Figure : "Hayabusa" (artist's conception)
Source: JAXA

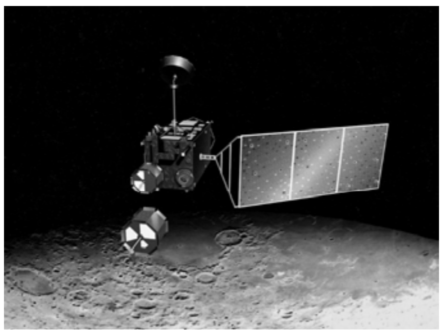

Figure : "Kaguya" (artist's conception)
Source: JAXA

(Original Japanese version:publishd in August 2008)

1

Food Poisoning and Infectious Disease caused by Norovirus Situation of the Outbreaks and Countermeasures in Japan

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1 Introduction

In Japan, the circumstances surrounding food has drastically changed due to development of the social economy and technological progress in recent years. A variety of food is on the market thanks to the improvement of production and processing technologies, as well as expansion of the area for distribution and globalization of food to contribute to diversification of our diets. However, on the other hand, people have anxieties for food further because of various problems as the outbreak of bovine spongiform encephalopathy (BSE), pesticide residue detected from import farm products, detection of toxic chemical substances from imported food and tableware, contamination to food of the genetically-modified crops which the safety is not assessed, and scandals of camouflage of production areas and ingredients of food products. Moreover, extensive outbreaks of food poisoning caused by new pathogenic microorganisms have presented problems with public health management.

Recently, norovirus has gained a lot of attention concerning the safety management of food. This is mainly because the number of infected persons tends to increase, due to the virus transmission via not only food (so-called food poisoning) but also feces and vomit of infected persons (so-called a infectious disease). Another reason of the attention is the microbiological characteristics of the virus, which leads the difficulty to multiply the virus in cultured cells. The reason is the barrier to hinder the studies about norovirus, resulted in lack of scientific information about the virus, such as how the virus would be distributed in our daily lives and the inactivation of the virus. Therefore, the researchers have failed to develop the necessary and sufficient measures to prevent the virus infection. As the extensive outbreaks of food poisoning or infectious disease caused by norovirus have become remarkable around the world, various research and development for the virus control have been actively conducted. However, it is still too soon to make the result. The lack of sufficient countermeasures against norovirus is in contrast to the established measures to prevent and control the food poisoning caused by salmonella spp. and so on.

Accordingly, preventative measures against food poisoning and infectious disease caused by norovirus should greatly contribute to the improvement of the public health of the world in the future. If a new measure to control the virus is invented, it should be valuable in the viewpoint of microbiology. This paper outlines the food poisoning and infectious disease cause by norovirus, focusing on the outbreaks and the trend of research and development for the virus control in Japan in order to take future preventative measures against the virus.

2 Microbiological characteristics of norovirus[1,2]

2-1 Name

Norovirus was discovered in the gastroenteritis patients from the mass-poisoning in an elementary school of Norwalk, Ohio, the United States in 1968. It was called SRSV , a small round structured virus (Figure 1) first based on a morphologic classification observed by the electron microscope, or sometimes called Norwalk-like virus. The name of the virus “norovirus” was authorized by the International Committee on Taxonomy of Viruses (ICTV). Subsequently, the name has been used as

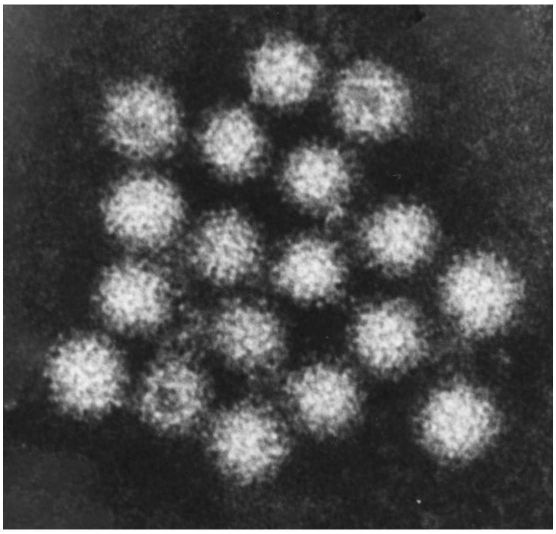

Icosahedron in diameter of 35-40nm

Figure 1 : An electron microscopy image of norovirus

Source : Provided by Dr. Osamu Nishio, the National Institute of Infectious Diseases

the common name in the world.

2-2 Virus structure and type

Norivirus has the cupped surface and single-stranded RNA as the genome, encoding two kinds of structural protein, VP1 and VP2 (virus particle). Although the virus structure is simple, the genotype of the virus is diversified. Norovirus is classified into GI and GII in general and the groups are respectively classified into 15 and 18 or more genome types. Therefore, it is considered that 30 or more norovirus genotypes currently exist. In addition, it is assumed that norovirus has the high mutation rate, which is a characteristic of RNA viruses. New genotypes of norovirus have been detected even now, and the total number of the virus genotypes may be quite large.

2-3 Virus growth and situation of study

Norivirus is thought to multiply only in the human intestinal tract. From the previous studies, it is considered that a large amount of the virus could be egested with feces from the human body after the virus growth in the intestinal tract. The number of virus particles in the feces is speculated as hundreds of millions per gram in terms of feces.

Norovirus can cause human infection only with 10-100 of the virus particles. The virus does not multiply in food or the environment, which is one of the characteristics of viruses, while it has the strong infectivity in humans. In addition, the virus is thought to retain the infectivity for relatively a long time in river or sea water. In the experiment with feline calicivirus related to norovirus, as to be mentioned below in 2-4, it was revealed that the virus retained the infectivity under the temperature of 4°C for 2 months, a room temperature for 2 weeks and 37℃ for about one week. The result of the experiment shows that rivers and sea water provide good conditions for maintaining the virus infectivity.

There is no report about the system for replication of norovirus in cultured cells (living cells outside the tissues of humans or animals from which they were obtained) and the animal models of human norovirus infection are under development.[NOTE 1] Therefore, the previous studies failed to obtain the native virus that has the infectivity to humans. In addition, the methods of experiments to analyze the details of either the vital dynamics or pathogenicity to human have not been established yet. Moreover, the distribution of the virus in human body or our living environment has not been fully analyzed. Regarding antiviral drugs, it is also difficult to develop them because of its simple virus structure. The difficulty is due to the limitation of the possible sites of the virus which the antiviral drug targets for inhibiting the synthesis of the virus structural proteins. Furthermore, the development of antiviral drugs and vaccines which are effective in all virus genotypes is difficult since the number of the genotypes is large.

2-4 Virus infectivity

As explained above, the methods for in vitro replication of norovirus are unavailable since the virus cannot multiply in cultured cells at this moment. The condition on inactivation of the virus has been presumed from the experiments in which

[NOTE 1]
Study on the experimental infection with norovirus in pig-tailed macaques showed that the infected animals had symptoms similar to the ones in human cases. Additionally the infection in pigs was reported, however, valid animal model for norovirus infection has not been established yet.

the viruses related to norovirus are applied. To take feline and dog caliciviruses as examples, the conditions on the inactivation of the viruses have been already demonstrated, because the viruses can multiply in cultured cells. Therefore, the conditions on the inactivation of the calciviruses are extrapolated to the one of norovirus. According to the experimental data on the above caliciviruses, norovirus is assumed to be completely inactivated under the temperature 85℃ for one minute or more. Norovirus is also thought to be partially resistant to chlorine agents. Therefore, it is recommended to use sodium hypochlorite solution containing around 1,000ppm of chlorine to inactivate the virus in feces of infected persons and on livingwares. Specifically, it is considered that the feces and livingwares should be soaked in the solution containing 1,000ppm of chlorine for one minute and 200ppm for 5 minutes. For feces and vomit in which a lot of organic matters are contained, the solution containing 1,000ppm of chlorine should be appropriate.[3] Furthermore, 70% ethanol solution, which is used for general sterilization, is thought to need the soaking for 5 minute or more to inactivate norovirus. Therefore, the spraying of 70% ethanol solution is considered to be insufficient to completely inactivate the virus. On the other hand, cationic soap is thought to have little effects to inactivate the virus. However, hand wash with the soap can eliminate the virus, which is a quite effective measure for preventing virus infections in general.

2-5 Method for detection

Since a large amount of norovirus exists in feces of the infected persons, the electron microscopic observation on the virus particles has been applied popularly to detect the virus. On the other hand, the methods based on genetic engineering technique have also applied to detect virus genes and virus structural proteins in recent years. The characteristics, issues and situation of research and development of the methods are described in 5-1.

3 Characteristics of food poisoning and infectious disease caused by norovirus

As described above, the knowledge about the dynamics and pathogenicity of norovirus in humans has been insufficient. Most of the below information are based on the reports about the analysis of virus genes.

3-1 Factors affecting virus infection in humans

When a virus infects humans, the virus binds first to the surface of human cells. The site of human cells to bind to the virus is called "receptor". In the case of norovirus, the experiments with norovirus structural proteins suggest that the sugar chains existed in the human intestinal epithelial cells might be the receptor.[NOTE 2] The sugar chains exist also on the erythrocytes and in the saliva of human, known as the histo-blood group antigens to determine the blood group of human. Therefore, the blood group and the infectivity of norovirus are speculated to have a close connection.[4,5]

3-2 Route of infection to human

Norovirus is known to be transmitted in several ways. The routes via food and water are also assumed as well as human feces. The former is considered as a food poisoning[NOTE 3] and the latter is an infectious disease.

The routes are shown below and Figure 2 (the numbers in Figure 2 corresponds to each item (1)-(4).[6,7]

[NOTE 2]
The term ‘sugar chain’ refers to a compound which consists of covalently-added monosaccharide. It is bonded with protein and lipid. As shown in 2-3, norovirus does not multiply in cultured cells established currently and its structural proteins cannot be extracted, therefore the virus structural protein was synthesized by genetic engineering technique, based on the reports about the analysis of virus genes in the study.

[NOTE 3]
A term “food poisoning” is defined by the Food Sanitation Law (the latest revision: June 7, 2006, Law No. 53), as “a poisoning attributable to food, food additives, apparatus or containers or packages”.

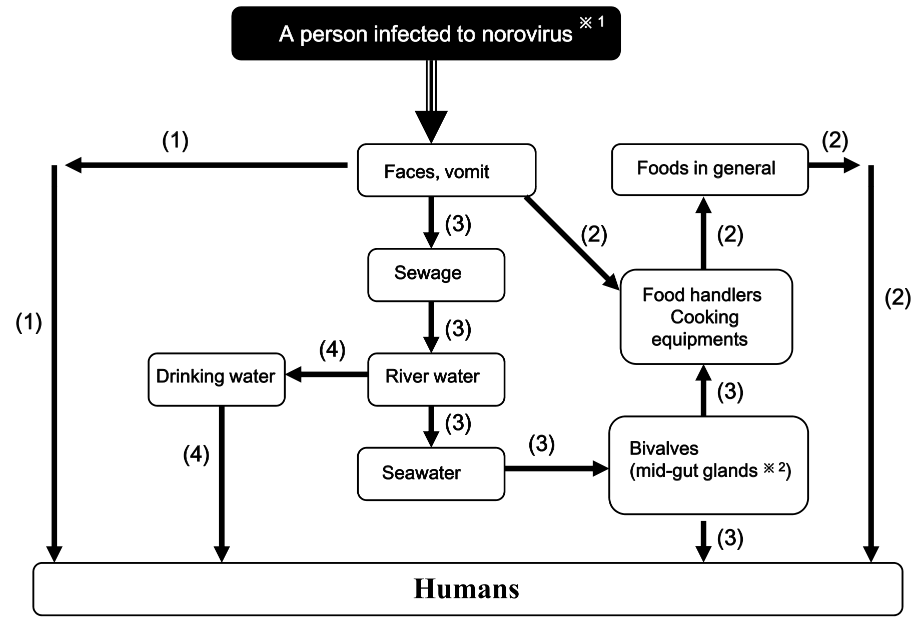


Figure 2 : Route of norovirus infection in humans

Prepared by the STFC based on the documents issued by the Ministry of Health, Labour and Welfare[6] and the National Institute of Infectious Diseases[7]

(1) Norovirus exists in feces and vomit of infected persons. The virus is transmitted from person to person via hands washed insufficiently after using the bathroom, or the droplets of the vomit or fecal matters of the infected persons (an infectious disease). It is possible for the virus to be excreted in feces of infected persons for about one week to more than one month, even after the persons recovered from symptomatic infection.

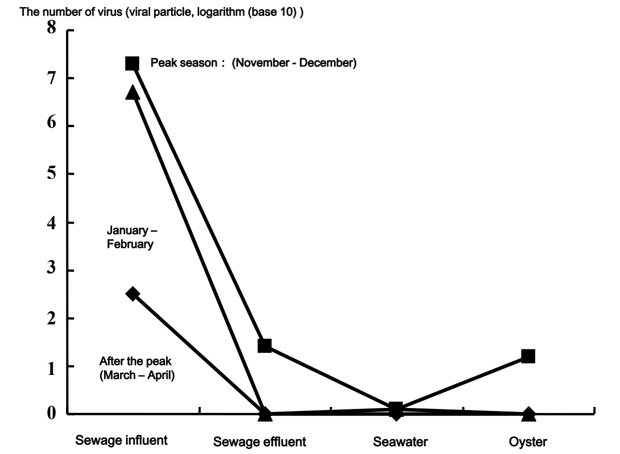
(2) Norovirus is transmitted via food which is contaminated with norovirus by infected food handlers (food poisoning). A food handler refers to people in a cooking service, cooks at mass feeding facilities such as restaurants and schools and people who cook at home.

(3) Norovirus is transmitted by eating raw or uncooked bivalves which are contaminated with norovirus (food poisoning). Bivalves have a possibility of norovirus contamination because the virus is transmitted from sewage, river water, seawater to bivalves, resulted in accumulation of the virus into the mid-gut gland of the bivalves. This phenomenon is affiliated with lack of efficiency of the current sewage treatment system for completely excluding norovirus.

(4) Norovirus is transmitted by the intake of well water or water tapped from a portable water-supply system (food poisoning).

Norovirus cannot multiply in the environment and the amount of the virus is relatively small except in the sewage water containing human feces. Therefore, it is difficult to conduct a survey of the contamination of the virus in the environment. On the other hand, the distribution of norovirus in the environment such as above (3) and (4) has been gradually clarified by applying the method to detect virus genes.[8] The amount of the virus existed in the environment is assumed to vary depending on the status of human norovirus infection in a sewage area, the difference of the water treatment capacity of each sewage treatment facility, and the increase/decrease of river water or the shift in ocean current. Figure 3 shows some examples.[9]

Generally speaking, the overall picture of norovirus contamination in Japan has not been fully identified. In parallel with the surveillance of human norovirus infection, the long term and nationwide study on norovirus contamination in the environment should be promoted in the future.



(Survey on the amount of virus in water and oysters collected in a designated area in Japan, by the method to detect virus genes)

Figure 3 : Existence of norovirus in the environment

Prepared by the STFC based on documents issued by the Food Safety Commission, Microbe/Virus Joint Meeting[9]

3-3 Clinical symptom[2] and treatment for food poisoning and infectious disease

There are little knowledge about the relation between the amount of norovirus and the appearance or the severity of the symptoms in food poisoning and infectious disease caused by norovirus.

It is generally considered that the symptoms of norovirus infection usually appear within 24 to 72 hours after the initial infection. The prominent symptoms are vomiting, diarrhea and abdominal pain and most of them recovered naturally within a few days. The symptoms may sometimes be like a mild cold such as headache, fever, chills, muscle aching, pain of the throat, and fatigue or a so-called inapparent infection without certain symptoms. However, it was reported that young children and elderly people had more serious symptoms than the ones shown above.

Since the duration of immunity against norovirus is considered to be relatively short as 6-14 weeks after the infection and there are many norovirus genotypes, people tend to be infected with the virus many times. The effective antiviral drugs and vaccines are not currently available and the medical treatment for the virus infection is limited to fluid replacement and so on. Therefore, the particular medical care for the infection would be needed for young children and elderly people who have potential to be suffered from a serious symptom by norovirus infection.

4 Situation in food poisoning and infectious disease caused by norovirus

As described in Chapter 3, norovirus infection can be considered as food poisoning and infectious disease. Regarding the food poisoning, the disease has been surveyed at national level in Japan, while the disease has not been surveyed systematically in foreign countries. In the countries, most of norovirus infection have been reported to be included in the category of infectious disease.

4-1 Situation of food poisoning in japan – food poisoning statistics[10]

The outbreak of food poisoning caused by norovirus has been compiled as the "Food Poisoning Statistics" by the Ministry of Health, Labour and Welfare, which is obligated by the "Food Sanitation Law" (the latest revision: June 7, 2006, Law No. 53). This statistics has reported the cases of food poisoning caused by norovirus as one of the targets.

The statistics revealed that there were many cases of food poisoning caused by norovirus. As shown in Figure 4 and 5, the food poisoning caused by norovirus accounts for 13.9- 33.5% of the total number of the outbreaks of food poisoning during the period in 2001-2006. The ratio of the patients infected with norovirus out of all persons affected by food poisoning is 28.5- 70.8% for that period. Compared to the cases caused by other agents of food poisoning, the outbreaks caused by norovirus are third-most in 2001-2003, second-most in 2004 and the most in 2006. The number of the patients is the highest during 2001-2006. For instance of the year 2006, the outbreaks caused by norovirus account for 33.5% (499 cases out of 1,491) and the patients for 71% (27,616 patients out of 39,026 in the total number). There are no dead from the food poisoning caused by norovirus in the same year.

As the source of the food poisoning caused by norovirus, composite food products provided by restaurants or hotels and lunch boxes are reported. In 2005, about 56% of all the cases caused by norovirus was attributed to composite food

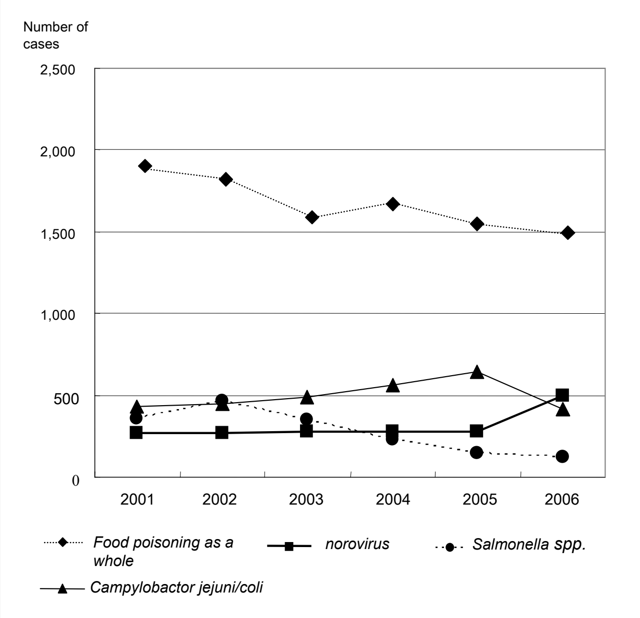


Figure 4 : Outbreak of food poisoning in Japan (Top 3 causative microbes)

Prepared by the STFC based on the Food Poisoning Statistics by the Ministry of Health, Labour and Welfare[10]

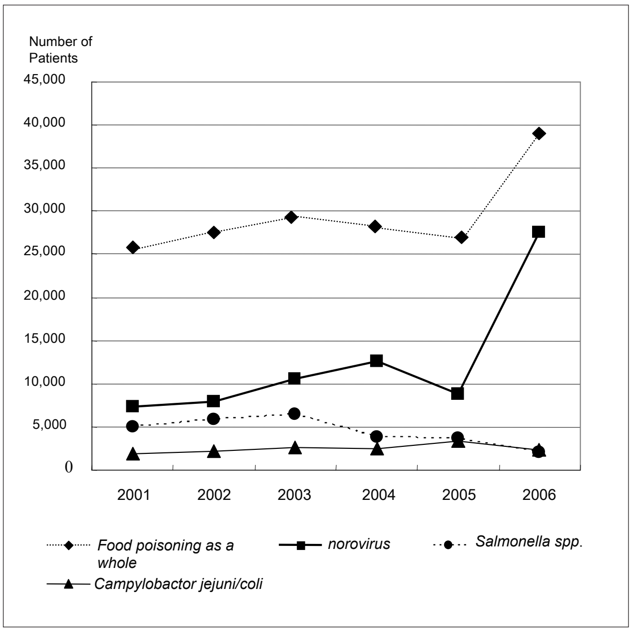


Figure 5 :Number of food poisoning patients in Japan (Top 3 causative microbes)

Prepared by the STFC based on the Food Poisoning Statistics by the Ministry of Health, Labour and Welfare[10]

products. In this cases, Sushi, bread, sandwiches, sashimi (raw fish), which people might touch directly during cooking, are reported frequently. Therefore, direct or indirect contamination of the virus from food handlers in the process of cooking or serving is assumed as the main cause for food poisoning caused by norovirus. Oysters are also known to be the causative agent of the food poisoning, however, the ratio of the outbreaks out of all cases of norovirus food poisoning has reduced significantly year by year; about 54% in January 2001 to October 2003 (154 of 287 cases), about 11 % in October 2003 to October 2005 (30 of 265 cases) and about 2.2% (11 of 499 cases) in 2006. Two reasons may be assumed for this trend. First, the monitoring of norovirus has been promoted in the process of production and processing of oyster breeding by the Ministry of Agriculture, Forestry and Fisheries, local governments and the related business, leaded to the decreased number of contaminated raw oysters on the market.[11] Secondly, the practice of appropriate cooking recipes of oysters has become popular among people due to the active guidance of the Ministry of Health, Labour and Welfare, local institutes for public health or the related corporations.

Regarding the outbreaks of norovirus food poisoning per facility, the majority of the outbreaks was reported from restaurants. The data in 2006 shows that about 58% of food poisoning caused by norovirus is reported from restaurants, about 34% from catering or offices, and about 2% from hospitals and schools.

Although the food poisoning caused by norovirus has been reported anytime of the year, the disease has the seasonal variation. The outbreaks of the disease tend to increase from around November and are peaked in December and January. The seasonality is in contrast with the frequent outbreaks of bacterial food poisoning such as salmonellosis in early summer to autumn.

A shown in Figure 5, the food poisoning caused by norovirus tends to increase. The reason is assumed to be not only an increase of the number of the outbreaks of norovirus food poisoning, but also the development of the methods to detect the virus described in Chapter 5 and an increase of the reports on the cases due to proliferation of the knowledge concerning the virus infection.[6]

4-2 Situation of Infectious Disease Outbreaks in Japan – Infections Disease Surveillance Report

The outbreaks of infectious disease caused by norovirus have not been surveyed independently, but as one of infectious gastroenteritis. The infectious gastroenteritis is the disease with symptoms of vomiting and diarrhea, which is stipulated as one of Category V infectious disease under the Law Concerning the Prevention of Infectious Diseases and Medical Care for Patients with Infectious Diseases (the latest revision: May 2, 2008, Law No. 30, hereinafter the Infectious Disease Control Law).[NOTE 4] The persons suffered from the disease are reported from about 3,000 pediatric medical institutions, though the report does not show the total number of the patients in specific. According to the report, 874,241-1,148,958 people were suffered from the disease during 2001-2006.[6]

4-3 Situation of food poisoning/infectious disease outbreak in other countries

The systems for surveying food poisoning or infectious disease caused by norovirus vary among countries. Food poisoning or infectious disease are considered to be often caused by not only norovirus but also other pathogenic microorganisms in Africa or part of Asian countries, where the sanitary control is insufficient. In the regions, it is difficult to obtain the reports on the outbreaks of such diseases because the surveillance has not been systemized yet.

On the other hand, many cases of the infectious gastroenteritis cause by norovirus have been reported from European countries and the U.S., but the survey methods are different among the countries. Therefore, it should be noted that the below results cannot be compared simply among the countries.

In Europe, the Food Borne Viruses in Europe Network (FBVE) has summarized and disclosed the outbreaks of infectious gastroenteritis caused by norovirus in 14 member nations.[12,13] According to the report, the number of epidemic outbreaks and people suffered from the disease remarkably increased in October and November in nine countries including Hungary, Germany, Netherlands, Denmark, Ireland, Finland, Norway, U.K. and Sweden, in comparison with the same period in 2004 and 2005 in the nations (Table 1).

In the United States, the outbreaks of infectious gastroenteritis caused by norovirus have not been surveyed regularly before 2006, however they have been surveyed currently by the Centers for Disease Control and Prevention (CDC), because of the concern of frequent outbreaks of the disease in the country.[14] The survey showed that 382 cases of 1316 acute gastroenteritis outbreaks in 24 states in October to December in 2006 were caused by norovirus. It also showed that the virus caused 69 cases of the gastroenteritis in California, 47 cases in Minnesota and 37 cases in Michigan. The outbreaks increased for 18-800% in 22 states, compared to the same period of 2005. The highest is 800% in Michigan, 490% in New York, and 445% in California.

5 Countermeasures against food poisoning/infectious disease caused by norovirus

Regarding the countermeasures against food poisoning and infectious disease caused by norovirus, it is necessary to control the virus in human and food as well as sewage, river and sea water by thought of the microbiological characteristics and routes of infection. The virus control has two aspects to consider: personal and public hygiene.

The personal hygiene means that people should cook food well, wash their hands thoroughly, keep cooking equipments clean and properly treat feces and vomit of persons infected with norovirus in order to eliminate the virus from the living environment. As shown in 4-1, more than half of the outbreaks of food poisoning caused by norovirus have been reported from restaurants. Therefore, food handlers in the facilities are

[NOTE 4]
In the Law Concerning the Prevention of Infectious Diseases and Medical Care for Patients with Infectious Diseases, about 100 infectious diseases were categorized in Category I-V on the basis of the infectivity or severity of the diseases, as well as to define the designated infectious disease, new infectious disease and other infectious diseases such as new type of influenza. The infectious diseases of Category V should be prevented by the disclosure of information to Japanese nationals and health professionals, based on the results of surveillance of the diseases conducted by the government.

Table 1 : Norovirus infection in Europe

Country	Norovirus activity increased	Number of cases or clinical specimens in subject countries ※1		
		2006	2005	2004
Germany	Yes	604 outbreaks	184 outbreaks	514 outbreaks
Denmark	Yes	249 samples	38 samples	222 samples
Spain	No	2 cases	6 cases	12 cases
Finland	Yes	Up to 120 cases	Up to 10 cases	Up to 10 cases
France	No	3 outbreaks	1 outbreak	2 outbreaks
U.K.	Yes	768 outbreaks 756 samples	83 outbreaks 281 samples	374 outbreaks 682 samples
Hungary	Yes	81 outbreaks	17 outbreaks	24 outbreaks
Ireland	Yes	7 outbreaks	No outbreak	22 outbreaks
Italy	Unknown	No report	No report	No report
The Netherlands	Yes	36 outbreaks	5 outbreaks	68 outbreaks
Norway	Yes	Up to 160 cases	Up to 65 cases	Up to 35 cases
Sweden	Yes	Up to 400 cases	Up to 50 cases	Up to 350 cases
Slovenia	Yes ※2	7 outbreaks	6 outbreaks	5 outbreaks

This survey is based on the email questionnaire to 13 FBVE member countries (the number of current member countries are 14, including Austria) . The research institutes designated by the governments made the report.

※ 1 The reports vary depending on countries, assuming because one outbreak or case may include multiple patients (samples).

※ 2 The report shows the tendency of increase, though it is not so remarkable.

Prepared by the STFC based on the Reports from the Food Borne Viruses in Europe Network, FBVE[12,13]

required to place strict sanitary control rules for keeping the facilities clean. Furthermore, the countermeasures against both food poisoning and infectious disease should be enhanced in nursery schools, schools, nursing facilities which provide accommodation for young children and elderly people who are likely of being severely affected from the virus. It is also important for the individuals including food handlers in the facilities to voluntarily keep the area clean in order to prevent the epidemic infection among people. The daily sanitation management by individuals is the key to control norovirus infection. The importance of the preventative measures taken by individuals has been known in Japan, due to the guidance by the related ministries and medical institutions.[6,15]

Meanwhile, the public hygiene means the understanding of the situation of norovirus contamination in human population, food, sewage, river and sea water and the elimination of the virus. Promotion of the countermeasures against norovirus infection requires the development of both comprehensive method to detect norovirus and effective and efficient method to eliminate or inactivate the virus. In Chapter 5, the trend of such research and development for the countermeasures is outlined to extract the technical requirements to control norovirus in the future. Moreover, the risk assessment of human norovirus infection, which is necessary for summarize the countermeasures against food poisoning and infectious disease caused by norovirus, is described. General information about the countermeasures can be also seen in reference.[16]

5-1 Research and development for detection of norovirus

Table 2 shows the major methods to detect norovirus.[17-22] The method to detect virus particle by use of electron microscope was developed first, which enables the detection of the virus without fail in the case of existing one million virus particles or more per milliliter of feces sample. The method is used as highly credible and popular measure for detection of norovirus by the experts.

The methods to detect virus genes have also been widely used for the diagnosis of food poisoning and infectious disease caused by norovirus and for the specification of the causes of the disease. Reverse transcription polymerase chain reaction (RT-PCR) and the real time PCR methods are also used as official methods designated by the Ministry of Health, Labour and Welfare. However, the method to detect virus genes is not available for all cases. As the specific condition settings for each genotype of norovirus are required, more than 30 genotypes and new ones, as shown in 2-2, might not be detected by a uniform method.

Other methods such as enzyme-linked immunosorbent assay (ELISA) and immunochromatography have been used to detect the virus structural proteins. ELISA has been authorized as diagnostic medicine. The method applies the antibodies against the virus structural proteins which are synthesized by genetic engineering technique, in order to detect the virus proteins. The method has become popular because of the lower cost relatively less than that of other methods and its simple operability. However, an attention for false negative cases is needed since the sensitivity to detect the virus structural proteins is relatively low in comparison with the other methods.

Generally for the reliable detection of norovirus, the method by use of electron microscope is preferred. The method to detect virus genes is better in viewpoint of sensitivity. With regards to the cost and convenience, ELISA and immunochromatography are superior to other methods. Therefore, the above methods are used depending on the situation and demands, however, the methods should be further improved to enhance the credibility of the assessment results. It is also necessary to pay attention to a possibility of overestimation of the amount of the virus detected by the method for virus genes, because the methods detect the parts of virus genome, not measure the level of the infectivity. In order to eliminate the possibilities, a virus detection system with higher credibility should be urgently established by the combination of developing the method to detect infectious virus using cultured cells and the current methods to detect virus genes. In this case, the method to detect virus genes is expected to be used for screening of many specimens while the method to detect infectious virus is used for concrete diagnosis in the future. Additionally, the virus detection system is desired to be further simplified in operation so that it can be widely used for human, food and environment water.

Furthermore, a new method to efficiently detect a very small amount of norovirus in the environment should be developed and applied for the virus detection system described above. As shown in 2-3, since norovirus dose not multiply in the environment and the amount of the virus in the environment might be very small, it is difficult to efficiently detect the virus under such conditions. In order to detect the virus from a large area of environmental water such as river or ocean, another method to filter a large amount of the water and make high concentration of the water should be developed. Currently, the membrane treatment system is widely applied. As examples, there are the method using positively charged membranes and the one to concentrate the virus by adsorption to and elution from a negatively charged membrane, with the insertion of an acid rinse step.[NOTE 5] However, the methods have good and bad points so that it should be selected depending on the purposes.[19] Thus, a new method which has broad utility and detects the virus more effectively and simply should be developed in the future.

5-2 Research and development for elimination and inactivation of norovirus

As described above, norovirus multiplies only in the human intestinal tract and is transmitted to other people or spread in the environment through feces and vomit of persons infected with the virus. Therefore, the countermeasures against the food poisoning and infectious disease caused by norovirus require the elimination and inactivation

Table 2 : Major methods to detect norovirus

	Detection subject	Available specimens	Lead time	Sensitivity※	Good points	Bad points	Remarks
RT-PCR method (reverse transcription – polymerase chain reaction method, gene amplification method)	Virus gene (the complementary DNA which was reverse transcripted from virus RNA)	Human feces Food Water	About 6 hours; (about 2 days including the identification test)	>100-1,000	-Able to specify virus genotype -High sensitivity -Able to examine many specimens	-Operation is complicated and requires some skills -Takes time for diagnosis because the identification test is needed. -High cost	Designated as official method by the Ministry of Health, Labour and Welfare notice (Food Safety No. 1105001, November 5, 2003) (including human feces and bivalve mid-gut gland as specific subjects)
Real time PCR method (gene amplification /quantitative method)	Virus gene (the complementary DNA which was reverse transcripted from virus RNA)	Human feces Food Water	About 4 hours	> 100 -10,000	-No need of an identification test -High sensitivity -Able to examine many specimens	-Unable to identify virus genotype -High cost	Designated as official method by the Ministry of Health, Labour and Welfare notice (Food Safety No. 1105001, November 5, 2003) (including human feces and bivalve mid-gut gland as specific subjects)
RT-LAMP method (reverse transcription – loop-mediated isothermal amplification method)	Virus gene (the complementary DNA which was reverse transcripted from virus RNA)	Human feces	About 1 hour (except preliminary treatment of specimens)	>1,000-100,000	-Few steps in operation -The method only requires a short time to conduct.	- High cost	Usage only for research
TRC method (reverse transcription concerted amplification method)	Virus gene (virus RNA)	Human feces	About 1 hour (except preliminary treatment of specimens)	>1,000-100,000	-Few steps in operation -The method only requires a short time to conduct.	- High cost	Usage only for research
NASBA method (nucleic acid sequence-based amplification method)	Virus gene (virus RNA)	Human feces	About 2 hours; (except preliminary treatment of specimens)	> 1,000 - 100,000	-Few steps in operation -Visual inspection available (no special unit required for determination)	- High cost	Usage only for research
SMAP method (smart amplification process method)	Virus gene (the complementary DNA which was reverse transcripted from virus RNA)	Human feces	About 30 minutes	Not disclosed	-High precision -Few steps in operation -The method only requires a short time to conduct.	- Few information how to use (because the product will be on market in September 2008)	Usage only for research
ELISA method (enzyme-linked immunosorbent assay method)	Virus structure protein	Human feces	About 3.5 hours	> 1,000,000	-Able to examine many specimens -Operation is relatively easy -Less cost compared to the method to detect viral genes	-Necessary to prepare antivirus antibody to bind virus structure protein -Low sensitivity of detection	Authorized diagnostic products available
Immunochromato-graphy method	Virus structure protein	Human feces	About 15 minutes	> 1,000,000	-The method only requires a short time to conduct. -Easy operation	-Necessary to prepare antivirus antibody to bind virus structure protein -Low sensitivity of detection	
Electron microscopy method	Virus particles	Human feces	About 6 to 12 hours	> 1,000,000	-Able to secure the virus detection if a certain amount of the virus are obtained -Available to new virus genotype	-Expert operation is necessary -A certain time required to conduct the method -Low sensitivity of detection	Effective to use the methods to detect viral genes or virus structure protein together (for high reliability)

※Shows the minimum number of viral particles detectable by each method (per ml).

Prepared by the STFC based on the documents issued by the Ministry of Health, Labour and Welfare, the National Institute of Infectious Diseases, and the Tokyo Metropolitan Institute of Public Health[17-22]

Table 3 : Outline of research and development for elimination/inactivation of norovirus in Japan

		Examples	Assumed subject for application
Elimination of virus	Elimination by membrane	-Absorb the virus in sewage to activated sludge and eliminate it by separation of sludge and sewage by a membrane (membrane separation and activated sludge method)	-Sewage etc.
	Elimination by sterilized seawater	-Culture oysters in sterile seawater by ultraviolet rays and eliminate the virus from the oysters. The system is based on the characteristics that oysters filter seawater for their breath and predation	-Oysters
Inactivation of virus	Inactivation by drugs	-Inactivate the virus by ethanol, DDAC (didecyldimethyl ammonium chloride) and alkali agent	-Daily life tools etc.
	Inactivation by ultraviolet treatment	-Inactivate norovirus by ultraviolet irradiation	-Sewage, seawater -Oysters etc.
	Inactivation by ozonation	-Inactivate the virus by action of free radical development at ozonolysis	-Sewage -Daily life water (e.g. bathtub water)
	Inactivation by micro-bubbles	-Inactivate the virus through the use of electrostatic charge of microbubbles and free radical development induced by compression of the bubbles	-Sewage -Oyster etc.

Prepared by the STFC based on Reference[23-27]

of the virus from infected persons, food, sewage, river and seawater.

Among the countermeasures, in particular, the treatment of sewage including a large amount of feces is extremely important. The methods to eliminate and inactivate general microorganisms in sewage are membrane filtering, chlorination, ultraviolet treatment, ozonation, and activated sludge method by use of edaphon which can absorb and resolve underwater organic matters. These methods have contributed to the effective elimination and sterilization of Escherichia coli spp., which is used as an indicator of contamination of feces in water. However, the methods mentioned above are still inadequate for elimination and inactivation of norovirus, because the virus remains in sewage, river and seawater after applying the methods. The research and development for the elimination or inactivation of norovirus in the process of sewage treatment have been actively promoted in recent years.

On the other hand, various methods have been developed for elimination and inactivation of norovirus, which might exist in bivalves, livingware such as clothes, cooking equipments and water used for daily life such as bathtub water. Table 3 shows the outline of the situation of research and development for the elimination and inactivation of norovirus in Japan, including the above method for the sewage treatment.[23-27]

The effectiveness of the methods shown in Table 3 is examined by using the viruses related to norovirus, as shown in 2-4 and the method to detect virus genes referred in 5-1. However, the efficacy to eliminate or inactivate infectious norovirus has not been directly verified. Therefore, the method to

[NOTE 5]
Both methods make use of the phenomenon that norovirus particles are negatively charged in the environmental water. In particular, the latter is known as a method adapted to the detection of norovirus genes by PCR, with the aid of newly developed liquid which can elute the virus from the membrane. See Reference[19] for details.

