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Executive Summary

Life Science

1 Trends in Recent Research of Epigenetics, a Biological Mechanism that Regulates Gene Expression

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Epigenetics is defined as the phenomena that regulate gene expression through a mechanism other than genome mutation and produce changes in cells and the body. Recently much attention has been focused on epigenetics because it overlaps with many areas of research in the life sciences, including development/differentiation, the biological effects of environmental pollutants, drug development for treatments of cancer and lifestyle diseases and pathogenic mechanisms leading to such diseases.

Epigenetics research has progressed significantly in recent years. Researchers from various research areas started to collaborate in order to understand regulation mechanisms of genetic expression, followed by the increase in the number of publications of academic papers in the related fields and research meetings and related networks in Western countries. In Japan, The Japanese Society for Epigenetics was founded in 2006. To support the progress of epigenetics research, NIH of the US has announced a plan to fund over 19 billion yen over 5 years starting in 2008, and the EU has been giving fund to epigenetics research in Europe as well. On the other hand, there is no large projects funded in Japan, and epigenetics research is supported only within the JST's iPS research program for projects related to iPS cells.

From the perspective of epigenetics, most human characteristics are decided at birth but the details are subject to change and thus we have various potentials and keep changing in response to the influence of the external world throughout life.

Epigenetics is a research area with great potential and is garnering international attention. Much is expected to come out of the research through the accumulation of knowledge about the regulation of genetic expression for homeostasis and the technological development that enables artificial control of gene expression. Epigenetics research needs active support in Japan. One of the most important research topics is the development of equipment for epigenetics analysis.

The genome of this cat clone (right) is identical to that of the calico (left) but the fur pattern and personality are different.

Photo courtesy: TAMU College of Veterinary Medicine

(Original Japanese version: published in June 2009)

Information and Communication Technologies

2

Confusion in Electromagnetism and Implications of CPT Symmetry
- System of Units Associated with Symmetry -

p.25

In the late 19th and early 20th century, physics experienced three major revolutions: electromagnetism, the theory of relativity, and quantum mechanics. After more than a century, signs of a comparable new revolution are now on the horizon. The keyword of the revolution would be the CPT symmetry, which was applied to the elementary particles by the 2008 Nobel-winners, Kobayashi and Masukawa. The CPT symmetry refers to symmetry under charge reversal, space reversal, and time reversal. Meanwhile, we don't know the reason why the universal constants, such as the speed of light c, the permittivity ε_0 or permeability μ_0 of free space, the charge e of electrons, and the Planck constant h, are constant, and why such values should be taken in the International System of Units (or MKSA units). Such artificial system of units can neither provide an answer to the questions nor suggest the essential meaning of the universal constants. Introducing a system of units where $c^2 = \varepsilon_0^2 = e^2 = h^2 = 1$ and associating these universal constants with the concept of CPT symmetry, we can reveal the profound meaning of the constants, which would be quite important to the coming revolution.

The electromagnetism, established by Maxwell, is a foundation of many fields, including electronics, electrical engineering, and material science. There is confusion, however, in standard textbooks of electromagnetism—*E-B* formulation or *E-H* formulation. There are two types of magnetic fields, $\boldsymbol{H}$ (magnetic field) and $\boldsymbol{B}$ (magnetic induction or magnetic flux density), and the different standpoints exist; which field is more fundamental. One of the reasons for this confusion is an insufficient study of space reversal symmetry of electromagnetic fields. The meanings of ε_0 and μ_0 can be understood through discussions of the symmetry of electromagnetic fields.

Maxwell predicted the existence of electromagnetic waves from the question of what the field Faraday proposed really was, and Einstein derived the theory of relativity from the question of what light would look like if we traveled at the speed of light. What we believe to be obvious is often not fully understood when all things are considered, and there are also many other questions that we are still unaware of. Even if they appear extraordinary, naive but reasonable questions are essential to science. It is extremely important for Japan to cultivate scientists who are able to address such problems seriously and to develop the appropriate research environments.

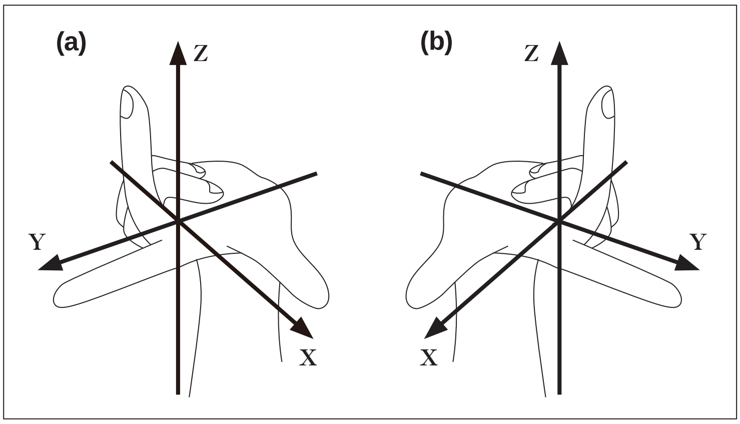


Figure : (a)the left-handed and (b) right-handed coordinate systems

(Original Japanese version: published in June 2009)

Nanotechnology and Materials

3

Developing Human Resources to Support Japan's International Competitiveness in Industry
– Human Resource Development Model for the Steel Industry, One of Japan's Key Industries –

p.41

Although Japan's steel industry has been leading the world in terms of quality improvement, the industry is now facing challenges such as expanding crude steel production and responding to user industries' shift to overseas production. Looking forward to 2030, it will also be important to respond to global changes in industrial structure. In particular, the largest issue is how to deal with environmental problems; that is to say, "green" steel production (minimized CO_2 emissions) and "third-generation" production (a flexible production system that solves problems caused by mass production) will become more desirable. To do so, further innovation will be necessary.

To respond to such circumstances, establishing a human resource development program based on a "backcasting" approach (which defines concrete requirements for future professionals and then works backwards to identify the programs necessary to develop these human resources) is more desirable than using existing human resource development programs (which aim to gradually improve the level of professionals). For example, by using the backcasting approach, students will learn, through industry-academia cooperation, things that people now normally learn only after they join a company or in continuing education classes. The gap between industry and academia will be closed, and PhD students will be ready to work effectively immediately after joining the industry.

In the steel industry, the Iron and Steel Institute of Japan has developed human development programs for each generation, and has been implementing these programs for more than 30 years. However, it is hoped that, by using the backcasting approach and reviewing these existing programs, the industry will investigate what kind of human resources it needs and take concrete action to maintain and improve Japan's industrial competitiveness.

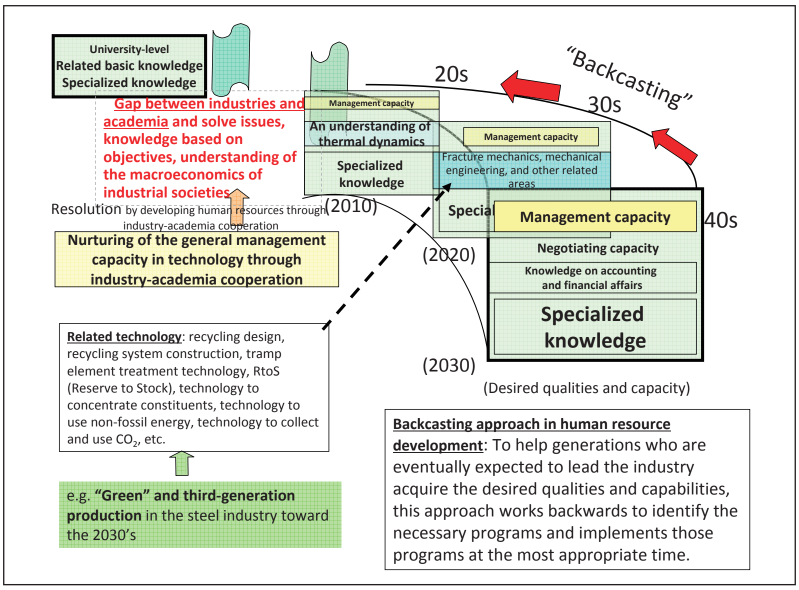


Figure : Backcasting Approach in Human Resource Development

Prepared by the STFC

(Original Japanese version: published in April 2009)

Energy

4

Steel Industry's Global Warming Measures and Sectoral Approaches

p.55

Japan's steel industry has tackled energy conservation since the 1970s and features lower greenhouse gas emissions per unit of steel production than in other countries. The Japanese industry has implemented global warming measures under its voluntary action plan since 1996, making steady achievements in energy conservation in steelmaking processes. The industry is considering exploiting further GHG emission reductions and the Clean Development Mechanism (CDM) under the Kyoto Protocol to attain its GHG emission reduction goal toward 2010. It has also launched the development of fundamentally innovative technologies from a long-term perspective.

Meanwhile, China and other emerging countries have fast expanded steel production since 2000, bringing about an increase in GHG emissions. The cap-and-trade regulations assumed under the Kyoto Protocol are expected to invite a GHG emission expansion as differences in competitive conditions prompt steel production to increase in countries where regulations are easier.

Under such conditions, Japan has called for sectoral approaches to reduce overall GHG emissions by diffusing best available technologies in major GHG-emitting industrial sectors to cut emissions per production unit on a global scale. International cooperation in CO_2 emission reductions has started. The ongoing cooperation among seven Asia-Pacific countries is viewed as a model that should be adopted for sectoral approaches. On the other hand, the World Steel Association has been promoting the Global Steel Sectoral Approach (GSSA). Sectoral approaches are about to be developed on a global scale.

From now on, empirical analyses of sectoral approaches will be required for the long-term promotion of innovative technology development.

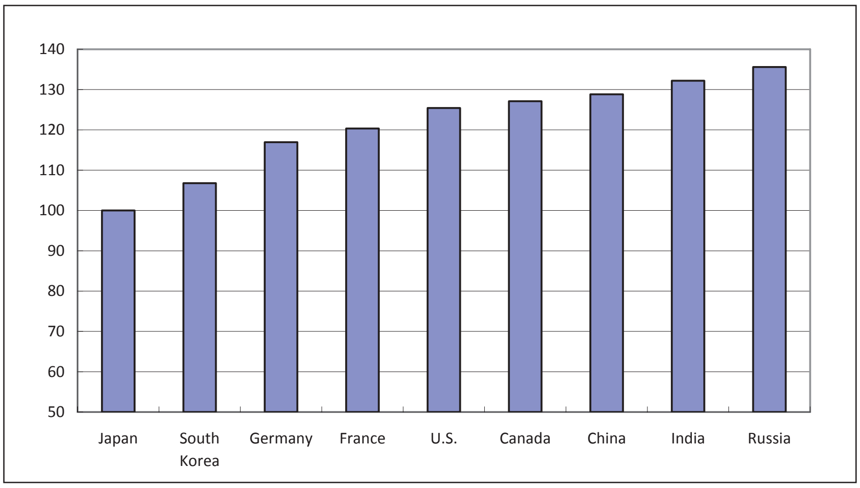


Figure : Comparison of Specific Energy Consumption for Steel Production (integrated blast furnace steelmaking processes) in Major Countries in 2000 (100 for Japan)

Prepared by the STFC based on Reference[8]

(Original Japanese version: published in May 2009)

Energy

5 High Thermal Insulation Technology Contributing to Residential Energy Saving

p.69

In November 2007, the Fourth Assessment Report by the IPCC (Intergovernmental Panel on Climate Change) presented that the reduction of energy consumption in housing, office buildings and other buildings is a key policy for mitigating global warming. In June 2008, the IEA (International Energy Agency), in its report “Energy Policies of IEA Countries – Japan 2008 Review”, stated that the Japanese energy policy leaves room for efficiency improvements in the housing sector.

In general, energy consumption for heating holds a large percentage of energy consumption by households in the developed countries. In Japan, energy consumption for heating of northern city Sapporo is large at over 50 percent of total energy consumption and energy consumption for heating accounts for about 20 percent of every region except Naha. These facts suggest the importance of reducing energy consumption for heating in winter season.

In order to reduce energy consumption accompanying heating in winter, a well-balanced improvement with both (1) “Energy saving in warm keeping of building” and (2) “Higher efficiency in heating equipment” should initially be considered. Japan has promoted energy conservation policy on heating equipment (2) with the top-runner system so far. However, what Japan should focus is to promote policies and technical development for reducing essential energy to maintain room temperature comfortable by concentrating on (1) “Energy saving in warm keeping of building”.

In energy conservation policy, the establishment of strict energy conservation standards, which meets long term vision and the support for technical development to correspond the requirements, will be urgent issues Japan should implement. In the technology side, to establish Japan’s low energy house suit for particular situation, which is cold climate in winter, hot and humid in summer, and earthquakes and typhoons are frequent, it will be necessary to develop new thermal insulation system technologies which incorporate unique technologies. For this, standardization of the system technologies beyond framework based on existing circle of housing construction method and academia will be the key action.

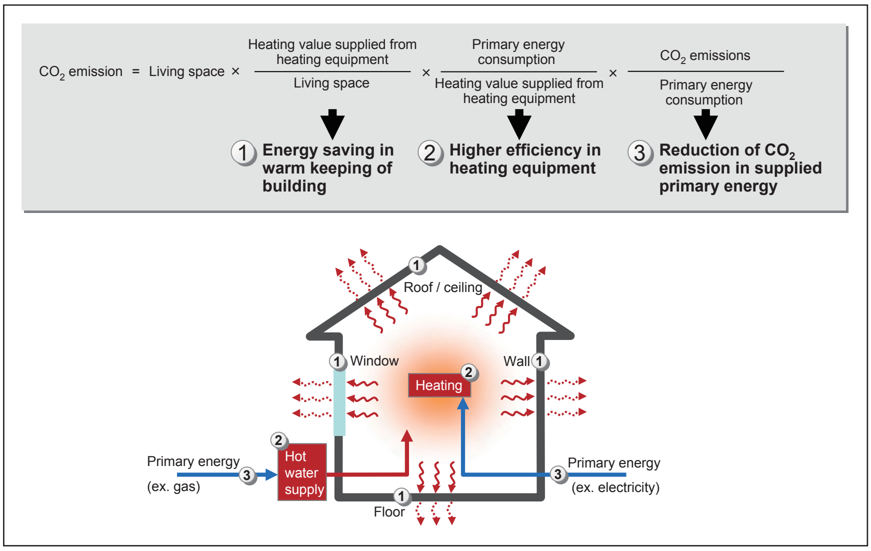


Figure : Concept of residential energy saving

Prepared by the STFC

(Original Japanese version: published in December 2008)

Social Infrastructure

6 Promotion of in Situ Verification Studies on Sediment Transport Systems Covering Mountains, Rivers, and Coasts

p.89

In Japan, a substantial amount of sediment is produced and flows into rivers each year due to the erosion of mountains and other factors. Since the period of high economic growth, many large dams have been constructed, and in the areas where outflow of sediment is great, a considerable amount of sediment is captured and deposited in reservoirs. In addition, a great amount of sedimentary sand and gravel are harvested from Japan's rivers and coasts, and the supply of sediment to the sea has been decreasing. The great number of ports and other large coastal structures also prevent coastal sediment from drifting. These conditions make dams less effective, cause riverbed degradation in areas downstream from dams, erode sandy beaches at river mouths and along coasts, and create many other problems by disrupting the balance of sediment transport systems.

To solve the problems surrounding sediment transport systems, it is essential to restore the mechanisms that secure the continuity of sediment transport and maintain its balanced supply. However, because sediment moves through wide areas in a complex manner and this movement is difficult to measure, our understanding of sediment transport is not sufficient. As such, we have not yet established the technology to assess and control the higher risk of flooding or the impact on ecosystems arising from elevated riverbeds that result from the downstream flow of sediment. Nor have we created technology to estimate the reduction in coastal erosion due to the supply of sediment from rivers.