[NOTE 6]
Risk analysis means a framework for the prevention of adverse effects on the health of humans or minimize the risk of the adverse effect. The analysis consists of 3 items: risk assessment, risk management and risk communication. An interaction among the items should provide better results. The Ministry of Agriculture, Forestry and Fisheries also discloses the risk profile sheet.[30]

detect infectious virus using cultured cells should be developed in order to develop not only the virus detection system but also the effective method to eliminate and inactivate the virus.

Next, the research and development for the medical treatment and preventative measures against food poisoning and infectious disease caused by norovirus, should be promoted. The pathogenicity of norovirus has not been fully analyzed, because valid animal models for the virus infection have not been established. Additionally, effective antiviral drugs and vaccines have not been developed yet, as described in 2-3. Therefore, the research and development for the medical treatment of persons infected with the virus and preventative measures against the virus infection should be promoted by developing the animal model for the virus infection or the alternative method for the animal model.

5-3 Trial on risk assessment – development of risk profile by the foodsafety commission

As one of the comprehensive preventative measures against food poisoning and infectious disease caused by norovirus, the Food Safety Commission under the Cabinet Office in Japan has drafted the "Risk Profile for Risk Analysis of Norovirus Infection" (draft)[28][NOTE 6] to promote the analysis of the degree and ratio of negative impacts on human health caused by norovirus infection. This is one of the projects for the assessment of the effects on human health due to food intake under the Food Safety Basic Law (the latest revision: March 30, 2007, Law No. 8). The risk profile will contribute to assess the risk for human health regarding food intake and to reflect the results to the risk management conducted by the related administrative organizations, leaded a comprehensive promotion of the food safety policies.[29]

The above risk profile shows the summary of the information which is needed for the risk analysis of food poisoning and infectious disease caused by norovirus. In the profile, there is the information about the three items including "Hazard Related Database", "Exposition Evaluation" and "Health Hazard Analysis". According to the profile, the Food Safety Commission has collected and consolidated the information necessary for the risk analysis.

Figure 6 shows that the information of the risk profile is still insufficient for the risk assessment of food poisoning and infectious disease caused by norovirus. In order to gain the information, it is essential to elucidate the distribution of the virus in human population, food and the environment by developing a highly sensitive and effective virus detection system, in combination with the method to detect the infectious virus using cultured cells and animal models for the virus infection. In addition, the surveillance specific for norovirus infection needs to be conducted to identify the distribution of the virus in human population, in addition to the current survey on the infectious gastroenteritis including norovirus infection. Effective preventative measures against food poisoning and infectious disease caused by norovirus will be available when the risk of the virus infection will be assessed by the sufficient information and the result of the assessment will be reflected to the risk management conducted by the administrative organizations.

6 Conclusion

Norovirus multiplies only in the human intestinal tract and continues to exist in human society in the case where human lives in a high density and there are water environments conducible to help the virus to maintain the infectivity for a long time. The overcrowded population that is forecasted worldwide shows a risk of accelerating the circulation of norovirus in the human society as well as a wide distribution of the virus in the environment. Thus, it is necessary to identify the distribution trend of norovirus in human population, food and the environment and take appropriate measures for elimination and inactivation of the virus. At the same time, the pathogenecity of norovirus should be also clarified, for the future development of the methods for effective prevention and medical treatment of the virus infection. The norovious control requires the development of the virus detection system and the methods for elimination and inactivation of the virus. These methods should not be accomplished without the method to detect the infectious virus using cultured cells or animal model for the

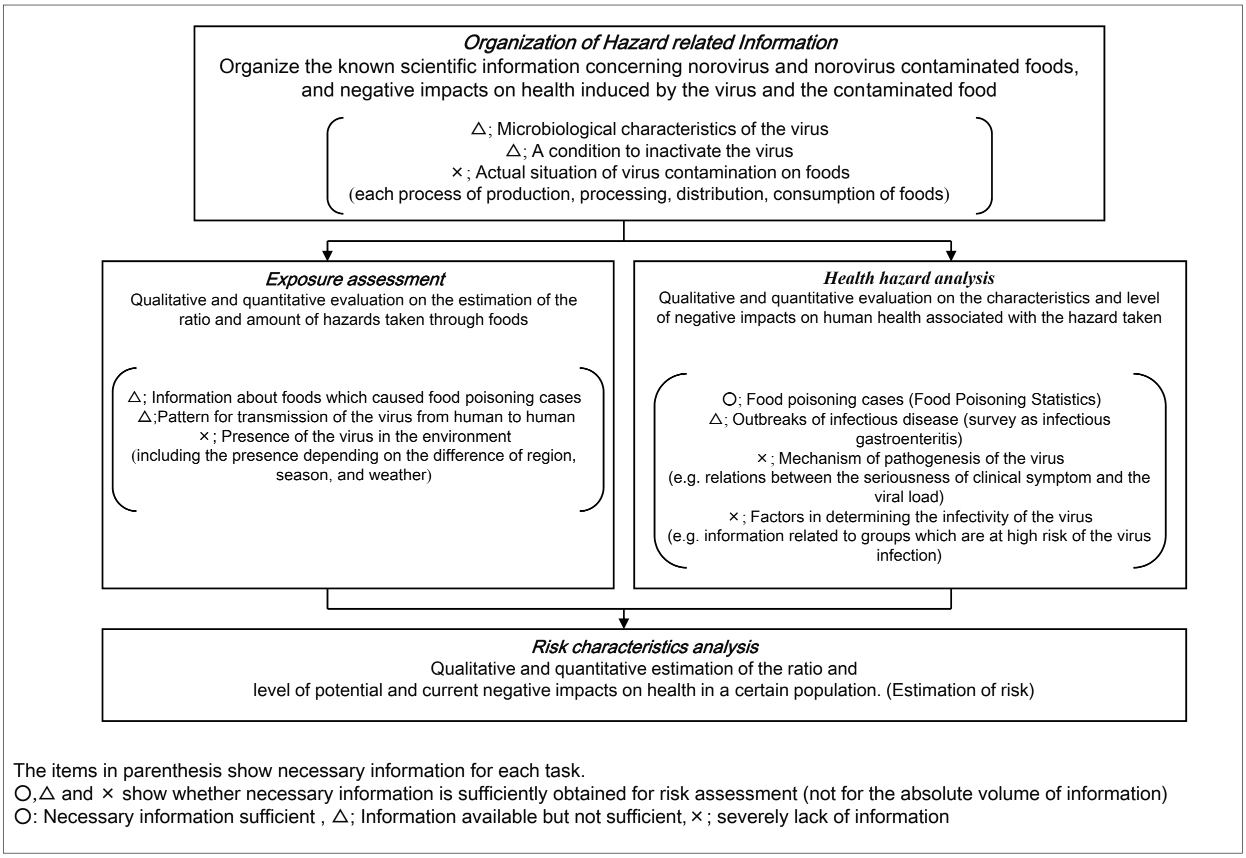


Figure 6 : Component and implementation procedure of risk assessment concerning food poisoning and infectious disease caused by norovirus

Prepared by the STFC based on the documents issued by the Food Safety Commission,Microbe/Virus Joint Meeting [28]

infection. The fundamental studies on norovirus, directly linked to its control, should cross the fields as microbiology, public health, food hygiene, water service engineering and will require a joint activity by the administration, research institutes including universities, medical institutes and the related business. As well as the fundamental studies, a partnership between the related organizations as above should be also enhanced in usual and emergent situation, ranging from the prevention of the infection to the medical treatment for both normal and emergency situations.

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References

[1] Infectious Diseases Weekly Report (IDWR), Infectious Disease Surveillance Center, National Institute of Infectious Diseases, Norovirus Infection,revised March 16, 2007 : http://idsc.nih.go.jp/idwr/kansen/k04/k04_11/k04_11.html (Japanese)

[2] Nishio O., Norovirus Infection, Public Health vol71,No.12, 2007 (Japanese)

[3] Infectious Disease Surveillance Center, National Institute of Infectious Diseases, Norovirus infection and its countermeasures/prevention (for health professionals and staffs worked for healthcare center): http://idsc.nih.go.jp/disease/Norovirus/taio-b.html (Japanese)

[4] Huang P et al., noroviruses bind to human ABO, Lewis, and secretor histo-blood group antigens: Identification of 4 distinct strain-specific patterns. Journal of Infectious Diseases 188:19-31, 2003.

[5] Rockx BH, et al., Association of histo-blood antigens and susceptibility to norovirus infections. Journal of Infectious Diseases

191:74954.2005.

[6] Ministry of Health, Labour and Welfare, Department of Foodafety, Inspection and Safety Division, Information related to food poisoning/food inspection, Q&A about norovirus, the latest revision December 20, 2007:
http://www.mhlw.go.jp/topics/syokuchu/kanren/yobou/040204-1.html (Japanese)

[7] National Institute of Infectious Diseases, Infectious Disease Surveillance Center, Route of norovirus infection, February 16, 2007 :
http://idsc.nih.go.jp/disease/norovirus/0702keiro.pdf (Japanese)

[8] Kazuyoshi Y. et al., Data organization and analysis regarding the cases of virus infections via the water environment, (Joint research report 3), Health and labour sciences research grants, Policy studies on public administration, Health and labour sciences special research "Study on revision of water quality criteria based on the latest scientific knowledge" (Head researcher: Shoichi Kunikane) (Japanese)

[9] Nishio O., Data concerning risk assessment of norovirus infection via raw oysters, Cabinet Office, Foodafety Commission, Microbe/Virus Joint Meeting, September 6, 2005:
http://www.fsc.go.jp/senmon/biseibutu/b-dai8/biseibutu8-tuikasiryou2.pdf (Japanese)

[10] Ministry of Health, Labour and Welfare, Department of Foodafety, Inspection and Safety Division, Information related to food poisoning/food inspection, Outbreaks of food Poisoning:
http://www.mhlw.go.jp/topics/syokuchu/index.html (Japanese)

[11] Fisheries Agency, Safety management on oyster breeding and production/delivery
http://www.jfa.maff.go.jp/norovirus/q4.pdf (Japanese)

[12] Foodborne Viruses in Europe:
http://www.eufoodborneviruses.co.uk/

[13] Increase in norovirus activity reported in Europe. Eurosurveillance Weekly 11, 14 December, 2006.:
http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=3093

[14] Centers for Disease Control and Prevention, Norovirus activity -United States, 2006-2007.
Morbidity and Mortality Weekly Report (MMWR). Volume 56, No.33, 842-846, 2007.

[15] Japan Food Hygiene Association, Let us Know! Prevent it! Food Poisoning caused by norovirus:
http://n-shokuei2.jp/food_ poisoning/faq/page12.shtml (Japanese):

[16] Ministry of Health, Labour and Welfare, Pharmaceutical Affairs and Foodanitation Council, Foodanitation Division, Food Poisoning Subcommittee, Countermeasures against food poisoning caused by norovirus, October 12, 2007:
http://www.mhlw.go.jp/shingi/2007/10/dl/s1012-5a.pdf (Japanese)

[17] Ministry of Health, Labour and Welfare, Method to detect norovirus, the Notification No. 1105001, November 5, 2003:
http://www.mhlw.go.jp/topics/syokuchu/kanren/kanshi/031105-1.html (Japanese)

[18] Nishio O. (head researcher), Evaluation of method to detect norovirus and surveillance of the contamination of the virus in food, FY2003 Health and labour sciences research grants, Foodafety research project (Japanese)

[19] Katayama H., Study on the method to detect viruses in the water environment (Joint Research Report 6), FY2005 Health and labour sciences research grants, Health and labour sciences special research project "Study on risk management for viruses existed in drinking water", (head researcher: Kunikane S.) (Japanese)

[20] National Institute of Infectious Diseases, Infectious Disease Surveillance Center, Infectious Agents Surveillance Report (IASR), Features of the kits for norovirus detection commercially available :
http://idsc.nih.go.jp/iasr/28/332/dj332a.html (Japanese)

[21] Tokyo Metropolitan Institute of Public Health, Study on the methods to check norovirus infection:

http://www.tokyo-eiken.go.jp/news/paper4.pdf (Japanese)

[22] Ebara Jitsugyo Co., Ltd., Commercialization of product, "Norovirus Inspection Kit" applying a new gene engineering technology (Japanese)

[23] Katayama H., Study on virus elimination/Inactivation by water treatment (Joint Research Paper 5), Y2005 Health and labour sciences research grants, Health and labour sciences special research project "Study on risk management for viruses existed in drinking water", (head researcher: Kunitake S.) (Japanese)

[24] Murakami T., Iwasaki S., Study on the development of sewage treatment technology for ensuring safety, Annual Report of the Technical Development Department, Japan Sewage Works Agency (FY2006): http://www.jswa.go.jp/gikai5/kanenndo-kenkyu/h18nenpou.pdf (Japanese)

[25] Sumishita Y. et al., Development of ethanol agent effective for feline calicivirus and various microorganisms substituted to norovirus, Boukin Boubai shi, vol. 35 no. 11, p725-732, 2007 (Japanese)

[26] Ito T., Kubota H., Countermeasures against norovirus infection in effluent treatment facility in fishery settlement, the Japanese Institute of Technology on Fishing Ports, Grounds and Communities: http://www.jific.or.jp/search/pdf_002/002_17.pdf (Japanese)

[27] Success on norovirus inactivation, National Institute of Advanced Industrial Science and Technology, 2004: http://www.aist.go.jp/aist_j/aistinfo/aist_today/vol04_03/vol04_03_topics/vol04_03_topics.html (Japanese)

[28] Cabinet Office, Foodafety Commission, Microbe/Virus Joint Meeting, Risk profile for risk analysis of norovirus infection (draft), April 19, 2005 (revised April 21, 2006): http://www.fsc.go.jp/senmon/biseibutu/b-dai15/biseibutu15-siryou9.pdf (Japanese)

[29] Cabinet Office, Food Safety Commission, Guidance for the assessment of health effect of exposure to microorganisms transmitted by food (provisional), September 2007: http://www.fsc.go.jp/senmon /biseibutu/hyouka-sisin.pdf (Japanese)

[30] Ministry of Agriculture, Forestry and Fisheries, Risk profile sheet for pathogenic microorganism concerning foodafety, September 4, 2006: http://www.maff.go.jp/syohi_anzen/biseibutu/b-07.pdf (Japanese)

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2

Japan's Critical Issues on IT Human Resource

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1 New sort of crisis

Since the 1960's, it has been repeatedly said of "IT engineer shortages for a certain number of people and the necessity of strengthening the IT industry". The government has kept investment in IT businesses and IT related departments were booming for the universities and the number of IT engineers also increased thanks to the efforts of half a century.

However, nowadays people more often talk about the shortage of IT engineers, which is now called 'IT human resources crisis'. The authors have studied this crisis in the industry and government and have visited acitivities which have taken to overcome the crisis. Although we have not completed our study, we have come to understand that this crisis is not just an issue for one industry sector but the issue of entire Japan. However, only a few people recognized the issue as a 'crisis'. This ignorenceitself is critical. This paper is to report the result of the study of this 'crisis' and "the efforts which have been made to overcome the crisis" as well as to offer a proposal for new solutions.

2 Nature of the new crisis

The current crisis has a difference from the ones in the past. Previous 'crises' were not 'real crises', as the past cases had more luxurious concerns based on "human resource shortages caused by market expansion". However, the current issue is not such a 'benign crisis' but a 'real crisis' in which Japan could go into decay due to the lack of IT human resources.

On January 18, 2008, Hiroko Ota, the minister in charge of economic and fiscal policy, stated at the national diet that Japan's economy is no longer in the first-class. The mass media, coincidentally began to talk about the 'decay' of the country and society.[1,2] It seems as if most Japanese people are beginning to accept the possibility that the Japanese economy, which held the position as the second largest economy for a long time, would be surpassed by other economies such as China sooner or later. The current crisis is the one at the time when Japanese economy has a sign of being weakened and it is more serious than that when it was said that this is the 'era of the Japanese economy to expand' or the 'Japanese economy was still strong'. This is a 'genuine crisis', in which the shortage of advanced IT human resources could accelerate the decay of Japan to the point where it will not be able to compete against other industrialized countries.

On the other hand, the acknowledgement of this 'real crisis' has brought about the possibility of the forming of a national action instead of the separated and limited actions taken so far to overcome the crisis. In particular, the Keidanren (Japan Federation of Economic Organizations), which had been quiet on the issue, has started to actively approach academia and government. In response to this, MEXT (Ministry of Education,culture,sports,science and technology) is leading the way for universities to review their IT education curriculums. Traditionally, industries did not interfere the academia and accept the students as-is to foster them within the company. This is even true for Japanese IT industries because most of their engineers are from humanities courses other than IT specialized courses. However, this is beginning to change. METI, MIC and MEXT tended to act individually in the past, while the Cabinet Secretariat IT Strategic Headquarters is now beginning to take the lead, which is a notable change.

Governments of the US, India, South Korea, and China have been making efforts to develop human resources of advanced level IT engineers in cooperation of industry-government-academia. Japan lags behind and is currently at the stage where some activities have just begun to take shape. The current 'crisis' is not just an issue for IT industry but also the national issue of the social infrastructure like food and energy issues which could have a significant affect on the entire society. Thus, an appropriate counteraction should be taken immediately. Section 2-1 explains how this crisis is serious.

2-1 IT system as nervous system of society and industry

On December 20, 2007, the Third Meeting for Industry-Government-Academia Cooperation on Advanced Information and Communication Human Resource Development (hereafter the 3rd meeting for industry-government-academia cooperation)[3] was held at the Keidanren Hall in Otemachi, Tokyo. Many speakers participated in the meeting including Fumio Kishida, the Minister of Science and Technology Policy and many other parties concerned from the industry, government and academia. Osamu Dairiki (Chairman, the Strategic Project Team on Advanced Information and Communication HR Committee of the Keidanren Information and Communication Committee) was especially the one to prominently state the significance of the crisis. Dairiki said that information is the "nervous system of industries in the 21st century" and these 'nerves' are in danger.

The Japanese industry is still strong. However, according to Dairiki's rhetoric, it will become a "giant without a nervous system" unless using the power of IT. No matter how powerful the muscles and bones may be, the body will not function without a nervous system. In the October 2006 issue of Science and Technology Trends,[4] the authors predicted and pointed out that all industries would depend upon IT eventually. As a result of this, the weakness of the Japanese software industry could 'seep' into all industries and there is a risk of the decrease of competitiveness of all Japanese industries. The issue of the 'nervous system' mentioned by Dairiki corresponds to this 'seeping phenomenon'.

During the era of mainframe computers, software was just an "accessory" for hardware. The focus then shifted to software, and then to the Internet. IBM, the world's largest hardware manufacturer around that time, has sold many of their hardware departments such as their PC division to Lenovo. Meanwhile, they rapidly strengthened its consulting and service facilities. IBM, which used to be an accounting machines manufacturer, is now the second largest software company next to Microsoft as of 2007. They also started to focus on their business towards 'services' such as consultancy.

One of the articles of ITmedia, the IT news website, explained IBM's service science[5] as follows: the era is ending where technological invention in product development was competitive. It is now generally accepted that a comprehensive service combining various solutions are the key to be competitive, such as the combination of business strategy, management science, social science, cognitive science, legal science, industrial engineering and so forth.[6]

In an era that it was difficult to create hardware, hardware was the key of IT business. However, as high-performance hardware became common, software took that place. As it is now easy to "write a complicated program", the critical issue is shifted to "design" the services of software. This change is similar to auto industry, where the emphasis has shifted from the engine performance to the "design for usability according to the users' lifestyles".
IT systems including the Internet are drastically changing the organizations in such fields as communications, finance, sales, advertising, government, education and entertainment. As a result of this, the competitiveness of products which at least relate to social activities is now depending on the quality of the services provided by, relating to, and wrapped around the product, not the product itself.[7]

If a service is 'physically intangible' such as a mailing service, it would be provided by IT systems. Even if it is a 'physically tangible' service such as the courier service to deliver parcels, an advanced IT system is necessary to support the function. The current courier system is a typical model of socio-techno system, which is realized by the IT systems consisting from electronic devices and the humans who use them and function as a component based on a predetermined protocol, where various IT technologies are deployed such as the logistics systems, WEB, GPS, mobile phones, and QR codes. With such a courier service, the delivery personnel keep delivering parcels while receiving instructions from the center though mobile phones. In reality, it may be the 'information' called 'parcels' are transferred from one place to another by the hand of the delivery personnel which behaves as part of the system according to orders given by the system. Courier companies are now the IT company, where IT is the key to their quality of services. Likewise, almost all industry sectors have started to use IT. This is the 'seeping phenomenon' the authors stated in the October 2006 issue of Science and Technology Trends.[4] Therefore, the 'nervous system for the industries in the 21_{st} century' as Dairiki mentioned is now used in all industries based on IT.[Note 1]

2-2 Human resources for top management in the era of Integration of IT and company management

IT technology, which was once a means to replace the existing human-systems with automated systems, has been transformed into the general-purpose technology to create new 'socio-technology systems for innovation' to innovate economic competitiveness.

Therefore, the first class IT personnel to create the future are required to make the maximum innovation available with the basic resources (hardware, software, human resources, social and corporate systems) and propose the optimum way to realize it while considering positive effects in the society, which is quite different from an entry-level ability just to copy a 'task protocol clearly defined' to a program. This innovative capability is a skill, which would be supposedly required for top management who make a strategy for organizations and companies.

In other words, this means that the potential of innovation would increase if top management within organizations or groups understands the significance of IT. It should be considered that IT is now a requirement of top management, in addition to the knowledge of politics, law, economics and corporate management as well as sociology and psychology.[7] IT capability has become a basic human ability like language, and plays an important role in the field of 'social science' which covers most of human activities, just like mathematics in physical science.

If there is a shortage in human resources who can handle such an important 'tool' called IT, the consequence is clear as crystal. Unfortunately, this shortage is already real so that this crisis is quite serious. The reality is more complex as there are also shortages in mid and lower-level human resources such as program managers and designers. There are opinions that these levels of human resources could be outsourced offshore as explained in 4-1 and 4-2. American companies are now deploying such a strategy. According to this opinion, the shortage of mid-level human resources is not so critical, but the shortage of top-level resources is very serious.

However, a crisis can also be an opportunity. In the September 2004 issue of Science and Technology Trends,[8] the authors pointed out that the agile method (agile software development method) which is currently one of the most cutting-edge technologies in IT, has its root in Japanese style production and management such as Toyota's production system. If IT and corporate management are to merge in the realm of innovation, there is no reason to think that Japan's proven ability to create a 'Japanese style of production and management',[9] which have changed the world a few decades ago, would work out once again. The driving force behind Nintendo's recent comeback was the new corporate policy[10] set out by the market and technologies insights of Satoru Iwata, the president, who was a programmer (graduated from Information Engineering Department, Tokyo Institute of Technology). As this example suggests,

[NOTE 1]
This is a book published by Yukio Noguchi and Satoshi Endo,[26] at the final stage of editing this report. The authors referred IT as a 'general purpose technology' or 'technology that can be used beyond the boundary of industries as well as for various purposes', which changed the world economy and society. This is almost the same view as ours.

Japan does have top-level resources. Therefore, it may not be impossible to turn this crisis into an opportunity.

3 Actions for a new era; trends of foreign countries

The current ‘human resource crisis’ is caused by changes in the social position of Information Technology. Such changes are obviously not only taking place in Japan but also all over the world. Topics such as globalization, flattening, Web2.0, etc., show that they are various aspects of the huge change of the social system. It may be natural that the United States, at the forefront of IT, has accommodated the changes and have strategies and policies to take advantages of the change. India, South Korea, China and Germany also have recognized such large-scale social changes and have taken actions for the human resource development. The activities in these countries are explained based on data from the Keidanren and MIC.[11,12] Then, we will introduce the most advanced establishment for human resource development, the Stanford University d.school from the viewpoint of IT human resources to bring about innovation as discussed in 2-2.

3-1 Advanced IT human resource development in the World - Focusing on the United States -

In the United States, universities have a high level of autonomy. IT human resource development has been a task of individual universities, groups of universities, academia and business organizations. The United States has been successful in developing a large number of qualified IT personnel and furthermore attracting IT personnel from rest of the world. The Council of Competitiveness is a NGO, which compiled the so-called ‘Palmisano Report’[13,14] and coined the word ‘service science’. In the United States, the industry, government and academia are spontaneously cooperating for human resources development.

In the federal government, chief information officers (CIO) are assigned in the government agencies under the Clinger-Cohen Act of 1996. The CIOs voluntarily formed CIO Council, which became a government organization and now operates the CIO University, a virtual CIO development institution. This “national university for training government officials” is open to anyone, and their graduates will also become CIOs in business organizations.

In business world, US educational institutions boast of the revolutionary IT engineers and founders of major companies including Microsoft, Apple, Yahoo and Google. Not a few of them were dropped out of college or graduate school. The Stanford University Department of Computer Science, which is regarded as “research-oriented, little education”, has been the alma mater of many advanced IT human resources including the founders of Google. US has been successful to nurture advanced IT human resources, and as a next step of the evolution, US is now trying to develop highly innovative human resources as in Stanford’s d.school.

In India, which is the major offshore outsourcing destination for the United States, the Ministry of Human Resource Development and NASSCOM (National Association of Software and Service Companies), a group of business organizations, are making joint efforts as reported in the September 2007 issue of Science and Technology Trends. [15] As the IT industry in India is evolving at a tremendous speed, Indian companies may have the chance to gain the major role of development, which currently tend to subcontrac American or Japanese companies.

China and South Korea are now emphasizing on IT human resource developments as a national policy, even though IT industry does not take the big share of their economy as India. Information and Communication University (ICU) in South Korea, and Chinese Software Institution (in 35 major universities) are the representative examples. In Germany, where the overall situation is more similar to Japan than that of India or China, the similar type of human resource development are underway to foster advanced IT engineers at the Hasso Plattner Institute (HPI) at the University of Potsdam, which was established through a donation by Hasso Plattner, one of the founders of SAP.

The HPI at Potsdam has a sister school, HPI d.school at Stanford, which we currently consider as the most advanced IT human resource development institution.

3-2 HPI d.school at Stanford and T-shaped people

In the United States where IT industry is one of their competitiveness, a new type of human resource indispensable for business is widely discussed. While the given names of this type of people vary widely, the common characteristics is the capability of being expert and generalist at the same time. As depicted in Figure 1, the cross-boundary knowledge of such people as a generalist is shown as a horizontal bar while the specific knowledge as an expert is shown as a vertical bar, so that we call them 'T-shaped people' because of the shape of the two characteristics is like 'T'. There are arguments that having one area of expertise is not enough, but they should be π-shaped people with at least two areas of expertise. Putting names aside, the idea is spreading that innovations created by T-shaped and π-shaped people, will be the source of the future competitiveness,[16] so that this is the basics for our view mentioned in 2-2.

In fact, the concept of T-shaped people has a tradition in Japanese companies which expect their employees to be both generalist and expert. The 'multi-skilled worker' concept in the Toyota production system incorporates several vertical bars. However, this old concept is now discussed as if it is a new concept in relation to IT and innovation.[16,17] How could this be?

Although the T-Shaped people discussed now are similar to the old T-Shaped people, these are different in nature. In terms of old T-Shaped people, represented by multi-skilled workers, they obtain some expertise such as mechanical or electronics engineering first, which is represented by the vertical bars, then 'additionally place' a horizontal bar on the top to create the T shape. It could be said that the emphasis was on the 'multiple vertical skills'. The horizontal bar was supposedly representing skills to be acquired on site, not through the education in universities. It is also regarded as a matter of personal development.
However, the current T-Shaped people, regardless of their educational process,[NOTE 2] are 'those who have the horizontal skill, and by using this horizontal skill, spontaneously extend their new vertical skills according to the needs at each point of time.' The horizontal bar is not what the individuals develop themselves through the years but something taught as 'meta-skills' to attain at the early stage of their personal career in educational institutions such as the d.school at Stanford University. Tim Brown explained T-Shaped people as follows:[16]

" *We look for people who are so inquisitive about the world that they're willing to try to do what 'you'do. We call them 'T-Shaped people'. They have a principal skill that describes the vertical leg of the T -- they're mechanical engineers or industrial designers. But they are so empathetic that they can branch out into other skills, such as anthropology, and do them as well. They are able to explore insights from many different perspectives*

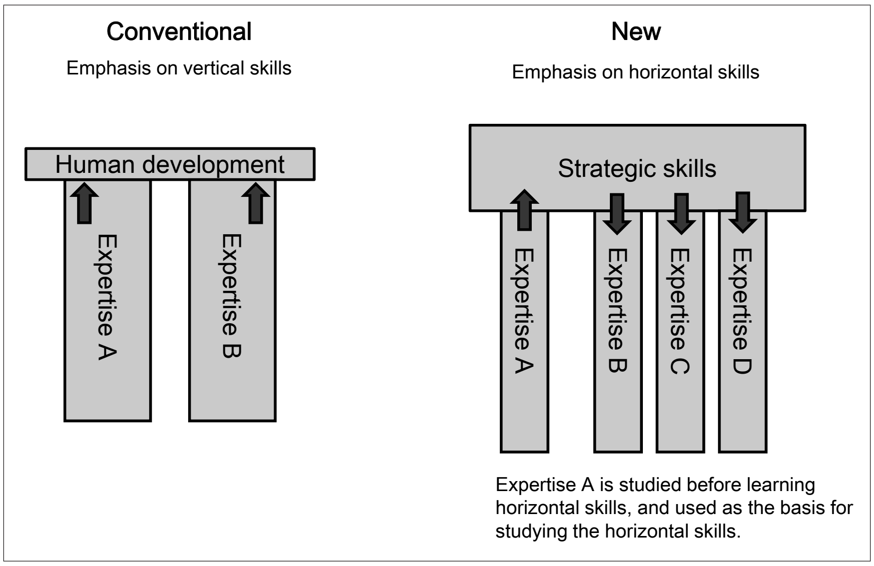

Figure 1 : Conventional and new T-shaped/Π-shaped people

Prepared by the STFC

and recognize patterns of behavior that point to a universal human need. That's what you're after at this point -- patterns that yield ideas."

The 'you' as above is one as a top management of a company or a leader of a development team. The T-Shaped people mentioned above are not the top-level management personnel but human resources at the next level down who assist the top management. However, T-shaped people are necessary in a wide range of levels from the top management to the middle class or above personnel. Whatever the case, it is not easy for us to acquire the ability of T-Shaped people and the number of those who has this ability would be limited.

In the United States, many universities are beginning to establish courses for foster such T-Shaped people. One of these schools is HPI d.school at Stanford University. This educational institution was established by donations from Hasso Plattner, which was the same case as HPI in Germany. The official name is Hasso Plattner Institute of Design at Stanford, which is commonly referred to as d.school.

HPI in Germany is a school for training IT human resources in the conventional sense, in which they teach software production methods.[NOTE 3] However, HPI in the United States is not. d.school is part of the Mechanical Engineering Department and one of the founding members is David Kelly, a famous designer and innovator as well as the founder of IDEO a design company.

The authors visited the d.school at Stanford in March 2008 and observed the session called "Agile Aging" by Professor Terry Winograd, who is one of the major members of d.school. He is also a famous IT researcher who pioneered the concept of the importance of 'design' in IT[18,19] and promoted this concept in the mid-80s.

While the session has a fixed timetable, the students and lecturers would come and leave as necessary. During the session, the participants discuss, assemble prototypes, and listen to visiting lecturers who are active designers or entrepreneurs. They even interviewed elderly people to find out the meaning of an "agile old-age life", which is the theme of this "Agile Aging" session. Such activities take place concurrently in various parts of the large room by four to five teams consisting of three to four people. There were five to six lecturers acting in various ways, some working with a team, and some moved from team to team like Professor Winograd.

The students have different fields of expertise and come from different departments. They learn the horizontal bar skill of T-Shaped people. Attending the project that develops a technology for an "agile old-age life" does not mean that the objective of the participants is social welfare. This is just an example for attaining the skills of the horizontal bar. In fact, items that we found on the whiteboards and memos in the large room of d.school were all about a structure of ideas, interaction of humans, and products and humans. In other words, the core target of this session is 'a process to generate ideas' common to many fields, not the knowledge of expertise such as programming, telecommunication or welfare. (Specific knowledge represented by the vertical bar would be available at each department).

Regarding the modern software engineering, the significance has become relatively low in tasks involved in writing programs nd running them, thanks to the advancements of hardware, tools and methodologies. On the other hand, system 'designs', as saying of Professor Winograd, has gained more significance including the requirement development at the upstream beyond programming and modeling. Under these circumstances, the most important issue in IT system for engineers is to gain an abstract understanding of the relation between things within the environment (the real world surrounding the system) and design the structure, layout and interface with environment of the system in order to allow the system to achieve the maximum effectiveness.

[NOTE 2]
It is difficult to obtain the horizontal skills from the beginning. It should be reasonable to have one vertical bar first and place the horizontal bar, then create other vertical bars below as related to the horizontal bar as a process of learning.

[NOTE 3]
Information on the application for the program is available at http://www.mext.go.jp/a_menu/koutou/it/index.htm

The skills needed for this purpose are surprisingly similar across the various fields such as mechanical engineering, system engineering, production engineering, business administration, and software engineering. This is 'to learn the patterns in generating ideas' of Brown. In terms of IT, 'the common pattern' is particularly important since its physical entity is vague or none. In other words, the computer that was once the essence of IT is now just one of the many 'technical areas'. Now, the very essence of IT system development is what is common among these areas. This is the reason why IBM goes into the business beyond software. This is also the reason why IT authorities like Professor Winograd and Hasso Plattner (also a lecturer of d.school) are working on nurturing T-Shaped people at d.school, rather than at a software educational institution.

The number of skills for vertical bars can be infinite. It is difficult to predict which vertical bar should be used to obtain 'the most optimum answer' for a project to achieve the objective, because there are wide variety of combinations of options and the speed of innovation is so fast. Therefore, the appropriate skill of the vertical bar may keep changing even in the course of the project.

Under such conditions, the most important skill is the horizontal bar of T to attain the necessary skill at its necessity because as it is not possible to prepare the ability beforehand. Due to the 'seeping phenomenon', this applies to many 'fields of expertise', including IT.

This means that the T-Shaped people in the field of so-called 'Information Technology arena' need to be 'information engineers' as well as to surpass the limitation of 'IT'. This is what we mean by the 'advanced IT human resources'. The top-notch field of the world requires this type people, and in fact, the action is taken to 'nurture' such human resources.

It seems almost impossible to bring forth such perfectly capable people. This is not education in the conventional sense but 'nurturing'. The skills of the horizontal bar of the T-shape may be similar to what was stressed by Professor Erwin von Bälz, saying 'a spirit since the era of Greece which lies in the background and supports the various fields of science, that the students could not learn from lectures in the classroom, but can only learn directly from us (teachers from abroad)', who taught at the Tokyo Imperial University in the Meiji era (late 19th Century). The authors pointed this quotation out in the October 2006 issue of Science and Technology Trends.[4] Since such human resources are the key to the competitiveness, there is no choice but we nurture such people no matter how difficult it may be. Thus, d.school attempts to nurture T-shaped people by applying any methods that would be extraordinary from the ordinal educatio systems.

This 'nurturing system' is currently about to be transferred from the United States to Germany. In March 2008, d.school has also opened in HPI Potsdam. According to Professor Winograd, Hasso Plattner is concerned about the potential decline of German industry due to the lack of 'designing' abilities of engineers, therefore he established d.school in Germany to transplant the sense of 'design' that people of Silicon Valley possess. Hasso Plattner is attempting to transplant the 'design' spirit to Germany, after accumulating the know-how of nurturing people for a few years at d.school in Stanford.

4 Current situation in Japan

Japan has only started to make efforts to develop advanced IT human resources while the United State and Germany are gaining their experiences. As a matter of fact, the actions to produce general IT human resources are not sufficient in Japan. Most of the current arguments on IT human resource development have not addressed the target type of people, which have caused significant confusions. The following is the overview of the Japanese IT human resource development situation.

4-1 Japan lags behind: Shortages of mid-level human resources Worsen the case

There are various types of IT human resources. The advanced IT human resource is important but just one of many types. To bring forth the idea produced by advanced IT human resources into reality, we need various types of people sharing and cooperating towards the goal . For example, the concept should be converted into a strategy, then into a project, then broken down into a set of programs, or sometimes turned into design and development of new hardware, and then proceed to the practical operation. Moreover, as the technologies vary from enterprise system like e-commerce to real-time embedded system like automobile engine control, the task may be divided on separate domains. Thus, the types of IT human resources are highly diversified. The needs of the society determines the type and the numbers of human resources required. The policies for human resource development depends upon the needs of Japan.

Nonetheless, not enough discussion and consensus have not been given for the IT people categorization, which further brought confusions. The first trial to categorize the types has appeared in the working group report on IT human resource development of METI in 2007 (Figure 2).[20]

Although we do not fully agree with this classification, we understand that this is a good starting point. According to this classification, the advanced IT human resources, whom we have been discussing, would be those who have the combined aspects of creativity and strategy making. We are afraid that, if these two types are considered to be different, innovation may not be brought in. Therefore, we concerned that this categorization could be a misleading with this report, however, we regard this report has provided an important platform to start with. Another working group report on ICT human resource development has recently been published by MIC.[12] It also contains important information that will contribute to the future discussions.

IT human personnel in general should be categorized as 'solution-oriented human resources' by the METI classification. The role of this type of people is to produce the system 'as requested' by the company/organization. This is a 'conventional' type of IT human resources, such as 'programmers', 'system engineers', and 'project managers'. Ordinary people would imagine those type of people from the word 'IT human resources'.