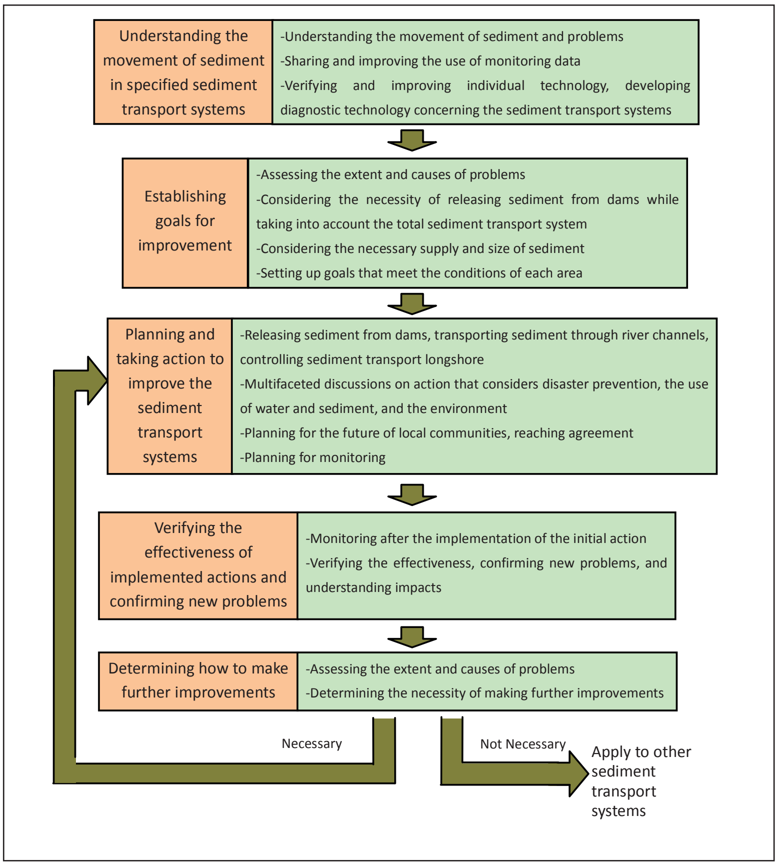


Figure : Flow of Consistent Pragmatic Studies on Issues Concerning the Sediment Transport Systems

Prepared by the STFC

First, it is necessary to select model sediment transport systems, to monitor and accurately understand the movement of sediment, and to precisely diagnose what problems exist and where, their causes and effects, and the extent of their impact while looking at the total sediment transport system. Next, it is essential to clarify goals for improvement concerning the necessary amount and the particle size of sediment to be transported to each area. It is also necessary to consistently conduct pragmatic studies that aim to solve problems and that consider, in a comprehensive manner, an appropriate sediment supply system while taking into account disaster prevention, the uses of sediment, and the environment. It is also desirable to conduct collaborate studies between a wide range of administrative and academic bodies, to develop an academic field concerning sediment transport systems, and to form a study forum to consider the establishment of a comprehensive sediment management institution.

(Original Japanese version: published in May 2009)

Frontier

7 R&D Activities for Aeronautics S&T in Japan, the United States and Europe

p.109

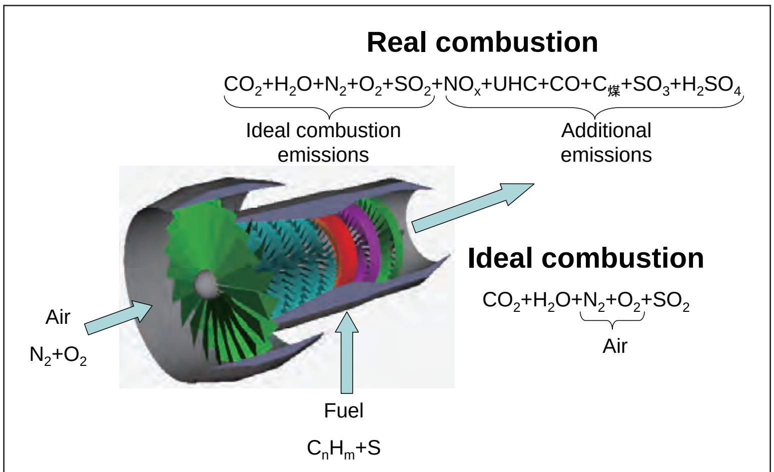
Unlike land-based transportation vehicles that need such infrastructure as roads and railways, aircraft can fly freely anywhere, even across national borders, thus realizing mankind's dream of traveling ever faster, higher and farther. As the volumes of traffic of people and goods are said to be positively correlated to economic activity (GDP), we may say that air transportation has contributed to the development of the global economy.

Meanwhile, in 1999, the Intergovernmental Panel on Climate Change (IPCC), which is studying the problem of global warming resulting from the emissions of human-derived greenhouse gases, drew up a special report on the impact on climate change of aircraft emissions including: carbon dioxide (CO_2), which is a major greenhouse gas; nitrogen oxides (NO_X), which generate tropospheric ozone and reduce methane; and water vapor, soot and aerosol particles, which lead to the formation of contrails and cirrus clouds. The IPCC's fourth report, issued in 2007, evaluated the impact on climate change of aircraft emissions other than those that lead to the formation of cirrus clouds, the mechanism of which is not well understood by modern science.

As achieving environmental friendliness is becoming an increasingly urgent challenge for aviation, the United States and Europe are implementing research and development (R&D) programs concerning environment-friendly aircraft through government-industry-academia collaboration with a view to significantly reducing CO_2 and other aircraft emissions as well as noise, with targets set for around the year 2020 and beyond. In addition, as some estimates are predicting that air traffic volume will double by around 2025 compared with around 2000, R&D programs concerning Air Traffic Management that uses navigation satellites such as GPSs (Global Positioning Satellites) are also underway in order to resolve air traffic congestion as represented by take-off and landing delays at airports and slow-speed flights.

Japan is also engaging in similar R&D programs through government-industry-academia collaboration. Although Japan leads the world in environmental technology, it is lagging in civil aircraft development, as is shown by the fact that development has just started for a Japanese small passenger jet aircraft that will be the first passenger plane to be developed in Japan in the 40 years since the YS-11. Japan should contribute more to the fight against global warming by enhancing its aeronautical technology development capability based on the full R&D cycle, from basic research by universities and other research institutions, and technology development and demonstration by R&D organizations such as the Japan Aerospace Exploration Agency (JAXA) to product development and data feedback from actual manufacturing and operations of aircraft by the aviation industry.

If a supersonic passenger plane capable of halving the current flight time across the Pacific, more than 12 hours, is realized, it is expected to bring about revolutionary change in economic activity. With an eye to participation in a future international joint development project, JAXA is engaging in an R&D project concerning quiet supersonic aircraft technology, which aims to achieve both environmental friendliness such as reduced sonic booms and lower noise during landings and take-offs and economic efficiency such as enhanced fuel efficiency through weight reduction and aerodynamic resistance reduction. In the future, this project is expected eventually to help to open the new frontier of space activities, including a space transportation system using air-breathing hypersonic aircraft as the first stage.



NOTE 1: UHC stands for unburned hydrocarbons

NOTE 2: The source of the image of the engine: NASA

Figure : Ideal and real combustion processes for jet engines

Source: Reference[5]

(Original Japanese version: published in April 2009)

1

Trends in Recent Research of Epigenetics, a Biological Mechanism that Regulates Gene Expression

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Life Science Unit

1 Introduction

The term "epigenetics" is starting to become a frequently used term, though it is not yet familiar to the general public. Epigenetics is defined as "phenomena which regulate gene expression through a mechanism other than genome mutation and produce changes in cells and the body" [Note 1, 2] (Figure 1).

The increased use of the term "epigenetics," a field under research, is due to the recent shift in major life science research from genome sequencing to the understanding of the mechanisms and regulation of genomes. Subsequently, people researching translation regulation mechanisms, the behavior of chromosomes and RNA, genes that cause disease, and development and regeneration started to exchange information so as to reveal the mechanisms that regulate genetic expression, resulting in a whole new research field. In other words, it was as if after putting some pieces of a jigsaw puzzle together, researchers started to see the big picture of a continent.

This new continent, called epigenetics, covers many areas of research in life sciences, including biological

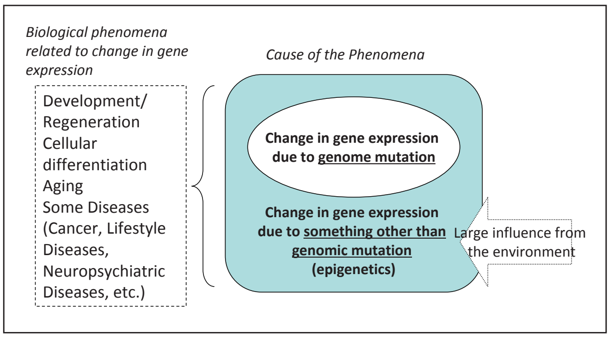


Figure 1 : Epigenetics in Biological Phenomena

Prepared by the STFC

[NOTE1] : Definition of Epigenetics

The definition of epigenetics is still under debate; however, I will adopt the following definition for this report.

*From Purpose of Founding, on The Japanese Society for Epigenetics website: *It is known that the expression of genetic information, which the genome possesses, is not regulated by only the base sequence and transcription apparatus. In organisms, gene expression is also regulated by the chemical and structural modification of chromatin, which is composed of genomic DNA and proteins, such as histones. These kinds of regulation are called" epigenetics," and are established during development and are known to work as cellular memory.*[2]

For reference, the following is the first stated definition of epigenetics.

* "Changes in genetic function, which is transmitted to offspring and daughter cells, caused by mechanisms other than changes in the underlying DNA sequence, and the study therof."[4]

[NOTE2] : Words Derived from Epigenetics

"Epigenetic" is used as an adjective as opposed to the research area of "epigenetics." In Japanese, "epigenetic" is sometimes used as the name of the research area as well. In addition, "epigenome" means epigenetic changes on the genome, and "epigenomics" is the study of epigenomes. "Epigenomic" is the adjective.

development/differentiation, the effect of pollutants, revealing the mechanisms of lifestyle diseases and developing drugs for treatment.

We wrote about epigenetics research in the field of cancer research in 2003 in this journal, Trends in Science & Technology.[1] This time we decided to focus on the trends in epigenetics research once again, since epigenetics research has branched into various research areas in the past six years and the research has advanced to the point where there is a great need for international collaboration. Therefore, I will introduce recent topics in epigenetics research and show the meaning, importance and expectations for the future in epigenetics research.

2 Examples of Epigenetics

Identical twins are known to have different body features, personalities and preferences, as well as differences in the onset of disease and the severity of symptoms, despite possessing identical genes. Moreover, these differences are small when twins are young and increase with age. Also, in the case of cloned animals, the exact same fur pattern is not passed down from the original animal to the clone, even though their genomes are identical. This means that even if a clone of your beloved calico can be created, the clone may turn out to have bi-colored fur, which does not at all look like the calico[5,6] (Figure 2). [Note 3] These are all familiar examples of epigenetics.

In addition, organisms operate strict regulation of gene expression, whereby necessary genes of the genome are expressed and unnecessary ones are terminated, at each step of development and differentiation. This regulation of gene expression allows cells with identical genomes to differentiate into tissues and organs with different shapes and functions, such as the heart, lungs and neurons, and stay that way in the body for a long time. This is also an example of epigenetics.

Moreover, epigenetics is associated with many diseases. Epigenetics is pliable and the condition of genetic expression changes in response to external stimulation, such as environment and lifestyle as well as aging, which may alter healthy genetic expression. This is called "epigenetic breakdown" and is deeply related to various diseases, including cancer.

The genome of this cat clone (right) is identical to that of the calico (left) but the fur pattern and personality are different.

Photo courtesy: TAMU College of Veterinary Medicine

[NOTE3] : Color of the Clone's Fur

When the cat clone was created, the cellular nucleus (derived from the calico) used for nuclear transplant was not fully initialized. This suppressed some gene expressions on the X chromosome, where the gene that determines the brown color of the fur is located, and as a result, the clone's fur lacked brown and was only bi-colored. However, recent research indicates that fur color and patterns are also influenced by the uteral environment during the fetal period as well as by the postnatal nurturing environment (this is also epigenetics). However, detailed mechanisms are still unclear, and it will take a little more time to create a true "copy animal."

On the other hand, this pliability is believed to be applicable for the treatment of diseases, and basic research in epigenetics is underway on how to return abnormal gene expression to normal. In addition, people involved in regenerative medicine are awaiting progress in epigenetics research since more advanced knowledge of epigenetics is required to freely create (customize) target cells and organs from cells possessing pluripotency (cells that can differentiate into any tissue or organ), such as ES cells and iPS cells.

Genomic DNA methylation is the most well known mechanism for genetic expression, but there are many others mechanisms. [Note 4] Much needs to be clarified about the mechanisms, and active investigation is underway.

3 Epigenetic Research is looming

Epigenetics research is blooming, with more academic papers being published and activities being carried out by the research community.

3-1 Number of Academic Papers on Epigenetics

How much did epigenetic research expand in the past 10 years? What is the state of research in Japan and throughout the rest of the world?

In order to answer these questions, I accessed the Web of Science, part of the ISI Web of Knowledge (THOMSON REUTERS) database, and conducted a search, using "epigen*" as the keyword, of the period from 2000 to 2008. Research articles (Articles or Reviews) published during this period were included in the search. I organized secular changes in the number of research papers, the number of research papers by country, the proportion of research papers on various research areas, and the number of research papers by research area of the authors' affiliation into graphs using the Analyze Results function of the ISI Web of Knowledge.

(1) Changes in the Number of Research Paper Publications

There were 10,110 published research papers in total related to epigenetics between 2000 and 2008 (as of February 23, 2009). Chronological change shows the significant increase in publications following 2004 (Figure 3).

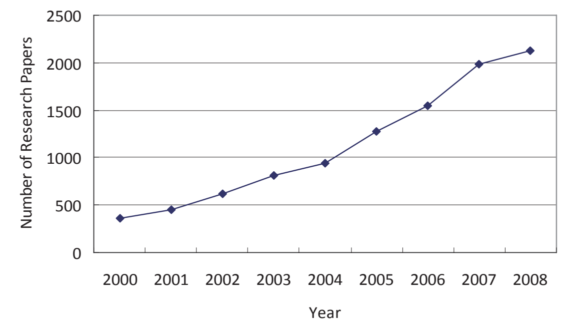


Figure 3 : Changes in the Number of Research Papers Related to Epigenetics

Prepared by the STFC

[NOTE4] : Major Mechanisms of Epigenetic Genetic Expression

Examples of Major Gene Expression by Epigenetics	Mechanisms
Methylation and Demethylation of Genomic DNA:	Cytosine base gets methylated and the methylation causes suppression of genetic transcription.
Chromatin Remodelling:	Genomic DNA in the cell forms a complex with histone, and sequences of these complexes form a structure called chromatin. Structural changes of chromatin cause activation and suppression of genetic trascription.
Methylation and Acetylation of Histones:	Methylation and acetylation of histone changes chromatin structure.
Genomic Imprinting:	The phenomena where genetic expression differs due to the discrimination of paternal or maternal genes due to difference in mehtylation pattern of DNA.
X-chromosome Deactivation:	The phenomena where mammalian female XX deactivates one of the X-chromosomes to balance out the genetic size with male XY.
Non-coding RNA Function:	Among the RNAs which do not code protein, RNAs involved in gene expression and regulation such as RNAi are involved in the mechanisms of genomic imprinting and X-chromosome deactivation.

Prepared by the STFC

(2) Number of Published Research Papers by Country

Research paper publication by country (Figure 4) shows that the US published the most: close to half of the total number of research papers. On the other hand, though Japan is second only to the US, it publishes only about 10% of the total (1,072 papers), which is a similar volume to those of Germany and England.

(3) Proportion of Research Papers on Various Research Areas

Figure 5 shows the top ten research areas for publication in the top four countries of publication shown in Figure 4: the US, Japan, England and Germany.

The result shows that in all four countries, most published papers were written by authors working in the fields of Biochemistry & Molecular Biology, Oncology, Cellular Biology and Genetics. In particular, the US and Germany had similar proportions of fields with large numbers of publications, including Biotechnology & Applied Microbiology, which was not seen in Japan or England. On the other hand, Oncology had a higher proportion in Japan compared to the other three countries, and Biophysics and Reproductive Cell Science were the characteristic areas found only in Japan. In England, Plant Science and Endocrinology & Metabolism were characteristic areas. As shown, epigenetics research is covered by a wide range of research areas and each country has a slightly different portfolio.