However, they are not the type of people that we call 'advanced IT human resources', because they are in the mid -level in the aforementioned vertical task sharing. India has a large population of this type of people. When American companies

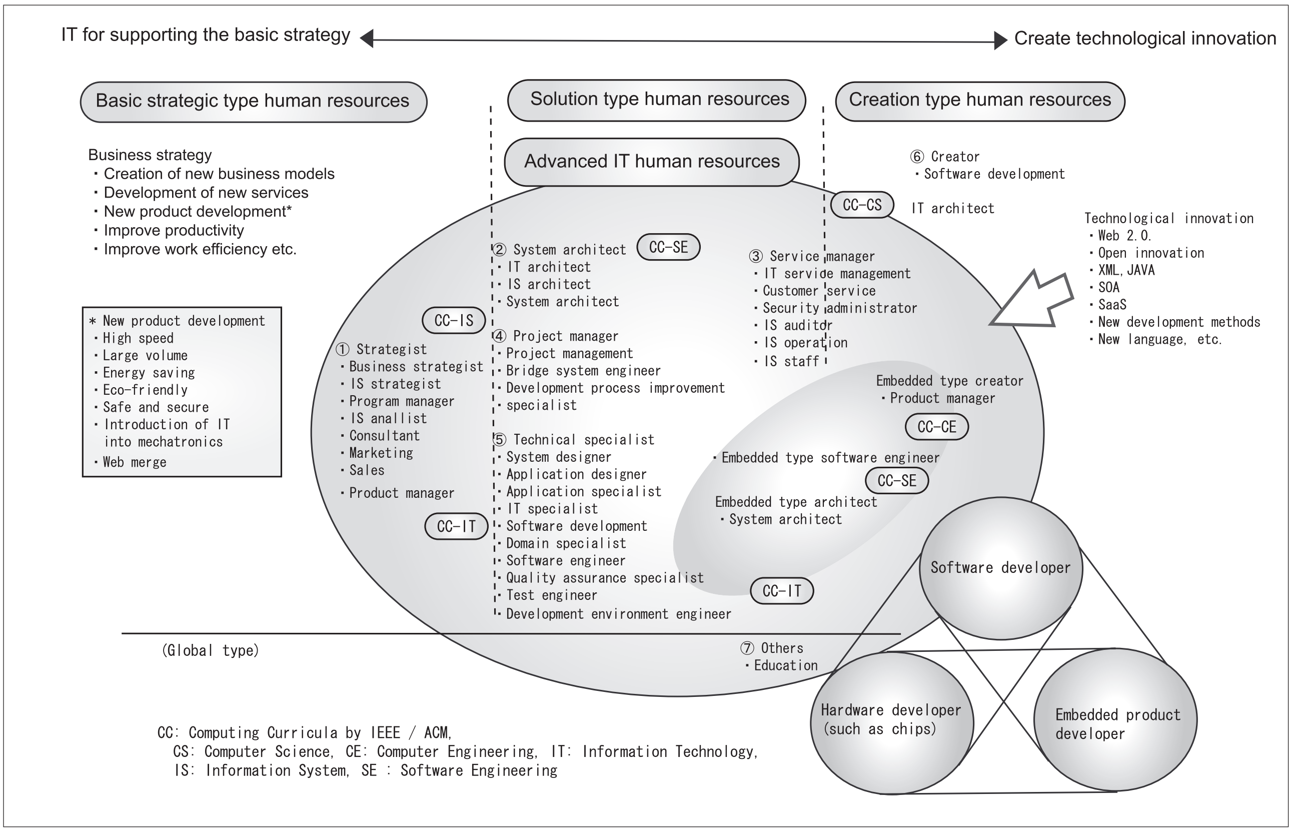

Figure 2 : Classification of the 'types of IT human resources' according to the study group by the Ministry of Economy, Trade and Industry[20]

Source: Reference[12]

see India as a place of offshore outsourcing of IT, it appears they are seeking this type of human resources. The United States, surpassing other countries in IT, are outsourcing these tasks offshore, because strategically these tasks are not so important. In fact, when discussing shortages of IT human resources in Japan, there are opinions that, "there is no need to do all tasks in Japan. Some can be handled by foreign engineers". This might be a reasonable opinion about the 'mid-level solution type human resources'. Offshore outsourcing is recently rapidly growing, partly because Japanese vendors can not meet domestic demands. This is referred to the end of 'national isolation policy of IT'.[21]

The manufacturing industry, which transferred many of its factories to overseas in 1980s and 1990s, may take the position that such 'overseas transfer' is inevitable for Japanese IT industry. However, a significant difference lies between IT and manufacturing industry, that is while manufacturing companies have products to sell overseas, IT companies, especially software companies are in 'regional industry' in the sense that the excess of imports at a rate of 100 to 1 except game software.[8] The increase of offshore outsourcing in this situation means that the Japanese IT industry cannot meet even domestic demands. This also strongly indicates that the level of Japanese IT industry is far below the global standard. In fact, there are many evidences for this fact as shown below,.

4-2 Japanese IT human resources below the global standard

The data and survey results, which explains the basis of Keidanren's working team on IT human resource development, have been published in 2007,[11] where Japanese IT human resources and its education system are indicated below the global standard. For instance, Japanese education system is criticized as no significant differences on the level of IT skills are observed between the various educational institutions, even from those who did not attend the higher IT education (Figure 3).

Furthermore, it was found that only 10% of newly graduates (20% in the case for those from IT-related departments) can start working without taking IT training at the company. Those who cannot qualify the IT job even after IT trainings are 22% of all, (16% of those from IT-related departments). Yamashita et al. point out that there is no significant difference between these 22 and 16 percent, which means that universities had failed to teach enough skills of IT.

The Keidanren team concludes that the cause lies in the curriculum and education methods in Japanese universities and pointed out the gap from the needs of IT companies, which is filled by foreign universities (Figure 4).

We need to be careful on these survey results. First of all, most of these numbers are based on self-assessment so that Keidanren team also admits the arbitrariness and lack of objectivity. Additionally, the curriculums of technical schools are supposed to satisfy the IT companies' needs, but Figure 3 indicates that there is no superiority in their graduates' skills, which may mean that the curriculum and education methods have no significance. It seems that more information is necessary to analyze the situation of IT education at Japanese universities.

However, we agree that 'on-the-job training are insufficient in Japanese universities due to its emphasis on research', which is reasonable from the authors' experiences in IT business and education in universities, and coincides our results from interviews. In fact, many educators in universities share the same opinion. The fact that practical IT education is insufficient in Japanese universities is undeniable.

In contrast, there is different opinion that it is important to teach the basic knowledge, not the practical skills and knowledge that are valid only

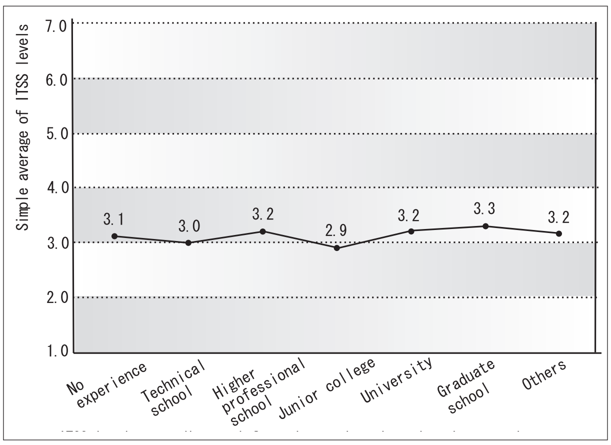

Figure 3 : Could IT education be useless?[11]

Source: Reference[11]

for short - time and narrow - region. In the top ranked universities, some says that the educational efforts are focused on competent students with excellent skills, while little attentions are paid to the rest who may become the mid-level engineers. If these kind of operations could have brought force enough number of high - level IT human resources, their basic research - oriented education might have no problems.

As a matter of fact, the Computer Science Department at Stanford University is known as being strictly research - oriented and providing little care for the students. However, the school has produced not only the world - class researchers but also some once - in - a - decade innovators such as Larry Page and Sergey Brin, Google founders as well as the number of advanced level people.

There should be no problem if the same thing happens in Japanese university. Unfortunately, it is not the case, even though several decades have passed since IT - related departments such as information science and computer science had been established in Japan. To make things worse, we hear that there are not enough young Japanese engineers who can qualify the global standard of global companies such as Google.

We interviewed some people in Google Japan and United States how they see Japanese young employees. Both Norio Murakami, CEO of Google Japan, and Manabu Ueda, the only Japanese manager of the Google headquarters in California, said that Japan is a large market for Google and they would like to hire Japanese engineers to respond the market. However, they cannot recruit enough number of students who qualify the requirements of Google. According to Mr. Ueda, Japanese students have no concrete answer to the question: 'Please explain what will you do to make a system like that'. Mr. Murakami added that he was surprised to see the newly hired graduates come from only the two laboratories of University of Tokyo

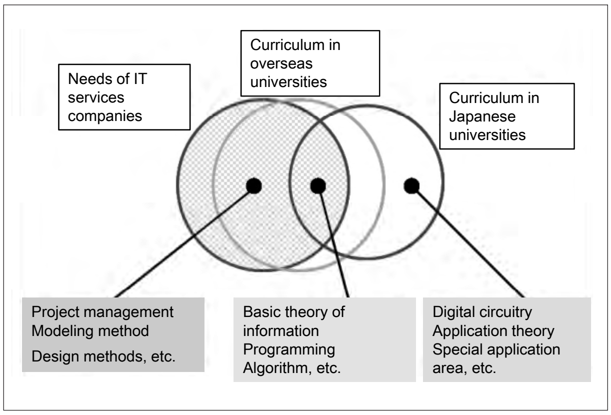

Figure 4 : Gap between IT engineering needs and education[11]

Source: Reference[11]

Yukako Uchinaga, a former executive of IBM, provides another case, who wrote in her article[22] that the 'skills survey' of the software laboratory in IBM Japan revealed the fact that Japanese new graduates need three years to reach the practical level, Level 3 (Level 5 is the best),while IBM laboratories in the United States and Israel observes that their new hires are qualified at the level 3.

According to IBM and Google, even the graduates from top-ranked Japanese universities fail to achieve the global level.

Based on the discussion in this section, we must say that Japanese IT education system is not functioning well to develop capable personnel at a practical level in almost all levels.

5 Advanced IT human resources development in Japan

The authors believe that actions should be taken by the society and government to overcome the issues of IT human resources. Therefore, it is worth mentioning the activities in these few years by METI, MEXT, and MIC in cooperation with the Cabinet Secretariat taking the lead, as well as the movements in private sectors such as Keidanren. This section will introduce some of the case studies that are significant for IT human resource development in Japan.

5-1 New course in graduate schools: efforts of MEXT and Keidanren

The ministries to supervise IT are METI, MEXT, and MIC. One of the characteristics of this new effort by the government for advanced IT human resource development is that the Cabinet Secretariat IT Strategic Headquarters is to coordinate the matters and lead the attempt as part of the so-called e-Japan strategy. The IT Strategic Headquarters is making the strategy, then METI, MEXT and MIC implement it. METI and MIC are focused on study groups with industry, and MEXT executes the policy of human development.

What worth mentioning is 'IT Specialist Program Initiative' by the Technical Educations Division, Higher Education Bureau of MEXT. This program was launched in FY 2006. 6 schools (Tukuba, Nagoya, Osaka, Kyushu, Keio and 2-8 its associate schools) were selected out of 26 applications. In FY 2007, another program focusing in the field of security was open, and two groups were selected. For the first program, an annual subsidy of roughly 100 million yen per one operating base was granted during four years. For the second program, an annual subsidy of roughly 80 million yen per group was granted for the same period.

At each universities, the new course on different tracks than the conventional master's course was established, with the clear goal of producing competent IT human resources. The initial class began in FY 2007. Currently, the second year of education is taking place.

Among these schools, we visited the "Social Information System Engineering Course" at Kyushu University Graduate School, and "Specialized Program for Practical Software Development for Advanced IT Human Resources Development" at Tsukuba University Graduate School. There are other universities worth mentioning such as the efforts of Nagoya University Graduate School's 'On - the - job learning (OJL)' as a new cooperative program between industry and academia with the academia' s leadership The courses at the two operating bases that we visited are promoted by "Advanced IT and Telecommunication Human Resources Development Project" of Keidanren, and are considered as test cases for the future, because of the active involvement of the industry with academia, such as having lecturers dispatched with the support from Keidanren.

5-2 Case study of Kyushu University and Tsukuba University: cooperation of industry, government and academia

The status of new courses under IT Specialist Program Initiative varies at each operating base. However, the education systems in Kyushu and Tsukuba are similar because the curriculum were designed in advance by Keidanren human resource development team. The most significant characteristic is that Project Based Learning (PBL) by full-time lecturers dispatched by Keidanren-related companies play the key role in their education. The overview is given as below.

(1) The first year first term: Learn how to implement projects by using beginner level PBL materials.
(2) The first year second term: Implement PBL by designing the development project with real 'clients', such as private companies or university departments, who may actually use the results.
(3) Faculties act as project managers.

[Programming as a performance]

The authors stated that focal point of IT competitiveness is shifting from programming to design. However, Google the cutting-edge global IT company stresses the importance of programming as one of the key skills of their employees. This appears to have a contradiction. In fact, the programming ability is very important for a truly innovative system development. When you make revolutionary software that you have no idea of how to make it, it would be possible if you are a programmer and write a tentative program to try it yourself. This is the same thing as a composer who could play the piano for example. When a new tune comes to his mind, he can check it by actually playing the instrument. Google seeks revolutionary but practical ideas. It may be a beautiful new song. In a sense the employees are required to have the ability to play the music being able to support the ability to compose. Junya Kondo, CEO of Hatena Co., Ltd., which is known as a search engine venture business that originated in Japan, said in his blog that even a graduate from the School of Information and Mathematical Science, Faculty of Engineering, Kyoto University would fail Google's employment test. He assumed that this might be because of the lack of programming education at School of Information and Mathematical Science, Faculty of Engineering, Kyoto University, compared to the University of Tokyo.[25] The programming ability in this case may be referred to be the programming to support the creativity of the employees.

(4) ‘Clients’ and 'project managers’ intentionally create ‘difficulties and conflicts’.
(5) Placing emphasis on interactions with business people. For example, omnibus lectures are performed by instructors dispatched by companies, and organizing PBL results presentations to the attendance from outside.
(6) Establish a system that students participate in the curriculum improvement.
(7) Special working environment is provided including PC, self-study books, and laboratories.

While it is yet the second year of the program and is too soon to evaluate the whole results, some successful cases have already emerged such as patent applications and a move to adoption of electronic - key system at the university campus. Furthermore, some of the produced documents are in higher quality than those of the actual small-scale system development projects in the industry. These results should be highly appreciated considering the fact that the students have only six months of learning the development methods. It could be said that the results so far are fully satisfactory.

The success of these courses proved that Japan has potential human resources, and that with effective educational system will bring forth qualified people such as project managers for solution businesses as described in Figures 1 and 2.

5-3 Issues and potentials of the new course in graduate schools

Some of the issues for the new courses of the two universities are the followings:
(1) Is it possible to maintain the course even after the end of the IT Specialist Program?
(2) Can they maintain the current level of education for a long -time?
(3) Is it possible to port and expand similar programs to other universities?
(4) Can they further develop more advanced courses for top management level that are discussed in 2-2.

Concerning the continuity of the course raised in the issue (1), the condition of the application for the program stated: there should be a plan for a 10 year period, including the period to implement the program, and assuming that its self-reliant and productive operation after the end of the period, to receive the subsidies.[Note 3] So, there should have been some plans by participating universities. Furthermore, there were opinions from the Cabinet Secretariat IT Department that the program should be continued due to its importance. We expect the universities to make efforts, and the government to provide budgetary support in response to such efforts.

For items (2) and (3), serious issues remain unsolved. Both Kyushu and Tsukuba Universities fully depend on teachers from member companies of Keidanren, from maintaining PBL, lectures and exercises. This means that the universities alone cannot perform these courses.

It would be preferable if the companies would continue their support, because it enhances the cooperative relationship between the industry and academia. Under the global tough competition, Japanese industry has no luxury to give enough support for continue the program, not to say the nation-wide expansion. On the other hand, in the case of OJL at Nagoya University Graduate School, the faculties of the university mainly cover the education while maintaining the partnership with companies. Considering the scale of human resources required for Japan, the Nagoya case is more realistic. Meanwhile, there remain doubts whether there are enough lecturers in the existing universities to perform the PBL.

5-4 Implications from preceding cases

There is an important example of PBL in Future University - Hakodate, Hakodate City. This should be a clue to solve the problem of ‘the faculties on active duties capable of PBL at the same level of Kyushu or Tsukuba Universities’.

Future University - Hakodate is a unique public university for engineering education by incorporating artistic aspects and their laboratories are called 'workshop'. This university applies PBL to the education of Grade 3 undergraduate students in the form similar to that of the new courses of the graduate schools in Tsukuba and Kyushu Universities.

At the beginning of their PBL programs, NS Solutions Corporation supported the program, who assists the new course of Kyushu University.

However, this program is now operated by the university faculties while still cooperating with the company. The significant characteristic of this university is that PBL is actively supported by both the president and faculties. They aware the positive effects of PBL, and they keep trying to make a fusion of PBL conventional education by biringing the achievements of PBL to the support for researches. This should be very important for the continuity of the current IT Specialist Program Initiative and its expansion throughout the country.

5-5 National center plan

Keidanren is proposing to establish National Center to support IT Specialist Program Initiative that are currently being performed at universities such as Kyushu and Tsukuba.[23] This is designed to make these efforts to be more stable and sustainable as well as to establish the nation wide program for IT human resource development. They also propose an integrated-type specialist graduate school. Specifically, National Center will function as follows.

(1) Researches for effective and practical IT education.
(2) Development and promotion of model curriculums
(3) Coordination hub for universities throughout Japan and its sponsor companies.
(4) Educational asset management
(5) Faculty Development

It is desirable for National Center to take full advantage of existing know - how such as - Kyushu, Tsukuba, Hakodate and so on. Management and faculties should visit the National Center graduate school to learn the know-how, or the Center should have a consulting system to support a construction of new education system. The nationwide activities for IT specialist development should come to realization with these supports by the National Center. This change of universities should solve the current issues of nurturing and education of middle class IT personnel. Technical Educations Division, Higher Education Bureau of MEXT is pursuing to implement the ‘project for sophistications of teaching materials for the operating bases’, which should be easily achieved by the establishment of National Center.

5-6 More advanced level IT specialist

National Center alone cannot the solve the issue (4) in 5-3. The PBL centered education like Kyushu and Tsukuba Universities can produce mid - level IT specialists such as project managers, but not for more advanced level of specialists such as CIOs, who are critically needed in Japan.

When we indicated this concern to Keidanren team, they responded that their targets include such higher level, and the current results are just from the first year experience. In fact, the omnibus type lectures at Kyushu University are similar to the CIO training in companies. One PBL project

Figure 5 : PBL presentation at Kyushu University

Prepared by Associate Professor Fukase, Kyushu University

'Clients' (from real companies) at the near side (Tsukuba University Graduate School, IT Specialist Program Initiative)

Figure 5 : Students interviewing ‘clients’

Prepared by Professor Komatani, Tsukuba University cooperates with engineers in Bangladesh for Grameen Bank. To find out such project, and to bring forth its design and implementation are what the more advanced specialists need to do. At this moment, the students are studying topics that are provided by the lecturerers, however, we would like to expect the students to find out and propose topics by themselves in the near future.

It is too soon to ask the education of corporate top management with the IT Specialist Program Initiative, which just started in its initial year. As mentioned earlier, T(Π)-Shaped people model and skills are not easy to achieve. The eventual results of IT Specialist Program Initiative will become clear only after the youth participating the course grow up and become the key players in the society. We hope to continue the survey to investigate the ourcomes of the program.

However, the world is changing rapidly, not waiting for us. It is too late to start the next action only after we get the final result of the new course. Therefore, we believe that National Center should provide more advanced-level IT specialists as well as the enhancement of the valuable experiments of current IT Specialist Program Initiative. We hope that the Cabinet Secretariat IT Strategy Division to take the lead on this direction.

5-7 Need of social changes: IT human resource problem as social issue

IT human resource issues can not be solved simply by the reform of academia. These issues are not just educational but socially structural in Japan. The ‘cause' and ‘effect’ are linked together in complex form and the ‘effect’ is producing the ‘cause’. Thus the problems cannot be resolved at ‘the place of production’ of human resources.

The current form of university education must have been good for the industries for a long time. Otherwise, the industries should have complained much sooner. As Yamashita, et al.[11] admit Japanese university IT departments have placed an emphasis on basic research because it matched with the needs of the industries until the collapse of the bubble economy. The companies had provided sufficient in-house training to their newly hired employees. Now, there are signs of change in this ‘practice’ such as the start of the ‘Public Private Partnership on Human Resource Development’ by METI and MEXT.

When university educations change, the companies and the society to receive the personnel should also change. The authors encountered an unforgettable case: one of the students of Kyushu University was so disappointed because he was told that the course he took is useless since it would be included in the company training. In PBL presentations at Tsukuba University, similar comments were given but the students strongly opposed to it. In the case of Future University - Hakodate, a student were disappointed that he got a job offer from a promising IT company but his parents hardly understand the value of what the company does. Even if the universities provide competent youth, the society and companies can easily spoil them if they do not change. When university educations for human resource development reform itsel, the companies and society should change accordingly. We hope that the start of Public Private Partnership of METI and MEXT is a symptom of such change.

For the development of advanced-level IT specialists to take solid root in Japanese society and to make Japan competitive in the global market in terms of innovation, the change of social structure is needed including laws and social practices. Who should play the key role in realizing such changes? Private companies should be important. Laws and legal system are also need to change. Nowadays, policies on science and technology are closely linked to the legal system. For instance, a new law was enforced to realize a new corporate model called LLC to support venture businesses in the United States and Europe. Research in mathematical economics revealed that innovations would hardly happen if the patent law is tightened. Google Print (Google Book Search) project to scan all the knowledge of the world, are hindered by the copyright law.

Advanced-level IT specialists are those who bring innovations. T(Π)-Shaped people should be capable to proceed political activities such as lobbying as part of their development project. While such people should be in the top management of companies, they should be politicians, government officials, or the top management of NGO and NPO. The authors believe that those who solve issues on advanced-level IT specialist shortage are in fact advanced-level IT specialists themselves.

6 Proposal

The above discussed the serious issue of IT human resource development in Japan, and changes in the world that caused such issues as well as the measures taken by industry, government and academia in Japan to solve the issue. The following proposes the policies based on these conditions.

6-1 IT human resource development for survival as a developed country

In the United States as the most advanced IT country, we often see signs of a new form of IT which would exceed the conventional IT, in a limited sense, because of the development of new concepts such as service science and T-shaped people. It seems that the emerging countries of IT such as India, South Korea and China are not at the level. However, given the fact that they have established an industry-government-academia cooperation in human resource developments and follow the United States in the policies, it should be a matter of time that these countries would be capable at the same level of the United States.

In Japan, the conventional way of human development of IT personnel is not function well. It is even said of the end of the ‘national isolation of IT due to the increase of 'offshore outsourcing’ of IT jobs, which weakens small and mid-sized Japanese IT vendors. Although it would not be necessary to complete all IT procedures within Japan, other industries should also have a negative impact because of neglects to develop IT personnel in Japan if the discussion in 2-2 is correct. Even though Japan sees a difficulty to be competitive in IT industry, this country at least should make efforts to develop capable and advanced level IT personnel. In 1980s, Japan once aimed to be the leading country in IT as the fifth generation computer project. However, what we should do is not to be the top ranked country but to remain its position at the global standard.

Therefore, the development of advanced IT human resources is an urgent and high-priority issue of Japan. This should not be an issue to be separately considered by the academia, industry, or just one of the government agencies respectively. The advanced IT human resource development issue needs to be resolved as the highest priority issue for the government to take on immediately, otherwise it would affect the future of this country. The Prime Minister's Office should recognize this significance of this issue of advanced IT personnel shortage, as explained in this paper, as a national crisis and take a strong initiative to tackle the issue. In this sense, it is natural for the Cabinet Secretariat IT Division to take the leadership in the human resource development. Then, academia, industry and the pertinent government offices such as MEXT should play a practical role for human development in the field while following the initiatives of Prime Minister’s Office.

6-2 New way of human resource development

It would be difficult to change Japanese universities drastically. If necessary, we should consider a new education system to be separated from the existing university system. One of the options is to privatize the graduate schools attached to the national center, as proposed by Keidanren to have more liberty in activities. In addition, the school should be branch school of American universities, which has been done in South Korea, so that the graduates would obtain the degree of the universities in the United States, not the degrees in the universities in Japan.

6-3 Teachers outside the conventional field of IT

The current deadlock may be immediately solved with a new idea of education system, not in the framework of the conventional educational systems. By expanding the concept of IT in the narrow sense and aiming to develop T-shaped people, teachers should not necessary be IT experts. For example, d.school in the United States is an educational institution of mechanical engineering and there are many lecturers from other fields such as industrial design. Thus, in the sense to foster a designer in a wide sense, not only IT, there should be quite a number of potential teachers in Japan.

If there are not capable teachers in Japan even with the new way of thinking, teachers can be invited from overseas, which may be a possibility to solve the teacher shortage issue soon. For example, the graduate school attached the national center proposed by Keidanren could be established as a virtual university like CIO University, an educational institute of CIO for the US federal government. This can provide an opportunity to develop T - shape skilled personnel beyond the boundary of business, universities or even countries as tutors are available for capable students who wish to be have T - shaped skills. Approximately a hundred elite students, business people, government employees, and academics are to become the students of the graduate school in the national center. Their education will be entrusted upon outstanding lecturers, regardless of the organization that the lecturer comes from, whether it is a university, business organization, public research institution, government organization, and NGO, from within Japan or abroad.

Such a system as above may contradict with the conventional Japanese education systems, which may still be controversial. To overcome these hurdles will require the activities of the Prime Minister's Office, the political community and related government agencies that fully understands the current crisis, and the private companies and some universities supported by them.

6-4 Roles of companies

Keidanren is the most active organization in policies related to IT specialist development and influencing the parties around them. In the United States, South Korea and India, the 'industry' has a significant presence in the organizations for human resource development so that it is natural for Japan to have high expectations on the role of Japanese private companies. Therefore, the government should actively support and use Keidanren and its activities. Furthermore, Keidanren is also requested to ‘be used’ by the government by acknowledging the human resource development of advanced - level IT specialists is an important national project affecting the future prosperity of Japan in the next generation.

Currently, IT industry, especially the software, is often abandoned as ‘3K job’ (KITSUI , KITANAI, KIKEN ; hard, dirty and dangerous in Japanese). Even though we could make a system of the human resource development for advanced IT specialists, the workplaces of the industry is not attractive to the capable young people. Some software engineers in the manufacturing industry even regrettably say that there is still a class system in Japanese manufacturing companies, as mechanics come first, and then followed by electric/electronics and software at the end. The entire Japanese society should taken some measures to improve the status of IT engineers, especially of the software industry, through the change of such mindsets or solving the issues in the multi-tiered subcontracting structure in the industry. Therefore, the industry should be at the center of the structure to tackle this issue, as they actually deal with such IT specialists. The authors strongly believe that the industry represented by Keidanren should take the lead on the reform of mindset of Japanese society and the reform of the industry structure. The government should then provide strong support on such activities of the private sectors such as Keidanren.

6-5 Needs to have advanced-level IT specialists for government, politics and media

The authors would like to point out one of the major concerns through the study of the concepts and proposals of Cabinet Secretariat, MIC, METI, MEXT and MIC and Keidanren as well as their human resource development programs as a collusion of this section, The target of human resource development in these concepts and programs is the private companies in most cases. There is little reference of human resource developments of CIO for the central and local governments, which is equivalent to CIO University in the United States. As discussed in 5-7, the shortage issue of Japanese IT specialist is a social problem so that we need people who really understand IT in the government organizations, and even in the legislature to make a fundamental solution. Journalists who have deep understanding of IT are also needed to write articles to help Japanese people to correctly understand the world of IT. Some IT related articles on the Japanese newspapers are incredibly low in quality, which may be because IT university graduates to find employment in the mass media. On the other hand, there are opinions that a certain number of people from the mechanical, electrical and electronics fields find their ways at journalism every year so that the articles are reasonable in contexts. Hence, the advanced-level IT specialists should also be needed not only by the industry but also in the world of politics, government administration and mass media to seriously consider the future of Japan.

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References

[1] Sakakibara, E.: "Japan is sinking", 2007. (Japanese)

[2] Noguchi, Y.: "Illusion of manufacturing is destroying the Japanese economy: the changing world, unchanging Japan", 2008. (Japanese)

[3] Nippon Keidanren: "3rd industry-government-academia cooperation meeting on advanced information and communications human resource development - Exchange of opinions among approximately 200 attendants. - Agreement on the national center concept. Jan. 17, 2008." : http://www.keidanren.or.jp/japanese/journal/times/2008/0117/04.html (Japanese)

[4] Hayashi, S.: "'Thoughts (Shisou)' as the ability for science and technology", Science and technology trends, No.67, October 2006 issue. (Japanese)

[5] Hidaka, K.: "Japanese and overseas trends in service science", Science and technology trends No.57, December 2005 issue. (Japanese)

[6] ITmedia: "Introducing science into services; frontline in service science", ITmedia Enterprise, September 9, 2005. : http:// www.itmedia.co.jp/enterprise/articles/0509/09/news122.html (Japanese)

[7] Ariga, T.: "Vendor turned user; paper upon leaving the IT industry by Teiichi Ariga", NIKKEI NET, IT+PLUS. June 18, 2008. : http://it.nikkei.co.jp/business/news/index.aspx?n=MMIT0z000018062008&cp=1 (Japanese)

[8] Hayashi, S., Kurokawa, T.: "Two rationalities and the Japanese software industry", Science and technology trends No42, September 2004 issue. (Japanese)

[9] Giddens, A.:"Sociology",5th issue (paperback), 2006.

[10] Gotoh, S.: "Interview with Satoru Iwata, president of Nintendo (1), The point is in making intuitive man-machine interface", Weekly overseas news by Hiroshige Gotoh, December 6, 2006. : http://pc.watch.impress.co.jp/docs/2006/1206/kaigai324.htm (Japanese)

[11] Yamashita, T.:"Recommendation for advanced IT human resource development - Restoring global competitiveness", NHK Publishing, 2007. (Japanese)

[12] Ministry of Internal Affairs and Communications, MIC: "Research report on advanced ICT human resource development, - Formulation of autonomous development mechanism for advanced ICT human resources that will support Japan", The results from the call for opinions after public announcement of the report by the 'study group for the development of advanced ICT human resources', May 30, 2008. : http://www.soumu.go.jp/s-news/2008/pdf/080530_3_bs2.pdf (Japanese)

[13] Council of Competitiveness: "Innovate America" National Innovation Initiative Summit and Report 5: Council of Competitiveness, 2005. (The second issue of; "Innovate America: Thriving in a World of Challenge and Change")

[14] Kitagawa, K.: "Impact of the Palmisano Report: Outlining the next generation of US technological strategy", Nikkei Computer, January 10, 2005. (Japanese)

[15] Takeuchi, H., Nomura, M.: "India's trend in human resource development that aims at industry development and knowledge based society", Science and technology trends No.78, September 2007 issue. (Japanese)

[16] Brown, T.:"Strategy by Design", Fastcompany.com December 19, 2007. : http://www.fastcompany.com/magazine/95/design-strategy.html

[17] Suzuki, T.: "Takahiro Suzuki's eye on considering business: Recommendation of the π-shaped people", IT. : http://premium.nikkeibp.co.jp/itm/col/suzuki/02/02.shtml (Japanese)

[18] Winograd, T., Flores, F.: "Understanding computers and cognition: A new foundation for design", Addison-Wesley, 1987.

[19] Winograd, T.: "Shifting viewpoints: Artificial intelligence and human-computer interaction", Artificial Intelligence 170 (2006), pp1256-1258. : http://hci.stanford.edu/winograd/papers/ai-hci.pdf

[20] METI: "Working toward the development of advanced IT human resources", Report by the industry structure advisory board, information economy sectional meeting, information service software subcommittee, human resource development working group, 2007. : http://www.meti.go.jp/press/20070720006/03_houkokusho.pdf (Japanese)

[21] Ohwada, N., Imai, T.: "Demise of the IT closed-door policy: The dawn of global outsourcing", Nikkei IT Pro, http://itpro.nikkeibp.co.jp/article/COLUMN/20080527/304286/?ST=global (Japanese)

[22] Uchinaga, Y.: "Japanese engineers and companies are missing three years", Nikkei Computer, p.94, January 9, 2006. (Japanese)

[23] Nippon Keidanren: "Accelerating the development of advanced information and communications human resources - Proposal of the national center concept", December 18, 2007. : http://www.keidanren.or.jp/japanese/policy/2007/106/index.html (Japanese)

[24] Hayashi, S.: "Thoughts about information science - From the point of sociology and history of science and technology", : http://www.shayashi.jp/2007/talks/kyodaiJyohoSymp.ppt (Japanese)

[25] Kondo, J.: "Night of the million ventures", jkono's diary, April 27, 2008. : http://d.hatena.ne.jp/jkondo/20080427/1209251526 (Japanese)

[26] Noguchi, Y., Endo, S.: "General purpose technology - Ultimate method for breaking the deadlock in Japan", ASCII Shinsho, 2008. (Japanese)

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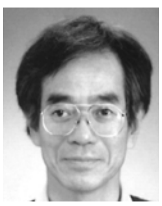

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3

Contribution of Electric Power Technology to Greenhouse Gases Reduction

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1 Introduction

World energy consumption has been increasing in recent years due to population growth, economic development, improved living standards, etc. Many countries are studying the introduction of biofuels to cope with the threat of oil depletion, rising oil prices, and similar problems. Since biomass-derived fuels are organic matter, they burn to produce CO_2. Because the carbon contained in the combustion gas derives from the CO_2 absorbed from the atmosphere by the biomass through photosynthesis during its growth process, burning of biofuels is considered to be carbon neutral. The latest research results, however, indicate that the amounts of CO_2 emissions are not always zero and that Greenhouse Gases (hereafter, GHGs) such as CH_4 generated by land reclamation activities for food production are increasing.[1] In countries with flourishing agriculture, like the developing countries, 2.5 billion people use firewood, charcoal, agricultural waste, and animal feces as cooking and heating fuels on a daily basis. These biomass resources account for more than 90% of total household energy consumption. Such use of biomass is inefficient, but more seriously, it causes damage to health and economic development. The results of a WHO (World Health Organization) survey suggest that indoor air pollution from burning biomass causes the deaths of as many as approximately 1.3 million people each year, most of whom are women and children.[2] Increasing competition for corn and sugar cane for fuel and food actually caused a rise in grain prices in 2007. In Japan, there are concerns about not only food issues but also problems such as a possible steep rise in the price of meat caused by the increased price of corn for animal feed produced in the United States.

The consumption of coal an alternative to oil has also been increasing. Developing countries, in particular, are concerned that the problems of sulfur oxides (SOx), nitrogen oxides (NOx), and soot and dust causing acid rain, as well as CO_2, will become worse and develop into health hazards and cross-border pollution as a result of the increased use of coal and other fossil fuels. To deal with its environmental problems, which were most serious in the 1970s, Japan developed exhaust gas treatment technologies including electrostatic precipitators to remove soot and dust and desulfurization equipment and denitration equipment for SOx and NOx, which are now considered among the most advanced technologies of their type in the world. However, because few power plants in the developing countries are equipped with such environmental purification systems, Japan may face problems of cross-border pollution caused by pollutants from the developing countries.

In the above context, this article discusses the current situation and issues in the electric power industry and policies to contribute to global environmental problems.

2 Estimated energy demand and current problems of exhaust gas emissions

2-1 Estimated energy demand

Figure 1 shows future energy demand by fuel type and by area. World Energy Outlook 2006[3] estimates that world energy demand in the mid-21st century will increase to 1.5 to 2 times the present

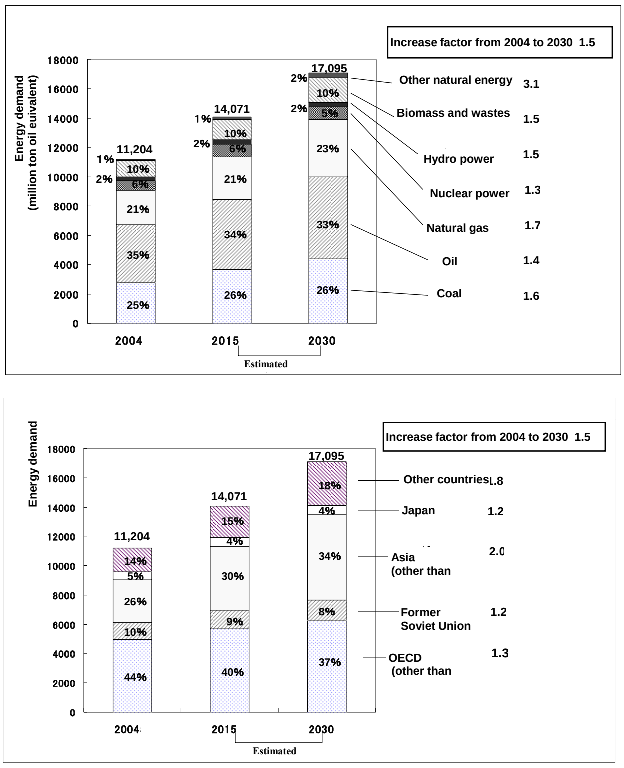


Figure 1 : Estimated world energy demand

Prepared by the STFC based on Reference[3]

level. Taking in account population growth and improvement in living standards in the developing countries, world energy consumption is tending to increase, particularly in Asia. Fossil fuels such as coal, oil, and natural gas will account for 83% of the total increase in energy demand by 2030, and their shares in world energy demand will remain virtually unchanged. The share of oil in fossil fuels will decrease, but will remain in the top position until 2030. The share of hydro power generation will increase slightly, but that of nuclear power generation will remain approximately the same. In the developing countries, the increase in modern commercial energy will offset the increase in biomass for biofuel production, power generation, and heat supply, resulting in a slight decrease in the share of biomass. The rate of increase of renewable energy other than hydro power (wind power, solar power, geothermal power, etc.) is highest, but the share will still be lower than that of fossil fuels in 2030.