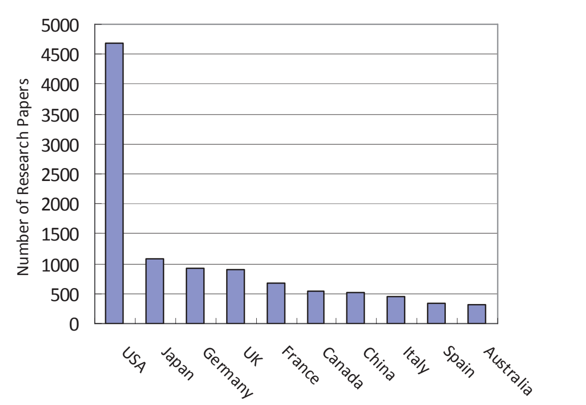
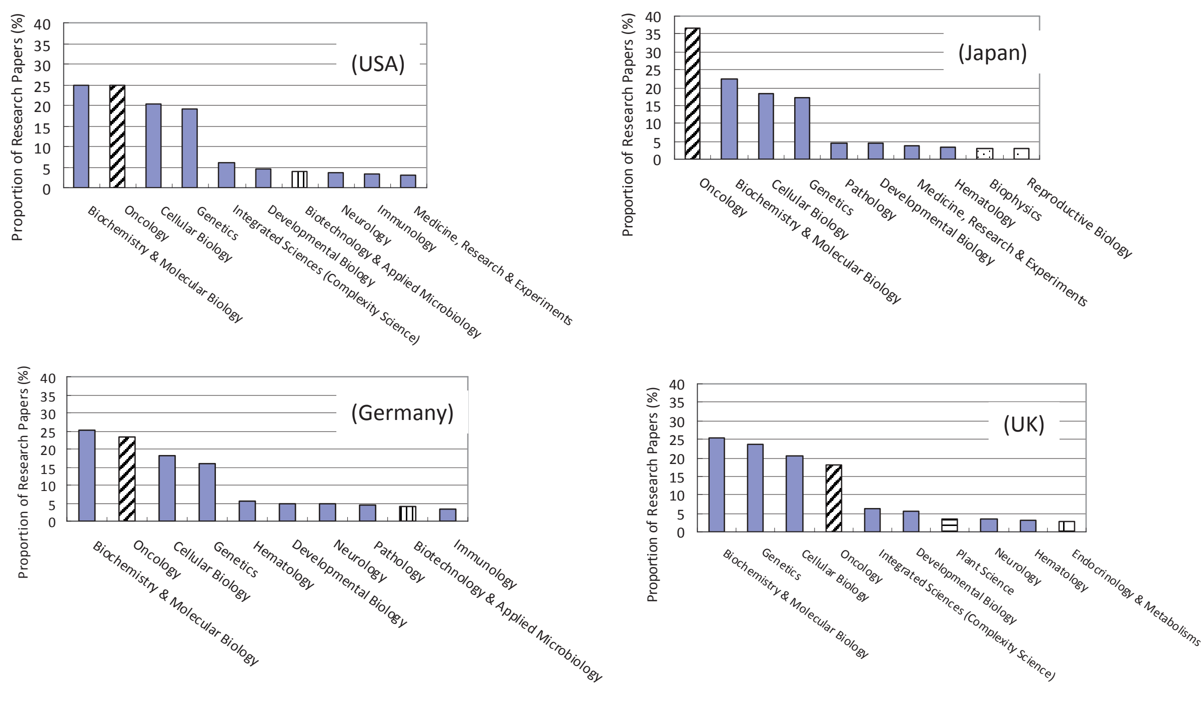


Figure 4 : The Number of Research Papers Related to Epigenetics by Country

Prepared by the STFC



*Only the top ten research areas are shown
*Papers that cover more than one research area are counted as one paper in each applicable area, therefore, the sum of the proportions may not equal 100%

Figure 5 : Proportion of Research Papers on Various Research Areas by Country (2000–2008)

Prepared by the STFC

(4) Research Institutes in Japan

Which university/public research organizations in Japan are undertaking epigenetics research?

Table 1 shows the research institutions in which the authors of 1072 research papers published between 2000 and 2008 belonged to in Japan. Among universities, the University of Tokyo, Kyoto University and Sapporo Medical University had the highest number of publications, and public research organizations with high numbers of publications included the National Cancer Institute, RIKEN, the National Genetic Research Institute and the Aichi Prefecture Cancer Center. There were generally no regional differences and epigenetic research was undertaken by various universities and research institutions in all regions.

Table 1 : The Number of Research Papers by Japanese Institutions (2000–2008)

Organization to which the authors of the paper belong	Number of papers
University of Tokyo	117
Kyoto University	91
National Cancer Institute	84
RIKEN	79
Sapporo Medical University	63
Japan Science and Technology Agency	51
Nagoya University	50
Osaka University	46
Kyushu University	44
Tohoku University	44
Tokyo Medical & Dental University	42
Chiba University	35
National Institute of Genetics	35
Okayama University	34
Hiroshima University	29
Gunma University	25
Aichi Cancer Center	24
Hokkaido University	23
Kumamoto University	22
Tottori University	22

*When authors belong to more than one institution, each institution is counted as one.

Prepared by the STFC

3-2 State of Research Community

The epigenetics research community is becoming more active in Western countries and in Japan. The following are examples of its activities.

(1) Large Scale Research Conference in the US—From the US to International Collaborative Projects—

One example of a large research conference related to epigenetics held in the US is the 69th Cold Spring Harbour Symposium[Note 5] entitled, "Genome of Homosapiens."[7] The cover of the program was a photograph of identical twin girls as if to emphasize that epigenetics differs even with the same genome, and received much attention from many researchers. Though the name of the symposium hints that it targets research on humans, most presentations were related to epigenetics of yeast, C. elegans, fruit flies, plants (Arabidopsis) and mice.

In addition, Gordon Research Conferences[Note 6] with the title of "Epigenetics" have been held every other year since 1995. The publicized program of the 2007

[NOTE5] : Cold Spring Harbor Symposium
Cold Spring Harbor Laboratory is a world renowned NPO research institute that provides frontier research and education in Biology (especially genetics), and is located in Long Island, New York. It has produced many Nobel Prize laureates, such as Barbara McClintock (maize transposons). Symposiums on the latest research topics have been held there every year since 1933.

[NOTE6] : Gordon Research Conferences
This organization has held research conferences since 1931 to facilitate free discussion and interaction for researchers of Biology, Chemistry and Physics. It has international authority and there are different section meetings (over 400) for each research topic. The conferences are financed by individual participation fees as well as financial support by governments, corporations and financial groups. The contents of the meetings are not publicized, and the participants are prohibited from citing contents from the meetings in research papers.

conference shows that there have been reports about "epigenome analysis,"[Note7] analyzing which part of the genome is causing epigenetics, and epigenetics related to human diseases in addition to the traditional main reports about gene regulation mechanisms using model animals.[8] Another conference is scheduled for August 2009, with a subtitle of "Role of the Environment and Epigenetics on Behavior, Health and Disease," suggesting there may be an increase in research on human diseases and the effect of the environment.[9]

In addition, the "Human Genome Task Force" of the American Association for Cancer Research hosted the "Human Epigenome Workshop" in 2005 as well as a conference with a selected target to plan international collaborative projects related to human epigenome mapping as a follow up in 2006.[10] At the conference, the importance of founding an international group of specialists, AHEAD (The Alliance for the Human Epigenome and Disease), was discussed. There were 29 members in the Task Force in 2006, including specialists from the US, and European countries such as England, Spain and the Netherlands, and from Asia including Japan, China, Korea and Singapore. Compared to the Human Genome Project, which was more centered on Western countries, this group has involved Asian countries from the start and has the potential to grow into a more international project. Since the analysis of epigenomes requires much more information compared to that of genomes, it requires collaborations involving many countries.

(2) Building a Large Scale Research Network in the EU

The EU founded the Epigenome Network of Excellence (NoE) as a part of Framework FP6 (2002–2006) in 2004 with funding of 12.5M Euros.[11] The NoE was founded solely to make academic profit for the epigenetics research community by supporting academic conferences, workshops, training and shared resources. The implementation period is from 2004 to 2009, however, FP7 (2007–2013) keeps it financially supported.

Recently a huge epigenetics research network was formed with the participation of 46 Universities and research institutions (83 research groups) from 12 countries: England, France, Germany, Spain, the Netherlands, Belgium, Switzerland, Italy, Austria, Croatia, Denmark and Sweden. In addition, 350 research groups from all over the world are participating in on-going research projects of the EU through the NoE website.

(3) Epigenetics Research Organizations in Japan

The Japanese Society for Epigenetics was founded in December 2006, and has been hosting annual meetings since 2007. The purpose for founding the society is as follows.

Since experimental organisms used in epigenetics research vary so widely, from yeast and plants to mammals, researchers have been split into many different specializations with many different conferences (including The Molecular Biology Society of Japan, The Japanese Biochemical Society, Japanese Cancer Association, Japanese Society of Developmental Biologists, The Genetics Society of Japan, The Botanical Society of Japan, The Japan Society of Human Genetics, The Japanese Society for Neurochemistry and Japan Society for Cell Biology). The Society was founded to promote communication, from the perspective that a place where researchers from various societies under the category of epigenetics research can gather and exchange information is absolutely necessary if progress is to be made in the research. (From The Japanese Society for Epigenetics website.) [2]

Moreover, volunteers from The Japanese Environmental Mutagen Society founded the Environmental Epigenomics Society in December 2008 as a place to discuss various toxicological phenomena with epigenetics as the keyword. The reason for its foundation was that the importance of research in the field of environmental epigenomics concerning the correlation between environmental factors and genetic expression was starting to be recognized in toxicology and clinical medicine.[12]

In addition, in order to clarify technological challenges for the industrial application of epigenetics, the New Industry and Industrial Technology Development Organization commissioned the Japan Biological Informatics Consortium to

[NOTE7] : Epigenomic Analysis (mapping)
Epigenomic analysis is the analysis of the epigenetic time course and the locus on the genome.

research "Investigation about the trends in research related to epigenetics and challenges for industrial application" in 2007, and the report was published in February 2008.[3] For this research report, an investigation committee consisting of academic-industrial committee members (including researchers representing the epigenetics field) was established, and considerations and suggestions were made based on lectures and debates held during the committee meetings. As a result, technological challenges of epigenetics were summarized in seven academic and applied areas, and the distance from practical application and the future importance were shown for each of them (Table 2). In the category of "Distance from Practical Application," there were many listed as "(far from practical application)" (10 challenges).

Table 2 : Summary of Technical Topics of Epigenetics by NEDO Investigation

Topics	Distance from practical application	Future importance	International competitiveness	Necessity of national support
1. Application for Prevention, Diagnosis and Treatment of Cancer				
Investigation of epigenetic abnormalities in each type of cancer	◎	◎	○	○
Application for diagnosis (risk, existence and characteristics of cancer)	◎	◎	◎	◎
Search for activation factors, targeting epigenetic modification molecules	◎	○	○	◎
Treatment development targeting epigenetic mutation in individual genes	△	◎	○	○
2. Investigation of Epigenetic Abnormality in Acquired Diseases other than Cancer				
Investigation of the involvement of epigenetic abnormalities in acquired diseases other than cancer (immunological diseases, neurological diseases and lifestyle diseases such as diabetes)	△	◎	○	◎
Application of epigenetic abnormalities in diagnosis	△	○	○	○
3. Factors that Induce Epigenetic Abnormalities				
Investigation of factors and lifestyles that induce epigenetic abnormalities	○	◎	○	◎
Development of prevention method for epigenetic abnormalities, such as functional food	○	◎	○	◎
4. Safety Evaluation of Chemicals, Tests				
Development of detection of potency of environment and chemicals with regard to induction of epigenetic abnormality	○	◎	○	○
Analysis of effect of fetal exposure on induction of epigenetic abnormality	△	○	○	○
5. Regenerative Medicine, Cellular Therapy, Cellular Bank				
Application for cellular evaluation and classification of clones, iPS Cells, ES Cells, organ regeneration	◎	○	◎	◎
Differentiation control of the cell by induction of epigenetic modification	△	○	○	○
Differentiation control by epigenetic regulation of individual genes	△	○	○	○
6. Evaluation, Diagnostic Tools and System Development				
Techniques and tools necessary for research (separating single cells, analysis, etc)	◎	◎	◎	◎
Development of high-sensitivity and high-precision detection equipment for diagnosis of epigenetic modification	△	◎	○	◎
Development of genome-wide analysis equipment of epigenetic modification for research	◎	△	△	○
Methods for analyzing the condition of cellular-level epigenetic modification (including imaging)	△	○	○	○
Analytical method of epigenetic modification at the tissue and individual levels	○	○	○	◎
Foundation of an epigenome database	△	◎	△	○
7. Agriculture, Livestock Farming and Food				
Strain improvement by inserting epigenetic mutation	△	○	○	○
Development of method to prevent epigenetic mutation, i.e. functional food	○	◎	○	◎

* The topics were given ◎, ○ or △ based on discussions with the investigation working group and the investigation committee, which comprises epigenetics researchers and influential members of the Industry and Academic committee.[3]
* ◎, ○ and △ in the figure indicate the level of positivity. Therefore, regarding "Distance from practical application," ◎ means close, ○ means fairly close and △ means far. With regard to "Future importance," "International competitiveness" and "Necessity of national support," ◎ means high, ○ means fairly high and △ means not very high.

Source: Reference[3]

These are considered as topics in epigenetics that are currently at the basic research level. Consequently, progress in basic research will bring about a breakthrough to the next technological development.

4 What can We Learn from Epigenetics?

Here I show what we have learned from epigenetics and what we can learn in the future.

4-1 Biological Research of Epigenetics

(1) Mystery of Mammalian Birth

One of the great mysteries of Biology is why a male and a female are necessary for mammalian reproduction. Some insects, fish, reptiles and birds are known to reproduce through parthenogenesis, the ability to reproduce without fertilization by a male; however, mammals only reproduce sexually and there have been no reports of naturally-occurring mammalian parthenogenesis in the wild.

For mammalian reproduction, genes of both a male (sperm) and a female (oocyte) are necessary, and though embryos (fertilized egg before the formation of placenta) form with only paternal genes or maternal genes, development stops before the embryo grows into an organism. Actually, a normally developed embryo's paternal and maternal genomes have different epigenetic patterns, and the combination of these two genomes, which differ epigenetically, are known to be necessary for mammalian development. This was revealed by a report in 2004[13] of two female mice (ova) that bore offspring when one of the ova was changed into a paternal epigenetic pattern. In the future, research will move ahead regarding why mechanisms that prevent parthenogenesis developed in mammals.

(2) Evolution of Mammals

The methylation of genomic DNA is conserved in a wide variety of organisms, including plants, insects, fish, birds and mammals, though genomic imprinting that differentiates paternal and maternal genes is only found in viviparous mammals. This means that genomic imprinting is not found in egg laying mammals such as the platypus.

In addition, different types of viviparous mammals, including marsupials such as kangaroos and koalas, for example, and other types such as humans and mice (eutherian), have different genes involved in genomic imprinting, which indicates that the genes of the common ancestor of marsupials and eutherians became involved in genomic imprinting after splitting off from the platypus in the evolutionary journey, and subsequently marsupials and eutherians split away and evolved to have their own genomes.[14] As shown, the process of mammalian evolution can be traced through epigenetic analysis.

(3) Essence of Plants

Though I have mainly introduced research on animals, epigenetic research on plants (Arabidopsis) is also progressing. Since the mutation of genes involved in plant epigenetics is not as fatal as it is in animals, a variety of morphology (with morphology of leaves and pollen different from normal) created through gene mutation is being studied in Arabidopsis to advance the research. In addition, morning glory, rice and wheat are used in research.

4-2 Research of the Role of Epigenetics in Disease

(1) Understanding the Pathogenesis of Cancer

Since the 1990s there have been many reports about the abnormality of the methylation of DNA in genes related to multiple cancers in various cancerous cells, bringing attention to the relationship between epigenetics and the onset of cancer.

In particular, gastric cancer is believed to be deeply related to epigenetics. One of the factors that increase the risk of gastric cancer is *Helicobacter pylori*, the infection of which was recently discovered as inducing epigenetic mutations.[15] When gene 7 on locus 8, known for its DNA methylation in gastric cancer, was compared between the gastric mucosa of subjects testing positive for *H. pylori* infection and those testing negative, positive subjects had methylation increases of 5 to 303 times those of negative subjects. In addition, non-cancerous mucosa of gastric cancer patients had methylation increases of 2 to 32 times those of gastric mucosa of healthy subjects. Moreover, the level of methylation of specific genes is reported to decrease after the eradication of *H. pylori*, indicating that knowledge of epigenetics may be useful for detecting risks of and preventing gastric cancer in the future.