The absolute energy consumption of coal will show the largest increase, and 80% of the increase in energy demand will come from China and India. The increased use of fossil fuels including coal and other resources may worsen the problems of sulfur oxides (SOx), nitrogen oxides (NOx), and soot and dust causing acid rain, as well as CO_2, resulting in health hazards and cross-border pollution. In China, which is called the “world’s workshop,” and other countries planning to build more electric power infrastructures, there is a concern that the increase in the emissions of sulfur fluoride (SF_6) and biomass-generated methane (CH_4) may generate a large amount of GHGs.

2-2 Current Greenhouse Gases emissions

The GHGs produced by power generation are mostly CO_2. According to Netherlands Environment Assessment Agency (MNP),[4] the country with the largest amount of CO_2 emissions in 2007 was China, followed by the United States. The shares of those two countries accounts for 47% of the world total. Neither country has signed the Kyoto Protocol. The emissions from the top five countries and regions including China, the United States, the European Union (EU), India, and Russia account for 71% of the world total. Effective reduction technologies and policies need to be introduced in the developing countries as well as in developed countries.

The Kyoto Protocol is intended to reduce the emissions of six types of GHGs, including CH_4, N_2O, hydrofluorocarbon (HFC), perfluorocarbon (PFC), and SF6, as well as CO_2. The Greenhouse Gases Inventory Office (GIO) of Center for Global Environmental Research, National Institute for Environmental Studies published GHGs emission trends for the period 1990-2006.[5] Figure 2 shows the amounts of GHGs emissions other than CO_2 from G8 countries in the year 2005. Even excluding CO_2, the United States is the largest GHGs emitting country. Countries with flourishing agriculture generally generate a large amount of CH_4 emissions. Since the non-CO_2 gases have a Global Warming Potential (GWP, the warming potential relative to that of CO_2, whose GWP is defined as 1) 310 to 20,000 times higher than that of CO_2, Japan cannot ignore the emissions of these gases (Table 1).

In 2006, China overtook the United States to become the world’s largest CO_2 emitting country, and in 2007, CO_2 emissions from India reached 8% of the world total. Development in other Asian countries is also likely to contribute greatly

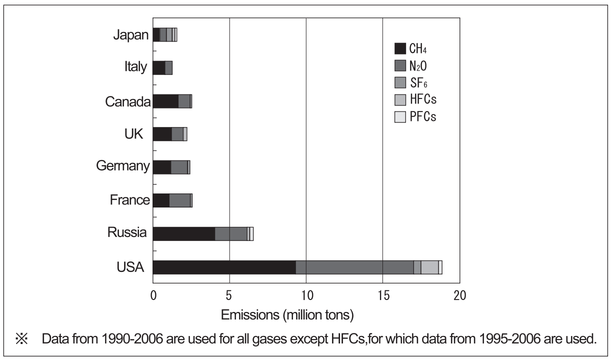


Figure 2 : Amounts of GHGs emissions other than CO_2 from G8 countries

Prepared by the STFC based on Reference[5]

to increased CO_2 emissions. The developing countries will account for more than 3/4 of the world increase in CO_2 emissions for the period 2004-2030. Their share of world CO_2 emissions may increase from 39% in 2004 to just over 50% in 2030. This increase is explained by the fact that the coal power utilization rate in these countries is higher than those of nuclear power and natural gas power.

2-3 Current problems of exhaust gas emissions and Japanese environmental technology

As described above, the increased use of coal for thermal power generation and other purposes in the developing countries has raised fears of the increase in emissions of air pollutants such as SOx, NOx, and soot and dust, in addition to CO_2. With its rapid economic growth in the 1950s, Japan took measures to solve the pollution problems, responding to damage to human health by air pollutants from factories. Power plants installed flue gas treatment systems for power generating equipment and improved combustion methods. Environment-friendly power generation is now the norm in Japan. As shown in Figure 3[6-7] the amounts of SOx and NOx emissions from thermal power plants in Japan are much lower than those in other major countries. This is the result of comprehensive promotion of coal use in harmony with the environment using Japan's advanced technologies for coal-fired power plants, i.e., clean coal technology.[8] The flue gas treatment technologies which Japan has developed in the past as measures against environmental problems, such as electrostatic precipitators to remove soot and dust and desulfurization equipment and denitration equipment for SOx and NOx, are the most advanced in the world. Thus, Japan can make an international contribution through the transfer of these technologies to developing countries.

3 World's top-level electric power technologies in Japan

3-1 Thermal efficiency of thermal power plants

Figure 4 compares the thermal efficiencies of thermal power plants by country.[5,9] The figure shows that Japanese power generation technology has realized the world highest thermal efficiency. Improving the thermal efficiencies of thermal power plants generally requires higher temperatures and pressures at the inlets of gas turbines and steam turbines. Gas turbines driven by high-temperature combustion gases operate in a temperature range which is limited by the turbine blade materials and the heat shield and cooling methods.

Early LNG combined cycle power generation (power generation system using a gas turbine in combination with a steam turbine) operated at a gas turbine inlet temperature of 1,100°C and a thermal

Table 1 : Greenhouse Gas emissions in Japan (total amount in million ton CO_2 equivalent)

	Emission source	GWP	Total amount for 1990-2006	Percentage to total amount
CO_2	Burning of fossil fuels, burning of biomass	1	20,881.9	93.7
CH_4	Rice paddies, exploitation of fossil fuels, landfill, waste/wastewater treatment, digestion activities of ruminants, nitrogen	21	485.4	2.2
N_2O	Burning, nitrogen fertilizers, agriculture and ranching, land improvement, sludge and sewage, etc.	310	511.7	2.3
HFCs	Aerosol propellants, refrigerants for car air-conditioners and refrigerators, insulation foaming agents, etc.	For example, HFC-134a: 1,300	181.3	0.8
PFCs	Manufacturing of semiconductors and parts, cleaning of electric parts, etc.	For example, PFC-14: 6,500	119.8	0.5
Sf_6	Insulation gas for transformers and others, manufacturing processes of semiconductors	23,900	107.8	0.5
		total	22,287.7	100

※ Data from 1996-2006 are used for PFC.

Prepared by the STFC based on Reference[5]

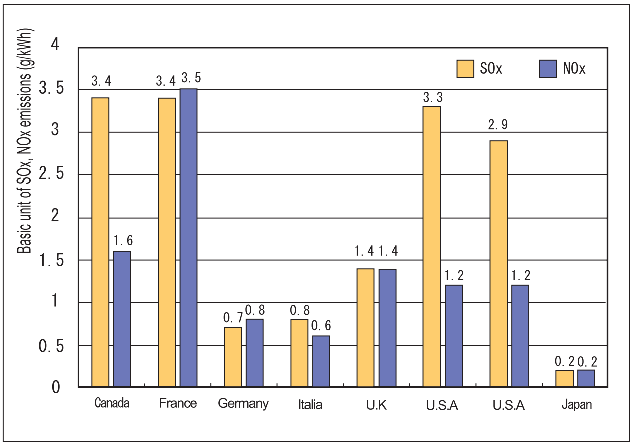


Figure 3 : Amounts of SOx and NOx emissions from thermal power generation in major countries

Prepared by the STFC based on Reference[6-7]

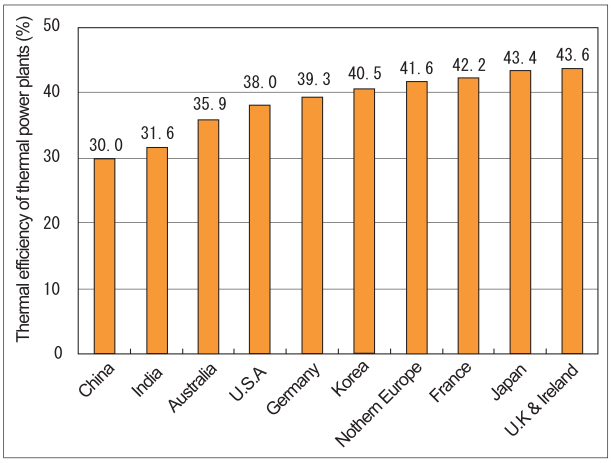


Figure 4 : Comparison of thermal efficiency of thermal power plants by country

Prepared by the STFC based on Reference[6,9]

efficiency of 47.2%. With the introduction of new materials and cooling methods, the latest systems achieve an increased inlet temperature of 1,500°C and a thermal efficiency of 59%. Tokyo Electric Power Company, for example, estimates that an increase of 1% in the average thermal efficiency of all power plants can reduce CO_2 emissions by 1.7 million tons.[10]

Higher temperature and pressure steam conditions at the steam turbine inlet have also been achieved in coal-fired power generation. The temperature has increased from 538°C in the early 1990s to 600°C at present. As a result, thermal efficiency also increased from about 42% to 45% or more. A demonstration test of coal gasification combined cycle power generation, as an application of combined cycle power generation technology, is underway using a 1,500°C class gas turbine with the objective of achieving a power generation efficiency of 48% or more.

Thus, improving the thermal efficiency of thermal power generation requires the development of turbine blades materials, heat shield materials, and cooling technology. Improvement of thermal efficiency is an important issue not only for cost reduction in power generation but also for control of GHGs emissions.

3-2 Technologies contributing to power generation infrastructures

Figure 5 shows the power transmission and distribution loss rates by country.[11] The loss rate in Japan is at the world's lowest due to improved transmission line materials and structures, higher transmission voltages, high-efficiency transmission and distribution equipment, improved transmission control technology, etc. Further improvement in the loss rate is required from the viewpoint of GHGs control. Improved equipment and materials, including amorphous transformers and superconducting transmission, for example, need to be developed for this purpose.

The sulfur fluoride (SF_6) used in the high-voltage breakers installed in transmission systems and other equipment has a warming factor approximately 24,000 times that of CO_2, and hence its discharge should be handled very carefully, even in small amounts. When these units are inspected or removed in Japan, SF_6 is recovered at a recovery rate of 98% or more and reused. In the future, the development of technology to further improve the recovery rate, research on alternative insulating materials to replace SF_6, and international transfer of the recovery technology are needed.

3-3 Power generation from wastes

A drastic increase in the amount of waste generation is expected in developing countries in the future due to mass consumption, hence, recycling and effective use of waste materials is desirable. One such measure is biomass power generation, which is the main method for generating power in developing countries,[12] as described above. Biomass fuels are classified into wastes and plants (cultivated crops). The main utilization methods include direct combustion and conversion into fuel through biochemical conversion such as

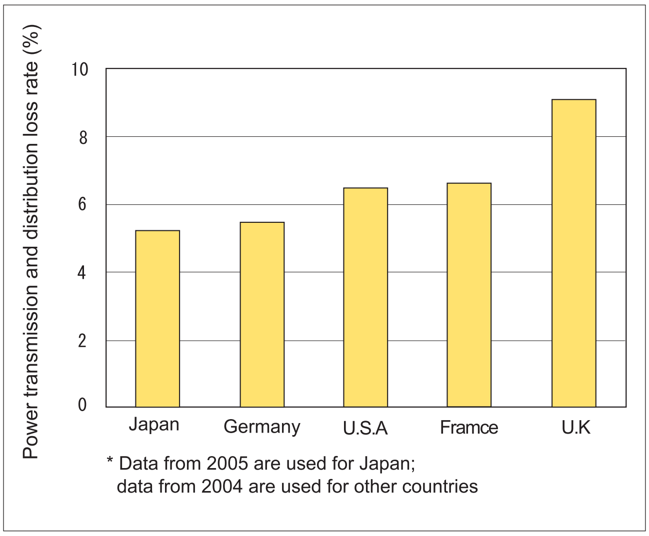


Figure 5 : Power transmission and distribution loss rate by country

Prepared by the STFC based on Reference[11]

CH_4 fermentation and thermochemical conversion by gasification and carbonization (Figure 6).[13] Power generation from waste incineration is the main use of biomass in Japan, which uses electric power or heat produced by burning the black liquor and waste chips generated in the manufacturing processes of paper and other products, the wood chips and bagasse (crushed sugar cane or similar plants after juice extraction process) produced in the processes of agriculture, forestry, and livestock farming, and garbage and trash from households and offices. Technologies which produce CH_4 gas from animal feces and food wastes have been established but are not yet widely used in Japan due to the problems of collection, transportation, and treatment of the residue after CH_4 fermentation. Collection and treatment systems have been established for sewage sludge, and facilities for converting the CH_4 gas generated at some sewage treatment plants into electric power or heat have been installed. This technology contributes to the reduction of N_2O.[14]

Plant (cultivated crop) biomass is used after converting plants such as sugar cane and rapeseed into fuels. Crop cultivation for energy use has hardly been developed in Japan because of problems of technology, the amount of cultivation required, land availability, and economy.

3-4 Heat pump technology contributing to energy saving

Measures to reduce electricity consumption are also important for GHGs control. The development and introduction of high-efficiency, energy-saving equipment are needed. Heat pumps are appropriate for cost reduction and load leveling in electric power systems (correction of the difference in power consumption between day and night) through energy-saving technology and late night power consumption. These systems can extract energy equivalent to 3 to 6 times the input electric energy from the atmosphere. Commercial ice thermal storage air conditioners (product name: Eco Ice) and domestic natural refrigerant heat pump

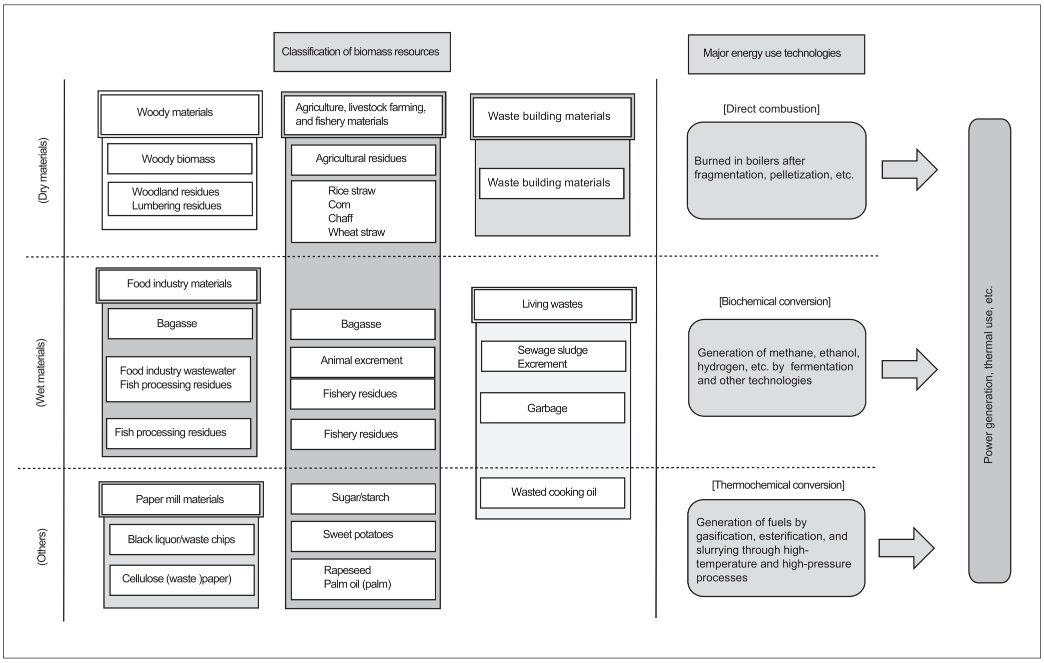


Figure 6 : Classification of biomass power generation and resources

Source : Reference[13]

water heaters (product name: Eco Cute) developed in Japan are being reviewed for introduction in the world as part of energy saving and total electrification. In particular, heaters can reduce the amount of CO_2 emissions to about 1/5 (compared to oil heaters) of those generated by systems that produce thermal energy by direct combustions of fossil fuels, and heat pump water heaters for cold areas can achieve a COP (coefficient of performance: ratio of produced energy to consumed power) exceeding 4. Hence, wider use of these technologies is desirable. The combination of thermal storage technologies, such as water thermal storage and ice thermal storage, and heat pump technology is effective not only for energy saving but also for load leveling. The heat pump air conditioning systems using low-temperature (10-20°C) geothermal energy shown in Figure 7[15] are expected to be widely used as measures for power demand peak cut, especially in summer. Some of the latest heat pumps use normally unused underground space for water thermal storage tanks (Figure 8).[16] Water in a thermal storage tank can also be used for fire-fighting or for emergency domestic purposes in time of disaster. From this viewpoint, this technology has potential value not only for earthquake-prone Japan, but also for the other Asian countries, which have suffered a series of natural disasters recently.

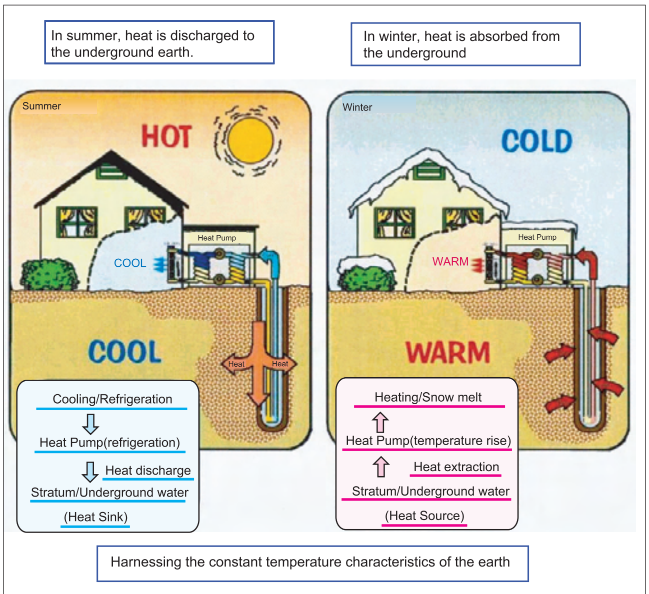


Figure 7 : Heat pump system using geothermal energy

Source : Reference[15]

4 Issues in the Japanese electric power industry from the viewpoint of Greenhouse Gases control

4-1 Improvement in the Energy Availability Factor of nuclear power plants

Nuclear power generation is vitally important in that it produces no GHGs emissions. It will play an important role in Japan in controlling global warming. Figure 9 shows the Energy Availability Factor of nuclear power generation plants by country.[17-18] France has a relatively low Energy Availability Factor due to load following operation, a technology in which output is changed in response to changes in power demand. Other major countries have high Energy Availability Factor of around 90%. Japan has a record low level of 60.7% because of the long-term shutdown caused by the Niigata Chuetsu-oki Earthquake and other factors. Improvement in the Energy Availability Factor is useful for controlling fossil fuel consumption, contributing to reductions in CO_2 emissions and power generation costs. In the case of Japan, a 1% improvement in the Energy Availability Factor results in a CO_2 emission reduction of about 3 million tons. Assuming that the rate increases

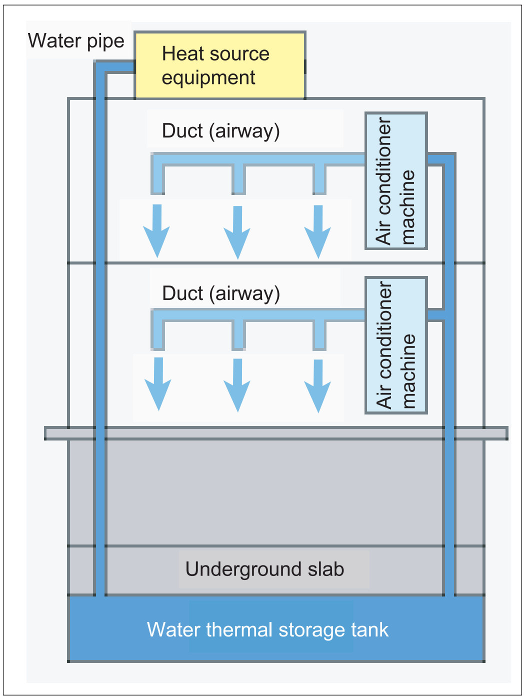


Figure 8 : Heat pump system equipped with underground water thermal storage tank

Source : Reference[16]

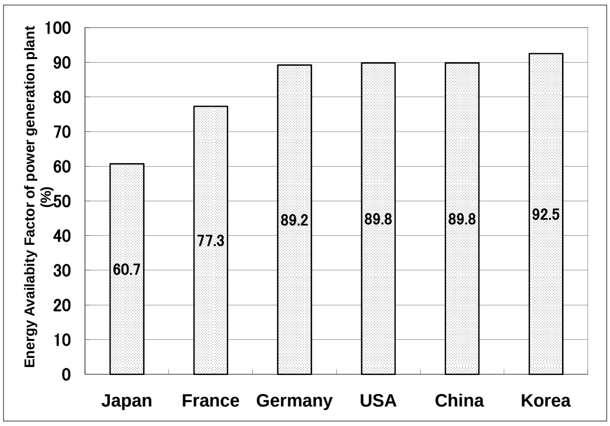


Figure 9 : Energy Availability Factor of nuclear power generation plants by country

Prepared by STFC based on Reference[17,18]

to 90%, as in other countries, a CO_2 emission reduction of about 88 million tons can be achieved (corresponding to about 6.9% of Japan's total CO_2 emissions in 2006). Improving the Energy Availability Factor requires assuring the safety of facilities, including appropriate measures against earthquakes, increasing transparency and openness, and gaining community trust. The requirements for this include wider use of constant rated thermal output operation (an operation method in which the thermal output generated from a nuclear reactor is held constant, unlike the conventional method of keeping electric output constant), extension of the continuous operation period through the adoption of online maintenance (carrying out maintenance and repair of spare machinery during plant operation) and monitored maintenance (monitoring the operation of equipment to determine its inspection dates), and increased rated output. Technologies for maintenance, inspection, and safety evaluation must be further improved for these purposes.

Studies on measures against aging, corrosion-resistant materials, high-level waste treatment, and human error are important for increasing the use of nuclear energy. Research on total efficiency improvement through the effective use of waste heat will also be important in the future.

4-2 Promotion of the use of natural energy

Figure 10 shows a comparison of CO_2 emissions by power source based on life cycle assessment (LCA).[19] Hydro power is apparently most appropriate from the viewpoint of CO_2 emissions. Japanese hydro power energy is all domestically produced, but about 70% of the country's potential output-based hydro power has already been developed. The remaining hydro power resources are located in up-country areas and are small in size, which makes it difficult to ensure economic efficiency. The effective use of low GHGs emitting hydro power energy under such conditions requires the development of small- and medium-scale hydro power generation plants using existing dams, agricultural irrigation channels, and water and sewage systems. Micro hydro power generation using small-capacity hydraulic power sources with a small head drop should be promoted in the future from the viewpoint of the compactification of cities. Application of the latest high-efficiency equipment such as water turbines and generators to existing large-scale hydro power plants is also effective. Research efforts to improve the efficiency of hydro power generation-related equipment need to be continued in the future. The Asian countries, on the other hand, have an abundance of undeveloped hydro power energy. Wide introduction of Japan's advanced hydro power generation technologies, such as hydraulic turbines and generators, is needed for stable energy supply and GHGs control in the Asian countries.

Figure 11 shows the amounts of geothermal resources and the capacities of power generation facilities[20] by country. Japan, one of most earthquake-prone countries in the world, has rich potential for geothermal energy, but it has a limited number of appropriate sites for building geothermal power plants due to restrictions on development in national parks and tourist spots. Enhanced geothermal power generation, from which

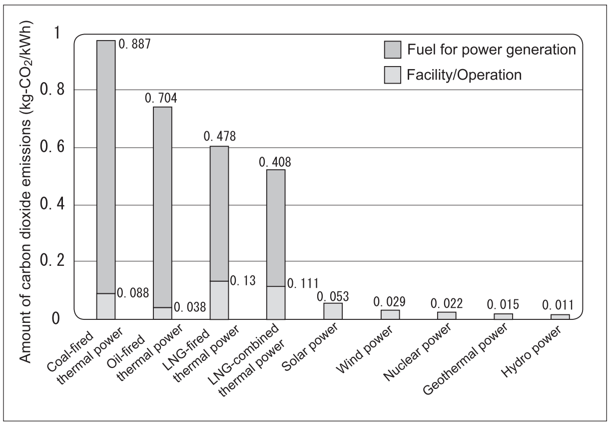


Figure 10 : Comparison of CO_2 emissions by power source type based on life cycle assessment

Prepared by STFC based on Reference[19]

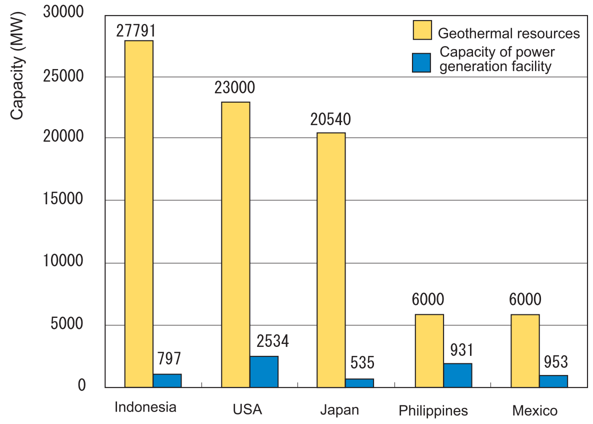


Figure 11 : Amounts of geothermal resources and the capacities of power generation facilities by country

Prepared by STFC based on Reference[20]

higher temperature and pressure steam can be produced, and currently unused binary cycle power generation, for which lower temperature steam and hot water (80-150°C) can be used, should therefore be developed for the effective use of geothermal energy. The air conditioning systems using low-level geothermal heat (10-20°C) described in Chapter 3 also need to be used more widely.

Solar power and wind power generation, on the other hand, are currently a focus of strong interest. These technologies have been introduced nationwide, and their further promotion should be encouraged. In the installation of generators, and wind power generators in particular, full consideration should be given to the environment and to measures against lightning strikes. Because these generators using natural energy can change output depending on weather conditions, concern about the effects of frequency and voltage variations on the electric system must be considered in case of large-scale introduction. Since stand-by operation of thermal power plants to balance out these effects is undesirable for GHGs control, the development of energy storage technologies such as storage batteries is essential. The use of solar thermal energy should also be encouraged.

4-3 Electric load leveling and power storage technologies

Figure 12 shows an example of the power generation configuration by power source when daily variations in power demand are considered.[21] Use of nuclear power with no power conditioning as base load is assumed, and in most cases, thermal power is used to adjust supply and demand. The gap between daytime and nighttime demand has recently been widening, mainly in summer. The need to cope with minimum nighttime demand makes further increases in the ratio of nuclear power generation difficult. Figure 13 shows the ratio of generated nuclear power and hydro power to total generated power. The basic unit of CO_2 emissions in France, which relies most heavily on nuclear power for electric power, is extremely low compared to those of the other major countries. Improving load leveling to correct the daytime-nighttime gap and increasing the ratio of nuclear power generation are effective for GHGs emission control in Japan. Since improved load leveling enables stable thermal power generation at high output, GHGs emission control can be expected as a result of the improvement in thermal power generation efficiency. Needless to say, the power source configuration must be optimized, comprehensively considering stable supply, economy, fuel procurement, and location, but efforts to provide better load leveling are crucial for GHGs emission control.

Load leveling technologies include peak shift technologies, such as the heat pumps described above, which shift power demand from day to night by using heat stored at night for daytime air-conditioning, bottom-up technologies, such as electric water heaters, which encourage nighttime power demand, and peak cut technologies, such as geothermal air conditioning systems, which control daytime power demand. Pumping-up hydro power is currently used as a peak shift technique for

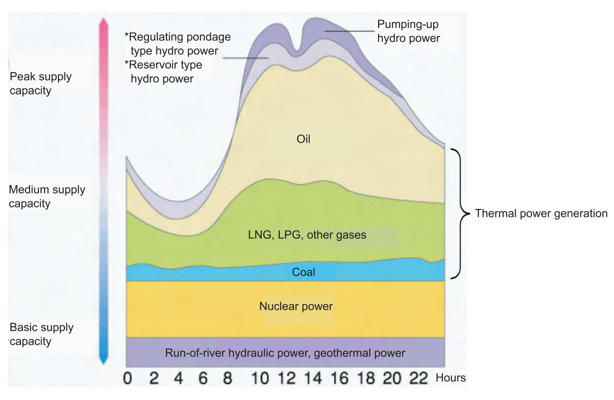


Figure 12 : Example of power generation configuration by power source considering daily variation in power demand

Prepared by STFC based on Reference[21]

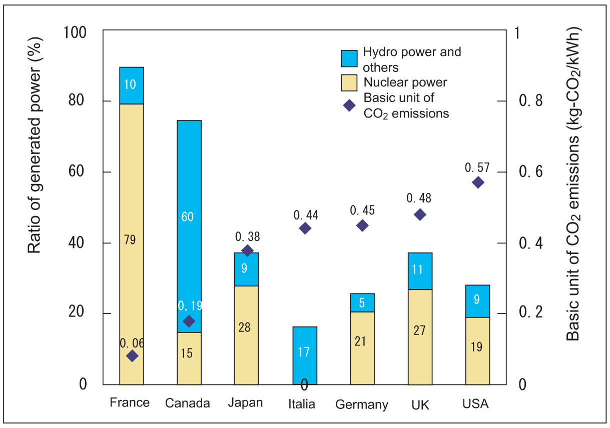


Figure 13 : Ratio of generated nuclear power and hydro power to total generated power and basic unit of CO_2 emissions

Prepared by STFC based on Reference[6]

storing power at night and using it during the day. As described above, however, no large increase in this type of power generation can be expected in the future. Cost reduction and wider use of power storage technologies using new types of storage batteries, such as sodium sulfur batteries and redox-flow batteries, both of which are in practical use, are needed. The early practical application of superconducting magnetic energy storage (SMES) technology, which is in the verification test stage, is also desirable. In particular, power storage technologies will be indispensable for the large-scale introduction of solar power generation and wind power generation.

5 Future approaches

Based on the above, the following discusses the future issues which Japan must address.

The increases in world population and energy demand will create many environmental problems, among which climate change should be actively addressed, as this will have a significant impact on human life and health and the living environment. For environmental problems such as regional air pollution and water pollution, Japan should provide other countries with technologies and information based on its experience.

5-1 Encouragement of CO_2 emission reduction through wider use of existing technologies

As clearly stated in Japan's Third Science and Technology Basic Plan, "integration of the environment and the economy" is the basic principle for building a sustainable society. The government of the United Kingdom published the Stern Review on the Economics of Climate Change[22] in 2006, which was based on reports by economists, scientists, policy makers, and participants from industry and NGOs who visited many major countries, including Brazil, Canada, China, EC, France, Germany, India, Japan, Mexico, Norway, Russia, South Africa, the United States, and international organizations to exchange information and opinions. At the Hokkaido Toyako G8 Summit held in July 2008, leaders discussed the environment and climate change as major subjects. The G8 countries agreed to "have a visionary objective of achieving at least a 50% reduction in world emissions by 2050 in common with all UNFCCC (United Nations Framework Convention on Climate Change) signatory countries, discuss the objective with them, and advise the UNFCCC to adopt it." The agreement includes a statement that developed countries need to accelerate the expansion of existing technologies and contribute to the world through the development and expansion of low-carbon technologies.[23] The "Action Plan for Building a Low-carbon Society" approved at a meeting of Japan's Cabinet in July 2008 set a long-term goal for this country. The plan intends to ensure that world emissions peak out in the next 10 to 20 years, and achieve a 60 to 80% reduction in Japanese emissions and a 50% reduction in world emissions by 2050.[24]

Japanese government ministries and agencies are studying various measures for GHGs reduction. Figure 14 shows a technical plan for GHGs emission reduction in which the Ministry of Trade, Economy and Industry (METI) is playing a leading role.[25] The plan intends to develop innovative technologies such as high-efficiency power generation and next-generation automobiles for reducing total CO_2 emissions by about 60%. A tentative calculation shows that existing technologies can contribute to a reduction of 40%.

The Environment and Energy Technology Innovation Plan prepared by the Council for Science and Technology Policy states : "Improving existing technologies greatly contributes to Greenhouse Gases emission reduction on a short-term basis. This approach has, however, limitations when aiming to reduce emissions drastically. On a medium- to long-term basis, the development of innovative technologies is essential to radically reduce emissions. Investment in research and development is made to improve existing technologies for a short period, but the focus of investment needs to be eventually shifted to innovative technology development."[26] On a short-term basis, therefore, Japan needs to put priority on transferring existing technologies to developing countries. These technologies include the world's most advanced technologies for high-efficiency power generation and transmission and distribution loss reduction, as well as technologies for energy-saving and pollutant removal. These activities will eventually help Japan mitigate environmental problems.

5-2 Encouragement of wider use of natural energy

The use of natural energy should be encouraged to reduce CO_2 emissions in the future. Solar power generation and wind power generation will be widely used in Japan. Because hydro power generation and geothermal generation can produce more stable outputs than solar and wind power generation, their importance should be emphasized. Hydro power, which is all domestically produced energy, produces a minimum amount of CO_2 emissions when generating energy. However, the effective use of unused hydro power energy resources will require a careful study of economic feasibility and appropriate locations. As for the maintenance of existing hydro power plants and water discharged from such plants, study and verification of their environmental condition and research and development on energy recovery are needed.

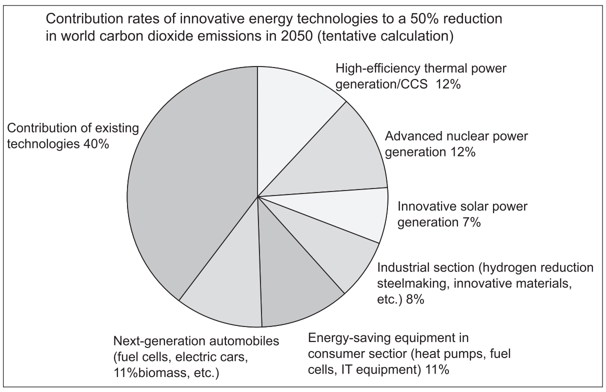


Figure 14 : Contribution rates of technologies to CO_2 emission reduction in 2050

Source : Reference[25]

Geothermal power and hydro power, produces only a small amount of CO_2 emissions when generating energy, and has a large resource potential in Japan. Many restrictions are also imposed on geothermal energy, these needs to be relaxed. Because the risk of the initial investment is a hurdle for geothermal power generation, support for the initial investment is necessary.

5-3 International contribution through transfer and implementation of technologies

As shown in Figure 4, the thermal efficiency of Chinese thermal power plants is lower than in the developed countries. As reasons for this, about 53% of China's thermal power facilities have a power generation capacity of 300,000 kW or less, and many existing small-scale power facilities with a power generation capacity of 100,000 kW or less have thermal efficiency in the 20% range.[27] In addition to technologies for modernizing these small-scale, low-efficiency facilities, transfer of technologies for plant operation, maintenance, and inspection to China is a significant international contribution. For example, a project to improve the thermal efficiency of aged coal-fired thermal power plants in China, which was carried out by Kyushu Electric Power Company in 2001, improved thermal efficiency by as much as 4.4% by introducing appropriate operation control, inspection, and maintenance practices. The thermal efficiency of these plants had been lowered by a reduction in the amount of transferred heat caused by coal ash deposits, increased pressure loss in air/flue ducts caused by ash deposits, and reduced efficiency caused by turbine blade wear and scale buildup on turbine blades. Thus, Japan's advanced plant control systems[28] and maintenance and inspection technologies, as well as power generation technologies, are highly valued in the world.

With increasing power demand, developing countries are building many power plants, and they need to improve their electric power systems. Transmission and distribution loss rates are extremely high in developing countries like India. Tokyo Electric Power Company and the Central Research Institute of Electric Power Industry, for example, concluded a technical cooperation agreement on 1 million volt transmission of electric power with China in 2005. Such international cooperation using Japanese advanced transmission and distribution technologies and SF_6 recovery technology to reduce transmission and distribution losses in developing countries is of great significance for global GHGs control.

As described above, Japan has the world's most advanced technologies for high-efficiency power generation and transmission, energy saving, power storage, and environmental measures. The use, establishment, and improvement of these existing technologies in this country are critically important for domestic GHGs emission reduction. Provision of knowledge, such as know-how on operation control, inspection, and maintenance, as well as Japan's high-efficiency equipment and other advanced hardware in the field of power technology, to technology-hungry developing countries is needed for regional environmental conservation and the reduction of total global GHGs emissions.

5-4 Better approaches and wider opportunities for consensus building

The implementation of energy and environmental policies requires not only technical development and infrastructure construction but also consensus building among the industrial, academic, public, and private sectors. In Japan, air pollution from smoke-emitting factories damaged human health during the high economic growth period of the 1950s. Administration, industries, and residents cooperated in tightening regulations, reviewing systems, developing technologies, and monitoring to overcome problems. These various efforts resulted in today's excellent environmental conditions in Japan.[29] Thus, cooperation between government agencies, industries, and the general public are essential to environmental improvement. Appropriate policies which expand platforms for consensus-building and widen opportunities for residents to actively participate by such platforms are necessary. Academic research through cooperation between the fields of social science and technology is important.

Building a vision of a desirable society in the future, such as an approach to climate change issues, for example, requires participation from many countries, a wide range of professional fields, and various viewpoints. In the case of the developing countries in particular, it is important for administration to play a central role in establishing platforms for consensus building among administration industries, and residents and increasing opportunities for discussion. These efforts are expected to lead to problem solving in individual countries. Referring to the example of other countries such as Germany, which are already actively grappling with consensus building processes, Japan should also introduce such processes into policy making more actively than it has in the past.

References

[1] "Topics in the Environmental Field: Tentative Calculation of the Effects of Land Reclamation for Biofuel Production on Greenhouse Gases Emissions," Science and Technology Trends, No. 85, April 2008.

[2] World Health Organization: http://www.who.int/indoorair/en/index.html

[3] International Energy Agency, World Energy Outlook 2006.

[4] Netherlands Environmental Assessment Agency: http://www.mnp.nl/en/dossiers/Climatechange/moreinfo/Chinanowno1inCO2emissionsUSAinsecondposition.html

[5] Website of Greenhouse Gases Inventory Office, "Database on Greenhouse Gases Emissions and Absorptions.": http://www-gio.nies.go.jp/aboutghg/nir/nir-j.html

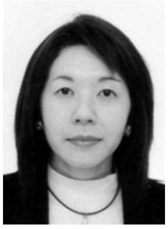
[6] Federation of Electric Power Companies, Environment and Energy–Japanese Electric Power Industry in the World 2007-2008.