The types of cancer that can be detected through epigenetics include gastric cancer, colon cancer, breast cancer and kidney cancer.[16]

(2) Relationship between the Pathogenesis of Mental Disorders and Behavioral Disorders

Recently, progress has been made in research based on the hypothesis that epigenetic breakdown is involved in neuropsychiatric disorders and neurodevelopmental disorders.

As for neuropsychiatric diseases, research includes: 1) research on the involvement of the epigenetic changes (change in histone modification) in the mechanisms of the effects of antidepressant and electric convulsive treatment, 2) research on the relationship between genomic imprinting and bipolar disorder, since the symptoms and the age of onset differs depending on whether the bipolar disorder is paternal or maternal, 3) comparative research on the methylation of DNA, which is thought to be related to the onset of bipolar disorder and schizophrenia, in postmortem brains of patients and the control group, and 4) the relationship between the variance of the onset of bipolar disorder in identical twins (cases where only one of them develops the disorder) and DNA methylation.[17] However, such research is all still heavily based on estimation, and the involvement of epigenetics is still to be clarified.

Regarding neurodevelopmental disorder, there are about nine disorders that are known to have congenital abnormality in genes related to epigenetics, such as DNA methylation, chromatin remodeling (conformational changes of chromatin), histone modification and X chromosome inactivation.[18] In addition, there was a report in 2004 that showed postnatal abuse decreases the gene expression of the glucocorticoid receptor due to methylation, which subsequently causes behavioral disorders in animals,[19] suggesting that epigenetics is involved in acquired neurodevelopmental disorders as well.

In the future, the importance of environmental factors on neurodevelopment and behavior will be understood based on scientific evidence like epigenetics. Furthermore, progress in research in this area will bring a great contribution to the prevention and treatment of behavioral disorders.

(3) Relationship with Lifestyle Diseases

Recently a hypothesis arguing that factors leading to lifestyle diseases form during the fetal period (Fetal Origins of Adult Disease) was introduced.[20] According to this hypothesis, exposure to poor nutrition or hypernutrition during the critical period of organ and metabolic formation in the fetal period induces epigenetic changes, such as DNA methylation, and disease develops as a result of postnatal hypernutrition and little exercise. In addition, the epigenetic changes caused by the fetal environment are passed down for a few generations. However, these hypotheses are not yet proven and the mechanism is still to be clarified.[21]

A report in 2005 investigated the effect of exposure to poor nutrition in the pregnant mother and normal feed to the offspring after birth on genes related to fat metabolism in the liver at postnatal day 50 in animals (adult). The result showed that DNA methylation was decreased and expressions of multiple genes were increased 3 to 10 fold, indicating that the effects of changes in the fetal environment are still observed in adults.[21,22]

In 2009, a knockout mouse lacking Jhdm2a, a gene involved in epigenetics, developed obesity and hyperlipidemia.[23]

The information above shows there is a number of indications that epigenetics is involved in the development of adult diseases.

4-3 Drug Development and Epigenetics

The development of drugs for cancer treatment targeting epigenetics is underway. In particular, inhibitors of DNA methyltransferase (DNMT) and Histone Deacetylase (HDAC) are reported to be effective.[Note 8] Table 3 shows that as of May 2009 there are three epigenetic medicines on the market, all approved in the US. In addition, there are drug candidates that are going through phase I and II of clinical trials in the US that are not listed in the figure (Belinostat, MGCD-0103, Panobinostat, Romidepsin).[24]

Decitabine, a DNMT inhibitor, is reported to be more effective when administered at a low dose for a long period compared to a high dose for a short period.[25] Since DNMT is necessary in healthy cells, its inhibitor may cause cell death at high doses and there are fewer side effects at lower doses. However, the mechanism of the effect of the long-term administration of a low dose is still unclear. In addition, a clinical trial of combined administration of

Table 3 : Current Status of Drug Development Targeting Epigenetics

Type of Inhibitor	Name of Drug	Applicable diseases	Status (May 2009)
DNA Methyltransferase (DNMT) Inhibitor	5-azacytidine (Trade name: Vidaza)	Myelodysplastic syndromes	Approved by US FDA in 2004
	5-aza-2'-deoxycytidine (decitabine) (Trade name: Dacogen)	Myelodysplastic syndromes	Approved by US FDA in 2006
Histone Deacetylase (HDAC) Inhibitor	Suberoylanilide hydroxamic acid (SAHA) (Trade name: Vorinostat, Zolinza)	Cutaneous T cell lymphoma	Approved by US FDA in 2006
	MS-275 (SNDX-275, Entinostat)	Under consideration for melanoma, hematological cancer, non-small cell lung cancer, etc.	Phase II of clinical trial in the US
	FK228 (Romidepsin)	Under consideration for cutaneous T cell lymphoma	Phase II of clinical trial in the US
	Valproate	Approved as an anti-epileptic drug Under consideration for expansion of application to include hematological cancer	Phase II of clinical trial in the US

Prepared by the STFC based on Reference [24, 25]

decitabine and various HDAC inhibitors is underway.

In Japan, there are not yet any approved epigenetic drugs. However, FK228, shown in Table 3, was discovered by a researcher at Fujisawa Pharmaceutical Co., Ltd (now Astellas Pharma Inc.) during an investigation of natural products of fermentation. It was subsequently developed into a drug by Gloucester Pharmaceutical, Inc., an American anti-cancer drug development venture company, which licensed out the product.[26]

4-4 Quality Evaluation of iPS cells with Epigenetics

Since stem cells possess the ability to differentiate into various types of cells, their application in regenerative medicine to regenerate tissues and organs damaged by disease has been long awaited. In particular, since iPS cells are produced by inserting genes into somatic cells, there are few ethical issues compared to ES cells produced by a fertilized embryo. The technology used for iPS cell generation has brought the practical use of regenerative medicine a step closer. However, current iPS cell generation technology produces inconsistent genetic expression signatures, so further technical progress is required to produce uniform and high quality iPS cells.[27] This inconsistency is caused by the variety of epigenetics of the somatic cells used to produce iPS cells.

Therefore, for practical application of iPS cells in clinical settings, the further establishment of methods to standardize iPS cells and also an epigenetic quality evaluation system to provide safe iPS cells to patients is required. For these reasons, the importance of research in epigenetics that targets iPS cells will increase in the future.

[NOTE8] : DNMT inhibitor and HDAC inhibitor

DNA methylation of DNA in epigenetics occurs when DNA methyltransferase (DNMT) causes the methyl base of S-Adenosyl-L-methionin to transfer to DNA. When DNMT is inhibited methylation decreases and genetic expression is induced.

On the other hand, during the acetylation of histone, which activates genetic transcription, the actions of histone acetyltransferase (HAT) and histone deacetylase (HDAC) oppose each other. When HDAC is inhibited, histone is acetylated and genetic transcription is activated.

As is shown, inhibiting DNMT and HDAC activates genetic expression and genetic transcription, so these two types of drugs are expected to possess therapeutic effects on diseases that are caused by suppression of genetic expression and transcription.

4-5 Development of Epigenetics Detection Equipment

It is important to detect which DNA base sequence in the genome have been methylated in order to know the epigenetic conditions as well as the diagnostic marker for diseases such as cancer in the future. However, ordinary genetic tests can not detect methylated regions.

In recent years, various methods have been developed to detect methylation. Currently, the most well known method is bisulfite sequencing, which determines the DNA sequence through bisulfite preparation of a DNA fragment to change the base.[28] Traditionally, such detection was time consuming; however, efficient high speed sequencers are starting to make exhaustive methylation analysis possible. For example, there has been a report about methylated genes of Arabidopsis thaliana detected by shotgun sequencing.[29] The size of the Arabidopsis genome is around 130 million bases, which is small compared to the 3-billion-base human genome. Nevertheless, this showed that we are a step closer to analyzing methylated genomes in mammals.

However, detection of other types of epigenetics, such as histone modification and genomic imprinting, still employ time-consuming traditional methods, including the chromatin immunoprecipitation method and the FISH method.[30] Therefore, the development of new methods and equipment that will enable high throughput (quick analysis) and hence facilitate the clinical application of epigenetics is awaited. In addition, as shown in the previous paragraph, equipment for the detection of epigenetics at the single cell level is necessary for the epigenetic quality evaluation of iPS cells. Therefore, one of the most important research areas is the development of analytical equipment for epigenetics, considering the clinical application of the findings from epigenetics research.

5 Progress of Epigenetics Research in the US and Europe

5-1 The US

NIH plotted the NIH roadmap in 2002 to promote more effective and productive medical research and it presented research topics that were the most important across the entire NIH (27 institutions).[31] Since then, there have been little changes made to the selected research topics included in the road map.

In 2007, epigenetics research was added to the NIH road map and project funding of $19 billion over 5 years starting in January 2008 was provided.[32] The funding was implemented to support the research community discussed in section 3-2.

For reference, major epigenetics research programs included in the road map as of May 2009 are indicated in Table 4.

In addition, the direction of American epigenetics research is rapidly heading toward targeting humans, as evidenced by the name of the March 2009 research achievement debriefing session related to the NIH

Table 4 : Major Epigenetic Research Program on NIH Roadmap (May 2009)

Content of Research Program	Universities in Charge
・Mapping of genomic region where epigenetics takes place in various human cells ・Development of the technology to utilize this knowledge as a reference	MIT, UCSF, Ludwig institute for cancer research, Washington University (Seattle)
Cooperate in the above projects	Baylor College of Medicine
・Epigenetic profiling, in vivo imaging of intracellular epigenetic changes	Stanford University, Rockefeller University, Fred Hutchison Cancer Research Center, Chicago University, University of North Carolina
	Cornell University, Washington University (Saint Louis), UCSD, Arkansas University Faculty of Medicine
・Discovery of new epigenetics in mammalian cells	University of North Carolina, Mount Sinai School of Medicine
・Research of epigenetics related to human health and diseases	Emory University, University of Virginia, Institute for Cancer Research, Massachusetts General Hospital, University of Texas

Prepared by the STFC

road map: “Emerging evidence for epigenomics changes in human disease.”

5-2 Europe

Support for epigenetics research in Europe started around 2000. A team participation project, EPITRON (Epigenetic Treatment of Neoplastic Disease)[33] is funded with 10.9M Euros under FP6, and seven countries participate, including France. In addition, another team project, HEROIC (High Throughput Epigenetic Regulatory Organization in Chromatin), is funded with 12M Euros also by FP6, and eight countries participate, including the Netherlands (2005-2010).[34] In addition, both projects receive additional, ongoing funding under FP7.

5-3 Japan

The activity of the research community does not seem to be reflected in the financial support, as there is yet to be a promotion of large projects (collaboration of multiple research institutions, etc.) for epigenetics in Japan. As a result, the majority of public funding goes toward individual research, such as Grant-in-Aid for Scientific Research. Starting in 2007, the “Generation Cycle and Epigenome Network of Germline” (Leader: Hiroyuki Sasaki, President of National Institute of Genetics) will be conducted for 5 years as a part of the Specific Area of Research of Grant-in-Aid for Scientific Research (approximately 2.3 billion yen).

There are some projects that include epigenetics as part of their program, for example, the “iPS Cells and Biological Function,” of the Sakigake Strategic Creative Research Promotion Project by Japan Science and Technology Agency (JST). JST has stated that “epigenetics is strongly related to cancer research, but it is also influential in stem cell research” in their G-TeC report published in January 2008 and entitled, “Stem Cell Homeostasis.”[35] In addition, they noted that they “believe that epigenetics related programs will be strongly promoted in Japan following the Western countries in the future,” indicating that large scale epigenetics research will be funded in the near future.

6 Conclusion—Expectations for Epigenetics Research in the Future—

What determines the outcome of organisms, including humans, is a question that has been debated since ancient times. Is it nature (genes) or nurture (environment), or both? Common sense tells us that it is a little bit of both. However, there has been no scientific evidence to support this belief.

As opposed to the genome, which does not change over a lifetime, epigenetics is constantly changing, right from the moment of fertilization. This means that epigenetics adds the two variables of the external influence of environment and the passage of time to the genetic information of an organism, called the genome.

Through the Human Genome Project, we became familiar with the idea that humans’ future behavior and susceptibility to disease is fully determined at birth. However, from the perspective of epigenetics, humans keep changing in response to external influences, and though the base is already determined at birth, the details are uncertain and possess much potential.

Epigenetics research has just begun and future progress is eagerly awaited. In particular, both 1) the accumulation of scientific knowledge about gene expression regulation for biological homeostasis, and as a result, 2) the development of technology to artificially regulate biological gene expressions are highly expected. This may bring about much discussion about gene control in society.

In addition, though I have only briefly touched upon it in this paper, epigenetics is known to change with the process of aging. Therefore, in the future, epigenetics research may contribute to the development of treatment for diseases and disorders specifically related to the elderly. Also, achievements in epigenetics research may help us understand how organisms are damaged by their environment or stress and how to measure the damage accurately, which may help us plan policies to protect us from such damage, by improving our lifestyles, for example.

As shown here, epigenetics is a research area that has the full potential for future achievements and is the subject of much international attention. Therefore, research on epigenetics needs active support in Japan as well. In addition, one of the most important research topics is the development of analytic equipment for epigenetics.

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Profile

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2

Confusion in Electromagnetism and Implications of CPT Symmetry
- System of Units Associated with Symmetry -

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1 Introduction

The year 2008 was a year that Japan impressed the world with its high level of science, with four Nobel Prize winners who were either Japanese or of Japanese origin. This Nobel Prizes also taught us the importance and potential of basic science. Basic science is not just important as the common knowledge of humankind. Persons with the scientific mind can play an active role in technological innovation beyond a mere extension of the present. History shows that physics, one of basic science, experienced three revolutions in the late 19th and early 20th century, namely, Maxwell and Hertz's electromagnetism, Einstein's theory of relativity, and quantum mechanics developed by Planck, Bohr, de Broglie, Shrödinger, Heisenberg, and Dirac. It goes without saying that many engineering fields, as well as physics, are still based on electromagnetism, the theory of relativity, and quantum mechanics. They are not simply academic disciplines; they significantly benefit our lives as well. For example, there would be no radio, TV, or cellular phone if we had not come to know of the existence of electromagnetic waves. Without the knowledge of quantum mechanics, the operating mechanism of semiconductor devices would be incomprehensible; there would be no computers. The theory of relativity has a key role in the definition of units of time and length.

The CPT symmetry, which was applied to elementary particles by Kobayashi and Masukawa, is an important concept. C-symmetry (charge symmetry) refers to the symmetry between particles and antiparticles. P-symmetry is the symmetry under space reversal. P-symmetry is also referred to as parity or chirality, which is the symmetry of the left-handed and right-handed coordinates. T-symmetry is the symmetry under time reversal. Associating the universal constants, such as the speed of light c, permittivity ε_0 or permeability μ_0 of free space, the charge e of electrons, and the Planck constant h, with reversal symmetries, we can reveal the profound meaning of the constants. It would be quite important to the coming revolution. In the International System of Units (or MKSA units), meter, kilogram, second, and ampere are the fundamental units, which are defined for human convenience without any universal meaning. The questions of why the light of speed has a constant value of approximately 300,000 km/s and why each individual electron has exactly the same charge of $-1.602773 \times 10^{-19}$ Coulombs are thus unexplainable. However, by adopting a system of units where $c^2 = \varepsilon_0^2 = e^2 = h^2 = 1$, and by associating the constants with CPT symmetry, we can answer the questions.

The electromagnetism, established by Maxwell, is essential in a variety of fields, such as physics, electronics, electrical engineering, and material science. There is confusion, however, in standard textbooks of electromagnetism as to whether to support E-B formulation or E-H formulation. There are two types of magnetic fields, $\boldsymbol{H}$ (magnetic field) and $\boldsymbol{B}$ (magnetic induction or magnetic flux density), and the difference standpoints exist; which field is more fundamental. One of the reasons for this confusion is an insufficient study of the space reversal symmetry in modern textbooks, although Maxwell pointed out the significance of P-symmetry in his textbook in the 1870s. We can reveal the meaning of ε_0 and μ_0 through a discussion of P-symmetry.