[7] Organization for Economic Co-operation and Development, OECD Environmental Data Compendium 2006/2007.

[8] Tatsuya Ohira, "Latest Trends and Future Prospects of Coal Use and Cleaning Technologies–Focusing on Clean Coal Technology," Science and Technology Trends, No. 44, November 2004: http://www.nistep.go.jp/achiev/ftx/jpn/stfc/tt044j/0411_03_feature_articles/200411_fa02/200411_fa02.html

[9] Ecofys, Updated Comparison of Power Grid Level 2007.

[10] Website of Tokyo Electric Power Company: http://www.tepco.co.jp/eco/report/glb/05-j.html
[11] Japan Electric Power Information Center, Overseas Electric Power Industry Statistics 2006.
[12] Seiji Maeda, "Research and Development Trends of Energy Resource Crops and Biofuel Conversion Technology," Science and Technology Trends, No. 75, June 2007: http://www.nistep.go.jp/achiev/ftx/jpn/stfc/stt075j/0706_03_featurearticles/0706fa01/200706_fa01.html(Japanese)
[13] Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry, White Paper on Energy 2006: http://www.enecho.meti.go.jp/topics/hakusho/2006EnergyHTML/index.html
[14] "Topics in the Environmental Field: Effects of Gas Reduction Approaches in Sewage Works," Science and Technology Trends, No. 87, June 2008: http://www.nistep.go.jp/achiev/ftx/jpn/stfc/stt087j/0806_02_topics/200806_topics.html#0806env01
[15] Brochure prepared by Geo-Heat Promotion Association of Japan: http://www.geohpaj.org/information/library/image/punf_back.pdf(Japanese)
[16] Website of Heat Pump & Thermal Storage Technology Center of Japan, "Thermal Storage Air Conditioning Systems.": http://www.hptcj.or.jp/chikunetu/whatecoice/type.html
[17] Press Release from the Ministry of Economy, Trade and Industry: http://www.meti.go.jp/press/20080408004/20080408004.html
[18] Japan Atomic Energy Commission, Cabinet Office, Government of Japan, White Paper on Nuclear Energy 2007: http://www.aec.go.jp/jicst/NC/about/hakusho/hakusho2007/index.htm(Japanese)
[19] Federation of Electric Power Companies, Environmental Action Plan by the Japanese Electric Utility Industry 2007.
[20] Thermal and Nuclear Power Engineering Society, Present State and Trend on Geothermal Power Generation 2005.
[21] Website of Federation of Electric Power Companies: http://www.fepc.or.jp/
[22] Stern Review on the Economics of Climate Change: http://www.occ.gov.uk/activities/stern.htm
[23] Website of Hokkaido Toyako Summit: http://www.mofa.go.jp/mofaj/gaiko/summit/toyako08/index.html
[24] Ministry of Environment, Action Plan for Building a Low Carbon Society: http://www.env.go.jp/press/file_view.php?serial=11912&hou_id=10025(Japanese)
[25] Ministry of Economy, Trade and Industry, Cool Earth–Energy Innovation Technology Plan: http://www.enecho.meti.go.jp/policy/coolearth_energy/coolearth-hontai.pdf(Japanese)
[26] Council for Science and Technology Policy, Cabinet Office, Government of Japan, Environment and Energy Technology Innovation Plan 2008: http://www8.cao.go.jp/cstp/project/kankyoene/index.html(Japanese)
[27] Chun Chun Ni, "CO_2 Reduction Potential in the Chinese Field of Coal-fired Thermal Power Generation," Energy Economics, Vol. 34, No. 4 (2008), 42-58.
[28] For example, S. Umezawa and S. Mutoh, "Advanced Thermal Efficiency Diagnosis System for Power Plants–TEPCO Heat Balance Analysis Method," 4th IERE General Meeting (2004).
[29] Kitakyushu City, Japan International Cooperation Agency, and Institute for Global Environmental Strategies, Handbook of Environmental Measures in Kitakyushu City: http://www.iges.or.jp/en/ue/pdf/handbook/jap/story/storyi1.htm(Japanese)



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R&D Trends in High Efficiency Thermoelectric Conversion Materials for Waste Heat Recovery

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1 Introduction

Fossil fuel utilization efficiency has virtually reached its limits. Therefore, use of waste heat energy is the only means of achieving further increases in energy use efficiency with this type of fuel. Because this means that a resource which had essentially been discarded will now be used, in effect, the total efficiency of the energy system using fossil fuel will be improved, even if the efficiency of the thermoelectric conversion system is not particularly high. Moreover, even assuming that the efficiency of the thermal energy system is low, the fact that waste heat is converted to electrical energy, which can be flexibly used, will have an important significance.

Development of materials which convert thermal energy to electrical energy with high efficiency (thermoelectric conversion materials) is being promoting using technologies that can realistically be applied. To date, however, the results of materials technologies and systems technologies have not reached a level that can support a thermoelectric power generation market, including cost competitiveness with other power generating systems.

This paper discusses the reasons why high efficiency thermoelectric power generation will be increasingly expected in the future from the viewpoint of various energy systems, the amount of unused waste heat, and a low carbon society based on effective utilization of thermoelectric generating systems, and introduces the thermoelectric conversion materials/manufacturing processes and the conditions for penetration of thermoelectric power generating systems. First, an outline of the thermoelectric conversion materials which have been the object of research and development to date is presented from the viewpoint of generating performance, and the thermoelectric conversion materials which should be the focus of priority in future R&D from the viewpoints of resource supplies and low environmental impact are recommended. Following this, the current status of R&D on innovative thermoelectric conversion materials by nanostructural control is described, and recommendations are offered as to how to proceed with R&D on these materials in the future.

2 Thermoelectric power generation: a long-awaited technology

2-1 Various energy systems and recovery of unused waste heat

Figure 1 shows the relationship between the temperature of the waste heat and the annual amount of waste heat in various types of social systems.[1,2] Because the temperature of the waste heat generated by large-scale power generating systems, steel industry furnaces, and waste incinerators is 200-300°C or higher, progress

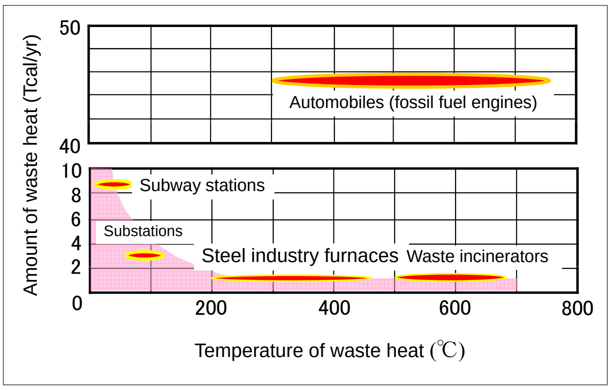

Figure 1 : Temperature and annual amount of waste heat generated by various social systems in Japan

Prepared by the STFC based on Referemces[1,2] in waste heat recovery is continuing. However, it still cannot be said that the recovery level is adequate. On the other hand, a vast amount of waste heat with temperatures of 150° or lower is generated each year by power substations, subway stations, and the like. If it is possible to establish technologies for recovering the waste heat in this low temperature region in effective energy in the future, this will contribute to a substantial reduction in energy consumption in the social system as a whole. For example, the annual waste heat generated by automobiles is estimated at 45.8Tcal,[2] and virtually all of this waste heat is discharged from engines using fossil fuels. Concretely, this is discharged in the exhaust system from the exhaust manifold immediately after the engine combustion chambers to the muffler in the latter part of the system (temperature of discharged gas: 300-700°C).

Figure 2 shows the current efficiency of various power generating systems in Japan[3] and the improvement in efficiency assuming use of thermoelectric generating systems (efficiency: 20%). Worldwide, 90% of large-scale power generating systems employ thermal power generation. Using combustion of fossil fuels as a heat source, generating efficiency is 40-60% (in combined cycle power generation using a gas turbine and steam turbine), which means that 40-60% of the heat of combustion of the fossil fuels (equivalent to approximately 15TW) is waste heat. This does not mean that all of this waste heat is simply discharged into the atmosphere without use; part of this heat is used in maintenance and control of the power generating system and as a heat source for hot water, heating, etc. Nevertheless, the amount of thermal energy which is discarded without use is quite large. If these forms of unused waste heat energy can be recovered effectively, an increase in the total efficiency of these power generating systems can be expected. In the case of automobiles with reciprocating engine drive using fossil fuels, represented by heat engines, the energy consumed for power is on the order of 30% of the energy possessed by the fuel. The amount of waste heat energy which is discarded as high temperature exhaust gas also reaches approximately 30%.

2-2 Low carbon society based on effective utilization of thermoelectric power generating systems

The establishment of technologies which recovery waste heat as effective energy will contribute to reducing the energy consumption of the social system as a whole, and thus can contribute not only to solving future energy problems, but also to solving environmental problems such as global warming. Figure 3 shows a trial calculation of

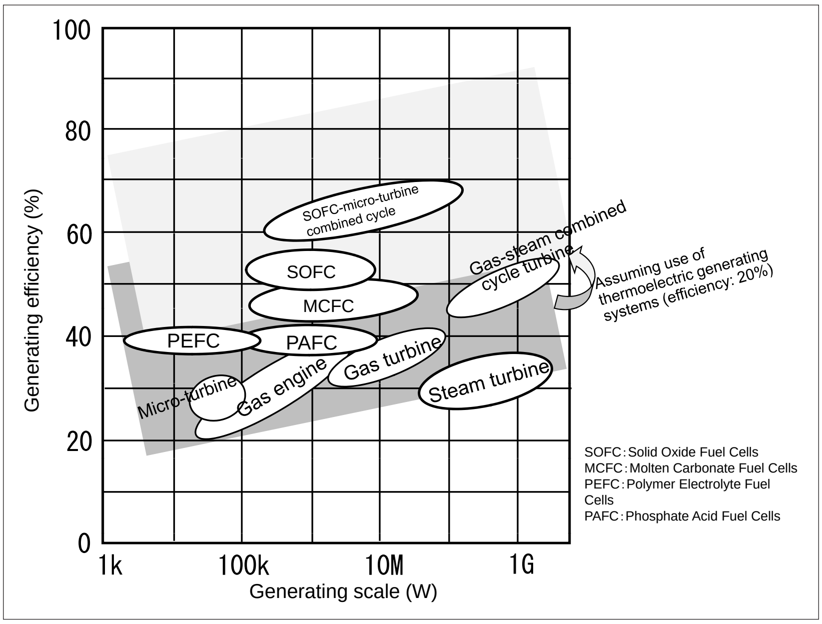

Figure 2 : Efficiency of current power generating systems and improvement of generating efficiency assuming use of thermoelectric generating systems (efficiency: 20%)

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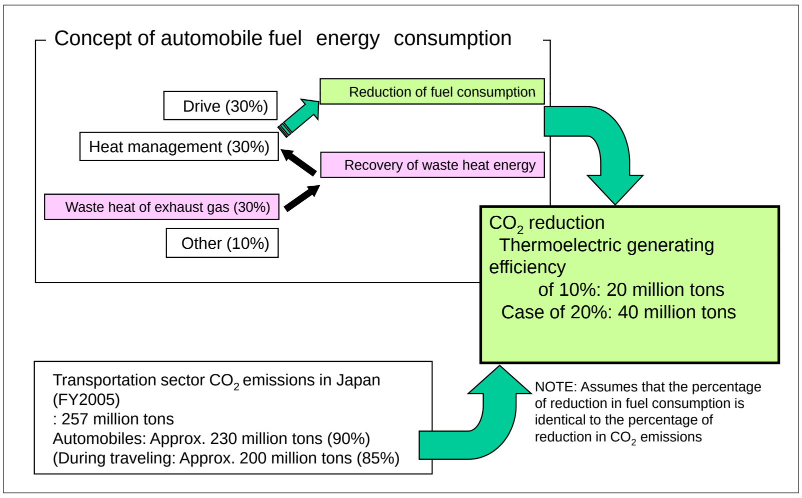

(Data from Reference[4] were used for transportation sector CO2 emissions in Japan in FY2005.)

Figure 3 : Trial calculation of CO2 reduction effect in case of thermoelectric power generation using waste heat energy of automotive exhaust gas

Prepared by the STFC

the CO2 reduction effect in case of thermoelectric power generation using the waste heat energy of exhaust gas in automobiles.

Transportation sector CO2 emissions in Japan in fiscal year 2005 were approximately 257 million tons, of which, automobiles accounted for 230 million tons, or approximately 90%.[4] Assuming the largest part of these CO2 emissions are generated during travel of automobiles with fossil fuel-burning engines, CO2 emissions during travel account for approximately 85% of the total CO2 emissions in the complete life cycle of the automobile.[5] From this, the CO2 emissions attributable to total automobile travel in Japan can be estimated at approximately 200 million tons. Fuel consumption can be reduced by converting the waste heat energy of the exhaust gas to electrical energy by a thermoelectric power generating system and reusing this energy. In simple terms, assuming that thermoelectric power generating efficiency and the percentage of reduction in fuel consumption are identical with the percentage of reduction in CO2 emissions, it is possible to reduce CO2 by 40 million tons per year by introducing thermoelectric power generating systems with efficiency of 20%. Approximately 50% of Japan's annual greenhouse gas reduction target (CO2 conversion) could be achieved by this method.

At present, the Ministry of Economy, Trade and Industry (METI) is studying financial aid systems and preferential tax systems for encouraging full-scale penetration of solar power generation. A similar aid system and tax system to encourage full-scale penetration of thermoelectric power generation is also considered necessary in the future. However, policies of this type will only be effective after the technical challenges described in the following are overcome, and are not yet required at the present time.

3 Thermoelectric power generating systems

3-1 Mechanism of thermoelectric power generation

Thermoelectric power generating modules comprise two types of elements, a p-type semiconductor element and an n-type semiconductor element. The mechanism of thermoelectric power generation is shown in Figure 4.[1] In the heated n-type semiconductor element (material in which the number of electrons is greater than the number of holes), the electrons in the high temperature region are activated (kinetic energy increases), these electrons are transferred to the low temperature region, generating thermal electromotive force, and the high temperature side reaches a high electrical potential. On the other hand, in the p-type semiconductor element (material in which the number of holes is larger than the number of electrons), the holes in the high temperature region are activated when heated,

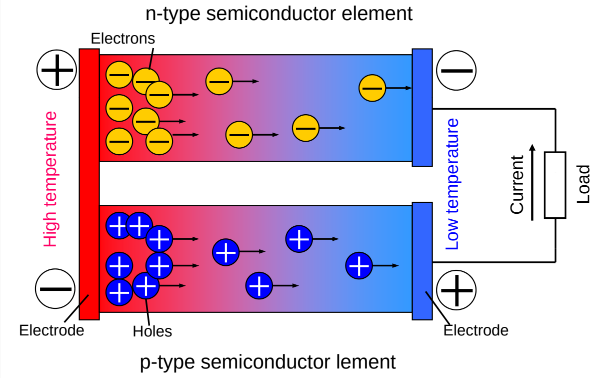

Figure 4 : Mechanism of power generation in thermoelectric power generating module (π-type structure)

Prepared by the STFC based on Referemces[1]

these holes migrate to the low temperature region, generating thermal electromotive force, and the low temperature side achieves a high potential. When these two semiconductor elements are combined, as shown in Figure 4, a current flows between the n-type and p-type semiconductor elements (this phenomenon is termed the Seebeck effect). The power generating performance of thermoelectric conversion materials is expressed by the index Z in the following equation.[6-8]

$ZT = S2\sigma T/\kappa$

where S: Seebeck coefficient (thermal electromotive force per 1K temperature difference, V/K), σ: electrical conductivity (1/(Ω・cm)),κ: thermal conductivity (W/(cm・K)), and T: absolute temperature (K).

The nondimensional power generating performance index ZT is a value obtained by multiplying Z by the absolute temperature and is used as an index of power generating performance. The thermoelectric conversion materials in which the performance index is high, that is, high efficiency materials, are materials in which σ and S are large and κ is small.

The power obtained depends on efficiency, which is determined by the heat flux from the high temperature heat source and the temperature differential during thermoelectric power generation, and the thermoelectric properties of the elements. The maximum efficiency of thermoelectric generating systems is given by Carnot efficiency, which is an index for an ideal heat engine, and the physical properties of the elements, which is termed material efficiency. The relationship between the performance index of a thermoelectric power generating module and the theoretical generating efficiency for the case when Carnot efficiency is 50% is shown in Figure 5.[6] This figure shows that the theoretical generating efficiency approaches Carnot efficiency as the nondimensional generating performance index becomes larger. In the current thermoelectric conversion materials in which ZT ≒ 1, theoretical generating efficiency is approximately 9%.

3-2 Manufacturing process for thermoelectric power generating systems and system efficiency

Thermoelectric power generating systems comprise a high temperature heat source, thermal energy conversion section, and a low temperature heat source, and are made up of a large number of thermoelectric power generating units. Units have a structure in which numerous power generating modules are connected in series, and consist of pairs in which a p-type semiconductor element and electrodes and an n-type semiconductor element and electrodes form the basic structure, as was shown in Figure 4.

Figure 6 shows a schematic diagram of the relationship between the thermoelectric power generating system manufacturing process and generating efficiency, and manufacturing costs. The most effective means of increasing the power generating efficiency of a system is to increase the thermoelectric generating efficiency of the semiconductor material/elements. Because the Seebeck coefficient S, which is one property of thermoelectric generating elements, is small, being on the order of several 100μV/K, the number of thermoelectric generating elements is determined by the output of the generating system, the type of heat source (temperature, temperature differential, thermal flux), and similar factors. Because resistance is smaller than that of ordinary semiconductors, at 10^{-5} to 10^{-4}Ωm, a thermoelectric power generating system takes the form of a high current, low voltage power source (voltage of several 100V or less). The output of the generating system is low voltage and direct current, which means that either a DC-DC converter or a DC-AC converter is required, and it is necessary to respond to the voltage required by the load and to AC load. Normally, auxiliary power such a fan

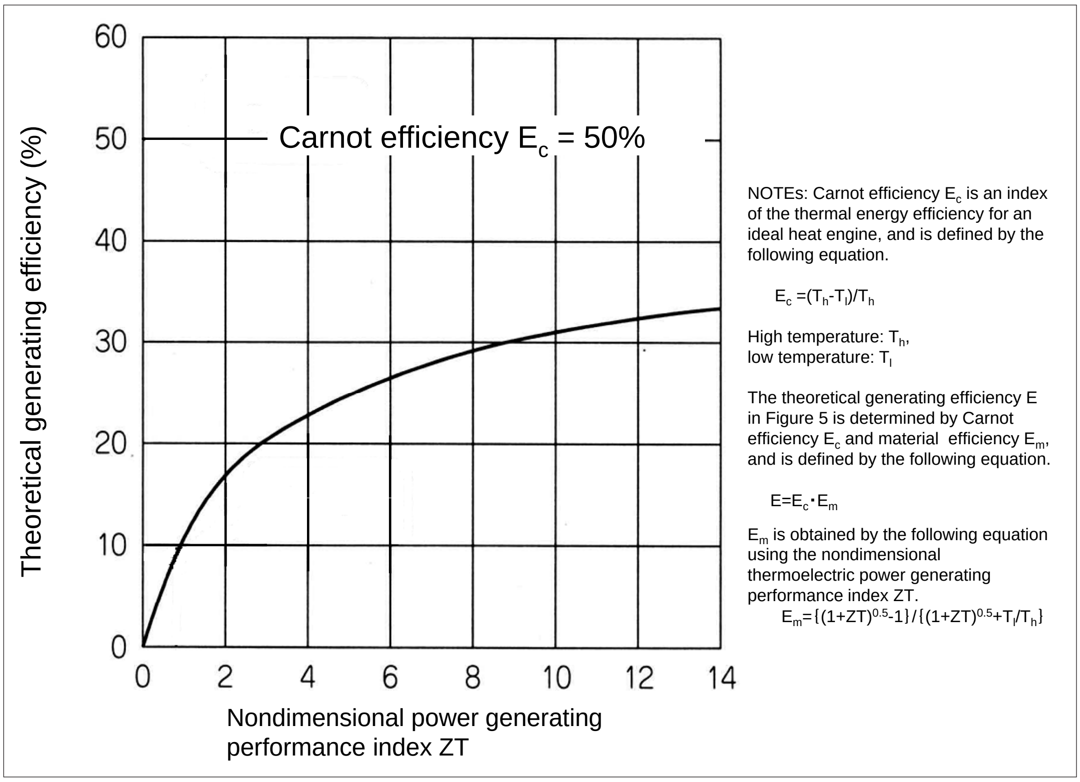

Figure 5 : Relationship between ondimensional power generating performance index of thermoelectric power generating module and theoretical generating efficiency

Prepared by the STFC based on Referemces[6]

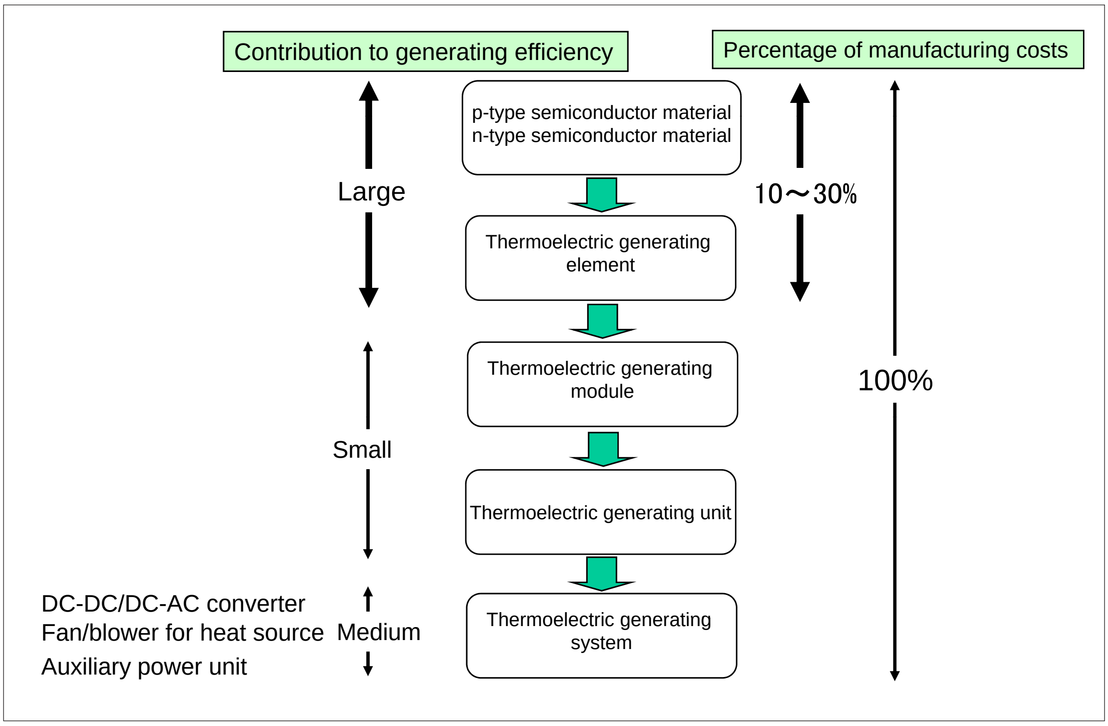

Figure 6 : Schematic diagram on manufacturing process for thermoelectric power generating system and power generating efficiency, and the manufacturing costs

Prepared by the STFC

or blower is used with the high temperature heat source and low temperature heat source in order to pass the heat flow. The output of the generating system is the net output obtained by subtracting these auxiliary power requirements from gross output.[6] As will be discussed in the following, when the temperature generating efficiency of the material/elements is low, it is necessary to increase the efficiency of the total system in the other manufacturing processes.

The largest obstacles to penetration of the present thermoelectric power generation are considered to be economy in the introduction/operation of systems and securing functionality. Therefore, the development of a lower cost system which is convenient to use and offers high reliability is necessary. One conceivable method of achieving this is to use not only as a waste heat energy recovery device, but also as a thermal functional device, for example, as a high speed heat flow control device for effective utilization of thermal energy. Furthermore, in various types of thermal energy systems, higher added value can be achieved in the total system by systematizing waste heat energy recovery devices as high efficiency exergy recovery equipment. For the challenges outlined above, it will be necessary to create a system for smooth competition and cooperation by the R&D organizations of private sector companies, including financial support from the national government.

3-3 Conditions for widespread of thermoelectric power generating systems

Penetration of thermoelectric power generation is considered possible if system efficiency exceeding 10% can be realized. Therefore, a material which satisfies a nondimensional power generating performance index of ZT>2 is necessary. Element efficiency of 15% or higher and output density of $1W/cm^2$ or higher are considered to be conditions for achieving this.[6]

The fields in which thermoelectric power generating technology should be applied will depend on the temperature level and form of the heat source used. Various fields exist, including application to large-scale systems for the purposes of energy saving and environmental protection, consumer products oriented to small-scale power

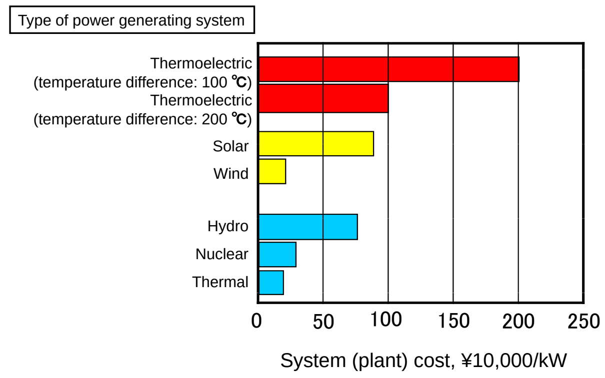

Figure 7 : Cost of various types of power generating systems (plants)

Prepared by the STFC based on Reference[9-12]

sources, etc. In practical application of these systems and equipment, it is important to secure economy, in other works, the cost of the power generating system and its performance. Figure 7 shows the system (plant) cost per unit of output in various types of power generating systems. If the cost of thermoelectric power generating modules can be reduced to the level of the current solar power generating systems, a broad expansion in the fields of application is conceivable. The system cost of the current solar power systems has been reduced to around \800/W.[9-12] Accordingly, the cost of the current thermoelectric power generating systems is approximately 1.3 to 2.5 times that of solar power generating systems.

4 Thermoelectric conversion materials and power generating performance

4-1 Thermoelectric conversion materials to date

As described in section 3-3, the ideal thermoelectric conversion material is a material with a nondimensional power generating performance index ZT of 2 or higher. Figure 8 shows the history of the development of the main thermoelectric conversion materials from the viewpoint of ZT. To date, the main materials have been intermetallic compounds such as bismuth telluride (Bi_2Te_3), lead telluride (PtTe), zinc antimonide (ZnSb), SiGe, iron silicide ($FeSi_2$), etc. Among these, in particular, Bi_2Te_3 based compounds have a large ZT in the comparatively low temperature region from room temperature up

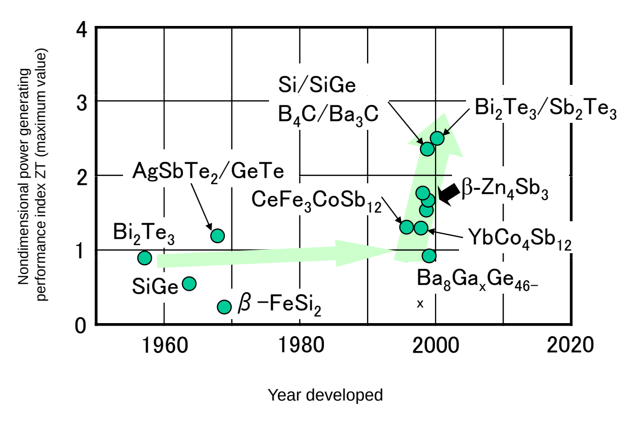

Figure 8 : History on development of main thermoelectric conversion materials from viewpoint of nondimensional power generating performance index

Prepared by the STFC based on Reference[6]

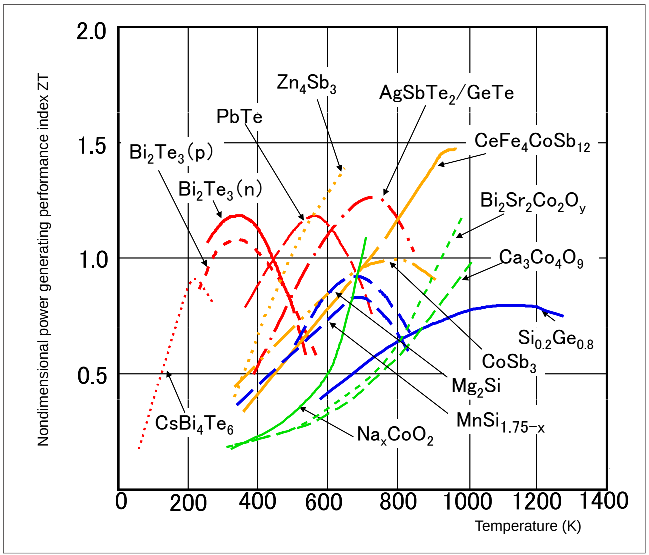

Figure 9 : Temperature dependency on nondimensional power generating performance index of main thermoelectric conversion materials

Prepared by the STFC based on Reference[6,13]

to approximately 450K, and are the most widely used thermoelectric conversion material at present.

Figure 9 shows the temperature dependency of the ZT of thermoelectric conversion materials.[6,13] The ZT of the respective materials tends to increase with temperature and then decrease after reaching a peak. The power generating performance of Bi_2Te_3 and Zn_4Sb_3 is ZT=1.0-1.25 in the low/medium temperature region of 300-700K, while a compound of $AgSbTe_2/GeTe$ (composition ratio 1:1) shows ZT ≒ 1.2 at 700K and $Si_{0.2}Ge_{0.8}$ shows ZT ≒ 0.7 at approximately 1100K. In the temperature region under 500K, BiTe based compounds display high ZT. In the medium temperature region of 700-900K, $AgSbTe_2/GeTe$ and $CeFe_4CoSb_{12}$ are high ZT thermoelectric conversion materials, and in the high temperature region above 900K, the high ZT materials are $Si_{0.2}Ge_{0.8}$, $Bi_2Sr_2Co_2O_y$, and $Ca_3Co_4O_9$.

With materials which were suitable for practical application, during the last 50 years, it was extremely difficult to increase performance to ZT>1 because electric resistance and thermal conductivity, which are parameters of ZT, display a property of mutual dependence. Recently, however, materials having performance of ZT>2 have been reported in several papers. There are also examples of research in which ZT>1 could be obtained in thermoelectric conversion materials by nanostructuring, even with the same material. However, with these materials (Bi, Te, Pb, Sb, and Ag based materials, etc.), no manufacturing processes have been developed for upscaling to the size of modules suitable for practical use.

4-2 Low environmental impact thermoelectric conversion materials with secure resource supplies

As shown in Figures 8 and 9, the thermoelectric conversion materials which have been used up to the present time are intermetallic compounds of Bi, Sb, Pb, and other heavy metals, and consist of elements with limited global reserves. It is also thought that full-scale practical application of these materials will be difficult in the future from the viewpoint of environmental impact. Recently, metal oxides have attracted attention, as these are materials which are familiar, exist in abundance, have low environmental impact, and also have high heat resistance. However, in comparison with the heavy metal materials, the thermoelectric power generating efficiency of these oxides is low.[6,14,15]

Figure 10 shows a schematic illustration of the main thermoelectric conversion materials researched to date and materials that should be priority objects of R&D in the future. Priority should be placed on R&D of silicide-based and metal oxide-based materials, as abundant reserves of raw material resources exit, systems can be composed at low cost, and these substances have low environmental impacts. With magnesium silicide (Mg_2Si), low generating efficiency is a problem, but it is thought that the efficiency of the module as a whole can be increased by innovations in the electrical circuit, etc.

Silicide-based compounds such as Mg_2Si, β-$FeSi_2$, $MnSi_{1.73}$, etc. will be promising candidate with low environmental impacts in the future. Although improvement of performance has been studied previously from the viewpoints of material microstructure and processes, performance is low, at ZT ≒ 0.2 (by element efficiency, 2-5%). However, element efficiency of 6.4% has reportedly been achieved with a module using a combination of microstructure-controlled $MnSi_{1.73}$ (p-type semiconductor) and Mg_2Si (n-type semiconductor).[6,15]

The process used to synthesize ceramics, which are metal oxides, from an aqueous solution at normal temperature and normal pressure is a manufacturing method which is suited to low cost mass-production, and the environmental impact of the materials themselves is small. In high efficiency thermoelectric conversion materials which operate at high temperatures, it would seem that metal oxides will become central, considering their high-temperature stability as substances and other advantages.[6,15]

$CeFe_3CoSb_{12}$ is a p-type semiconductor which is called a Skutterudite compound and has an unusually large value of hole mobility of 2000-8000cm2/Vs at room temperature due to the unique band structure and electronic structure of the compound. Performance of ZT ≒ 1.3 (800K) has been realized with this substance by reducing its thermal conductivity to approximately 1/5 that of $CoSb_3$.[6,15]

A semiconductor material which possesses low thermal conductivity on the level of amorphous materials and high electron mobility on the level of crystals is the clathrate compound Ba_8Si_{46}. Here, the term “clathrate compound” refers to compounds in which small molecules are contained in spaces created by the crystal lattice and exist as stable substances without depending on a covalent bond. These materials have a complex cage structure, and lattice thermal conductivity is small, being on the order of amorphous α-Ge and quartz glass (α-SiO_2), due to phonon scattering of the atoms in the cage. At present, power generating performance is ZT ≒ 0.6 (900K), but ZT ≒ 1.5 is expected to be possible by optimization of the carrier (electron, hole) concentration and element substitution.[6,15]

Other thermoelectric conversion materials include Zn_4Sb_3, which is a zinc antimony-based substance, strongly correlated electron system compounds, superlattice compounds, and $NaCO_2O_4$ and other

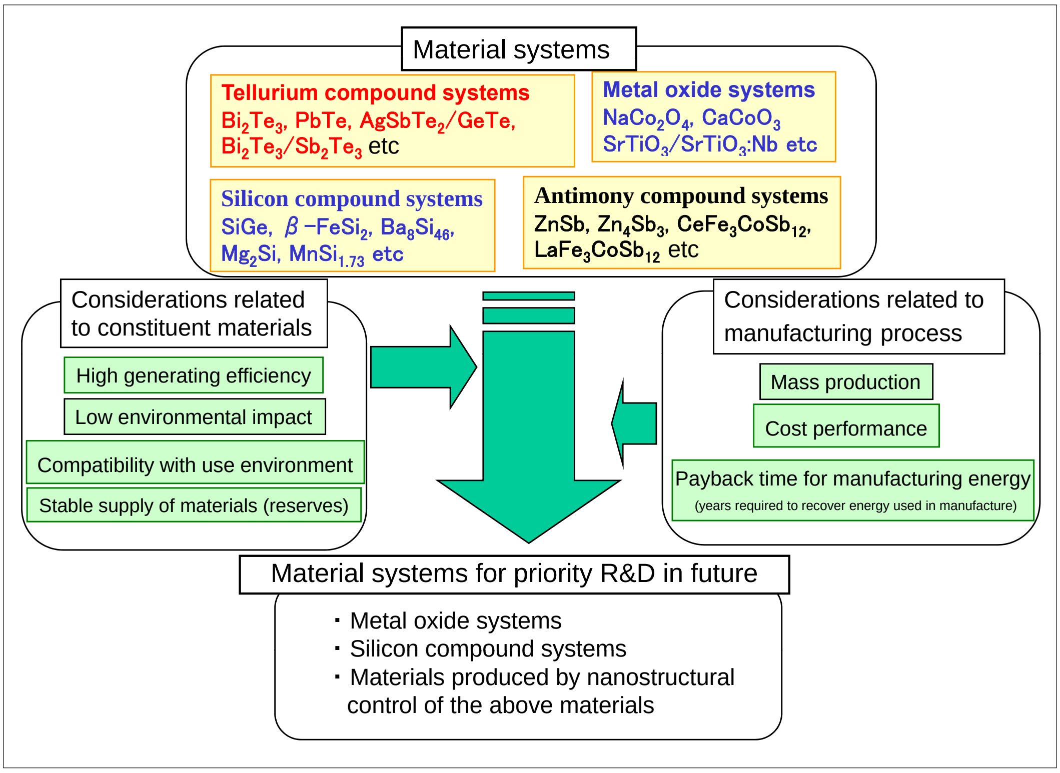

Figure 10 : Main thermoelectric conversion materials researched to date and material systems for priority R&D in the future

Prepared by the STFC

metal oxides. Results exceeding ZT=1 have also been reported with needle-shaped single crystal $CaCoO_3$.

4-3 Trends in R&D on thermoelectric conversion materials in foreign countries

In the United States, research and development on thermoelectric power generating technologies is being promoted with the priority narrowed to the waste heat energy of automotive exhaust gas in the FCVT (Freedom Car & Vehicle Technologies) Program, which is part of the Energy Efficiency and Renewable Energy Project of the U.S. Department of Energy (DOE). Vigorous development is underway, including R&D extending to the nanostructured materials technology region, as represented by superlattice materials and their applied technologies.[16-18]

In the past, only a small amount of research and development in connection with thermoelectric power generating technologies had been carried out in Europe, but recently, R&D in this field has continued to be active, centering on Germany. The Fraunhofer Gesellschaft (FHG) research organization is conducting research and development centering on applied technologies for industry in Germany and other countries, but among the 56 FHG laboratories in Germany, the Institute for Manufacturing Technology and Applied Materials Research (IFAM), in cooperation with the Institute for Physical Measurement Techniques (IPM) and the Institute for Integrated Circuits (IIS), is carrying out R&D related to nanoscale thermoelectric conversion material processes and the practical applicability of energy supply modules and systems.[19] On the other hand, the Deutsches Zentrum fur Luft- und Raumfahrt (DLR), which is a German aerospace research center, is engaged in R&D activities in connection with planning of the use of thermoelectric power generating sensors in space and the creation of international standards for thermoelectric power generating performance evaluation techniques.[20]

5 Innovative thermoelectric conversion materials by nanostructural control

The development of thermoelectric conversion materials with dramatically higher efficiency is considered possible using nanostructural control techniques, etc. If it is possible to achieve a level at which these material technologies can be applied to modules and systems that are competitive in terms of cost performance, a large expansion of the energy saving/low environmental impact technology industry is expected, with thermal functional devices, thermal energy recovery devices, etc. as its objects.