While introducing the "confusion" in electromagnetism, we also would like to emphasize here that we need scientists who persevere in pursuing such fundamental problems.

2 Time, Space, and Relativity - In the beginning there was light-

2-1 On time reversal symmetry

In CPT symmetry, T-symmetry is the symmetry under time reversal. Equations of motion, such as Newton's equations, Maxwell's equations, and Shrödinger's equations, always include time t as a parameter. The reversing of time refers to the transformation from a system where the parameter t flows forward to a system where t is reversed ($t' = -t$). If the equation remains exactly the same regardless of whether time is reversed or not, the equation will be referred to as conserving (or satisfying) the time reversal symmetry. Newton's equations and Maxwell's equations conserve the time reversal symmetry. Assuming that the sign of the imaginary unit i changes under time reversal, Shrödinger's equation also conserves the time reversal symmetry. Newton's, Maxwell's, and Shrödinger's equations are all differential equations, and if the equations are integrated (for example, the parabolic curve of a free fall) they also satisfy the time reversal symmetry. In discussions of time reversal symmetry, simple conversion of an increase in time into a decrease in time (i.e., playing a film in reverse) is insufficient; we must always consider the situations where the forward flow of time is switched to the reverse flow of time, and where the future is switched to the past.

When the direction of time is reversed, some quantities do not change the sign (or direction) like position vector $\boldsymbol{x}(t) \rightarrow \boldsymbol{x}(t') = \boldsymbol{x}(-t)$, while some quantities change the sign (or direction) like velocity $\boldsymbol{v}(t) \rightarrow -\boldsymbol{v}(t') = -\boldsymbol{v}(-t)$. This will be referred to as parity under time reversal. Other quantities that do not change the sign or direction are area, volume, acceleration, force, electric field, voltage, electric resistance, and energy. Quantities that change the sign or direction under time reversal are time itself, time derivatives, momentum, angular momentum, electric current, and magnetic field. We can easily determine the time reversal symmetry of an equation, if the symmetry that changes sign (or direction) under time reversal is denoted by T(-) and the symmetry that does not change sign by T(+). The values of T(-) and T(+) are -1 and +1, respectively. By definition, T(+) = T(+)・T(+), T(-) = T(+)・T(-), and T(+) = T(-)・T(-). The symbol T is added for the sake of distinction from C-symmetry and P-symmetry. The dot mark (・) represents an ordinary multiplication, and is used to make a distinction from a cross product to be described later. For example, symmetry T(+) = T(-)・T(-) holds for the equation x (distance) = v (velocity)・t (time), showing that time reversal symmetry is conserved. Thus the symmetry of an equation is conserved when the symmetries of the left side and the right side are the same.

An equation always conserves time reversal symmetry, with one significant exception. Time reversal symmetry breaks when entropy (or randomness) increases or when energy is dissipated in the form of heat: the examples are Ohmic law and air friction acting in proportion to velocity. In Ohmic law V (voltage) = I (current)・R (resistance), current is reversed under time reversal, while voltage and resistance are not. Thus, equation of symmetry is T(+)≠T(-)・T(+). If time reversal symmetry of resistance is T(-), the resistance that had been consuming energy through heat generation would in turn generate electricity, which violates the laws of thermodynamics. Consequently, the time reversal symmetry of resistance should be T(+), and symmetry of the left side of Ohmic law differs from the right side. Such a situation is referred to as time reversal symmetry being "broken" or "not conserved." The breaking of time reversal symmetry always follows an entropy increase.

2-2 History of One Second

One second is the fundamental unit of time in physics and engineering. The unit of time used to be determined from a single day on the Earth or from the rotation period. Historically (from the 1930s to 1956), the second was defined in terms of the rotation of the Earth as 1/86,400 of a mean solar day. The period of the Earth's rotation was then found to slightly fluctuate because of tides and other factors and to become longer as well. The definition of the second was thus changed to an ephemeris time (ET) based on the period of revolution of the Earth around the Sun, i.e., one second is 1/31,556,925.9747 of the solar year, which was used from 1956 to 1967.

The reason for this is that the period of revolution is more stable than that of rotation. Incidentally, the length of a single day 500 million years ago is estimated to be approximately 21 hours.[1]

Subsequently, with the development of atomic clocks, the definition of the second was changed to atomic time no longer based on the Earth's rotation or revolution; i.e., one second is the duration of 9,192,631,770 periods of radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium-133 atom. This definition in atomic time has hitherto been used. Using the periods of electromagnetic waves (microwaves) generated by the cesium-133 atom as the reference does not necessarily imply that a single day of the Earth no longer serves as the standard. If we are indeed going to adopt atomic time based on the periods of electromagnetic waves, one second might be defined not as 9,192,631,770 periods but as a round number of 10,000,000,000 periods. However, such a definition results in a discrepancy from the Earth's rotation time and is inconvenient for daily life, which is why the odd figure of 9,192,631,770 periods has been used.

Despite the adoption of atomic time, time standards are still based on the rotation (to be precise, one day) of the Earth. Since the Earth's rotation is gradually slowing down and one second is gradually getting longer, it is necessary to "adjust" atomic time. A "leap second" is thus inserted for the sake of adjustment. On January 1, 2009, a leap second adjustment was carried out by inserting "8:59:60" between 8:59:59 a.m. and 9:00:00 a.m.[2] Twenty-four leap seconds have already been inserted since 1972. The reason for the adjustment is that we essentially use the Earth's rotation time. With the Earth's rotation slowing down, it will be necessary to insert leap seconds more frequently in the future.

As has been described above, even though the second is one of the fundamental units in physics and engineering, it is an artificial (and arbitrary) unit based on the Earth's rotation for the sake of human convenience. The second is therefore not a unit of time suited to describing universal truths or phenomena.

2-3 History of One Meter

Space is measured with unit of length, and we use a meter as the base unit of length. The meter was originally defined as one ten-millionth of the Earth's meridian from the North Pole to the Equator through Paris, from which value several platinum-iridium standard bars were made. Today, it is known that the exact distance from the North Pole to the Equator is 10,002.288 kilometers and the Earth is slightly oblate. It is not accidental that the Earth has a circumference of almost exactly 40,000 kilometers.

The standard meter bar may vary in length depending on temperature (thermal expansion), corrosion, or other reasons. In 1960, at the 11th General Conference of Weights and Measures, the meter was thus redefined as 1,650,763.73 wavelengths of light corresponding to the transition between the 2p10 and 5d5 levels of the krypton-86 atom. The idea of using the wavelength of light as the unit of length had already appeared in Maxwell's writings in the 1870s, but took almost 90 years to realize.

It was at the 17th General Conference of Weights and Measures in 1983 that the definition of length changed in essence; one meter is the distance traveled by light in vacuum during a time interval of 1/299,792,458 of a second. To be precise, however, length was not defined directly, but rather the speed of light was defined as c = 299,792,458 m/s. Length is not defined until time, i.e., 1/299,792,458 of a second, is determined. In other words, length is defined by time. It follows that the speed of light is no longer a quantity to be measured by experiment but to be assigned by definition. We can see this as a step toward "the principle of constancy of the speed of light" which is one of the fundamentals of Einstein's theory of special relativity. The constancy of the speed of light has been proven by experiment, whereas the physical reason, why the speed of light should be constant, remains unexplained. Einstein called it "principle" because it was a "correct but theoretically unprovable hypothesis."

The current definition of length, even using the universal quantity of the speed of light, is based on the size of the Earth, which is not universal from a cosmic point of view. In fact, length is defined using the odd figure of 1/299,792,458 of a second, but not using one second. The original idea of the metric system that depends on the Earth's scale still survives, and we can never understand the meaning of defining length in terms of the speed of light nor enjoy the essential merits. The metric system of units currently in use is only significant as a world common language. In terms of physics, the base units of seconds, meters, kilograms, and amperes thus have no universal meaning.

2-4 Why the Speed of Light is Constant

Length is defined by time using the speed of light because time and length can no longer be defined independently. Using the speed of light c, the distance x for light to travel is expressed as:

$$x \text{ (distance)} = c \text{ (speed of light)} \cdot t \text{ (time)}. \qquad (1)$$

This relation shows that time and length (or distance) are not independently determinable. Length is determined once time is set, and time is determined once length is set. That is, we can only set either time or length freely, but not both of them at once.

The unit of the "light-year" used in astronomy represents the distance that light travels in one year. The light-year expresses length in terms of time. Using this terminology, we can say that the current definition of one meter is 1/299,792,458 light-seconds. A light-second is a more natural unit of length to take unless we do focus on the size of the Earth. One light-second is equal to approximately 300,000 kilometers. If the figures are too high, we can use nano-light-second, which is 0.299792458 meters or approximately 30 centimeters. The scale may be suitable for our daily life because it close to one shaku (= 0.303 meters) or one foot (= 0.3048 meters). Conversely, time can be defined in terms of length. For example, "a light-meter" may be the time necessary for light to travel one meter. This, however, complicates correspondence with the Earth's rotation time. Such a unit might become necessary in the distant future, but for now it would be more convenient to adopt the light-second as the base unit of length, leaving time intact.

The use of the light-second as the base unit of length means that the speed of light is defined as one. In physics, we sometimes use natural units where $c = 1$, the essential meaning of which is that length and time are the same dimensions. Accordingly, velocity is a dimensionless value and has no unit. Velocity can be expressed as 0.1 times or 0.00001 times the speed of light, for instance, so that velocity can be described without definitions of time and length. The International System of Units (or MKSA system of units) currently in use is a system with four base units; meters, kilograms, seconds, and amperes. When time and space are unified by $c = 1$, the unit of length (or unit of time) disappears, resulting in a system with three base units.

When an entropy does not increase, time reversal symmetry must be conserved in any and all equations, including equation (1). The time reversal symmetry of distance x is T(+) and that of time t itself is T(-). In order for equation (1) to conserve time reversal symmetry, the speed of light c should therefore have symmetry T(-). That is, $c = -1$ in the time-reversed world. It is natural for the sign to change since the speed of light represents a velocity. Since $c^2 = 1$ holds even in such a case, equation (1) can be rewritten as:

$$t \text{ (time)} = c \text{ (speed of light)} \cdot x \text{ (distance)}. \qquad (2)$$

This equation holds because the speed of light has no unit, and because time and distance are expressed in the same unit. The speed of light c is either +1 or -1, which is yet to be determined and thus cannot be written numerically.

Equation (1) suggests that time multiplied (or operated) by the speed of light becomes distance. Equation (2) suggests that distance multiplied (or operated) by the speed of light becomes time. This reveals that the speed of light c is a quantity (or operator) that transforms time into space and space into time. Equation $c^2 = 1$ is the condition under which time and space maintain their original scale without expansion or contraction after "time"→"space" →"time" transformations or "space"→"time"→"space" transformations. Such a condition can be said to provide the exact explanation for the principle of the constancy of the speed of light. It also implies that space is curved under $c^2 \neq 1$ (the general theory of relativity).

Multiplying (or operating) a certain equation by the speed of light c (= ±1) changes the time reversal symmetry of the equation. The speed of light c can thus be interpreted as an operator for changing time reversal symmetry or as an operator for time reversal. Here, $c^2 = 1$ is the condition under which time maintains it's original scale. As described so far, the universal system of units where $c^2 = 1$ is important in discussing the symmetry of space and time. Such a system of units even includes the essence of the theory of relativity.

3 Application of Space Reversal Symmetry to Electromagnetism

3-1 On Right-handed and Left-handed Relations in Space

Spatial translational symmetry and rotational symmetry have significance for crystal engineering, semiconductor physics, quantum mechanics, etc. This report will not deal with translational symmetry and rotational symmetry, however, but only with space reversal symmetry. Space reversal symmetry refers to P-symmetry within CPT symmetry, and is also called parity. It signifies the symmetry of transformation between right-handed coordinate system and left-handed coordinate system.

We usually use a "rectangular coordinate system" (Cartesian coordinates) which is defined by three mutually orthogonal reference lines, *x, y*, and *z* axes in a three-dimensional space. The *x*, *y*, and *z* axes are collectively referred to as coordinate axes, which we can chose in two ways. One is to associate the coordinate axes with the left thumb and fingers as shown in Figure 1(a). The other is to associate the coordinate axes with the right thumb and fingers as shown in Figure 1(b). The resultant systems are called the "left-handed coordinate system" and "right-handed coordinate system", respectively. The left-handed coordinates can be strictly distinguished from the right-handed coordinates since a rotation of the coordinates will not transform one into the other.

Although the right-handed coordinate system is used traditionally as a rule, laws of nature never choose one out of the right-handed and left-handed coordinates. The symmetry of the right and left hands is also referred to as chiral symmetry. Some biogenic substances, such as amino-acids produced by living matter, are known to choose the left-handed symmetry. Physical laws, however, have the same expressions in both systems of the right-handed and left-handed coordinates, with one exception of beta decay (or weak interactions).

The two coordinate systems shown in Figures 1(a) and 1(b) have the *z* axis in common, with the *x* and *y* axes exchanged, so that the axes are not in equivalent positions. To flip from the right-handed to the left-handed coordinates with the equivalent position of three axes, all three axes are reversed (Figure 2). Suppose now that vectors, or quantities that have both length and direction, are transformed from the right-handed to the left-handed coordinates; see the thick arrows in Figure 2. There are two types of vectors, ones that are transformed in the same direction and others that are transformed in the reverse direction. The ones transformed in the same direction are called axial vectors (or pseudovectors). The ones transformed in the reverse direction are called polar vectors (or true vectors). Examples of polar vectors are a position vector ***r***, velocity ***v***,

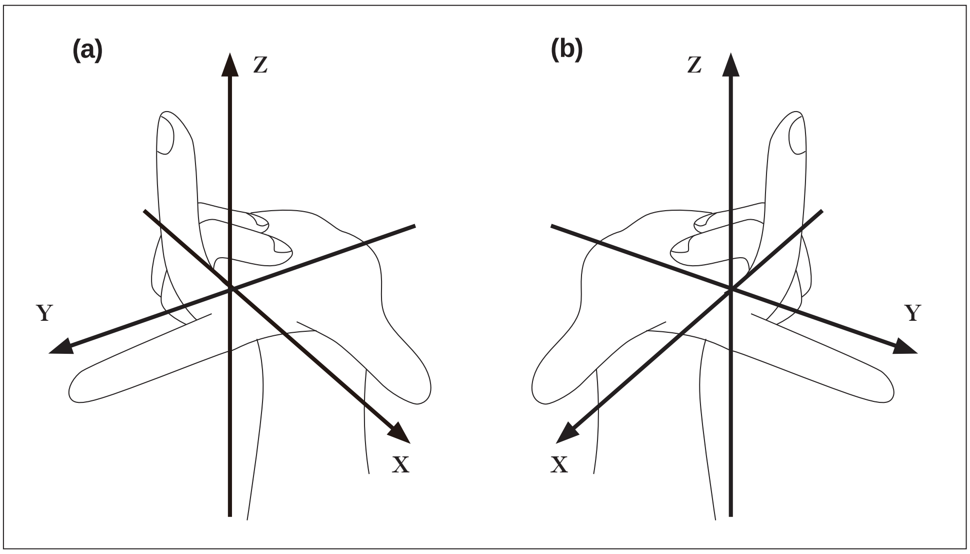

Figure 1 : (a)the left-handed and (b) right-handed coordinate systems

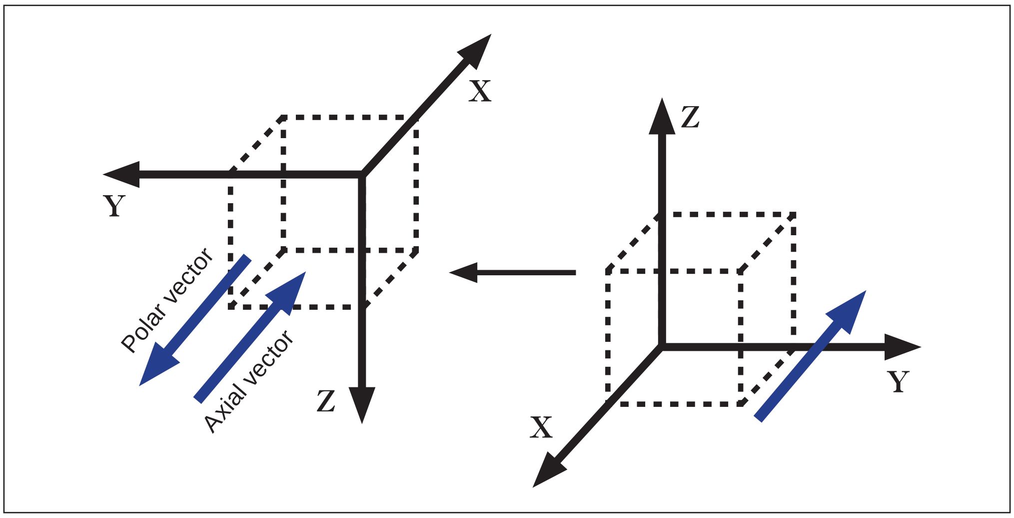

Figure 2 : How vectors are transfered from the right-handed to left-handed coordinates

acceleration ***a***, momentum ***p***, force ***F***, and electric field ***E***. Examples of axial vectors are angular momentum ***l***, torque ***N***, and magnetic induction ***B***. Many of the axial vectors are relevant to rotation in some way.