Among the material systems shown in Figure 10, Table 1 shows examples of innovative thermoelectric conversion materials by nanostructural control, which is considered to be an important area for promotion of R&D in the future. Figure 11 is a schematic diagram of the main measures related to nanostructural control for improving power generating performance, with the main thermoelectric conversion materials arranged from the viewpoint of the energy gap, thermal conductivity (lattice composition), and carrier (electron, hole) mobility of the thermoelectric conversion materials, these being the factors which control performance. The following presents an outline of examples of research in these respective areas.

5-1 Thermoelectric conversion materials with nano thin film structure

The following are examples of research aimed at realizing high efficiency thermoelectric conversion materials by structural control at the nano level using only abundant elements, without use of scarce elements.

The fact that $SrTiO_3$, which is an insulator, becomes a thermoelectric conversion material in the high temperature region (approximately 750 °C) when a small amount of Nb is added has attracted attention. Because its power generating efficiency is low, at less than one-third that of the heavy metal-based materials, a method of accumulating electrons in an extremely thin film sheet with a thickness of several nm has been proposed as a method of increasing its thermal electromotive force. Conversely, because it is difficult to accumulate electrons in heavy metals, as these substances pass electricity readily, it is difficult to increase the power generating efficiency of the heavy metal materials by this method. However, it is possible to store electrons by using an insulator. By creating a sandwich structure ($SrTiO_3/SrTiO_3$: $Nb/SrTiO_3$), comprising an $SrTiO_3$ thin film sheet with a thickness of 0.4nm, in which electrons are formed by addition of Nb, between upper and lower sheets of non-Nb-added $SrTiO_3$,which is an insulator, the thermoelectric power generating efficiency of this composite thin film was successfully increased to approximately double that of the conventional heavy metal-based material.[21,22]

If it is possible to develop a manufacturing process that is not limited to the small area, thin film level, but can expand this type of nano thin film structure thermoelectric conversion material to large area films and bulk materials consisting of nanostructures, this will open the way to application to practical systems.

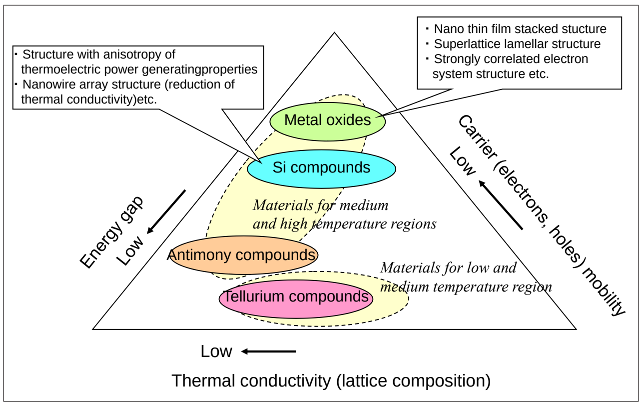

Figure 11 : Schematic diagram on factors controlling performance in main thermoelectric conversion materials systems and measures for improvement of power generating efficiency from viewpoint of structural control

Prepared by the STFC

5-2 Superlattice compound thermoelectric conversion materials

This is a concept which attempts to achieve high thermoelectric power generating efficiency by independently controlling electrical conductivity and thermal conductivity in different nanoblocks. An attempt to realize high thermoelectric power generating efficiency in hybrid crystals consisting of a regular periodic arrangement of lamellar-structured oxides, and particularly, two or more different symmetrical sub-lattices has been announced. This is an attempt to create a high efficiency thermoelectric conversion material by constructing a low-dimensional, anisotropic structure by combining multiple types of nanoblocks having a thermoelectric function. Theoretical calculations in connection with low-dimensional crystal structures have

Table 1 : Examples of research and development on thermoelectric conversion materials by nanostructural control

Class	Example of materials being studied	Concrete technique or research results
Nano thin film structure	$SrTiO_3/SrTiO_3$:$Nb/SrTiO_3$	・Sandwich structure in which an Nb-added $SrTiO_3$ thin film sheet (thickness: 0.4nm) is put between upper and lower insulators of $SrTiO_3$.
Superlattice compound	Bi_2Te_3/Sb_2Te_3	・Construction of low-dimensional anisotropic structure by combining multiple nanoblocks having a thermoelectric function. ・Possibility to realize ZT ≒ 2.4(room temperature) by thin film elements with by superlattice structure (quantum well, quantum wire, quantum dot) .
Nanowire array	Si nanowire array	・Electrochemical synthesis of large area array of Si nanowires (diameter; 20-300nm). The thermal conductivity of Si nanowires with diameter of approximately 50nm was reduced to 1/100 (ZT=0.6).
Strongly correlated electron system	$NaCo_2O_4$ $(Ce_{1-x}La_x)\,Ni_2$ $(Ce_{1-x}La_x)\,In_3$ $CeInCu_2$	・Confirmed that lamellar oxide $NaCo_2O_4$ has a large thermal electromotive force of 100μV/K (at room temperature) and large electrical conductivity of $5x10^3/(\Omega\cdot cm)$.
Plane structured element	$Na_xV_2O_5$ V_2O_5	・Power generation using only an n-type semiconductor elements (an abundant variety of n-type semiconductors are available) by producing a temperature gradient between the two sides of the element plane and obtaining an electron flow within the plane. ・Thin film, compact size, and high density are possible in thermoelectric elements, as in conventional semiconductors thin film devices.

Prepared by the STFC

also indicated the possibility that thermoelectric power generating efficiency can be dramatically increased by superlattice structures such as quantum wells, quantum wires, quantum dots, and the like. In addition, Z ≒ T2.4 (room temperature) was reportedly obtained with a Bi_2Te_3/Sb_2Te_3 superlattice thin film element.[6,15]

5-3 Nanowire array thermoelectric conversion materials

This is an example of research in which a non-dimensional power generating performance index of ZT=0.6 at room temperature was obtained by reducing the thermal conductivity of Si nanowires with a diameter of approximately 50nm to 1/100 that of bulk Si when a large area array of wafers, in which a large number of coarse Si nanowires with diameters of 20-300nm were arranged, was synthesized electrochemically. Because the thermal conductivity of nanowires should be near that of the limit value of amorphous Si, the behavior of the nanowires in this report cannot be explained by the existing theory. The thermoelectric power generating property of bulk Si is inferior to that of conventional thermoelectric conversion materials. If it can be assumed hypothetically that a large reduction in thermal conductivity can be achieved with virtually no effect on the Seebeck coefficient or electrical conductivity, then Si nanowire arrays are promising as high performance thermoelectric conversion materials.[23-25]

Large-scale processing of Si is possible, but because the electrical and thermal conductivity of htis substance are high, its thermoelectric power generating property is low. However, from the viewpoint of resource supplies and low environmental impact, assuming the ZT value of Si nanowires can be improved by approximately 100 times that of bulk Si over a wide temperature range by optimizing the dimensions of the nanowires and amount of impurity doping, this would be an extremely significant achievement which would heighten the potential for industrial application. If it is possible to establish a method of structuring Si in nanowire arrays and closely controlling the shape of the nanowires and the amount of impurity doping, Si nanowires will have great potential as high efficiency thermoelectric conversion materials. This research will also attract attention from the viewpoint of use of a material with a stable supply and low environmental impact, and from the viewpoint of cost performance.

5-4 Thermoelectric conversion materials with strongly correlated electron system

The term “strongly correlated electron system” indicates a system in which the effective Coulomb interaction between pairs of electrons in a substance is strong. Many substances with strong electron correlation exist in systems including transition metals and rare earth metals (REM). As strongly correlated compounds in which attention has focused on the f-electrons in REM, $(Ce_{1-x}La_x)Ni_2$, $(Ce_{1-x}La_x)In_3$, $CePd_3$, $CeInCu_2$, etc. have attracted interest as materials with high thermoelectric power generating performance in the temperature region below room temperature.[6,15]

It has been found that $NaCo_2O_4$, which is a lamellar oxide, has a large thermal electromotive force of 100μV/K and large electrical resistance of $5x10^3$ (Ω・cm) at room temperature. This lamellar oxide system has a large thermal electromotive force of 100μV/k irrespective of the fact that it also has a high carrier concentration of 1021-1022cm^{-3}. The cause of this phenomenon has been explained by the fact that the strong electron correlation in the crystal plays an important role.[6,15]

On the other hand, although it had conventionally been thought that metals with high electrical conductivity have low thermoelectric power generating efficiency, a large thermoelectric power generating effect was discovered in a cobalt oxide ($CaCoO_3$) in Japan in 2000. At present, it is thought that guidelines for searching for higher efficiency thermoelectric conversion materials can be obtained by elucidating the mechanism responsible for the manifestation of the large thermoelectric power generating effect in this substance. [6,15]

5-5 Thermoelectric power generating elements with plane structure

To date, as shown in Figure 4, thermoelectric power generating elements have comprised thick pn junctions which utilize the temperature gradient in the thickness direction of the element, and materials having both p-type and n-type electrical conduction characteristics are necessary. Because virtually all of the abundant types of metal oxides are n-type, and metal oxides having both p-type and n-type electrical conduction characteristics are rare, the realization of conventional type of pn junction thermoelectric power generating element structure with only metal oxides had been considered difficult.

In plane-structured thermoelectric power generating elements, ,power is generated using only an n-type semiconductor element by producing a temperature gradient between the two sides of the element plane and obtaining an electron flow within the plane. If this structure and principle are used, it is expected to be possible to produce thermoelectric power generating elements with a thin film structure, compact size, and high density, like those in conventional semiconductor thin film devices, in plane-structured thermoelectric power generating element.[26,27]

6 Current status of R&D projects on thermoelectric power generating technology in Japan

This region was mentioned as part of the target of "Materials technologies to realize use of unused energy," which is a priority R&D theme in the Materials region in the Nanotech & Materials field in Promotion Strategies by Field in Japan' s Third Science and Technology Basic Plan.[28] Subsequently, this was reviewed based on the "Cool Earth – Innovative Energy Technology Program" (established March 2008), and was taken up in the "Technology Strategy Map 2008" of the Ministry of Economy, Trade and Industry (METI) as "Unused micro-energy power conversion." However, it is not included in the individual technologies that are expected to make a large contribution to the policy goal of "Improvement of total energy efficiency" (Figure 12).[29] As mentioned in section 2-1, the thermal energy discarded from energy systems of all types is not negligible.

In the Nanotechnology Field of the above-mentioned "Technology Strategy Map," the fields of Environment and Energy, Electronics and Communications, and certain others are set as important exit fields for nanotechnology. A map was established to provide an overview of technologies from the viewpoint of how nanotechnology can contribute to realizing the functions demanded by the respective technical regions in these fields. Figure 13 shows a summary of the technical issues related to the Waste Heat Power Generating Technology region in this technology map. Waste heat power generating technology was selected as an important technology in waste heat utilization technologies in the Electronics, Information, and Semiconductor region, and is shown in the technology roadmap together with the issues for development in that year.[29,30]

The report by the New Energy and Industrial Technology Organization (NEDO) on achievements in connection with thermoelectric power generating technologies published to date mentions 115 items.[31] However, much of this research and development is work carried out as Grant for Industrial Technology Research Projects, which are budgeted on a one-year basis. In popularizing thermoelectric power generating technologies in effective recovery of unused waste heat energy, the timing for achieving high efficiency and low cost in materials/modules, development of low environmental impact thermoelectric conversion materials, and achievement of 15-20% module power generating efficiency shown in Figure 13 should be moved up (to before 2020). For this, as will be discussed in Chapter 7, it will be necessary to strengthen the R&D promotion system, narrow the focus of the object thermoelectric conversion materials, and invest R&D funds on a priority basis.

Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) has positioned research and development of "Innovative technologies for substitute materials for scarce and inadequate resources which will be decisive for solving resource problems" in the "Strategic Prioritized S&T" enumerated in the "Nanotech/ Materials" field, which is one of the four "Priority fields to be promoted" in the "Third Science and Technology Basic Plan," and began its "Element Strategy Project" in FY2007. Thermoelectric conversion materials were taken up as one assumed research topic in the public invitation to submit project proposals in FY2008, and scientific elucidation of the role of the elements which make up those materials and the mechanisms by which their functions are manifested are mentioned (Figure 14).[32,33]

7 Future approaches to R&D on thermoelectric conversion materials

As future approaches to research and development in connection with thermoelectric conversion materials, the following should be considered.

(1) In Japan, which is a resource-poor nation, efforts to construct a next-generation energy utilization society by development, introduction, and penetration of innovative energy technologies are indispensable. While the government continues to indicate the directions for future technologies over the long term, it should also promote research and development through prioritized investment, particularly in the case of materials systems which involve high risk and hurdles. R&D in connection with thermoelectric conversion materials falls under this category.

(2) If it is possible to develop modules and systems with high cost performance by utilizing thermoelectric conversion materials, a large expansion in the energy saving/low environmental impact technology industry can be expected, with objects including thermal functional devices, heat recovery devices, etc. In the future, Japan should take a position of world leadership in this field and secure its technical superiority over other countries.

(3) As an approach to promoting future R&D projects, the roadmap from R&D of fundamental and basic technologies to practical application and the issues which require prioritized efforts should be clarified, and concrete measures which promote R&D in connection with materials technologies, device technologies, and applied technologies in

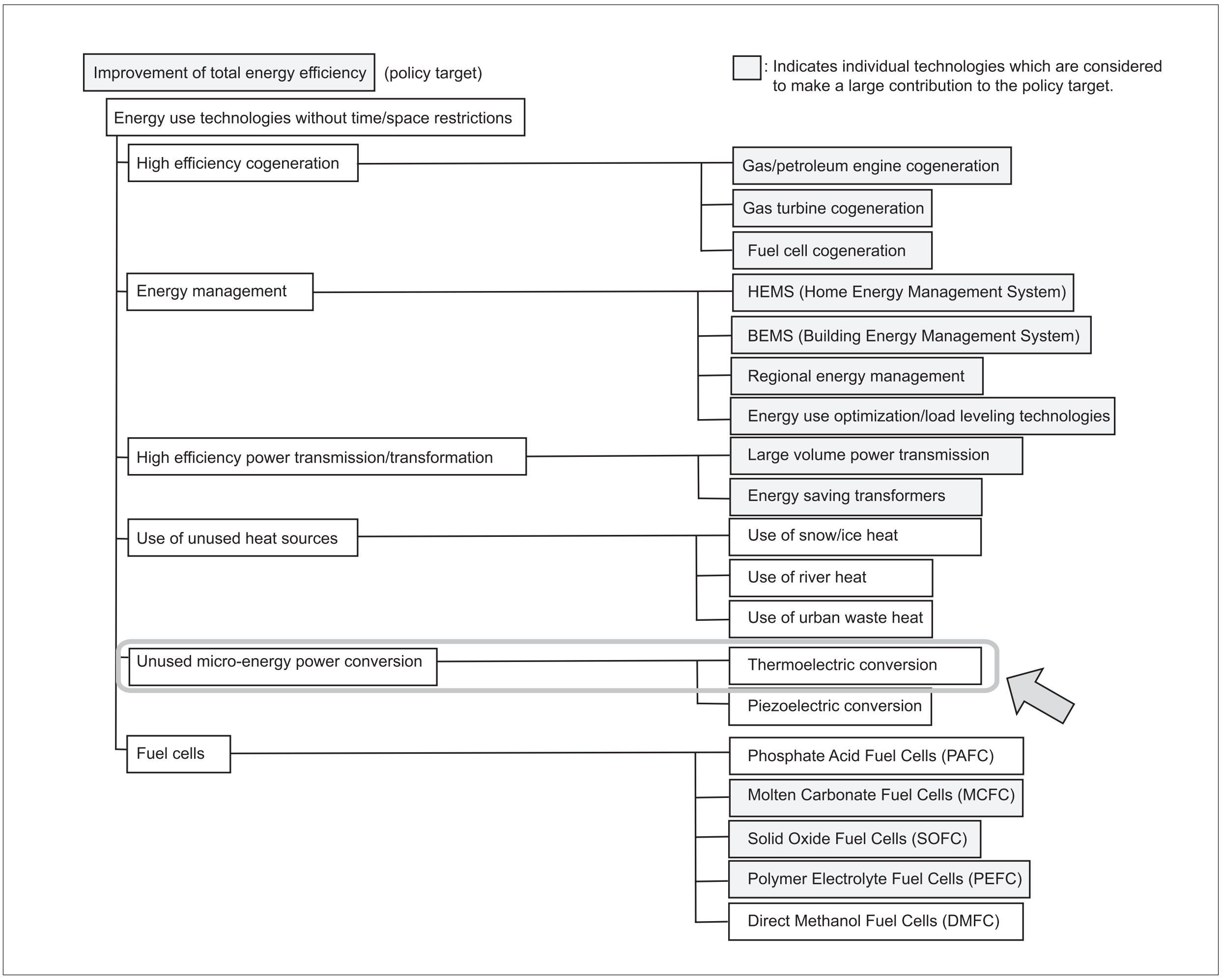

Figure 12 :Technologies for "Unused micro-energy power conversion" in technologies contributing to "Energy field – Improvement of total energy efficiency" in METI Technology Strategy Map

Prepared by the STFCbased on Reference[29] parallel should be taken, based on a division of short-term and long-term issues.

(4) As a long-term issue, development of new materials with revolutionary power generating efficiency and R&D on thermoelectric power generating devices using these materials should be promoted. As materials technologies, it is desirable to study novel nanomaterials systems based on superlattice and quantum structures (quantum wells, fine wires, dots) using nanostructural control and related manufacturing processes, metal oxides with low environmental impacts, etc. In parallel with this, it is also desirable to promote high efficiency, downsizing, and operability in a wide temperature range in power generating module technologies.

(5) In projects promoted by the government, clarification of priorities when implementing research and development of new thermoelectric conversion materials is demanded, based on a total scenario from fundamental and basic development to practical application or expanded penetration.

8 Conclusion

In the realization of a low carbon society, reductions in unused waste heat and various energy systems will be necessary. For this, popularization of thermoelectric power generating system will be indispensable. At present, thermoelectric power generating systems have been applied practically in limited fields, but the materials used in these systems have the problem of unstable supplies of resources, and because their main components are heavy metals, high environmental loads are a concern. Moreover, the current systems are also inferior economically due to the low power generating efficiency of the elements. For these reasons, full-scale penetration of thermoelectric power generating systems has not progressed, even though the history of technical development has now reached the half-century mark.

The highest priority for solving the problems associated with these thermoelectric power generating materials is considered to be research and development of thermoelectric conversion materials which offer high efficiency, stability in the use environment, and low cost. The use

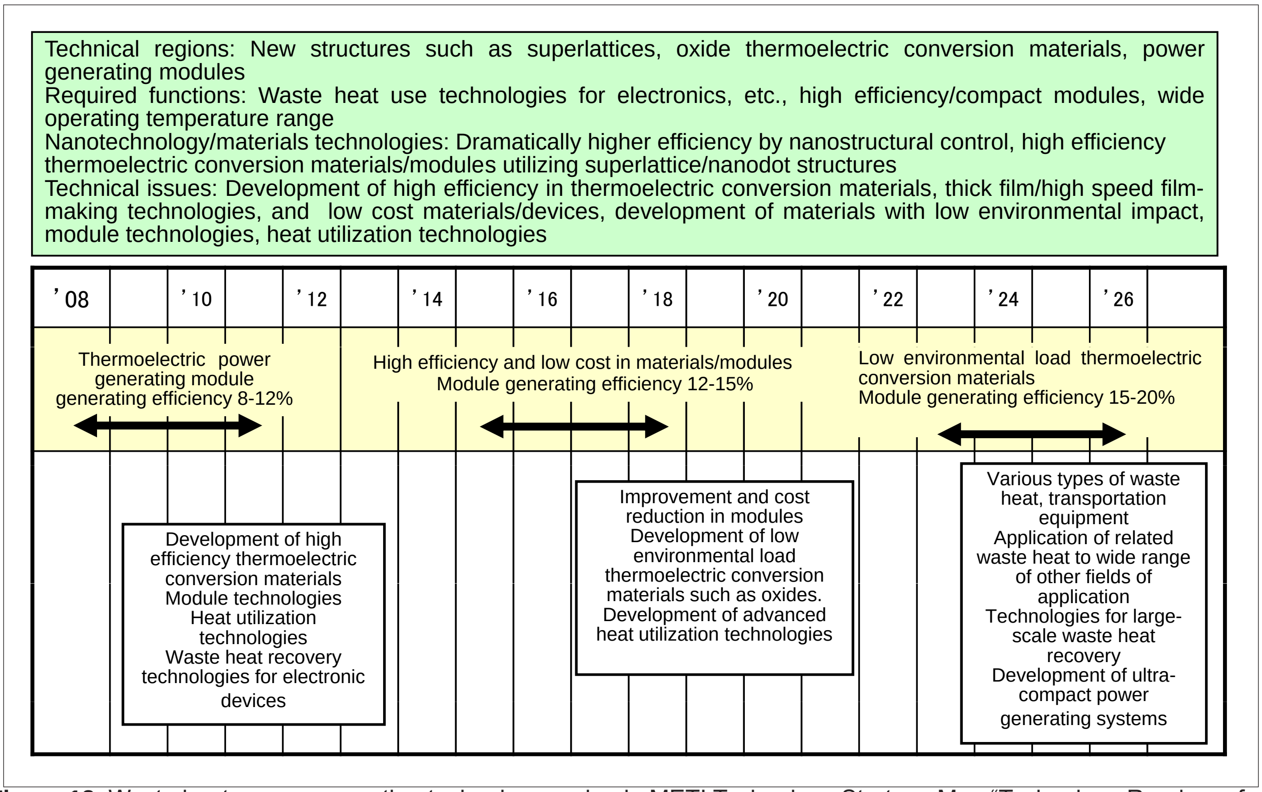

Figure 13 :Waste heat power generation technology region in METI Technology Strategy Map "Technology Roadmap for Nanotechnology Field – Electronics, Information, and Semiconductors"

Prepared by the STFCbased on Reference[29]

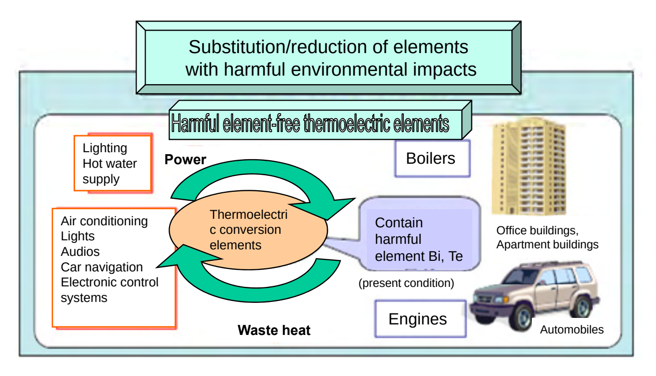

Figure 14 Examples of issues for research in MEXT "Element Strategy for Solving Resource, Environmental, and Energy Problems"

Source : Reference[33]

of materials with secure resource supplies and low environmental loads is also indispensable. Therefore, future research and development should shift to metal oxides and silicon compounds. In particular, attention will focus on nano thin film structures, superlattices, nanowire arrays, strongly correlated electron system compounds, etc. of these substances as objects of research and development.

In view of the importance of the ripple effect on the realization of a low carbon society, etc., as a future approach to R&D on thermoelectric power generating technologies, R&D projects based on scenarios which further clarify the roadmap from R&D of fundamental and basic technologies to practical application and the issues that require prioritized efforts should be divided into short-term and long-term issues, and materials technologies, device technologies, and applied technologies should be promoted in parallel. In particular, R&D on nanostructural control of metal oxides, etc. and their manufacturing processes is a long-term challenge, but because the technical hurdles are high, projects promoted under government leadership are demanded. If it is possible to discover revolutionary thermoelectric power generating elements with power generating efficiency of 20% or higher by using innovative materials, and to develop modules and systems with high cost performance, the ripple effect on the energy saving/low environmental impact technology industry will be immeasurably large.

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References

[1] T. Shindo et al., "Thermoelectric Generating System for Effective Use of Unutilized Energy," Toshiba Review, Vol. 63, No. 2, pp. 7-10. (Japanese)

[2] I. Terasaki, "Cobalt Oxide as a Fuel Cell Material": http://www.f.waseda.jp/terra/pdf/parity.pdf (Japanese)

[3] H. Kawamoto, "Research and Development Trends in Solid Oxide Fuel Cell Materials From the Viewpoint of Electrolyte-Related R&D as Key," Science & Technology Trends, July 2007, No. 82, pp. 10-22. (Japanese)

[4] "White Paper on the Environment and the Sound Material-Cycle Society in Japan 2007, Chapter 3 Technologies for Promoting Global Warming Countermeasures, Section 4 Familiar Countermeasure Technologies," ed. by Ministry of Environment: http://www.env.go.jp/policy/hakusyo/h19/html/hj07010304.html (Japanese)

[5] H. Kawamoto, "R&D Trends in Automotive Resin Materials," Technologies for High Functionality in Automotive Resin Materials, Technical Information Institute Co., Ltd., pp. 14-24 (2008) (Japanese)

[6] "Thermoelectric Conversion Materials," ed. by The Ceramic Society of Japan/ Thermoelectrics Society of Japan, Nikkan Kogyou Shimbun, Ltd. (2005) (Japanese)

[7] G.Chen,et al., lnt. Mater. Rev.,48,1-22(2003)

[8] National Institute of Advanced Industrial Science and Technology, press release

"Generating Power from Waste Heat": http://www.aist.go.jp/aist_j/press_release/pr2005/pr20050531/pr20050531.html#b (Japanese)
[9] "Personal Distributed Energy Systems," ed. by Y. Itoh, Yokendo, pp. 122-138.
[10] T. Katsuta et al., "Considerations on the Economy of Nuclear Power Generation," Japan Society of Public Utility Economics, Proceedings of 55th Annual Meeting, p. 1 (2005): http://cnic.jp/files/cost20060612abst.pdf (Japanese)
[11] K. Tatematsu, "Economics of Nuclear Power Generation in the United States and the Position of the Fuel Cycle": http://www.jaea.go.jp/03/senryaku/seminar/06-6.pdf (Japanese)
[12] "Solar Power Generation": http://www.taiyokohatuden.jp/index.html (Japanese)
[13] "Environmental and Energy Materials Outlook," NIMS (2008) (Japanese)
[14] "Thermoelectric Conversion," ed. by R. Sakata, Shokabo (2005) (Japanese)
[15] Report of results for FY2006 "Survey of Innovative Thermoelectric Conversion Materials," New Energy and Industrial Technology Development Organization (NEDO) (Japanese)
[20] "Report on Developmental Project for High Efficiency Thermoelectric Conversion System and International Technology Survey," GEC News: http://www.enaa.or.jp/GEC/active/gecnews/168.htm#top (Japanese)
[21] H. Ota, NEDO, Report on Grant for Industrial Technology Research Project FY2007 "Fabrication of Dielectric Artificial Superlattice with Localized Two-Dimensional Electron Gas and Application to Thermoelectric Conversion Material" (Japanese)
[22] Y.Ota,et al.,"Giant thermoelectric Seebeck coefficient of twodimensional electron gas in a SrTiO3", Nature Materials (electronic edition), Jan. 2007:http://www.jst.go.jp/pr/info/info373/index.html
[28] "Third Science and Technology Basic Plan, Promotion Strategy by Field – Nanotechnology & Materials Field," Council for Science and Technology Policy: http://www.Mext.go.jp/a_menu/kagaku/kihon/06032816/001/001.pdf (Japanese)
[29] "Technology Strategy Map 2008 - Energy Field, Nanotechnology Field," Ministry of Economy, Trade and Industry (METI): http://www.meti.go.jp/policy/economy/gijutsu_kakushin/kenkyu_kaihatu/str2008.html (Japanese)
[30] Technology Strategy Map 2007," METI: http://www.meti.go.jp/policy/economy/gijutsu_kakushin/kenkyu_kaihatu/str2007.html (Japanese)
[31] "NEDO Technology Information Database": http://www.nedo.go.jp/database/index.html (Japanese)
[32] "Public Invitation for Element Strategy Projects FY2008," Ministry of Education, Culture, Sports, Science and Technology (MEXT) http://www.mext.go.jp/b_menu/houdou/20/04/08041402.htm (Japanese)
[33] Ministry of Education, Culture, Sports, Science and Technology (MEXT), materials related to budget request for FY2008 "Promotion of Research and Development in the Nanotechnology/Materials Field": http://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu2/shiryo/017/08032419/001.pdf (Japanese)

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5

Japan's Space Capabilities for Lunar and Planetary Exploration

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1 Introduction

The National Aeronautics and Space Administration (NASA) of the United States of America has initiated a manned lunar and Mars exploration program for the first time since the Apollo Program pursuant to the vision of space exploration announced by President George W. Bush on January 14, 2004. Not only new space transportation and crew exploration vehicle systems are being developed to replace the Space Shuttle, which is scheduled to retire in 2010, but also unmanned lunar missions are planned to collect information on lunar surface to select a landing site, resources such as water ice necessary for sustainable development of human activities there, the radiation environment that may affect human health, and other features to prepare for human lunar exploration. Furthermore, based on the recommendations of a report[1] on exploration of the Solar System published by the National Research Council (NRC) in July 2002, NASA is also carrying out unmanned science missions.

The European Space Agency (ESA) is also carrying out unmanned science missions, either independently or in cooperation with NASA, and is planning a Mars mission by a robotic rover under the Aurora Programme, envisioning a future manned Mars mission. China and India have also initiated unmanned lunar exploration programs called Chang'e and Chandrayaan respectively, to acquire new spacecapabilities.

Japan has already achieved impressive scientific results in a challenging effort in which its asteroid explorer HAYABUSA (Muses-C) made detailed scientific observations of asteroid Itokawa and collected samples from its surface. In recognition of this accomplishment, "Science," an American scientific journal, devoted a Special Issue to HAYABUSA (June 2, 2006). Japan's lunar orbiter KAGUYA (SELENE) is conducting the first full-scale scientific exploration of the Moon since the end of the Apollo Program to study the mysteries of the origin and evolution of the Moon. A series of scientific results from this mission are now beginning to appear, and have attracted keen interests, both in Japan and abroad. On February 12, 2008, the Japan Aerospace Exploration Agency (JAXA) became the first organization other than those of the United States to receive the Jack Swigert Award for Space Exploration, which recognized JAXA for the "groundbreaking scientific discoveries" being made by HAYABUSA and KAGUYA, together with the SUZAKU X-ray astronomy satellite, the AKARI infrared astronomy satellite, and the HINODE (Solar-B) solar observation satellite, and its contribution to expanding the frontiers of human knowledge.[2] This award was established in 2004 to honor Mr. Jack Swigert, who was elected to the U.S. House of Representatives after being an astronaut in Apollo 13, which made a miraculous return to the Earth after an oxygen system failure. Other past recipients include NASA's Martian exploration team, U.S. President George W. Bush, the Jet Propulsion Laboratory (JPL), and the astronomical observation division of the California Institute of Technology (Caltech).

This paper analyzes Japan's space development capabilities, after having compared the HAYABUSA and KAGUYA missions with similar missions by other nations.

2 Continually changing solar system images

2-1 Definition of planet

Astronomers wondered whether Pluto should be considered a planet for a variety of reasons such as that its diameter is only approximately 2,390km, which is smaller than that of the Earth's Moon (approx. 3,476km), that both the eccentricity and inclination of its orbit are larger than those of the other planets, and that an object called Eris, which has a diameter of approximately 2,400km, has been discovered in the vicinity of Pluto.

In August 2006, the International Astronomical Union (IAU) adopted the definition of a planet (Figure 1),[3] and Pluto was declassified as a planet. Although this adoption reduced the number of planets to eight from the traditional nine (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto), our image of the Solar System is continually changing to a ever-richer one thanks to technical progresses of astronomical ground-based telescopes, as well as remarkable observations by the Hubble Space Telescope and other astronomical probes, which observe heavenly bodies from space through various wavelengths, without being affected by the problems of absorption, scattering, and fluctuation caused by the Earth's atmosphere.

Based on the above-mentioned decision of the IAU, the IAU Subcommittee and the Astronomy and Astrophysics Subcommittee, Physical Sciences and Engineering Section Meeting of the Science Council of Japan, have recommended classification of celestial objects in the Solar System other than the planets as "trans-Neptunian objects (TNOs)," "dwarf planets," "small solar system bodies," and "plutoids," as shown in Table 1.[3]

1) A celestial body is classified as a planet if it meets the following three conditions:
   (a) Is in orbit around the Sun.
   (b) Has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (near-round) shape.
   (c) Has mechanically cleared other celestial bodies in the neighborhood around its orbit.
2) Celestial bodies which satisfy (a) and (b) but do not satisfy (c), and are not satellites, are classified as "dwarf planets."
3) All other celestial bodies except satellites which orbit the Sun shall be referred to as "small solar system bodies."

Figure 1 : Definition of a planet by the International Astronomical Union (IAU)

Source : Reference[3]

Although Pluto is one of the TNOs, it is also classified as a dwarf planet because of its size, and its name has been adopted in the definition of "plutoids." Thus, its reasons of existence have remained. On the other hand, on February 28, 2008, Kobe University Researcher Patryk S. Lykawka and Prof. Tadashi Mukai published the results of a numerical simulation suggesting the existence of an unknown outer planet outside the TNO belt.[4] It may be noted that the region where the TNOs exist is also the birthplace of the short-period comets.

The asteroids, which belong to the small solar system bodies, exist mainly in the asteroid belt between Mars and Jupiter. Asteroid Itokawa, which was explored by Japan's HAYABUSA," is one of those asteroids. The region which is called the Oort cloud, because its existence was predicted in 1950 by Dutch astronomer Jan Oort based on the orbits of long-period comets, extends from 10,000 to 100,000AU and is thought to contain innumerable lumps of ice and stone.

2-2 Solar system formation theory

Solar System formation theories based on modern physics were proposed in the 1970s by two groups, one led by Dr. Chushiro Hayashi of Japan's Kyoto University and the other led by Dr. A.G.W. Cameron of Harvard University in the United States of America. Both groups hypothesized that the Solar System formed from a primeval solar nebula consisting of dust and gas surrounding the primeval Sun (the nebular hypothesis), and that small celestial bodies called planetesimals formed from this dust (the planetesimal hypothesis). The Kyoto University group proposed that the mass of the solar nebula was one hundredth of that of the Sun, while the Harvard University group held that its mass was on the same order as that of the Sun. The current standard model of the Solar System formation is as shown in Figure 2.[5]

The planets of the Solar System can be classified into three types; that is, (1) "terrestrial planets" consisting of rock and iron (Mercury, Venus, Earth, and Mars), (2) "Jovian planets," which consist mainly of gaseous atoms and molecules

Table 1 : Classification of Solar System bodies other than planets

Class	Outline
Trans-Neptunian objects (TNOs)	· Celestial bodies which are covered with ice and are distributed around the Sun from the vicinity of Neptune, which is approximately 30 astronomical units (AU)[NOTE 1] from the Sun, to a distance of approximately 50AU or further; this class includes Pluto. Since 1992, more than 1,000 TNOs have been discovered (as of April 2007). · Formerly called Edgeworth-Kuiper Belt Objects
Dwarf planets	· A total of three celestial bodies have been classified as "dwarf planets" (as of April 2007), these being Pluto (diameter: approx. 2,390km) and Eris (approx. 2,400km), and Ceres (approx. 950km), which is the largest object in the asteroid belt. · Because it is difficult to determine whether a celestial body is a dwarf planet or not, there is room for study in the definition.
Small solar system bodies	· All celestial bodies in the solar system other than planets, dwarf planets, and satellites (asteroids with the exception of Ceres, TNOs with the exceptions of Pluto and Eris, comets, and the like).
Plutoid	· Is a celestial body which is classified as both a TNO and a dwarf planet. · Although resolved by the General Assembly of the IAU in 2006, the official English name has not been determined.[NOTE 2] · Pluto and Eris fall under this class (as of April 2007). Because other TNOs which may satisfy this definition also exist, it is possible that their number will increase in the future.
[NOTE 1] One astronomical unit (AU) is the average distance between the Earth and the Sun; its value is approximately 150 million km. [NOTE 2] According to a press release by the IAU dated June 11, 2008, the English name "Plutoid" has been adopted. (See http://www.iau.org/public_press/news/release/iau0804)	

Source : Reference[3]

of hydrogen, helium, etc. (Jupiter and Saturn), and (3) "Uranian planets" consisting of icy water, methane, ammonia, etc. (Uranus, Neptune).[5] Although the standard model of the Solar System formation still has several drawbacks, it can generally explain the basic features of today's Solar System. In order to better refine the model to deepen our understanding of the Solar System, remote sensing observations by exploration probes, in-situ observations by landers and rovers, and detailed analyses on Earth of samples taken by exploration vehicles as well as ground-based telescope observations are necessary.

3 Trends in small solar system body exploration by Japan and other nations

3-1 Why explore small solar system bodies?

The small solar system bodies include asteroids, comets, and other objects (Table 2). According to the standard model of the Solar System formation, it is thought that, through collision and coalescence, protoplanets formed from planetesimals, and today's planets from these protoplanets (Figure 2). On the other hand, there exists the asteroid belt, consisting of asteroids resembling planetesimals, between Mars and Jupiter (Figure 3). To explain the existence of the asteroid belt, one theory postulates that because the orbital eccentricities and inclinations of objects in the asteroid belt became large due to Jupiter's massive gravity effects resulting in their relative speeds becoming very high, they were shattered by violent collisions with each other, and it became impossible for them to grow into planets. However, because the total mass of all the objects in today' s asteroid belt is less than that of the Moon, the Earth's satellite, another theory speculates that the amount of dust in the asteroid belt was originally small. There is also a theory that the origin of life on Earth was falling nuclei of comets to earth,

1. Formation of the primeval solar nebula

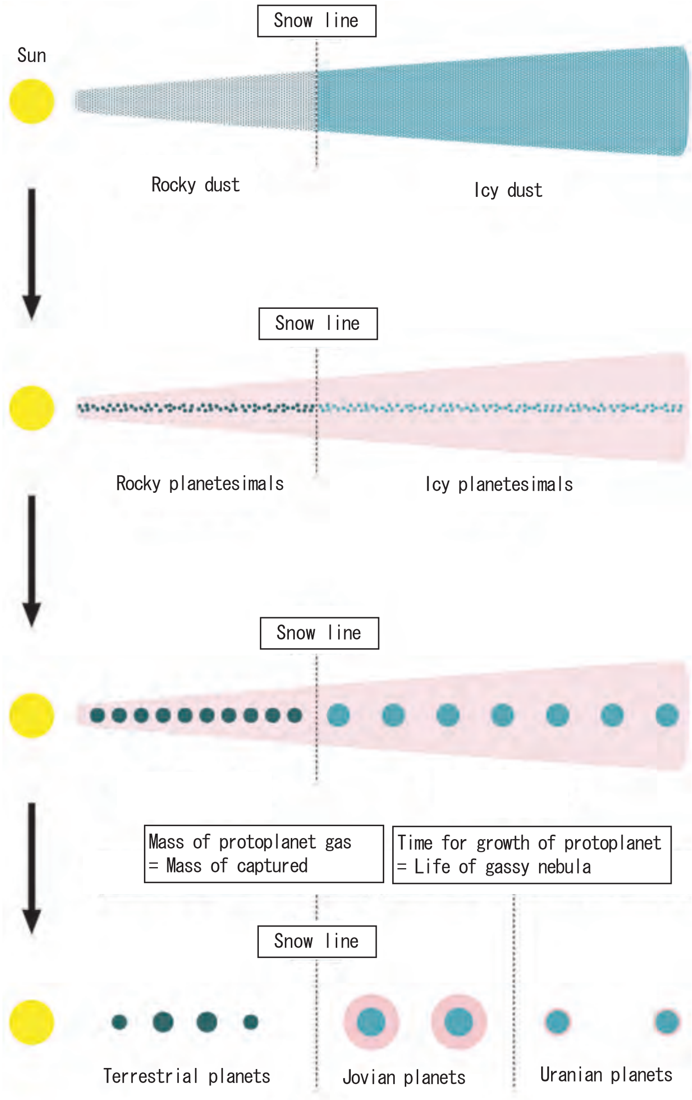
· 4.6 billion years ago, part of a molecular cloud of hydrogen, helium, and other gases, fine lumps of dust of metals, minerals, etc. which were floating in space began to condense under its own gravitational force, occasioned by the explosion of a nearby supernova or other cause, and the Sun was born in the center of this mass.

· A primeval solar nebula revolving around the sun formed from gas and dust. The total mass of the nebula was approximately 1% that of the Sun, and approximately 1% of this was large dust on the μm order. The main components of this dust inside a boundary called the "snow line", which is located approximately 3AU from the Sun, were rock and metals. Outside of the snow line, the main component was ice.

2. Formation of planetesimals (10^6 years)

· The dust in the primeval solar nebula settled onto the ecliptic plane as a result of the perpendicular component of the Sun's gravity, forming a dust layer. When the dust layer exceeded a critical density, it became gravitationally unstable and split into fragments.

· The fragments coalesced rapidly, forming small celestial bodies called planetesimals (mass of approximately 10^{15}-10^{18}kg).



3. Formation of protoplanets (10^6-10^7 years)

· The planetesimals grew by mutual collision and coalescence while revolving around the Sun. Larger planetesimals grew more rapidly by collecting the surrounding planetesimals with their stronger gravitational force. (This phenomenon is called "runaway growth.")

· Celestial bodies (10^{23}-10^{26}kg) called protoplanets formed by runaway growth of planetesimals. When the protoplanets reached a certain size, their growth slowed because the surrounding planetesimals were shaken by their gravity, and neighboring pairs of protoplanets grew while maintaining a certain distance due to gravitational interaction.

4. Formation of planets (10^7-10^9 years)

· In the region of the terrestrial planets (inner Solar System), rocky terrestrial planets formed by collision between protoplanets.

· In the region of the Jovian and Uranian planets (ice giants), large protoplanets formed, and the Jovian and Uranian planets formed by gravitationally attracting gas from the primeval solar nebula.

Figure 2 : Route of norovirus infection in humans

Source: Reference[5]

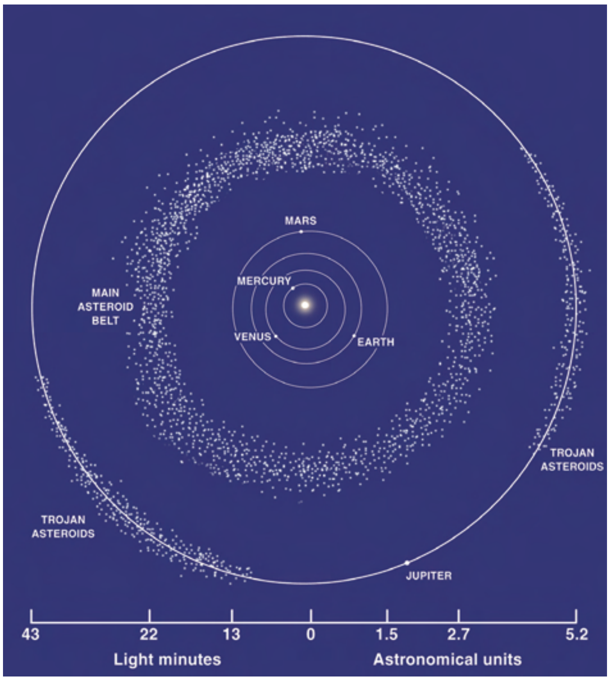


Figure 3 : Asteroid belts

Source: NASA

which contained organic matters. Thus, asteroids and comets, which are also called "primitive bodies," may hold information on the formation of the Solar System and its early evolution. From this viewpoint, exploration of these celestial bodies is also important.[6]

3-2 Trends in Japan and other nations

The missions exploring small solar system bodies carried out since the 1980s are shown in Table 2.[7] Here, it should be noted that this section will treat, as small solar system body exploration missions, exploratory missions to dwarf planets Ceres and Pluto and its moons, in addition to those to the small solar system bodies.

Exploration of Halley's Comet in the 1980s involved joint observations by the former Soviet Union's VEGA 1 and VEGA 2, Japan's SAKIGAKE and SUISEI, Europe's Giotto, and the United States' ICE (International Cometary Explorer) joining after exploring comet Giacobini-Zinner. In the 1990s, the Galileo spacecraft made close approaches (hereinafter, referred to as "flyby") to asteroids Gaspra and Ida while en route to Jupiter, and Giotto, which had observed Halley's Comet, made a flyby of comet Grigg-Skjellerup.

The main specifications of probes after Galileo are shown in Table 3. NEAR Shoemaker was the first spacecraft in the U.S. Discovery Program[8] that promotes small solar system body exploration missions. In this program, upper limits are set on mission budgets, and researchers are invited to submit proposals, which are then selected for actual missions. The main purpose of the NEAR Shoemaker mission was to approach (hereinafter, referred to as "rendezvous") an asteroid for the first time and to make detailed remote sensing observations.[9] The spacecraft took detailed images while making a controlled landing on the asteroid, and continued to send back data before the end of its mission.

Deep Space 1 was the first mission in the U.S. New Millennium Program, the main purpose of which is in-space testing of new technologies.[10] The world's first solar electric ion propulsion

Table 2 : Main missions to small solar system bodies

	1980s	1990s	2000s
Flyby/impact	·1985[NOTE 1]: <Comet Giacobini-Zinner> ICE ·1986: <Halley's Comet> VEGA 1, VEGA 2, SAKIGAKE, SUISEI, Giotto, ICE	· 1991 <Asteroid Gaspra> Galileo · 1992 <Comet Grigg-Skjellerup> Giotto · 1993 <Asteroid Ida> Galileo · 1997 <Asteroid Matilda> NEAR Shoemaker · 1999 <Asteroid Braille> Deep Space 1	· 2001 <Comet Borrelly> Deep Space 1 · 2002 <Asteroid Annefrank> Stardust · 2004 <Comet Wild 2> Stardust · 2005 <Comet Tempel 1> Deep Impact
Rendezvous /landing			·2000 <Asteroid Eros> NEAR Shoemaker ·2005 <Asteroid Itokawa> HAYABUSA (Muses-C)
Sample return			·2004 <Comet Wild 2> Stardust (returned in 2006) ·2005 <Asteroid Itokawa> HAYABUSA (scheduled to return to Earth in 2010)

[NOTE 1] Year when the probe arrived at the small solar system body. Same in the following.
[NOTE 2] Excludes satellites of Solar System planets. Spacecraft in flight toward object celestial bodies are Rosetta, arriving 2014 at Comet Churyumov-Gerasimenko, New Horizons, arriving 2015 at Pluto and Charon, and Dawn, arriving 2011/2015 at Vesta/Ceres.

Source: Reference[7]

engine for interplanetary space flight was among the technologies tested in space by this mission.

Stardust was the fourth spacecraft in the Discovery Program. The main purpose of the mission was to, as the world's first, sample and return dust discharged from the nucleus of a comet and cosmic dust in interstellar space (hereinafter, referred to as "sample return").[11] In order to reduce launch costs by optimizing the amount of propellant carried by the spacecraft, a flight path circling the sun almost three times was adopted. As the first circuit required about 2 years, and the second and third circuits required approximately 2.5 years each, the total duration of this mission was approximately 7 years.

The main purpose of HAYABUSA was to demonstrate in space the technologies which would be essential and key to small solar system body exploration.[12] The technologies to be demonstrated in space were (1) interplanetary flight using an ion engine as the main propulsion system, (2) rendezvous and landing on a celestial body via autonomous guidance and navigation using optical information, (3) collection of samples from the surface of a celestial body under microgravity conditions, (4) sample recovery by reentering an capsule into the Earth's atmosphere from an interplanetary trajectory, and (5) combined use of orbit transfer by terrestrial gravity (hereinafter, referred to as "swing-by") and the ion engine. Return to Earth was postponed from June 2007 to June 2010 due to an accident involving leakage of the craft's chemical propellant.

Rosetta, which is a large-scale science project of the European Space Agency (ESA), consists of an orbiter and a lander called Philae. Its main purpose is to observe comet Churyumov-Gerasimenko.[13] The lander will actually descend to its nucleus, where it will make detailed observations, while the orbiter will pass the perihelion together with the comet and will continue its observations over a period of approximately one year to investigate the comet. By the way, comets are sometimes described as "dirty snowballs."

The Deep Impact probe was the eighth mission in the Discovery Program. Its main purpose was to collide an impactor into comet Tempel and observe substances emitted due to this collision to investigate the elemental composition of the comet's interior.[14] The impactor, whose gross weight was approximately 372kg, was released from the probe on July 3, 2005 at a distance of approximately 880,000km from the comet, and impacted into the comet about one day later at a relative velocity of approximately 10.3km/s. The mechanical energy released by the impact was approximately 19GJ, which is estimated to be equivalent to about 45 tons of TNT.

New Horizons is the first mission in the United States' New Frontiers Program, which promotes medium-class planetary missions. The program caps mission costs and selects missions from proposals submitted by researchers. The main purpose of New Horizons is to observe Pluto and its satellite Charon, and other bodies.[15] Launched by a large rocket, the spacecraft escaped from the Earth's gravitational field at a velocity of approximately 16km/s, which was the fastest among the missions launched by rockets, and reached the Moon's orbit around the Earth ,whose orbital radius is approximately 384,000km, in approximately 9 hours after launch. Because the craft uses a radioisotope thermoelectric generator (RTG) and doesn't need to orient toward the Sun to generate power, it is to be placed in a hibernation mode after a swing-by of Jupiter in order to reduce operating costs and avoid wear of onboard electronic devices. Excluding when course adjustments and periodic inspection are made approximately once a year, the power supplies to one of the redundant systems are cut off, and the craft travels in a spin stabilized mode at about 5rpm, with its antenna pointed toward the Earth. After arriving at Pluto, it will turn toward observation targets using its attitude control system propulsion units.

Dawn is the ninth mission in the Discovery Program. Its main propulsion system consists of the same type of ion engines as that used for Deep Space 1, and its main purpose is to rendezvous with asteroid Vesta and dwarf planet Ceres.[16] Except when its antenna is turned toward the Earth several hours a week for communication, the ion engine operates continuously during interplanetary flight. The engine is also used for orbit insertion.

Table 3 : Main specifications of small solar system body probes of various countries

	NEAR Shoemaker	Deep Space	Stardust	HAYABUSA (MUSES-C)
Country (organization) developed by	USA (NASA)	USA (NASA)	USA (NASA)	Japan (JAXA)
Launch date	Feb. 17, 1996	Oct. 24, 1998	Feb. 7, 1999	May 9, 2003
Launch vehicle	Delta II	Delta II	Delta II	M-V
Dimensions of body (m)	[NOTE 1]	(Unknown)	1.7×0.66×0.66[NOTE 3]	1.0×1.6×1.1
Launch weight (kg)	805	486.3	385[NOTE 4]	510[NOTE 7]
Power generated (W)	1,800@1AU 400@2.2AU	2,500@1AU	170~800[NOTE 5]	2,600@1AU
Attitude control method	3 axes	3 axes	3 axes	3 axes
Mission period	To Feb. 28, 2001	To Dec. 18, 2001	To Jan. 15, 2006[NOTE 6]	June 2010 (scheduled)
Mission cost (million USD)	224.1	149.7[NOTE 2]	168.4	(Approx.¥23.5 billion)

[NOTE 1] Octagonal body comprising 8 aluminum panels with area of approximately 1.7m^2.
[NOTE 2] 1995-1999 U.S. accounting years.
[NOTE 3] Dimensions of recovery capsule: φ0.8m x 0.5m.
[NOTE 4] Includes sample recovery capsule: 46kg.
[NOTE 5] Generated power varies depending on the distance from the Sun.
[NOTE 6] Date of return to Earth of sample recovery capsule.
[NOTE 7] Includes reentry capsule: 16kg, target marker: 280g x 3, surface probe Minerva: 591g.

	Rosetta	Deep Impact	New Horizons	Dawn
Country (organization) developed by	EU (ESA)	USA (NASA)	USA (NASA)	USA (NASA)
Launch date	March 2, 2004	January 12,2005	January 19.2006	Sept. 27, 2007
Launch vehicle	Ariane V	Delta II	Atlas V	Delta II
Dimensions of body (m)	2.8×2.1×2.0	3.3×1.7×2.3[NOTE 10]	0.7×2.1×2.7[NOTE13]	1.64×1.27×1.77
Launch weight (kg)	3,000[NOTE 8]	973[NOTE 11]	478	1,217.7
Power generated (W)	850@3.4AU 400@5.2AU	750 (max.)[NOTE 12]	234@Jupiter 200@Pluto	10,300@1AU 1,300@3AU
Attitude control method	3 axes	3 axes	3 axes/spin	3 axes
Mission period	To Dec. 2015 (scheduled)	To Aug. 2005	To July 2015 (scheduled)[NOTE 14]	To July 2015 (scheduled)
Mission cost (million USD)	Approx. 1.0 billion Euros[NOTE 9]	333	700	357.5

[NOTE 8] Includes comet surface lander Philae: 100kg.
[NOTE 9] Includes additional costs of approximately 70 million Euros due to launch delay caused by problems with Ariane V.
[NOTE 10] Dimensions of impactor: φ1m x 1m.
[NOTE 11] Probe: 601kg + impactor: 372kg.
[NOTE 12] At rendezvous with comets : 620W
[NOTE 13] Shape is a roughly triangular prism.
[NOTE 14] Date of scheduled arrival at Pluto.

Source: Reference[9-16]

3-3 Technologies necessary for small solar system body exploration

For asteroid exploration, remote sensing observation devices are used to investigate elemental compositions, mineral compositions, topographies, shapes and sizes, and other characteristics of asteroids. Asteroids' gravitational fields are measured by analyzing asteroid probes' tracking data to study asteroids' masses and densities. For comet exploration, in addition to remote sensing observation devices like those used for asteroid exploration, comet probes are also equipped with such devices as sounders to investigate comets' nuclei, dust flux and composition analyzers to study comets' comas, plasma measurement devices to investigate interactions between comets and the Sun.

On the other hand, the dust collector of Stardust, the surface sampling technology of HAYABUSA, the in-situ observation by Rosetta's lander, and the impactor of Deep Impact are unique when compared with other probes' instruments, and researches done by new techniques like these seem to become increasingly more important in the future. Therefore, this section will discuss the ion engine, sampling, and reentry capsule technologies considered necessary for sample return that enables Solar System sample analyses on the ground.

(1) Ion engine technology

While one approach to send a probe to a target celestial body is to launch the probe by a large rocket like New Horizons to obtain a high initial velocity to escape the Earth's gravitational field, followed by inertial flights combined with swing-bys, the other approaches, which employ smaller rockets desirable to reduce mission costs, include onboard propellant optimization by selecting flight trajectories as done for the Stardust mission as well as the use of ion engines as main propulsion systems as done for the Deep Space 1, HAYABUSA, and Dawn missions.

The approximate launch capabilities of the United States' Delta II and Atlas V,[17] Europe's Ariane V,[18] and Japan's M-V and, for reference, H-IIA[19] are shown in Table 4. The launch capability of M-V is significantly lower than those of the other rockets, but thanks to the creative ingenuity of Japanese scientists and engineers concerned, the HAYABUSA mission, which was in no way inferior to the efforts of other nations, was indeed realized.

Chemical propulsion systems generate thrusts by discharging high temperature gases generated by combustion or catalytic reaction processes of chemical propellant, whereas ion engines ionize xenon propellant and accelerate ions in electrical fields, and the ions are discharged after being neutralized by bonding with electrons.

The rocket equation where no propellant is replenished during space flight is shown in Figure 4.[20] Ion engines are not suitable for escaping from the Earth's gravitational field because their thrust forces (i.e. horsepower) are much smaller than those of chemical propulsion systems, but because their specific impulses are approximately ten times higher than those of chemical propulsion systems, hey can obtain the same amount of orbit transfer as with chemical propulsion systems while consuming only one tenth as much propellant (meaning lower fuel consumption). Therefore, in addition to lowering launch weight by reducing the amount of propellant onboard and enabling launching with a smaller rocket, an ion engine, after escaping from the Earth's gravitational field, enables flight to a distant celestial body by realizing a greater amount of orbit transfer than a rocket, as was demonstrated by HAYABUSA.[21] Furthermore, the drawback of longer-term flight with lower thrust conversely enables flexibility in orbital trajectory planning, enebliing an extended launch window period.

The orbital lifetime of a satellite is effectively determined by the amount of propellant onboard the satellite. Since the 1980s, American commercial geostationary telecommunications satellites have been equipped with ion engines for orbital control in order to extend their orbital lifetime by taking advantage of the feature of high specific impulse (i.e. lower fuel consumption). Orbital control is performed by operating the ion engines approximately 0.5 to 5 hours daily. In this connection, it may be noted that Japan's KIKU 8 is also equipped with an ion engine for orbital control.

The first use of an ion engine onboard a space probe was a NSTAR engine aboard the U.S. Deep Space 1 mission, which was followed byμ10 engines aboard Japan's HAYABUSA mission and a PPS1350 engine aboard European lunar probe SMART-1, which will be discussed later. The main specifications of these engines and their flight results are presented in Table 5.[22] The U.S.'s Dawn is also equipped with three NSTAR units, and the total empty weight of the ion engine system is approximately 129kg. The μ10 ion engine system onboard HAYABUSA, which holds the record for the longest total operating time, generates approximately 24mN of thrust with electric power consumption of approximately 1.1kW and a maximum of three of four units in

Table 4 : Launch capabilities of Japanese, U.S., and European rockets

	Delta II	Atlas V	Ariane V	M-V	H-IIA
GTO(kg)	900 - 2,120	4,950 - 13,000	6,000 - 9,600	―	3,700 - 5,700
LEO(kg)	2,450 - 5,430	9,750 - 29,420	21,000	1,850	10,000

Source: Reference[17-19]

$$\Delta v = V_{ex} \ln(M_i/M_f),\ V_{ex} = g I_{sp}$$

- Δv: change of velocity or orbit transfer.
- V_{ex}: exhaust velocity; ln is a natural logarithm.
- M_i and M_f: initial and final masses of a probe before and after operation of the propulsion system.
- I_{sp}: specific impulse; value obtained by dividing V_{ex} by the acceleration of gravity of the Earth (approximately 9.8m/s^2).

  ➢For a given value of Δv, the conditions for higher performance of a propulsion system are arrival at the target object with a larger final mass M_f relative to the initial mass M_i, in other words, achievement of a larger exhaust velocity V_{ex} with the same amount of propellant consumption (= lower fuel consumption).

Figure 4 : Rocket equation

Source : Reference[20]

Table 5 : Main specifications and mission results of Japanese U.S., and European ion engines

Mission	Deep Space 1	HAYABUSA (MUSES-C)	SMART-1
Ion engine	NSTAR	μ10	PPS1350
Number of engines	1	4	1
Empty weight (kg)	64.4	59	(Unknown)
Power consumption (W)[NOTE 1]	2,300	350	1,500
Specific impulse (s)	3,280	3,200	1,650
Thrust (mN)[NOTE 2]	91	8[NOTE 3]	88
Orbit transfer (m/s)	4,300	1,400	3,700
Total operating time (hr)	16,265 (approx. 678 days)	25,800 (approx. 1,075)	4,958 (approx. 207)
Propellant consumption (kg)	73.4	22	81.7
Ground life test (hr)	30,352	20,000	10,530

[NOTE 1] Specific impulse and thrust are values for the power consumption shown in figure.
[NOTE 2] 1N: 0.1kg weight, 1mN: 0.1g weight.
[NOTE 3] Value per engine. When 3 engines are in operation, 24mN.

Source: Reference[22]

operation at one time. The number of units in operation and the thrust generated vary depending on power conditions. As of October 18, 2007, following the chemical propellant leak accident, this ion engine system had set a new record for total operating time of approximately 31,400 hours (approximately 1,308 days), and had achieved orbit transfer of approximately 1,700m/s. The remaining orbit transfer necessary for return to the Earth is approximately 400m/s. This craft has recorded the longest operating time for a single engine of approximately 13,400 hours (approximately 558 days).[23]

SMART-1's PPS1350 engine was developed by SNECMA, a French company, based on an ion engine manufactured by Russia, and generated approximately 9.1-65.7mN of thrust with power consumption of approximately 462-1,190kW. Among Dawn's three NSTAR units, one is operational (system redundancy), generating approximately 19-91mN of thrust with power consumption of approximately 500-2,300W. The estimated total operating time is approximately 2,000 days, and the xenon consumption amounts necessary to reach Vesta and Ceres are approximately 288kg and 89kg, respectively.

Extremely long operating times are necessary for ion engines to accomplish interplanetary flights. While NSTAR's ion-forming electrodes are thought to be susceptible to deterioration, μ10, which is a microwave discharge ion engine that forms ions by a microwave generator instead of electrodes, is thought to be less susceptible to deterioration.[24]

To realize high performance propulsion systems for interplanetary flight, NASA is developing a next-generation ion engine called NEXT as a successor to NSTAR, and a lightweight, high temperature combustion type bipropellant chemical propulsion system called AMBR (the Advanced Material Bipropellant Rocket) using advanced materials,[25] and recommends to study their use in making proposal for the third mission in the New Frontiers Program.[26] Likewise, Japan is now engaged in research and development on the increased thrust type μ20 ion engine (thrust: approx. 30mN, specific impulse: approx. 2,500s with power consumption of approx. 1kW) and the increased specific impulse type μ10Hisp engine (thrust: approx. 30mN, specific impulse: approx. 10,000s with power consumption of approx. 2.5kW) as successors to the μ10 engine, aiming to be main propulsion systems for the HAYABUSA Mk-II (Marco Polo) primitive body probe and the Solar Powered Sail mission to Jupiter, respectively.[27,28]

(2) Sampling and reentry capsule technologies

The Stardust mission (Figure 5) sampled dust from comet Wild 2 while flying before and after its nearest approach to the comet on January 2, 2004, and also sampled dust in interplanetary space while flying for a total of approximately 195 days during its first (February to May 2000) and second circuits (August to December 2002). Its tennis racket-shaped dust catcher used jelly-like solid silicon called aerosol, which had an ultra-low density, was inert, and had a high void ratio. The dust sampling area of the front and back surfaces was approximately 1,000cm2 each. The front and back surfaces were used in passive sampling of the dust from the comet and sampling from interplanetary space, respectively. The sample recovery capsule housing this dust catcher reentered the Earth's atmosphere on January 15, 2006, and after deceleration using a parachute, fell to the Earth and was recovered in the state of Utah in the United States.

The recovered dust samples were processed at NASA's Johnson Space Center, and samples were then distributed to initial analysis teams consisting of a total of approximately 187 participating researchers from more than 100 institutions in nine countries. Chemical composition analysis, infrared spectroscopy analysis, mineral and rock analysis, isotope analysis, organic analysis, and impact crater analysis were carried out over a period of about six months.[29] With the exception of meteorites, whose original celestial bodies are difficult to identify, this was the first time that extra-terrestrial samples had been recovered from a body in the Solar System since the Apollo Program and the former Soviet Union's Luna Program. Research on the Moon has progressed using samples from the lunar surface taken in the Apollo Program. Because comets are thought to retain the original materials of the Solar System, the scientific significance of returning the substances which make up comets to the Earth and direct analysis utilizing various types of analytical equipment is considered enormous. The analysis work for which Japanese researchers were responsible included nondestructive analysis by synchrotron radiation using the facilities of the High Energy Accelerator Research Organization (KEK) and SPring-8.

HAYABUSA (Figure 6) performed sampling by an active technique, in which the surface of asteroid Itokawa was crushed by metal balls weighing several grams which were shot into the surface at approximately 300m/s, and the fragments which scattered from the surface under the microgravity conditions of the asteroid were collected in a container in the probe via a sample horn.[12] Diversification[30] of surface sampling techniques, and higher heating resistance and reduced weight of the return capsule[31] are currently being studied in order to meet the requirements of various missions using Japan's sample return technology, which uses a combination of technologies including the ion engine of long-term operation.

In addition to the S type asteroid explored by HAYABUSA, other potential targets for sample return include asteroids which are classified as the C, P, and D types,. based on differences in their solar reflectivity, and dead comets, or “Comet-Asteroid Transition Objects (CAT),” which are considered to be the remnants of comets captured in the asteroid belt. Thus, there are still many small solar system bodies from which researchers hope to receive samples for detailed analysis on the ground.

4 Trends in lunar exploration in Japan and other countries

4-1 Significance of lunar exploration

The Moon was born approximately 4.5 billion years ago, in the same period as the Earth, but because the Moon, unlike the terrestrial planets, has not been affected by plate tectonics, volcanic activities, weathering, and other phenomena, it offers a faithful record of the history of its early evolution. Moreover, because it is relatively close to the Earth, it is a favorable object for research in planetary science.[32] The United States of America made a total of six successful manned landings on the Moon in its Apollo manned space exploration program, during which astronauts made various scientific observations and collected a total of approximately 400kg of samples from the Moon' s surface. In spite of steady progress in lunar research, for example, various theories explaining the mystery of the Moon's origin have been advacated, including (1) the "fission hypothesis," which holds that part of the Earth was spun off due to its high rotational speed, and that part formed the Moon, (2) the "co-formation hypothesis," which stipulates that the Moon formed from an accretion disk of rock and gas near the Earth, (3) the "capture hypothesis," which says that a celestial body which had formed in a region different from the Earth was captured by the Earth, and (4) the "giant impact hypothesis," which has been prevalent since the Apollo Program and proposes that the Moon formed from debris resulting from a collision between the proto-Earth and a protoplanet with the size of Mars or larger. However, this mystery has not yet been resolved.

4-2 Trends in Japan and other nations

The Clementine probe was a joint project of the United States' National Aeronautics and Space Administration (NASA) and Department of Defense (DOD). Its main purpose was to evaluate the long-term resistance of sensors and components to the space environment.[33] The probe was launched on January 25, 1994. After insertion into a lunar orbit on February 21 of the same year, remote sensing observation was performed for a period of approximately two months. In order to research the topography of the Moon, the Clementine took images of the lunar surface in the ultraviolet, visible light, and infrared wavebands and measured the altitude of the lunar surface with a laser altimeter. The probe was also equipped with radar in order to investigate the existence of ices of water and other volatile substances in the permanently shadowed areas in the Moon's polar regions. The surface layer of the Moon was surveyed by directing radio waves at the Moon from the probe and measuring the waves reflected from the Moon's surface with receivers on Earth. Observational data suggesting the existence of frozen water in the Moon's southern polar region were obtained in certain orbits, but such data were not obtained in other orbits.

Japan launched lunar orbiter KAGUYA to conduct the first full-scale scientific exploration of the Moon since Apollo. This was followed by

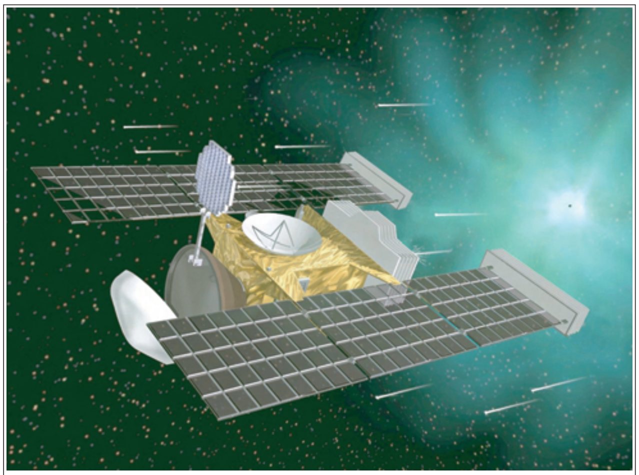


Figure 5 : Stardust (artist's conception)

Source: NASA

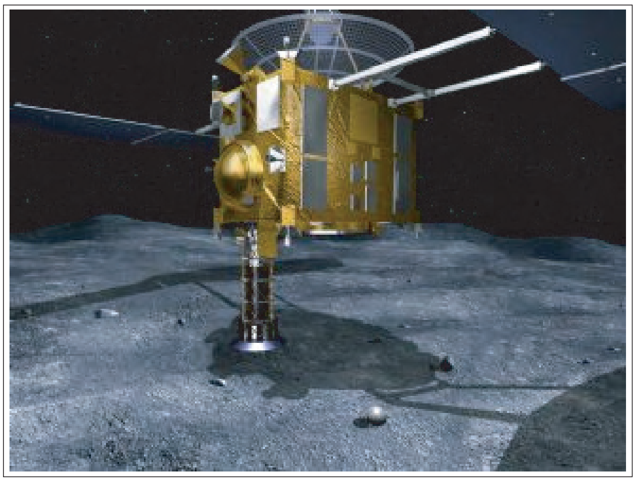


Figure 6 : HAYABUSA (MUSES-C) (artist's conception)

Source: JAXA

China's launch of Chang'e 1 and by India's launch of Chandrayaan 1, both with the aim of acquiring new space capabilities of lunar exploration technology. Thus, the beginning of the 21st century marked the start of renewed activities in lunar exploration. The main specifications of the major lunar missions since Clementine are shown in Table 6.

As a Moon orbiting observation mission , KAGUYA observes the Moon's surface elemental distribution, mineral composition and distribution, topography and surface layer structure, global gravitational field, magnetic anomalies, plasma environment, and other lunar characteristics with the aim of studying the mystery of the origin and evolution of the Moon.[34] Also being Japan's

Table 6 : Main specifications of lunar probes of various countries

		KAGUYA (SELENE)	Chang'e 1	Chandrayaan 1	SMART-1
Country (organization) developed by		Japan (JAXA)	China (CNSA)	India (ISRO)	Europe (ESA)
Launch date		Sept. 14, 2007	Oct. 24, 2007	Oct. 22, 2008	Sept. 27, 2003
Launch vehicle		H-IIA	Chang Zheng (Long March) IIIA	PSLV	Ariane V
Dimensions of body (m)		2.1×2.1×4.8	2.0×1.7×2.2	1.5×1.5×1.5	1×1×1
Launch weight (kg)		2,885[NOTE 1]	2,350	1,304[NOTE 3]	366.5
Power generated (W)		3,486	(unknown)	700	1,850
Orbit	Altitude (km)	100[NOTE 2]	200	100	300×3000
	Type of orbit	Polar orbit	Polar orbit	Polar orbit	Polar orbit
Attitude control method		3 axes	3 axes	3 axes	3 axes
Mission period		1 year[NOTE 2]	1 year	2 years	1.5 years[NOTE 4]
Mission cost		Approx. ¥55.0 billion	Approx. 1.4 billion yuan	Approx. 3.86 billion Indian rupee	Approx. 110 million Euros

[NOTE 1] Main satellite: 2,779kg, sub-satellites: 53kg x 2
[NOTE 2] After steady operation, was changed to an orbital altitude of 40-70km.
[NOTE 3] 590kg @ lunar orbit.
[NOTE 4] Initially scheduled for half-year, but extended by 1 year.

		Lunar Prospector	LRO	LCROSS	GRAIL
Country (organization) developed by		USA (NASA)	USA (NASA)	USA (NASA)	USA (NASA)
Launch date		Jan. 1, 1998	Feb. 27, 2009 (scheduled)		Sept. 2011 (scheduled)
Launch vehicle		Athena II	Atlas V		Delta II
Dimensions of body (m)		φ1.37×1.28	(Unknown)	(Unknown)	(Unknown)
Launch weight (kg)		202	1,846	834[NOTE 5]	466.1[NOTE 7]
Power generated (W)		3,486	1,850	600	(Unknown)
Orbit	Altitude (km)	100	50	(Elliptical earth orbit by performing swing-by with Moon.)	50
	Type of orbit	Polar orbit	Polar orbit		Polar orbit
Attitude control method		Spin	3 axes	3 axes	3 axes
Mission period		1.5 years	1 year	Approx. 86 days[NOTE 6]	Approx. 90 days[NOTE 8]
Mission cost (million USD)		63	421		375

[NOTE 5] At time of lunar impact, probe: 700kg, upper stage of rocket: 2,000kg.
[NOTE 6] Time to lunar impact.
[NOTE 7] Two vehicles will be launched simultaneously. Weight when launching 1 vehicle: 202.4kg.
[NOTE 8] After completion of the mission, the twin satellites will be impacted on the Moon.

Source: Reference[34-41]

first lunar probe, the orbiter aims to establish the lunar orbit insertion technology, and the tri-axial attitude control, orbit control and thermal control technology in lunar orbit. Chang'e 1 is the first in a series of lunar exploration missions planned by China. Its technical aims includes acquisition of lunar probe development and launch capabilities, verification of technologies necessary for lunar exploration and establishment of requisite technical infrastructure, and accumulation of experience for subsequent missions.[35] Its scientific objectives are to obtain 3-dimensional images of the Moon' s surface and measure the distribution of surface elements and the thickness of the surface soil as well as to investigate resources such as helium 3 fuel for nuclear fusion. Chandrayaan 1 is developed by the Indian Space Research Organisation (ISRO), and was India's first lunar probe. Its aims are to verify and improve India's space development technologies and to obtain data on the Moon's surface.[36]

SMART-1 is a probe which was launched by the European Space Agency (ESA) with the aim of space testing of technologies, such as an ion engine, which will be necessary for future missions.[37] This probe was transferred from Earth orbit to lunar orbit by its ion engine. After reaching lunar orbit, the probe collected scientific data associated with the geology, topography, mineral and elemental composition, near-Moon environment and other lunar characteristics, and finally made a hard landing on the Moon's surface. Because it was equipped with an ion engine, its power generation was larger than that of other spacecraft.

Lunar Prospector was the third mission in the NASA Discovery Program. Its objectives were to collect data on the elemental composition of the Moon's surface, the existence of water ice in the permanently shadowed areas in the polar regions, magnetic anomalies, the gravitational field, and other lunar features.[38] Observational data suggesting the existence of frozen water were obtained by neutron spectroscopy, and the craft then crashed into the Moon's surface in an attempt to verify the presence of water ice, but confirmation was not possible from Earth-based telescope observations of the resulting plume.

NASA's Lunar Reconnaissance Orbiter (LRO) is the first mission in the Lunar Precursor Robotic Program being carried out in anticipation of a resumption of manned lunar exploration activities.[39] Its purpose is to obtain detailed information on the Moon's surface topographical structure, usable resources such as water ice deposits, radiation environment, and other characteristics in order to decide future landing sites and locations for the construction of lunar bases. The Lunar Crater Observation and Sensing Satellite (LCROSS) will be launched together with the LRO to investigate the existence of ice deposits in the permanently shadowed lunar polar regions. In this mission, the upper stage of the rocket and the observation vehicle will be crashed successively into the Moon, and the resulting plumes will be observed.[40] It is estimated that the energy released by crashing the upper stage into the Moon at a relative velocity of about 2.5km/s will be approximately 6.25GJ, or the equivalent of approximately 1.5 tons of TNT. Japan's KAGUYA will make observations of the Moon's entire gravitation field, including the farside of the Moon, by 4-way Doppler measurements and differential VLBI (Very Long Baseline Interferometry) observation using a pair of smaller satellites. In contrast, NASA's GRAIL (the Gravity Recovery and Interior Laboratory) is planned to measure the global gravitational field of the Moon by measuring the changes of the relative distance between twin lunar orbiters.[41]

4-3 Technologies necessary for lunar exploration

KAGUYA is engaged in observations including (1) as science of the Moon, its distribution of elements, distribution of minerals, topography and surface layer structure, and global gravitational field, (2) as science at the Moon, its magnetic anomalies, radiation environment, plasma environment, and ionosphere, and (3) as science from the Moon, the Earth's plasma environment. Views of KAGUYA at the time of testing on the ground and an outline of the instruments carried onboard KAGUYA are shown in Figure 7 and Table 7, respectively.