The distinction between polar vectors and axial vectors appears even in ordinary textbooks on vector algebra. One of the examples reads: "If a polar vector such as velocity is reflected in a plane mirror perpendicular to its direction, the direction of the velocity appears to reverse. On the other hand, if an axial vector such as angular velocity is reflected in a mirror perpendicular to the vector, the angular velocity in the image remains unchanged in the direction of rotation."[3] In fact, the direction of velocity appears to reverse when reflected in a plane mirror perpendicular to its direction. It should be noted, however, that the coordinate axis of that direction also reverses. The description that an axial vector remains unchanged while a polar vector changes it's direction under the transformation is nothing but a case of the left-handed coordinates being seen from the viewpoint of the right-handed coordinates. In other words, the image in the mirror is viewed and described from outside the mirror, which is not correct reversal of space. As seen in Figure 2, the fact is that space itself is inverted, or equivalently, the coordinate axes are reversed. With this in mind, we can conclude that the direction of polar vectors remains unchanged whereas the direction of axial vectors reverses. A clearer explanation could be given by using mathematical expressions with unit vectors along the coordinate axes and vector components, but this is omitted here to avoid complexity.

The space reversal does not change the direction of polar vectors but it reverses the direction of axial vectors. When the sign or direction does not change under space reversal, we will denote the symmetry by P(+). When the sign or direction changes under space reversal, we will denote the symmetry by P(-). We assign +1 and -1 to P(+) and P(-), respectively. P(+) and P(-) can be used in the same way as the foregoing T(+) and T(-). An equation where the left-hand side and right-hand side coincide on the symmetry is referred to the symmetry being satisfied or conserved. The symbols P(+) and P(-) are useful in clarifying the space reversal symmetry and in checking the conservation of the symmetry. All equations, including Newton equation, Maxwell equations, and Shrödinger equation, are known to conserve the space reversal symmetry. One and only exception is the equation that include weak interactions. However, there is confusion in Maxwell equations as will be described later. That is, a confusion about space reversal symmetries of magnetic field ***H*** and electric induction field ***D***.

It is well known that the cross product of two polar vectors is an axial vector, like angular momentum ***l*** = ***r***(position vector) × ***p***(momentum) and torque ***N*** = ***r***(position vector) × ***F***(force), where ***r***, ***p***, and ***F*** show the symmetry P(+). Given that the cross product "×" shows symmetry P(-), the foregoing two equations have symmetry P(-) = P(+) • P(-) • P(+), thus conserving symmetry. We give the symmetric symbol P(-) to the cross product × itself, because it differs from dot product (or scalar product) of two vectors and from ordinary multiplications in terms of space reversal symmetry. This is related to the fact that cross product changes direction if the order of multiplication is reversed, while dot product and ordinary multiplication maintain the same sign even if the order is reversed. In this report, we will use the symbol "×" for cross product and the symbol "・" for both dot product and ordinary multiplication. Using P(+) and P(-), we can easily deduce that a cross product of polar vector and axial vector is a polar vector. An example of this is the Lorentz force, which is given by a cross product of velocity $\boldsymbol{v}$ and magnetic induction $\boldsymbol{B}$. When we consider rot $\boldsymbol{A}$ (or $\nabla\times \boldsymbol{A}$) which is the rotation of vector $\boldsymbol{A}$, the derivative operator "rot" or " $\nabla\times$ " has the symmetry P(-). An example of this is the relation between vector potential $\boldsymbol{A}$ and magnetic induction $\boldsymbol{B}$ (i.e., $\boldsymbol{B} = \text{rot}\,\boldsymbol{A}$).

Under space reversal, some quantities change sign even though they have no spatial direction. An example of this is the triple scalar product $V = (\boldsymbol{a} \times \boldsymbol{b}) \cdot \boldsymbol{c}$. As shown in Figure 3, this scalar product represents the volume of the parallelepiped (or rectangular parallelepiped) formed by the coterminous sides $\boldsymbol{a}$, $\boldsymbol{b}$, and $\boldsymbol{c}$. The triple scalar product is sometimes written simply as [$\boldsymbol{abc}$] since it remains the same even if the order of the three vectors is cyclically shifted. Replacing $\boldsymbol{a}$ with $\boldsymbol{b}$ to give [$\boldsymbol{bac}$], however, changes the sign. This means that triple scalar products in the left-handed and right-handed coordinates differ in the sign, and they show the symmetry P(-). This is because the triple scalar product contains a cross product. "Such a scalar that changes sign depending on the configuration of the coordinate axes is named pseudoscalar."[3] In contrast, a scalar that does not change sign irrespective of the configuration of the coordinate axes is referred to as true scalar or simply as scalar. Pseudoscalars and true scalars show the symmetries P(-) and P(+), respectively.

The foregoing discussion implies that volume is defined as a negative quantity in the left-handed coordinates although it is a positive quantity in the right-handed coordinates, which was pointed out by Maxwell in his famous textbook on electromagnetism, *A Treatise on Electricity and Magnetism*.[4] The textbook contains a section titled "On Right-handed and Left-handed Relations in Space", and it reads: "*This relation between the two (cross) products dx×dy and dy×dx may be compared with the rule for the product of two perpendicular vectors in the method of Quaternions, the sign of which depends on the order of multiplication; and with the reversal of the sign of a determinant when the adjoining rows or columns are exchanged. For similar reasons a volume integral is to be taken positive when the order of integration is in the cyclic order of the variables x, y, z, and negative when the cyclic order is reversed*." Here, the term determinant has the same meaning as triple scalar product because the product is equivalent to the determinant when components of vectors are arranged properly. As Maxwell pointed out, volume is negative in the left-handed coordinates. In the following section, the implication of negative volume will be discussed in more detail.

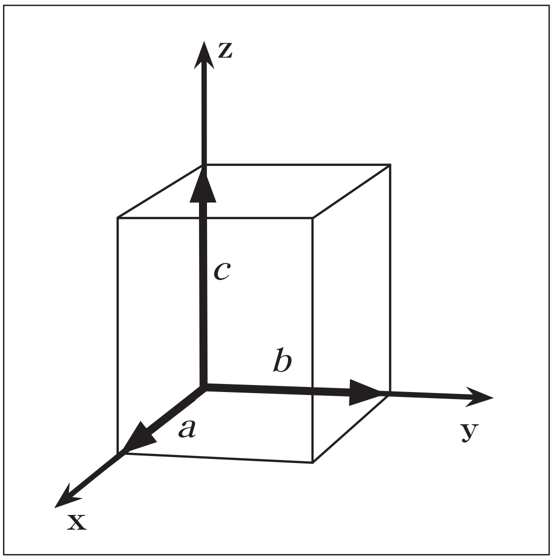

Figure 3 : A triple product of three vectors $\boldsymbol{a}$, $\boldsymbol{b}$, and $\boldsymbol{c}$ represents the volume of a parallelepiped (or rectangular solid)

3-2 Negative Volume in Left-handed Coordinates

There are only two textbooks that clearly state that volume is negative in the left-handed coordinates: the one written by Maxwell himself and *Mathematics in Classical Physics*[5] by Isao Imai. The latter is based on Maxwell's textbook and it is not surprising that it states that volume is negative in the left-handed coordinates. Imai's textbook also gives us clues about what Maxwell thought of electric and magnetic fields. Shigeo Kobata's *Thus were Created the Electromagnetic Units*[6] points out that the confusion in post-Maxwell electromagnetism started with Sommerfeld's textbook.

It is commonly understood that the triple scalar product of three vectors is a pseudoscalar and thus changes sign depending on the left-handed and right-handed coordinates, and none would argue against it. The question is whether to take an absolute value of the product and to define volume as positive all the time. If we were to take only the right-handed coordinates and not the left-handed coordinates, volume is always positive and this problem would not occur. The problem is unavoidable, however, since space reversal symmetry refers to a transformation from the right-handed to the left-handed coordinates or from the left-handed to the right-handed coordinates. The artificial operation of taking the absolute value to keep volume positive all the time would bring discontinuity and inconsistency in the description of space. In the following discussion, volume in the left-handed coordinates will thus be considered negative as Maxwell intended.

What is the implication of negative volume in the left-handed coordinates? Density, defined by dividing the mass of a body by the volume it occupies, becomes negative in the left-handed coordinates. Negative mass is problematic, but negative density is not if it is defined so. The symmetry of the equation M(mass) = ρ(density) • V(volume) is P(+) = P(-) • P(-), where the space reversal symmetry is conserved. Similarly, energy is positive and energy density is negative in the left-handed coordinates. Charge and charge density also have opposite signs. Mass, energy, and charge have the space reversal symmetry P(+) while density, energy density, and charge density P(-).

Since the symmetry of charge density is P(-), that of current density is also P(-). Maxwell equations include both charge density and current density that may affect the space reversal symmetry of the equations. When volume is negative in the left-handed coordinates, resultant symmetries of electromagnetic fields are as follows: electric field $\boldsymbol{E}$ and magnetic field $\boldsymbol{H}$ are polar vectors with symmetry P(+), and electric induction $\boldsymbol{D}$ (or electric flux density) and magnetic induction $\boldsymbol{B}$ (or magnetic flux density) are axial vectors with symmetry P(-). The conclusion (see Table 1) was previously stated in the textbook of *Mathematics in Classical Physics* mentioned above. Maxwell himself made a clear distinction between them. He considered $\boldsymbol{E}$ and $\boldsymbol{H}$ as quantities defined with respect to a line, and $\boldsymbol{D}$ and $\boldsymbol{B}$ as quantities defined with respect to a plane.[4,6] This suggests that Maxwell himself thought of $\boldsymbol{E}$ and $\boldsymbol{H}$ as polar vectors and $\boldsymbol{D}$ and $\boldsymbol{B}$ as axial vectors.

On the other hand, starting from the assumption that volume is positive even in the left-handed coordinates, the conclusion is that $\boldsymbol{E}$ and $\boldsymbol{D}$ are polar vectors and $\boldsymbol{H}$ and $\boldsymbol{B}$ are axial vectors. The different starting points thus result in different conclusions as to the space reversal symmetry of $\boldsymbol{D}$ and $\boldsymbol{H}$. For $\boldsymbol{E}$ and $\boldsymbol{B}$, the same result is obtained irrespective of whether volume is positive or negative in the left-handed coordinates. The fact that $\boldsymbol{E}$ is a polar vector and $\boldsymbol{B}$ is an axial vector is correct even from the standpoint of vector potential $\boldsymbol{A}$. Some textbooks explicitly state the symmetry of $\boldsymbol{E}$ and $\boldsymbol{B}$, whereas none contains a clear description of the symmetry of $\boldsymbol{D}$ and $\boldsymbol{H}$ except Reference 5. If $\boldsymbol{E}$ and $\boldsymbol{D}$ have the same symmetry and $\boldsymbol{H}$ and $\boldsymbol{B}$ the same symmetry, there is no reason for the existence of two kinds of fields for both electric and magnetic

Table 1 : Space reversal symmetry of various electromagnetic quantities

Scalar P(+)	q (Charge)
Pseudoscalar P(-)	ρ (Charge density), U (Energy density of electromagnetic fields) ε_0 (Permittivity of free space) μ_0 (Permeability of free space)
Polar vector P(+)	$\boldsymbol{E}$ (Electric field), $\boldsymbol{H}$ (Magnetic field)
Axial vector P(-)	$\boldsymbol{D}$ (Electric induction or electric flux density) $\boldsymbol{B}$ (Magnetic induction or magnetic flux density) $\boldsymbol{J}$ (Current density) $\boldsymbol{g}$ (Momentum density of electromagnetic fields) $\boldsymbol{S}$ (Poynting vector)
Tensor P(-)	T_{ij} (Maxwell's stress)

Source: Reference[5]

fields. Consequently, we may ask which field of ***H*** and ***B*** is more essential. This is the origin of *E-H* and *E-B* formulations. These formulations, however, are meaningless, if symmetries of ***H*** and ***B*** are different from each other. When volume is negative in the left-handed coordinates, the permittivity and permeability of free space are pseudoscalars. As will be discussed in the next section, pseudoscalar permittivity (or pseudoscalar permeability) can play an essential role as a quantity or an operator that is relevant to the reversal of space. If the permittivity and permeability of free space is a true scalar, on the other hand, it can bear no other meaning than that it is a mere proportional constant, which precludes the understanding of the true meaning of the universal constant.

3-3 Space Reversal Caused By Permittivity

Numerical values of permittivity and permeability of free space are defined as $\varepsilon_0 = 8.854187817\times10^{-12}$ F/m and $\mu_0 = 4\pi\times10^{-7}$ N/A^2. Today, we cannot measure them because they are defined. The permittivity ε_0 and permeability μ_0 determine the following relations between ***E*** and ***D*** and between ***H*** and ***B*** in free space (or in the air):

$$\boldsymbol{D} = \varepsilon_0 \cdot \boldsymbol{E}, \quad \boldsymbol{B} = \mu_0 \cdot \boldsymbol{H}. \qquad (3)$$

When ***E*** and ***H*** are polar vectors with symmetry P(+) and ***D*** and ***B*** are axial vectors with symmetry P(-) as already discussed, the symmetry of ε_0 and μ_0 is P(-), satisfying P(-) = P(-)・P(+). Namely, ε_0 and μ_0 are pseudoscalars that are positive in the right-handed coordinates and negative in the left-handed coordinates, which appeared in Imai's textbook.[5] The energy density of electromagnetic fields includes both ε_0 and μ_0 together with $\boldsymbol{E}^2$ and $\boldsymbol{H}^2$. Since the energy density is negative in the left-handed coordinates, ε_0 and μ_0 are also negative in the coordinates, which can also provide an explanation for why ε_0 and μ_0 are pseudoscalars.

The permittivity ε_0, the permeability μ_0, and the speed of light c satisfy the relation $1/c^2 = \varepsilon_0 \cdot \mu_0$. In fact, Maxwell calculated the propagation speed of electromagnetic waves using this relation, and proposed that the visible ray of light is a kind of electromagnetic waves. The relation clearly shows that permeability is automatically determined once speed of light and permittivity are set. In this report, I have already explained that a system of units where $c^2 = 1$ should be adopted. Since permittivity ε_0 and permeability μ_0 are defined values today, both values can be defined as one to create simpler systems of units. Such systems of units were actually used in the past. For instance, $\varepsilon_0 = 1$ in the system of cgs-electrostatic units (cgs-esu), and $\mu_0 = 1$ in the system of cgs-electromagnetic units (cgs-emu). In the electromagnetic units, ***H*** and ***B*** are measured by oersted and gauss, respectively, though they show the same values in free space (or in the air). The concurrent use of electrostatic and electromagnetic units leads to $c^2 = 1$, which differs from about 300,000 km/s. For that reason the concurrent use of the two systems of units has been avoided. If $c^2 = 1$ is accepted, however, the two systems of units become concurrently usable. As mentioned above, the permittivity and permeability of free space are pseudoscalars, and they shows negative values in the left-handed coordinates. That is, $\varepsilon_0 = \mu_0 = \pm1$, or equivalently $\varepsilon_0^2 = \mu_0^2 = 1$. Here, ε_0 and μ_0 may be regarded as identical, having exactly the same meaning. Although either one of the two will therefore suffice for the discussion, the following deals with both to avoid confusion.