The instruments carried onboard the lunar probes of each nation are listed in Table 8. Because the purpose of LRO, LCROSS, and GRAIL is to collect information in anticipation of manned activity, an outline of these missions is shown separately in Figure 8.

From Table 8, it can be deduced that the objective of KAGUYA is precisely the full-scale scientific investigation of the Moon. For research on elemental/mineral distribution, KAGUYA carries observational equipment similar to those of other nations; however, it is also equipped with a radar sounder for measurement of the weak reflected radio waves from the surface and a depth of several kilometers underground, and a lunar magnetometer which enables measurement of magnetic anomalies with an accuracy of 0.1nT or smaller. It will also measure the farside gravitational field of the Moon by 4-way Doppler measurements with ground stations on the Earth via a relay satellite, OKINA (RSAT), which is a world's first. It will make precise measurements of the Moon's gravitational field by differential VLBI observation using sub-satellite OUNA (VRAD) and OKINA (RSAT), and will observe the Moon's rarified ionosphere by detecting phase changes in the radio waves transmitted by OUNA (VRAD). Thus, this mission is conducting comprehensive lunar exploration not seen in other nations' missions.

Regarding the laser altimeter, on April 9, 2008, the Japan Aerospace Exploration Agency (JAXA) publicized a map of the entire Moon, which was prepared jointly by the National Astronomical Observatory of Japan and the Geographical Survey Institute.[42] Altitude data on approximately six million points had been obtained as of April 9, 2008, greatly exceeding the results of previous observations, and also including the Moon's polar regions for the first time. A topographical map of the Moon prepared using observational data from a 2-week period of January 7-20, 2008 was published. Regarding the High Vision (high definition television: HDTV) camera, on April 11 of the same year, an image of the rising full Earth was taken, which could be observed from lunar orbit when the Sun, Moon, satellite orbit, and the Earth were aligned along a straight line, and an image of the entire Earth, which appears bright blue, was published.[43]

A distinctive feature of India's Chandrayaan 1 is international cooperation with Europe and the United States of America. In addition to five units of observational equipment supplied by India itself, this mission includes two units provided by NASA (M3, MiniSAR), three provided by ESA (C1XS, SIR-2, SARA), and one unit provided by Bulgaria (RADOM), for a total of 11 instruments, and can therefore be considered a good example of international cooperation to obtain richer scientific

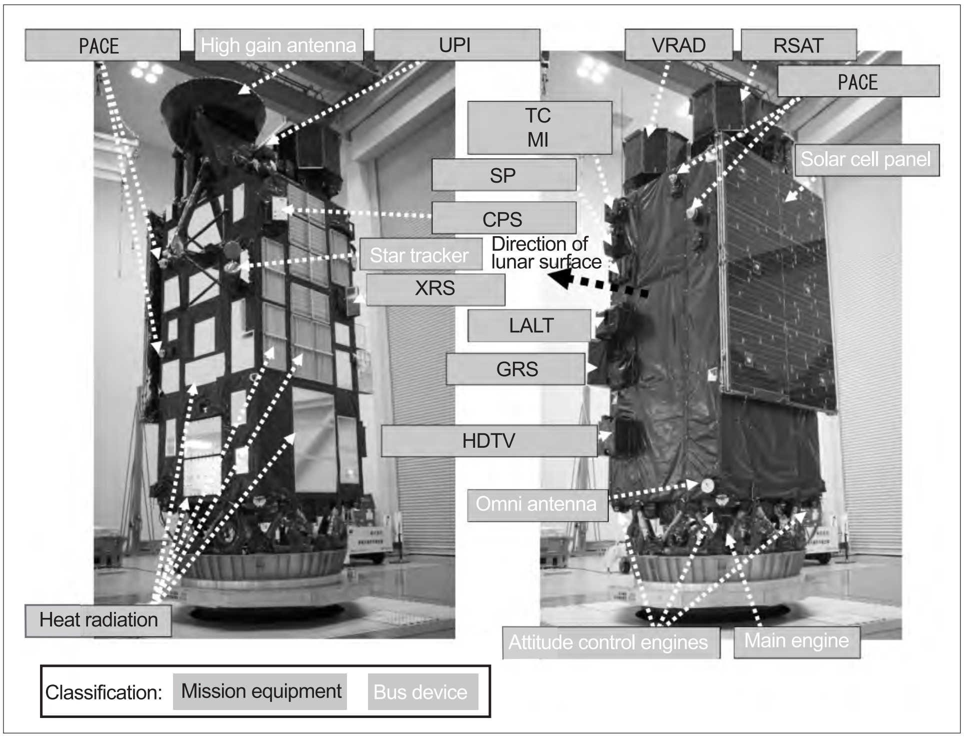


Figure 7 : KAGUYA (SELENE) during testing on Earth

Source : JAXA

Table 7 : Outline of instruments aboard KAGUYA (SELENE)

Elemental distribution of lunar surface	X-Ray fluorescence Spectrometer (XRS)	Observes X-ray fluorescence emitted by elements at the lunar surface as a result of solar X-rays; surveys the elemental distribution of Mg, Al, Si, S, Ca, Ti, Fe, etc.
	Gamma Ray Spectrometer(GRS)	Observes gamma rays emitted from elements at the lunar surface; surveys the elemental distribution of U, Th, K, H, O, Mg, Al, Si, Ca, Ti, Fe, etc.
Mineral distribution of lunar surface	Multi-band Imager (MI: visible light/ infrared radiometer)	Observes visible and infrared light from the lunar surface in 9 wavelength bands; surveys mineral distribution.
	Spectral Profiler (SP: visible light/infrared spectrometer)	Observes the continuous spectrum of visible and infrared light from the lunar surface; surveys mineral distribution.
Topology and surface layer structure of Moon	Terrain Camera (TC)	Photographs with 2 cameras having resolution of approximately 10m; used in preparing 3-dimensional images of the lunar terrain.
	Laser Altimeter (LALT)	Obtains the distance between the satellite and the lunar surface by irradiating a laser beam on the lunar surface and measuring the round-trip time until its return; measures changes in terrain and altitude.
	Lunar Radar Sounder (LRS)	Investigates the surface layer structure of the Moon to a depth of several km underground based on reflected radio waves from the Moon.
Global gravitational field of Moon	Relay Satellite (RSAT)	Observes disturbances in the orbit of the main satellite by relaying radio waves from the main satellite while travelling on the farside of the moon and Doppler measurement of those radio waves by ground stations on Earth; used to obtain data on farside gravitational field.
	Differential VLBI Radio source (VRAD)	Makes high accuracy determination of the orbit of the sub-satellite by differential VLBI * measurement by ground stations of the radio sources transmitted by the two sub-satellites (RSAT, VRAD), and accurately measures the gravitational field of the Moon. (* : Very Long Baseline Interferometry. Used to obtain the position of a radio source from differences in paths of radio waves.)
Environment at lunar surface	Lunar Magnetometer (LMAG)	Observes the distribution of magnetism at the lunar surface and in the vicinity of the Moon.
	Charged Particle Spectrometer (CPS)	Observes cosmic rays in the vicinity of the Moon, high energy radiation emitted by the Sun, and alpha rays emitted by radon on the lunar surface.
	Plasma energy Angle and Composition Experiment (PACE)	Measures the distribution of electrons and ions in the vicinity of the Moon originating from solar wind, etc.
	Radio Spectrometer (RS)	Measures changes in the phase of radio waves from the VRAD satellite; used in research on the rarified lunar ionosphere.
Terrestrial plasma environment	Upper atmosphere and Plasma Imager (UPI)	Image sensor observation of the Earth's magnetosphere and plasmasphere from lunar orbit.
Imaging	High Definition Television (HDTV) Camera System	High definition imaging of the Earth and Moon, for example, photograph of "Earthrise."

Source: Reference[34]

results. It may be noted that two of the ESA devices (C1XS and SIR-2) are improved versions of those carried onboard SMART-1.

NASA is continually investigating the presence of water ice on the Moon. In addition to the fact that water will be indispensable for manned activities, it can also be used to form hydrogen and oxygen, which could become propellant for space transport vehicles, by electrical decomposition using solar power generation. Because transportation of water from the Earth would be extremely expensive, mission costs can be greatly reduced if water ice deposits exist on the Moon and these can be extracted and processed into water.

5 Japan's space capabilities demonstrated by the HAYABUSA and KAGUYA missions

(1) Establishment of Japanese original space technologies unrivaled by other nations

The United States of America succeeded in one-way interplanetary space travel with an ion engine with its Deep Space 1, and in sample

Table 8 : Instruments aboard lunar probes of various countries

		KAGUYA (SELENE)	Chang'e 1	Chandrayaan 1	SMART-1	Lunar Prospector
Elemental distribution of lunar surface	X-ray fluorescence spectrometer	○ (XRS)	○	○ (C1XS)	○ (D-CIXS)	—
	Gamma ray spectrometer	○ (GRS)	○	○ (HEX)[NOTE 3]	—	○ (GRS)
Mineral distribution of lunar surface	Visible-infrared radiometer	○ (MI)	○ [NOTE 1]	○ (HySI,M3) [NOTE 1]	—	—
	Visible-infrared spectrometer	○ (SP)	—	○ (SIR-2)[NOTE 4]	○ (SIR)[NOTE 4]	—
Topography and surface layer structure of Moon	3D camera	○ (TC)	○	○ (TMC)	○ (AMIE)[NOTE 6]	—
	Laser altimeter	○ (LALT)	○	○ (LLRI)	—	—
	Radar sounder	○ (LRS)	○ [NOTE 2]	—	—	—
Global gravitation field of Moon	Main- and sub-satellite system	○ (RSAT,VRAD)	—	—	—	— ○ (DGE)
Environment at lunar surface	Magnetometer	○ (LMAG)	—	—	—	○ (MAG,ER)
	Charged particle spectrometer	○ (CPS)	○	○ (RADOM)	—	○ (APS)
	Plasma observation device	○ (PACE)	○	○ (SARA) [NOTE 5]	○ (SPEDE)	—
	Radio observation	○ (VRAD)	—	—	—	—
Others	Terrestrial plasma environment	○ (UPI)				
	High definition television	○ (HDTV)				
	Water-ice at lunar poles			○ (MiniSAR)		○ (NS)
	Lunar impact			○ (MIP)		
	Motion on Moon's axis of rotation				○ (RSIS)	

[NOTE 1] Imaging spectrometer.
[NOTE 2] Measurement of thickness of lunar soil by microwave radiometer.
[NOTE 3] Observation to hard X-ray region.
[NOTE 4] Near-infrared spectrometer.
[NOTE 5] Measurement of neutral atoms pulled from lunar surface by solar wind.
[NOTE 6] 2-dimensional multi-color image.

Source: Reference[34-38]

return involving passive capture of cometary and interstellar dust and capsule recovery with Stardust. However, Japan's "HAYABUSA" succeeded in demonstrating a sample return technology by round-trip interplanetary flight utilizing its ion engine system, active collection of samples from the surface of the object celestial body, and capsule return (scheduled for demonstration in June 2010). As a total package, this can be considered one technical system for future exploration of small solar system bodies. Thus, it can be said that Japan has established an original space technology which is unrivaled by other nations.

(2) Integration of Japan's intellectual resources by an inter-university research system

The Institute of Space and Astronautical Science (ISAS), which is part of the Japan Aerospace Exploration Agency (JAXA), functions as an inter-university research institute, requesting

LRO
(Purpose) To collect information on the topography of the Moon, obstacles to landing/inclination, water-ice and other resources, the radiation environment, and temperature, illumination conditions, and terrain, etc. in polar regions at candidate lunar bases. 1. Lunar Orbiter Laser Altimeter (LOLA) · Produce a high-resolution global topographic model for development of precise and safe landing and exploratory activities. Characterize the polar illumination environment and identify ice in permanently shadowed polar regions. High resolution: 0.1m (approx.) 2. Lunar Reconnaissance Orbiter Camera (LROC) · Observe obstacles/illumination conditions at candidate landing sites. · Narrow angle (resolution: approx.0.5m), wide angle (resolution: approx. 100m) 3. Lunar Exploration Neutron Detector (LEND) · Observe distribution of water-ice and hydrogen, radiation environment. Spatial resolution: 10km (approx.) 4. Diviner Lunar Radiometer Experiment (DLRE) · Observe temperature distribution at lunar surface. Temperature measurement accuracy: 5°C (approx.) 5.Lyman-Alpha Mapping Project (LAMP: ultraviolet imaging spectrometer) · Detect ice/frost in surface layer of permanently shadowed areas, observe topography. Wavelength resolution: 3.5nm (approx.), spatial resolution: 260m (approx.) 6.Cosmic Ray Telescope for the Effects of Radiation (CRaTER) · Observe galactic cosmic rays, etc. in order to assess effects on human body using tissue-equivalent plastic. Spatial resolution: 77km (approx.) 7. Miniature Synthetic Aperture Radar (mini-RF) · Observe water- ice and other volatile substances in polar regions.

Source: Reference[39]

LCROSS
Lunar Crater Observation and Sensing Satellite (LCROSS) (Purpose) To conduct a survey in connection with the existence of water-ice in the permanently shadowed areas of the lunar surface. · Comprises the upper stage of the Centaur launch rocket and an observation vehicle (Shepherding Space Craft: S-S/C). Will be launched together with the LRO. · The upper stage rocket will be inserted into an impact trajectory with the permanently shadowed area under control by the S-S/C, and the plume produced by the impact of the upper stage will be observed by the S-S/C and earth-based telescopes. The S-S/C will then impact into the Moon's surface. · In the past, the Lunar Prospector was also crashed into the Moon's surface for the same purpose, but the existence of water-ice remained unconfirmed.

Source: Reference[40]

GRAIL
(Purpose) To measure the global gravitational field of the Moon for research on the internal structure from the mantle to the core and the thermal evolution of the Moon. The 10th mission in the Discovery Program. ·Rate of change in the distance between twin probes in polar orbit around the Moon at a relative distance of 175-225km and altitude of approximately 50km will be measured in order to measure the global gravitational field of the Moon. ·Spatial resolution is approximately 30km x 30km; gravitational field measurement accuracy ≦ 10mGal (approx.). ·Images taken by remote control of onboard cameras will be used for educational purposes. ·After scientific observations for approximately 90 days, the vehicles will be impacted into the lunar surface by orbit control. Data will be analyzed over a period of about 12 months.

Source: Reference[41]

Figure 8 : Outline of unmanned lunar probes in NASA's Lunar Precursor Robotic Program

broad participation by researchers from Japanese universities, research institutes, and other related organizations. while promoting space science projects based on consensus among these researchers, it also cooperates in graduate school education in the space and aeronautics field through a joint graduate school program responding to the request from universities.

Sample return from small solar system bodies such as asteroid Itokawa is considered to be easier than return from celestial bodies where the effect of gravity is larger. However, because primitive bodies such as asteroids are thought to hold information on the early formation of the Solar System, investigation and research on primitive bodies, including sample analysis on the Earth, has great scientific value. Furthermore, autonomous descent, landing, and takeoff ("touch & go") using optical information is an advanced engineering technology. ISAS is involved in planning and promoting missions of both scientific and engineering significance, like HAYABUSA, by integrating the intellectual resources of Japan's researchers and engineers.

The successful touchdown of HAYABUSA on an asteroid, which was the world's first, and the recovery from the near-fatal propellant leak accident following the successful landing, are evidence of the presence in ISAS of outstanding researchers and engineers who have an indomitable spirit which remains steadfast in the face of unexpectedly difficult events, and the capabilities to respond appropriately and in a timely manner to such events. For Japan, which is an export-dependent nation with few natural resources and low food self-sufficiency, human resources are the source of the nation's power. Thus, training of the next generation of human resources by researchers and engineers like those of ISAS is a critical function. It may be noted that the operation of HAYABUSA and KAGUYA and the planning and promotion of their successor missions are now being carried out under the responsibility of a newly-established lunar and planetary exploration program group in JAXA, that is, the Space Exploration Center (JSpEC).

(3) Promotion of comprehensive lunar scientific research

KAGUYA was truly the world's most advanced full-scale scientific lunar exploration mission since the Apollo Program, as it not only carried high performance instruments for observation of the elemental/mineral distribution and topography/ surface layer structure of the Moon, but also resulted in the creation of a detailed topographical map of the entire Moon, including the polar regions, which was the world's first, and measured the global gravitational field of the Moon, including the farside, which was another world's first, using a unique Japanese main- and sub-satellite system. In comparison with the missions of other nations, this mission also suggests the sincere attitude of the Japanese researchers toward seeking a comprehensive elucidation of the mysteries of the origin and evolution of the Moon as a pure scientific research object. In order to realize a radar sounder for detecting weak reflected radio waves so as to observe the surface layer structure of the Moon, and a magnetometer for measuring the Moon's weak magnetic anomalies, high technical capabilities were necessary in all the stages of design, manufacture, and testing.[44] Thus, the success of these efforts demonstrated the high level of Japan's space development technologies. There are also strong interests among the general public in high definition television images such as the earthrise image of the full Earth.

6 Recommendations and future directions

(1) Continuing development of unique Japanese space technologies unrivalled by other countries and promotion of international cooperation

Researchers from Europe and Japan jointly proposed Marco Polo, which is a sample return mission from primitive bodies such as comet-asteroid transition objects (CAT) as part of ESA's Cosmic Vision program. This proposal has passed the first selection process.[45] According to this proposal, Japan would develop a probe to perform sample return, which is one of Japan's unique technologies, taking advantage of its experience in the development of HAYABUSA, and the European side would be responsible for the development and launch of a lander, utilizing its experience in the development of Rosetta.

Perhaps because Japan's solar observation satellite HINODE carried three advanced, high performance instruments (SOT, XIT, EIS), to which there were no instruments comparable in other countries, and perhaps because these instruments also attracted strong interests from foreign researchers, satellite operation and research activities are being planned with the participation of researchers from the United States and the United Kingdom, as well as Japanese researchers, in observation planning meetings held at the JAXA Sagamihara Campus, and international researchers are also making long-term stays at the campus.[46]

These examples show that international cooperation can be promoted, either on an equal basis or under Japanese leadership, based on Japan's unique advanced technologies. In Solar System exploration, including small solar system bodies, it is expected that Japan should further continue to develop its unique technologies which are unrivalled by those of other nations, as exemplified by the sample return using the ion engine, and to promote international cooperation with its friendly nations to maintain and strengthen its relationship of trust with those nations.

On March 12 2008, NASA proposed the concept of an International Lunar Network (ILN) and called on Japan and other countries to participate. As a successor mission to KAGUYA, Japan is studying an unmanned lunar soft lander/surface exploration vehicle/overnight stay technology.[47] High expectations are placed on the development of unique Japanese technologies and various forms of international cooperation. Japan once planned the LUNAR-A project, originally intended to explore the interior structure of the Moon by constructing an observation network of lunar seismographs and thermal flux meters on the lunar surface using two spear-shaped penetrators to penetrate the lunar surface, rather than the conventional remote sensing observation. Although this project was cancelled due to difficulties in the development of the penetrators,[48] both the United Kingdom's MoonLITE (the Moon Lightweight Interior and Telecoms Experiment) mission[49] and the United States' New Frontiers Program[50] study the feasibility of Solar System exploration using penetrators, and the potential of this technology is high.

Lunar and planetary exploration is generally said to require approximately 10 to 20 years from mission planning to mission completion. Thus, if next missions are planned based on results of prior completed missions, the base of researchers and engineers will be lost due to retirement. From this viewpoint, systematic planning and promotion of missions are necessary.

(2) Promotion of science and mathematics education activities for young generations

Since the publication of the still and video images of the lunar surface, earthrise, and others taken by KAGUYA, JAXA has received numerous requests for images from science museums, high schools, universities, and other educational institutions in Japan and from educational institutions and research institutes in other nations. In response to these requests and the high domestic and international interests, JAXA recorded images and prepared an educational DVD which also includes a voice commentary, and began free-of-charge distribution to educational institutions in Japan and other nations at the end of May 2008.[44] Thus, it can be said that the results of lunar and planetary exploration are a good example which inspires interests in science and technology of young generations. In order to secure the science and engineering human resources required for the future, it is expected that Japan should continue and strengthen its outreach activities based on the scientific achievements of its lunar and planetary exploration missions.

NASA is also actively developing science and mathematics education activities for young generations, for example, by preparing excellent educational materials based on each of its missions in the Discovery, New Frontiers, and other programs. Perhaps due to the high global reflection of the high definition television images taken by Japan's KAGUYA, NASA is also planning educational activities using the images taken by an onboard camera on its GRAIL mission.[41]

Furthermore, may be triggered by the performances of the HAYABUSA, KAGUYA, and other Japanese missions, students at Tokyo Institute of Technology, Nihon University, and other universities are now engaged in planning, design, manufacture, launch, and operation of ultra-small micro-satellites (sometimes called "nano-satellites") under a cycle of approximately 2 years, and graduates who have experienced the total process of "monozukuri" (distinctively Japanese manufacturing) in this work are finding jobs not only in the aerospace sector, but also in the automobile manufacturing industry and other sectors.[51] In space development, it is necessary to construct systems which achieve mission requirements by assembling various subsystems, components, and alike, and even the handmade satellites manufactured by these students must function in space of severe high vacuum, radiation, and heat environments. We can expect that graduates who have acquired system engineering techniques through above activities should continue to play an active role in Japan's manufacturing industries.

In order to support such small satellite development activities, JAXA provides opportunities for piggyback launching of small satellites with other mission, utilizing H-IIA rocket extra launch capacity. Four small satellites from Waseda University, Kagoshima University, and other Japanese universities and organizations were selected as candidates for such piggyback launch with Venus probe PLANET-C.[52] JAXA intends to maintain and strength these support activities in the future as well. As part of NASA's educational activities, it is studying a concept called the American Student Moon Orbiter (ASMO) in order to nurture the next generation of American aerospace engineers, and is planning to provide technical support by NASA engineers, use of its facilities, and other support for the design, manufacture, launch, and operation of a small lunar orbiter by American students.[53] Similarly, the European Space Agency (ESA), as part of its educational activities, is also making efforts to train the next generation of European aerospace engineers by launching a European Student Moon Orbiter (ESMO) and European Student Earth Orbiter (ESEO).[54]

7 Conclusion - Various images of the terrestrial planets

The earthrise image of the full Earth taken by KAGUYA shows the blue, watery planet Earth rising over a desolate Moon in the pitch-black darkness of space (Figure 9). Amid urgent voices speaking of the crisis of global warming caused by anthropogenic environmental pollution, this image makes us recognize anew the importance of our irreplaceable home, the planet Earth.

The focus of this paper has been exploratory missions which have taken up the challenge of elucidating the mysteries of the origin and evolution of the Solar System. On the other hand, the author would like to point out that research on the unique and universal features of the planets of the solar system is also important, and this is in no way inferior to the work of these missions. The Earth on which humankind lives is a blue, watery planet. In contrast, the environments of the other terrestrial planets, Mercury, Venus, and Mars, are too severe for us humans to live. Like the Earth, Mercury has an intrinsic magnetic field, but its atmosphere is extremely rarefied, and the daylight side, which is illuminated by the Sun, is a world of scorching heat where the surface temperature reaches approximately 430°C, while the nighttime side is a world of extreme cold, at approximately 180°C below freezing point. On Venus, which is roughly similar to the Earth in size and distance from the Sun and is sometimes called our twin planet, 96% of the thick atmosphere is carbon dioxide. Due to the greenhouse effect of this CO_2, the surface temperature reaches 460°C, and the atmospheric pressure at the planet's surface is thought to be approximately 90 times that on the Earth. Mars, which is also called the Red Planet, is a cold planet covered with an atmosphere which is rarefied, at only about 1% that of the Earth, and consists mainly of CO_2. However, the observational data suggest that abundant water may have existed on that planet in the past.

Figure 7 : KAGUYA (SELENE) during testing on Earth

Source : JAXA

In spite of the fact that the terrestrial planets consist of the same elements, such as rock and iron, each has taken a completely different evolutionary course. From this viewpoint, researching the individual differences of these planets and the universal features that they have in common is considered to be of great significance for understanding our present Earth and predicting its future. NASA's Phoenix Martian lander will investigate the existence of subsurface water ice, and Japan is also currently developing BepiColombo as a joint Japanese-European Mercury exploration program and Venus probe PLANET-C.

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References

For general trends in connection with the Solar System, the author referred to the Newton publication "More that We'd Like to Know about the Solar System: The Science of the Planets – A Succession of Recent Results," published July 20, 2007, by Newton Press (Japanese).

[1] "New Frontiers in the Solar System: An Integrated Exploration Strategy," Solar System Exploration Survey, National Research Council:
http://www.nap.edu/catalog/10432.html

[2] Homepage of the Space Foundation (United States of America), "Japan Aerospace Exploration Agency Wins 2008 Jack Swigert Award for Space Exploration, Colorado Springs, Colo. (February 12, 2008):
http://www.spacefoundation.org/news/story.php?id=459Bbsp

[3] External report: "The Second Report on a New Image of the Solar System – The Shape of the Solar System Revealed – ," Science Council of Japan, Physical Sciences and Engineering Section Meeting, IAU Subcommittee and the Astronomy and Astrophysics Subcommittee, June 21, 2007:
http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-20-t39-3.pdf (Japanese)

[4] Homepage of Kobe University: "Bulletin: Is there an unknown planet at the outer edge of the Solar System?":
http://www.kobe-u.ac.jp/info/topics/t2008_02_28_01.htm (Japanese)

[5] Official Site of Chronological Scientific Tables: "Special Edition on Pluto - What Happened in the Solar System in the Summer of 2006? : Mercury, Venus . . . Neptune, Pluto Now":
http://www.rikanenpyo.jp/top/tokusyuu/index.html (Japanese)

[6] "Exploration of Small Solar System Bodies as Program Exploration," Makoto Yoshikawa, Japan Aerospace Exploration Agency, Proceedings of the 29th Symposium on Solar System Science 2007, pp. 58-61, December 19-20, 2007. (Japanese)

[7] "JAXA Briefing: JAXA Program for Exploration of Primitive Bodies in the Solar System," Makoto Yoshikawa, Japan Aerospace Exploration Agency, Journal of the Japanese Society for Planetary Science, Vol. 17, No. 1, pp. 50-53, 2008. (Japanese)

[8] Homepage of NASA Discovery Program:
http://discovery.nasa.gov/index.html

[9] Homepage of NEAR Shoemaker:
http://near.jhuapl.edu/

[10] Homepage of Deep Space 1:
http://nmp.jpl.nasa.gov/ds1/

[11] Homepage of Stardust:
http://stardust.jpl.nasa.gov/home/index.html

[12] Homepage of Institute of Space and Astronautical Science, JAXA, "Asteroid Explorer HAYABUSA":
http://www.isas.jaxa.jp/j/enterp/missions/hayabusa/index.shtml (Japanese)

[13] Homepage of European Space Agency (ESA), "Rosetta":
http://www.esa.int/SPECIALS/Rosetta/index.html

[14] Homepage of Deep Impact:
http://solarsystem.nasa.gov/deepimpact/index.cfm

[15] Homepage of New Horizon:
http://pluto.jhuapl.edu/science/scienceOver.php

[16] Homepage of Dawn:
http://dawn.jpl.nasa.gov/

[17] Homepage of ULA, "Products and Services":
http://www.ulalaunch.com/index_products_services.html

[18] Homepage of ESA, "Launchers":
http://www.esa.int/SPECIALS/Launchers_Home/index.html

[19] Homepage of JAXA "Rockets and Transportations Systems":
http://www.jaxa.jp/projects/rockets/index_j.html (Japanese)

[20] "Seminar: Space Probe "HAYABUSA" and Plasma Engineering: 2. 'Microwave Discharge Ion Engine Aboard the "HAYABUSA" Asteroid Explorer,'" Hiroshi Kuninaka, Japan Aerospace Exploration Agency, Journal of Plasma and Fusion Research, Vol. 82, No. 5, pp. 300-305, May 2006. (Japanese)

[21] Forefront of Space Science, "Presentiments of an Age of Great Space Voyages – The Asteroid Explorer 'HAYABUSA' and Ion Engine Technology," Hiroshi Kuninaka:
http://www.isas.jaxa.jp/j/forefront/2004/kuninaka/02.shtml (Japanese)

[22] Information provided by Prof. Hiroshi Kuninaka, JAXA Institute of Space and Astronautical Science, May 16, 2008. (Japanese)

[23] "Deep Space Travel Using the Ion Engine of

HAYABUSA Probe," Hiroshi Kuninaka, Special Materials of JAXA, "Collected Papers on Space Missions Using Low Thrust/Continuous Acceleration," (JAXA-SP-07-020), Japan Aerospace Exploration Agency, ISS1349-113X, pp. 1-6, February 2008. (Japanese)

[24] JAXA Press Release, "Current Status of No. 20 Science Satellite (MUSES-C) 'HAYABUSA'": http://www.jaxa.jp/press/2005/03/20050316_sac_hayabusa_j.html

[25] Homepage of NASA In-Space Propulsion: http://www.grc.nasa.gov/WWW/InSpace/ (accessed August 19, 2008)

[26] "Discovery & New Frontiers News – New Frontiers Program Announcement," NASA, May 14, 2008: http://discoverynewfrontiers.nasa.gov/news/news_archive/2008/news_051408.html

[27] Information provided by Prof. Hiroshi Kuninaka, JAXA Institute of Space and Astronautical Science, May 19, 2008. (Japanese)

[28] "Plans for Demonstration of Solar Powered Sail," ISAS News No. 288, March 2005: http://www.isas.ac.jp/ISASnews/No.288/mission-05.html

[29] "The Shape of the Primeval Solar System Explained by the Stardust Mission," Takashi Mikouchi, Journal of the Japan Society of Planetary Science, Vol. 16, No. 4, pp. 270-273, 2007. (Japanese)

[30] "Improvement and New Development of Sampling Techniques Aiming at a Successor to the HAYABUSA," Saburo Matsunaga et al., Proceedings of the 29th Symposium on Solar System Science 2007, pp. 54-67, December 19-20, 2007. (Japanese)

[31] "Marco Polo Capsule and DASH-II Program," Tetsuya Yamada, Proceedings of the 29th Symposium on Solar System Science 2007, pp. 72-74, December 19-20, 2007. (Japanese)

[32] "The Scientific Context for Exploration of the Moon: Final Report," Committee on the Scientific Context for Exploration of the Moon, National Research Council, 2007.: http://www.nap.edu/catalog/11954.html

[33] Homepage of the NASA Space Science Data Center, "Clementine Project Information": http://nssdc.gsfc.nasa.gov/planetary/clementine.html

[34] Homepage of the JAXA Institute of Space and Astronautical Science, "Moon Orbiter KAGUYA": http://www.isas.jaxa.jp/j/enterp/missions/kaguya/index.shtml (Japanese)

[35] Homepage of the NASA Space Science Data Center, "Chang'e 1": http://nssdc.gsfc.nasa.gov/nmc/spacecraftDisplay.do?id=2007-051A

[36] Homepage of ISRO, "Chandrayaan": http://www.isro.org/chandrayaan/htmls/home.htm#

[37] Homepage of ESA, "SMART-1": http://www.esa.int/SPECIALS/SMART-1/index.html

[38] Homepage of Lunar Prospector: http://lunar.arc.nasa.gov/

[39] Homepage of LRO: http://lro.gsfc.nasa.gov/

[40] Homepage of LCROSS: http://lcross.arc.nasa.gov/

[41] Homepage of GRAIL: http://moon.mit.edu/

[42] JAXA Press Release, "Publication of Topographical Map Using Global Observation Data of the Moon Obtained with the Laser Altimeter of the Moon Orbiter 'KAGUYA (SELENE)' – Measurement of the Altitude of the Moon at Approximately 6 Million Points, 10 Times the Former Data," April 9, 2008: http://www.jaxa.jp/press/2008/04/20080409_kaguya_j.html (Japanese)

[43] JAXA Press Release, "Success in Photographing 'Earthriese: Full Earth Rising over the Moon' by the High Vision Camera (HDTV) of the Moon Orbiter 'KAGUYA (SELENE),'" April 11, 2008: http://www.jaxa.jp/press/2008/04/20080411_kaguya_ j.html (Japanese)

[44] Interview with Dr. Yoshisada Takizawa, Project Manager, SELENE, JAXA, May 9, 2008. (Japanese)

[45] "First Selection of Candidate Missions for CV2015 Assessment Studies," ESA, October 18, 2007.: http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=41438

[46] ISAS News, "Special Edition on the Solar Observation Satellite 'Hinode,'" JAXA Institute of Space and Astronautical Science, No. 323, February 2008:
http://www.isas.jaxa.jp/ISASnews/No.323/ISASnews323.pdf (Japanese)

[47] Homepage of the JAXA Space Exploration Center (JSpEC):
http://www.jspec.jaxa.jp (Japanese, with link to English)

[48] Homepage of the JAXA Institute of Space and Astronautical Science, "Lunar Probe LUNAR-A":
http://www.isas.jaxa.jp/j/enterp/missions/lunar-a/index.shtml (Japanese)

[49] "Lunar exploration - Potential UK and US collaboration," British National Space Centre, February 15, 2008:
http://www.bnsc.gov.uk/content.aspx?nid=7208&hl=MoonLite

[50] "Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity," Committee on New Opportunities in Solar System Exploration: An Evaluation of the New Frontiers Announcement of Opportunity, pp. 28-32, National Research Council:
http://www.nap.edu/catalog/12175.html

[51] Materials of the 18th Meeting of the Space Activities Commission (MEXT), "18-1 Committee Report on the Trends in the Development of Micro-Satellites by Universities and the Development, Launch, and Operation of SEEDS2 and Cute-1.7 + APDII," Saburo Matsunaga, Yasuyuki Miyazaki, May 21, 2008. (Japanese)

[52] JAXA Press Release, "Results of Selection of Small Satellite to Piggyback on PLANET-C":
http://www.jaxa.jp/press/2008/07/20080709_sac_sat_j.html (Japanese)

[53] Homepage of ASMO:
http://asmo.arc.nasa.gov/

[54] Educational homepage of ESA:
http://www.esa.int/esaED/index.htm

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About SCIENCE AND TECHNOLOGY FORESIGHT CENTER

It is essential to enhance survey functions that underpin policy formulation in order for the science and technology administrative organiztions, 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 provied timely and detailed information about the latest science and technology trends both in Japan and overseas, comprehensive analysis of these trends, and reliable predictions of future science and technology directions to policy makers.

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

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

The following are major activities:

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

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

— Through the networks, 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. Reserch into trends in major science and technology fields

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

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

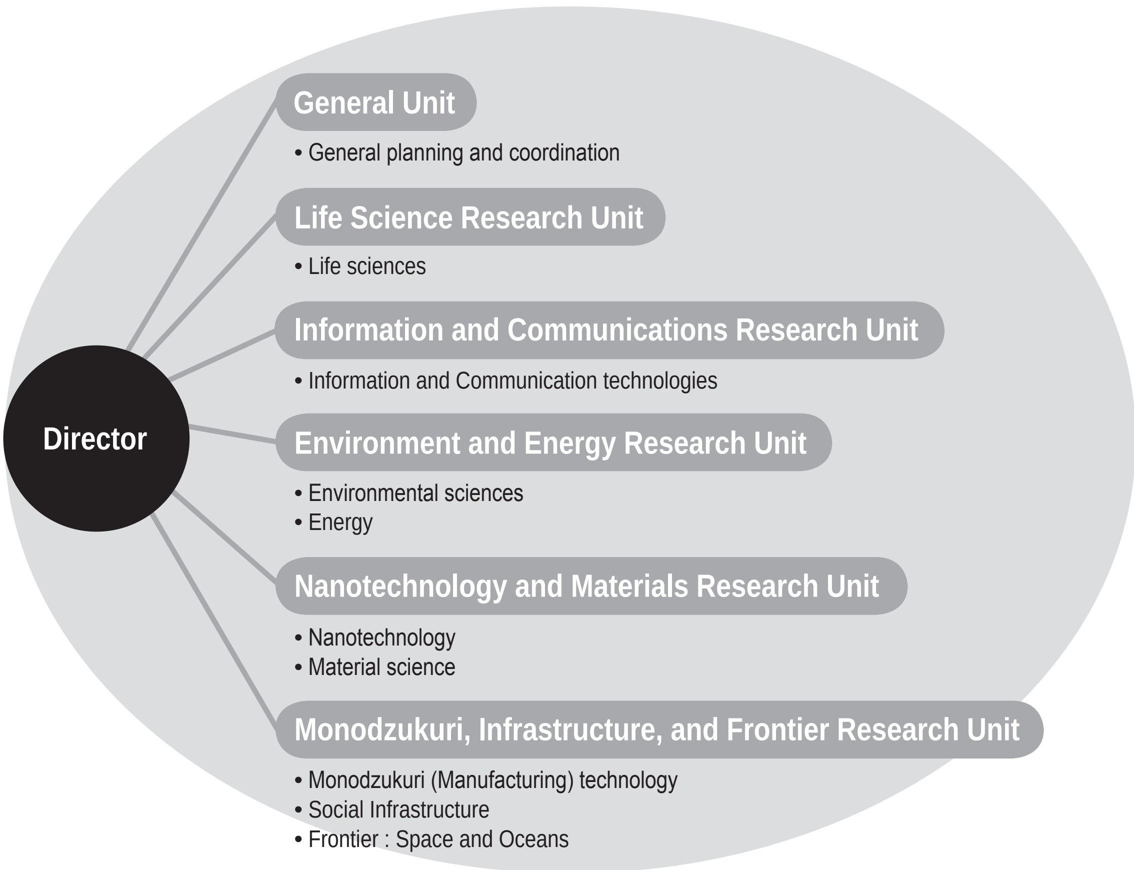
3. S&T foresight and benchmarking

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

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

— The research results are published as NISTEP report.

Organization of the Science and Technology Foresight Center



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