If $\varepsilon_0^2 = \mu_0^2 = 1$, equation (3) is rewritten as:

$$\boldsymbol{E} = \varepsilon_0 \cdot \boldsymbol{D}, \quad \boldsymbol{H} = \mu_0 \cdot \boldsymbol{B}. \qquad (4)$$

The comparison between equations (3) and (4) shows that permittivity ε_0 and permeability μ_0 play the role of transforming a polar vector into an axial vector, and transforming an axial vector into a polar vector. We can say that $\varepsilon_0^2 = 1$ (and $\mu_0^2 = 1$) is the condition under which the original scale is maintained after transformations of "polar" →"axial" → "polar" vector, or "axial" → "polar" → "axial" vector. Since $\varepsilon_0 = +1$ refers to right-handed coordinates and $\varepsilon_0 = -1$ to left-handed coordinates, ε_0 may be considered an operator that distinguishes the coordinate system, or an operator that causes reversal of space.

In the universal system of units where $c^2 = \varepsilon_0^2 = 1$, two of four base units are eliminated, and we have only two base units. For instance, $c^2 = 1$ integrates time and length, and eliminates either meter or second. In either case, the unit of velocity disappears, and energy is measured in terms of mass. Equation $\varepsilon_0^2 = 1$ eliminates the ampere, and electric currents are described by a combination of the remaining two units. In such a system of units, the electromagnetic fields ***E***, ***D***, ***H***, and ***B*** have the same unit, with the only differences being in the symmetries of time reversal and space reversal. Specifically, ***E*** is P(+) and T(+), ***D*** is P(-) and T(+), ***H*** is P(+) and T(-), and ***B*** is P(-) and T(-). The four types of electromagnetic fields are all different and unique in symmetry. This is the reason why the four electromagnetic fields need to exist.

4 Confusion in Textbooks on Electromagnetism

Descriptions in electromagnetism vary greatly depending on whether to start from a magnetic field generated by an electric current (or electromagnet) or by magnetic charges (or a permanent magnet). The former standpoint is referred to as *E*-*B* formulation, and the latter *E*-*H* formulation. Their characteristics are as follows:

a) *E*-*B* formulation:

1. Assumes neither magnetic charges nor monopoles, and the existence of monopole is denied. Magnetic field ***B*** is induced by electric currents. One of Maxwell equations, div ***B*** = 0, shows that magnetic field lines of ***B*** are continuous.
2. Compatible with the theory of relativity. When an electron moves at the speed of ***v***, ***v*** × ***B*** is the electric field that the electron feels. Further, it is ***E*** and ***B*** that are derived from the vector potential ***A*** of an electromagnetic field.
3. It has the disadvantage that a virtual electric current must be assumed around the permanent magnet because the presence of magnetic poles “N” and “S” on both ends of the magnet is denied. Such a model is referred to as the electric current model of magnetization.

b) *E*-*H* formulation:

1. Assumes an magnetic dipole or a pair of magnetic charges that have opposite signs. The magnetic poles “N” and “S” on both ends of the magnet are responsible for the magnetic field ***H***. It is supported by the fact that div ***H*** ≠ 0 at the boundary of magnets; i.e., magnetic field lines of ***H*** are not continuous at the boundary. One of Maxwell equations, div ***B*** = 0, shows that the same amounts of magnetic charge with opposite signs should appear on the respective sides. This model is referred to as the magnetic charge model of magnetization.
2. It is the magnetic field ***H*** that an electric current produces through Ampere’s law rot ***H*** = ***J***. Actually, the magnetic field ***H*** is measured by ampere/meter.
3. It has the disadvantage of requiring the concept of a magnetic monopole, the existence of which has not been confirmed.

Many recent textbooks support the *E*-*B* formulation, while the ones that deal mainly with magnetism or microwaves often adopt the *E*-*H* formulation. The choice of the formulation may be a matter of taste, because it is not that one of formulations is correct and the other is wrong. However, different definitions and units of magnetization and susceptibility between two formulations cause the confusion far beyond a matter of taste. It is students or beginners who suffer the most from this confusion.

The confusion of *E*-*B* and *E*-*H* formulations is well recognized by authors of recent textbooks and teachers in the field of electromagnetism. There are many references to this issue.[7-9] In particular, Reference 7 contains a table that classifies some textbooks according to the formulations. Table 2 is reproduced from the classified table in Reference 7. Further, it says, “There are many textbooks on classical electromagnetism. The authors are all strongly committed to their work, several of which were written with the intention of providing a critical discussion of conventional textbooks. For example, one textbook (Hosono) insists that the *E*-*H* formulation is wrong and should be absolutely avoided, while another (Mizoguchi) insists that the electric current model of permanent magnet, which is the basic idea of the *E*-*B* formulation, is anachronistic.”

The difference between the *E*-*B* and *E*-*H* formulations is caused by two different standpoints, i.e., ***B*** is fundamental field or ***H*** is the fundamental field. We should say again that it is a matter of choice and not a matter of which is right and which is wrong. Some textbooks that support the *E*-*B* formulation refer to ***B*** as magnetic field, without using ***H*** at all. Some textbooks on microwaves use ***E*** and ***H*** only. The unique textbook[5] that describe the space reversal

Table 2 : *E-B* and *E-H* formulations in textbooks on electromanetism

Author (translator)	Title	Publisher	*E-B*	*E-H*	Note
Barger, Olsson (trans. by Kobayashi, Tosa)	Classical Electricity and Magnetism	Baifukan	○		
Serway (trans. by Matsumura)	Physics for Scientists and Engineers (Electromagnetism)	Gakujutsu Tosho Shuppan	○		
Feynman (trans. by Miyajima)	The Feynman Lectures on Physics (Electromagnetism)	Iwanami Shoten	○		
Nagaoka, Tankei	Introductions to Physics: Q&A Exercises on Electromagnetism	Iwanami Shoten	○		
Katsurai	Fundamental electromagnetism for science and engineering	Ohmsha	○		
Stratton	Electro-Magnetic Theory	McGrow-Hill	○		
Jackson	Classical Electrodynamics	Wiley	○		1
Nakayama	Electromagnetism	Shokabo	○	○	2
Iida	New Electromagnetism	Maruzen	○	○	
Mizoguchi	-SI UNITS- Electromagnetism	Shokabo		○	3
Bleaney, Bleaney	Electricity and Magnetism	Oxford		○	
The Institute of Electrical Engineers of Japan	Exercises on Electromagnetism	Ohmsha	○	○	4
Halliday, Resnick, Walker (trans. by Nozaki)	Fundamentals of Physics, III: Electromagnetism	Baifukan	○		
Goto	Comprehensible Electromagnetism	Kodansha		○	
Kumagai, Arakawa	Electromagnetism	Asakura		○	
Takahashi	Physic Selection: Electromagnetism	Shokabo		○	
Shimoda, Chikazumi	Exercises in College: Electromagnetism	Shokabo		○	
Tokai Univ	Physics: Electromagnetism	Tokai Univ. Pres	○		
Hirose	Physics One Point: ***E*** and ***H***, ***D*** and ***B***	Kyoritsu Shuppan		○	
Hosono	Meta-electromagnetism	Morikita Publ.	○		5
Kozuka	Electricity and magnetism: Its physical images and details	Morikita Publ.		○	
Landau, Lifshitz (trans. by Inoue, Yasukouchi, Sasaki)	Electromagnetism	TokyoTosho	○		1
Suematsu	Electromagnetism	Kyoritsu Shuppan	○		
Sunakawa	Electromagnetism	Iwanami Shoten	○		6
Slater, Frank	Electromagnetism	McGrowHil	○		
Nagaoka	Introductions to Physics: Electromagnetism I, II	Iwanami Shoten	○		
Murakami	Electromagnetism	Maruzen		○	
Sommerfeld (trans. by Ito)	Electromagnetism	Kodansha	○		
Purcell	Berkeley physics coures vol. 2 Electricity and magnetism	McGrowHill	○		1
Ota	Fundamentals of Electromagnetism I, II	Springer Japan	○		7

(Notes 1 to 6 are quoted from Reference 7)

1) This old textbook is written in Gaussian system of units (cgs-emu).
2) Supports both *E-B* and *E-H*. Leaning toward *E-H*.
3) Closer to the standard theoretical development on *E-H* model, but rejects the idea of a "magnetic charge" even as a virtual entity. Takes the strict stance that magnetic substance is essentially a set of magnetic moments.
4) A textbook that deals equally with both *E-B* and *E-H* formulations.
5) A unique book that is critical of *E-H* formulation. Claims that *E-H* formulation is wrong since a single moving magnetic charge violates relativistic invariance.
6) A textbook that is based on a compromise between *E-B* and *E-H*. Uses a pole model for magnetic substance.
7) Claims that *E-H* formulation lacks theroretical basis since *E* and *B* are inseparable under the theory of relativity.

Source: Reference[7]

symmetry of ***H*** and ***D*** takes a stance closer to the *D*-*B* formulation, because it states that "the most fundamental quantities in describing electromagnetic fields are ***D*** and ***B***."

Which quantities are more fundamental is only a subjective matter. The important thing is to discuss the space reversal symmetry of electromagnetic fields because it is confused at present, although the time reversal symmetry of electromagnetic fields may not be confused. I feel that almost all textbooks lack sufficient discussion of the space reversal symmetry of electromagnetic fields. If ***E*** and ***H*** are polar vectors and ***D*** and ***B*** axial vectors, then the necessity of the four types of fields is concluded. If, on the other hand, ***E*** and ***D*** are polar vectors and ***H*** and ***B*** are axial vectors, there is no reason for the existence of two types of fields for both electric and magnetic fields, and the conclusion must be that there are fundamental fields and secondary fields. It causes unnecessary controversy as to whether *E*-*B* or *E*-*H* formulation.

5 On Charge Reversal Symmetry

All electrons and all protons have the same amount of electric charge of 1.6021773×10^{-19} Coulombs, which is called a unit charge or an elementary charge. However, it is not known exactly whether such a fundamental unit of magnetic charge exists, or whether a magnetic charge can exist by itself. If magnetic charges exist, it is certain that magnetic field lines start from positive charge and end with negative charge in the same way as electric field lines. So, the question is thus whether a magnetic field line is continuous or has a start point and an end point. Figures 4(a) and 4(b) shows magnetic field lines of ***B*** and ***H***, respectively, in and around the spherical permanent magnet. While textbooks often show magnetic field lines of a bar magnet, there is no difference between a spherical and a bar magnets except that the magnetic field lines inside a bar magnet are somewhat more complicated.

Given $\mu_0 = 1$, the magnetic field lines of ***B*** and those of ***H*** coincide with each other outside the magnet, although the lines of ***B*** are denser than those of ***H*** inside the magnet. An essential difference between the magnetic field lines of ***B*** and ***H*** is that the lines of ***H*** are not continuous at the surface of the magnet and have a start point and an end point (Figure 4(b)) there, while lines of ***B*** are continuous and have no start point or end point (Figure 4(a)). This suggests that magnetic charges of N and S poles exist as the source of the magnetic field ***H***. Here, we note that ***B*** and ***H*** show different directions inside the magnet. Meanwhile, some textbooks of *E*-*B* formulation do not accept the existence of magnetic charge, often denying the reality of magnetic field lines of ***H***.

Dirac, who is famous for predicting antiparticles, argued based on the quantum mechanics that if a magnetic monopole exists, its magnetic charge *g* and electron charge *e* have to satisfy the following equation:

$$g \text{ (monopole charge)} = h \text{ (Planck constant)} \cdot c \text{ (speed of light)}/e \text{ (electron charge)}. \tag{5}$$

The Planck constant *h* is a universal constant characteristic to quantum mechanics, and *c* is the

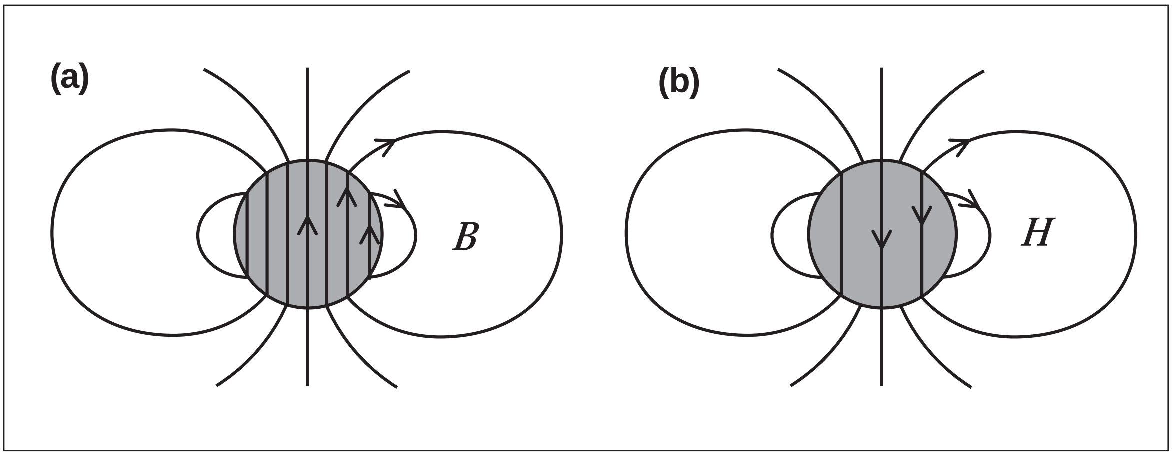

Figure 4 : The field lines of (a) magnetic induction ***B*** and (b) magnetic field ***H*** inside and outside a spherical magnet

speed of light as previously mentioned. According to Dirac, a line with phase singularity, which is call Dirac string, extends from a magnetic monopole to infinity (Figure 5(a)) like a filament appearing in the center of a vortex. The discovery of a particle with monopole charge, i.e., a particle with either only a N or S pole, would answer the question of "why every electron in the universe should have exactly the same electric charge"[10] on the basis of equation (5). Many scientists have been searching but have yet to find a particle with monopole charge.

If the electron charge e is replaced with the charge $2e$ of a Cooper pair, equation (5) coincides with the equation of the flux quantum in a superconductor. A magnetic field penetrates a superconductor not uniformly but in a quantized form, which is referred to as the flux quantum (Figures 5(b) and 5(c)). Flux quanta have been actually observed and ascertained to exist. The immediate cause of the quantization of the magnetic field is a persistent current flowing around the magnetic field lines. At the center of the vortical current, there is a string where superconductive phase cannot be defined. The flux quantum is thus sometimes called a vortex string, which is nothing but a Dirac string excepting the difference of the charge e or $2e$. The magnetic monopole given by Dirac and the flux quantum share exactly the same theoretical basis, with the only difference being whether there are one or two electrons. In view of this, we can assume that a flux quantum is accompanied by magnetic monopoles at the respective ends. Even in such a case, the field lines of the magnetic induction $\boldsymbol{B}$ are continuous (Figure 5(b)), and the magnetic charges serve not as the source of the magnetic induction $\boldsymbol{B}$ but as the source of the magnetic field $\boldsymbol{H}$ (Figure 5(c)). In that sense, Figures 5(b) and 5(c) correspond to Figures 4(a) and 4(b), respectively.

In Maxwell's equations, doubling the electric quantity results in double the magnetic fields $\boldsymbol{H}$ and $\boldsymbol{B}$. If a magnetic monopole (or it's pair) exists as the source of $\boldsymbol{H}$, the magnetic monopole charge g is expected to be proportionate to the charge e of the electron:

$$g \text{ (monopole charge)} = c \text{ (speed of light)} \cdot e \text{ (electron charge)}. \qquad (6)$$

In this equation, the speed of light c (= ±1) is multiplied for the reason that the electric field $\boldsymbol{E}$ and the magnetic field $\boldsymbol{H}$ differ in time reversal symmetry. Equation (5), where monopole charge is inversely proportional to electron charge, and equation (6), where they vary in direct proportion, seem to be contradictory but actually need to hold at the same time. Equations (5) and (6) immediately yields $e^2 = g^2 = 1$, showing that both electron and monopole charges have unique value except for it's positive or negative sign. In this discussion, we assumed $h = 1$ and $c^2 = 1$. In the ordinary MKSA system of units, we will obtain the magnetic monopole charge of $\pm 4.14\times10^{-15}$ Webers, which is twice the value of magnetic flux quantum in a superconductor.

The charge of an electron was historically defined to be negative. In $e^2 = 1$, $e = -1$ represents an electron and $e = 1$ represents a positron or an antiparticle of the electron. In semiconductors, $e = -1$ represents an

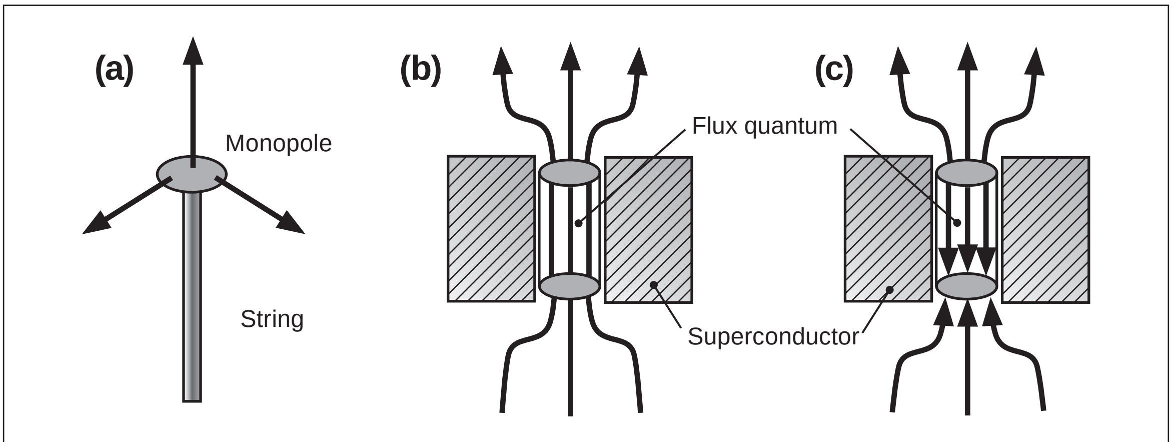

Figure 5 : (a) Dirac's magnetic monopole, (b) the field lines of a flux quantum in terms of ***B***, and (c) those in terms of ***H***. The flux quantum can be considered to have monopoles on both ends

n-type carrier or electron, and $e = 1$ a p-type carrier or hole. As can be seen, elementary charge e (= ±1) is a quantity (or operator) that distinguishes a particle from an antiparticle, and can thus be regarded as an operator that is relevant to C-symmetry (charge symmetry or particle reversal symmetry) within CPT symmetry. There are quantities whose sings (or directions) are reversed when a particle is reversed to an antiparticle or when all particles are reversed to antiparticles. Examples of these quantities are electromagnetic fields, $\boldsymbol{E}$, $\boldsymbol{D}$, $\boldsymbol{H}$, and $\boldsymbol{B}$. We will denote this particle reversal symmetry by C(-). In contrast, the symmetry where the sign does not change will be denoted by C(+). Time derivatives, spatial derivatives, permittivity, and permeability show C(+) symmetry. By help of notations C(+) and C(-), the symmetry of equations can be easily discussed in the same way as in the case of T and P. We will find that Maxwell's equations conserve the particle reversal symmetry.

6 Particle-Wave Duality

I have explained that the speed of light c is relevant to time reversal, permittivity ε_0 to space reversal, and elementary charge e to particle reversal. Thus, universal constants are (eigenvalues of) operators closely associated with CPT symmetry, provided that $c^2 = \varepsilon_0^2 = e^2 = 1$. The remaining universal constant is the Planck constant h (= $6.62606896 \times 10^{-34}$ joule-seconds), which appears in quantum mechanics.

The most important conclusion of quantum mechanics is that an electron has two mutually contradictory properties of a particle and of a wave. It is the Planck constant h that links the particle and wave. This constant was found by Planck through spectrum analyses of black body radiation, pioneering quantum mechanics. Later on, Einstein and de Broglie derived the significant relations:

$$E = h \cdot \nu \text{ and } \boldsymbol{p} = h \cdot \boldsymbol{k}, \qquad (7)$$

which provided photonic quanta by Einstein and matter waves by de Broglie. De Broglie himself did not consider electrons to be waves, but assumed the electron to be on top of the wave and formulated the foregoing relations. In equations (7), ν is frequency and $\boldsymbol{k}$ is wave vector (= reciprocal of the wavelength), both of which are quantities of waves. E and $\boldsymbol{p}$ are energy and momentum of a particle or quantum, both of which are quantities that describe the state of a particle. Consequently, equations (7) show that wave-describing quantities multiplied (operated) by the Planck constant h make particle-related quantities.

If we assume $h^2 = 1$, or employ such a system of units, then equations (7) give:

$$\nu = h \cdot E \text{ and } \boldsymbol{k} = h \cdot \boldsymbol{p}. \qquad (8)$$

Equations (8) show that particle-related quantities multiplied (operated) by the Planck constant h make wave-describing quantities. The Planck constant h = ±1 can thus be regarded as a quantity or operator that transforms a wave and a particle into each other. $h^2 = 1$ is also the condition that prevents a change in scale (such as energy and momentum) under transformations. Since $h = \pm 1$, energy and frequency have the same unit, and momentum and wave vector have the same unit.

In the presence of equations (5) and (6), however, the quantity h is automatically determined once $c^2 = \varepsilon_0^2 = e^2 = 1$ is given. Thus, even if we let $c^2 = \varepsilon_0^2 = e^2 = h^2 = 1$, three units disappear out of the four units in the MKSA system of units, leaving just one. The remaining unit may be any one of the four. For example, if the unit of time is left, all quantities are measured by the unit of time or by no units.

The assumption that $h^2 = 1$ implies that there is a negative Planck constant ($h = -1$) as well as the positive Planck constant ($h = 1$). The positive and negative values can be associated with the symmetry of particles and antiparticles. A reasonable explanation can be provided by assigning the Planck constant h, the imaginary unit i, and the wave-related quantities ν and $\boldsymbol{k}$ as C(-) and assigning the particle-related quantities E and $\boldsymbol{p}$ as C(+). For example, equations (7) and (8) have particle symmetries C(+) = C(-)・C(-) and C(-) = C(-)・C(+), respectively. Since the symmetry of energy E is C(+), energy E is always positive for both particles and antiparticles, while frequency of the positron (or antiparticle) waves is negative. From equations (7) and (8), the application of the Planck constant to a wave produces a particle, and the application of the Planck constant to a particle produces a wave. What is actually occurring has yet to be clarified, however. I would venture to say that a particle is not other than a wave, and a wave is not other than a particle, because a particle is immediately transformed into the wave and a wave is immediately transformed into the particle ("emptiness is not other than form, form too is not other than emptiness; form is emptiness, emptiness is form"— *The Heart Sutra*). Each individual electron, repeating such a process of reincarnation, would make existence eternal, but why a single electron survives eternally is not yet clearly understood.

7 Conclusion

Having started from the questions of why the universal constants in physics, such as the speed of light c, permittivity ε_0 or permeability μ_0 of free space, the electron's charge e, and the Planck constant h, are constant and why such values should be taken, I have deduced that universal constants are closely associated with CPT symmetry, i.e., reversal symmetries of time, space, and particle. I have also pointed out that the system of units where $c^2 = \varepsilon_0^2 = e^2 = h^2 = 1$ is essential to the discussion.

Some people already had these kinds of questions. Those who claim that the theory of relativity is wrong, for example. Although it is absolutely clear that their argument is wrong and the theory of relativity is correct, it should be noted that what they are concerned with is the principle of the constancy of the speed of light, or the question of why the speed of light is constant. Specialists have so far not answered this question squarely. It may be because they have considered its constancy to be natural and beyond question, or perhaps they have regarded it as an axiom that is unexplainable and unnecessary to be explained. Some scientists, however, raised the question of why every electron in the entire universe has exactly the same electric charge. Dirac and Yukawa were among them. In order to solve this question, Dirac introduced the existence of a unit magnetic charge or monopole through a duality of electric and magnetic fields in Maxwell's equations. This was only half-successful, however, in providing a complete solution to the question. Electrons have a magnetic moment called spin, which is well known to be the source of a permanent magnet. Recently, the properties of spin have been utilized in electronics, and the term spintronics has become prevalent. Electron spin or it's magnetic moment is often described as a rotation model of an electron. The electron itself, however, is known to be a point charge with no dimensions, and the rotation of a point charge will not produce any magnetic moment. A valid model of spin has not been constructed yet. Likewise, what we consider obvious is often not yet fully understood. Meanwhile, there are questions that many people have been aware of, such as the question of how to interpret the particle-wave duality. This question was relevant to the Bohr-Einstein debates about the probabilistic interpretation of wave functions, and is still discussed as a measurement problem.

Such "naive but reasonable" questions are essential to a new revolution. Undoubtedly, there are also important questions that we are still unaware of. The question of whether the volume in the left-handed coordinates is positive or negative was raised by Maxwell some 130 years ago, but has been neglected thereafter. This question, that has not been fully resolved, is responsible for the confusion of *E*-*B* or *E*-*H* formulation in the modern textbooks on electromagnetism. Since *E*-*H* formulation may need magnetic charges, the confusion may be relevant to the question of how Dirac's monopole (or it's pair) should be dealt with in Maxwell's equations.

Finally, I want to say that it is important to discover and unearth naive but reasonable questions. Such questions are, however, less likely to be found among specialists in their fields. Furthermore, we have to recall the history such as "what many people consider as a fiction can turn out to be true, like Planck's quantum and de Broglie's matter wave."[11] One possible approach may be to offer a prize for finding such reasonable questions, but not for solving the questions. This will be a new version of prize essay that made a considerable contribution to mathematics and basic science in 18th- and 19th-century Europe. In any case, scientists who engage in tenacious efforts aimed at finding novel and reasonable questions and at pursuing such basic problems are increasingly significant. It is of extreme importance to develop such research environments and human resources in Japan.

Acknowledgement

This report has benefited from information and comments on the confusion in textbooks on electromagnetism offered by Prof. Endo, along with permission to quote from his website. Professor Yasue also provided information and comments on the interpretation of electromagnetic fields and the monopole from the standpoint of elementary particle theory. I would like to express my deepest gratitude to them.

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Profile

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3

Developing Human Resources to Support Japan's International Competitiveness in Industry

– Human Resource Development Model for the Steel Industry, One of Japan's Key Industries –

Susumu CHIDA
Affiliated Fellow

1 Introduction

Anticipated changes in the labor force population between the ages of 15 and 64 in different countries between now and 2030 (Figure 1) show that the labor force populations in China and India are expected to increase to about one billion each. Over the same time period, the populations of the United States, Japan, Russia, and the United Kingdom will not change very much: about 200 million in the United States, about 80 million each in Japan and Russia, and about 40 million in the United Kingdom (changes in the make-up of the population and population aging are not taken into account). A look at steel consumption per person (an indicator of industrialization) suggests that even if steel consumption in India (where the total population is approx. 1.2 billion and steel production is 44 million tons) in 2030 were to be half of the current world average of 140kg per person, demand would still increase by 40 million tons even if the population remained constant. Forty million tons is more than the amount of crude steel produced by a Japanese steel company ranked about second in the world in terms of production (such as Nippon Steel Corporation or JFE Steel Corporation).

Considering changes in the environment surrounding steel over the next 20 years based on the relationship between demographic changes and steel products, it is apparent that not only quality improvement through technological development, but also global changes in industrial structures need to be considered. Looking forward to 2030, the largest issue for the steel industry is how to deal with these great changes in the environment. For that, comprehensive technological capacity will be necessary, and instead of vague long-term human resource education, concrete medium-term programs that look over the next 20 years or so need to be examined.

The Japanese steel industry, emphasizing quality, has been growing while keeping up with the

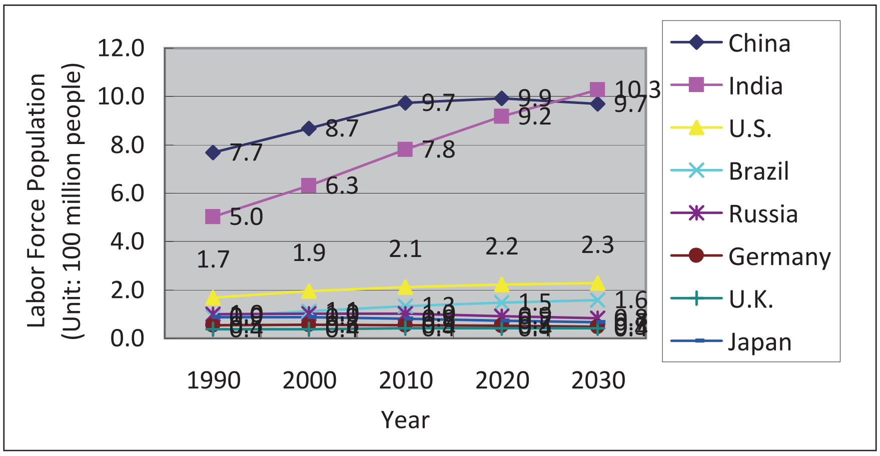

Figure 1 : Trends of the Labor Force Population

Prepared by the STFC based on Reference[1]

increasing demand for steel in emerging nations. It has also been responding to users' shift to overseas production. Looking toward 2030, the demand for steel products is expected to increase substantially. In order for Japan to continue to be a key player in the world, establishing a global steel product cycle that includes a recycling system is essential. Looking at world trends, Europe focuses on a recycling system with the use of material marking but does not pay much attention to collecting materials from mixed scrap. Advancements in recycling technology have not been seen either. In the United States, a supply (recycling) system of raw material scrap has not been established. As such, full advantage has not been taken of their smelting technology.[2] The Japanese steel industry must play a major role in building a global cycle of steel products. For this, the industry needs to actively use its smelting technology overseas and educate professionals in acquiring the comprehensive technological capacity to construct a global recycling system.

2 Backcasting in Human Resource Development

According to the ranking compiled by the International Institute for Management Development (IMD), Japan's international competitiveness was at the top level in the 1990s but deteriorated to 27th in 2002. In 2006, it temporarily rose to 16th but declined again to 24th in 2007. Additionally, according to the Japan Center for Economic Research, Japan is not doing so well in terms of potential economic competitiveness, ranking 12th in 2006 and 13th in 2007. With these considerations in mind, this author would like to focus here on human resource development in those industries that aim to improve international industrial competitiveness and to reexamine human resource development using the backcasting approach (which can be a core concept for technological management). This does not mean an examination of continuing study programs. Backcasting was a concept proposed by Dr. Karl-Henrik Robèrt, founder of The Natural Step, an environmental NGO in Sweden. He suggested that the environment would not improve in the desired direction via the "forecasting" approach (which analyzes the past and the present to predict the future) and instead proposed the opposite approach of defining an ideal future and working backward to determine what needs to be done in the present.

The backcasting approach as used in this article for human resource development means defining an ideal professional in his/her late 30s or 40s, who is expected to play a major role in enhancing industrial competitiveness, and to work backward to establish human resource development programs that will connect that future to the present. By identifying what qualities and knowledge need to be acquired at which career stages, it should be possible to establish human resource development policies according to the type of industry and business (Figure 2). This approach aims to achieve high labor productivity among professionals in their late 30s and 40s. By analyzing what expertise and general knowledge they should have acquired before reaching their late 30s and 40s (back to when they are in their late 20s and around 30), we will be able to create development programs to connect the future to the present. Once the prerequisite qualities and knowledge have been determined for those who have graduated from college and spent several years in industry, this approach can also determine what they need to have learned by the time they finish their undergraduate, masters, or PhD programs.

Steel engineers who are expected play a major role in 2030 should acquire sufficient specialized knowledge, as well as the capacity to conduct all-around activities and the capability, through collaboration with other fields, to innovate. To achieve this, engineers need to learn about related technology and management, in addition to their expertise, when they are in their 30s. In their 20s, they need to have an understanding of a wide range of knowledge and ideas about steel in addition to specialized college-level knowledge. When educating people who are currently in their 20s to improve industrial competitiveness in 2030, it is essential to define a desirable future and identify concrete requirements whenever we discuss human resource development for young people. It is also essential that the discussion lead to the establishment of development programs in each company or in the industry. If we can clarify the

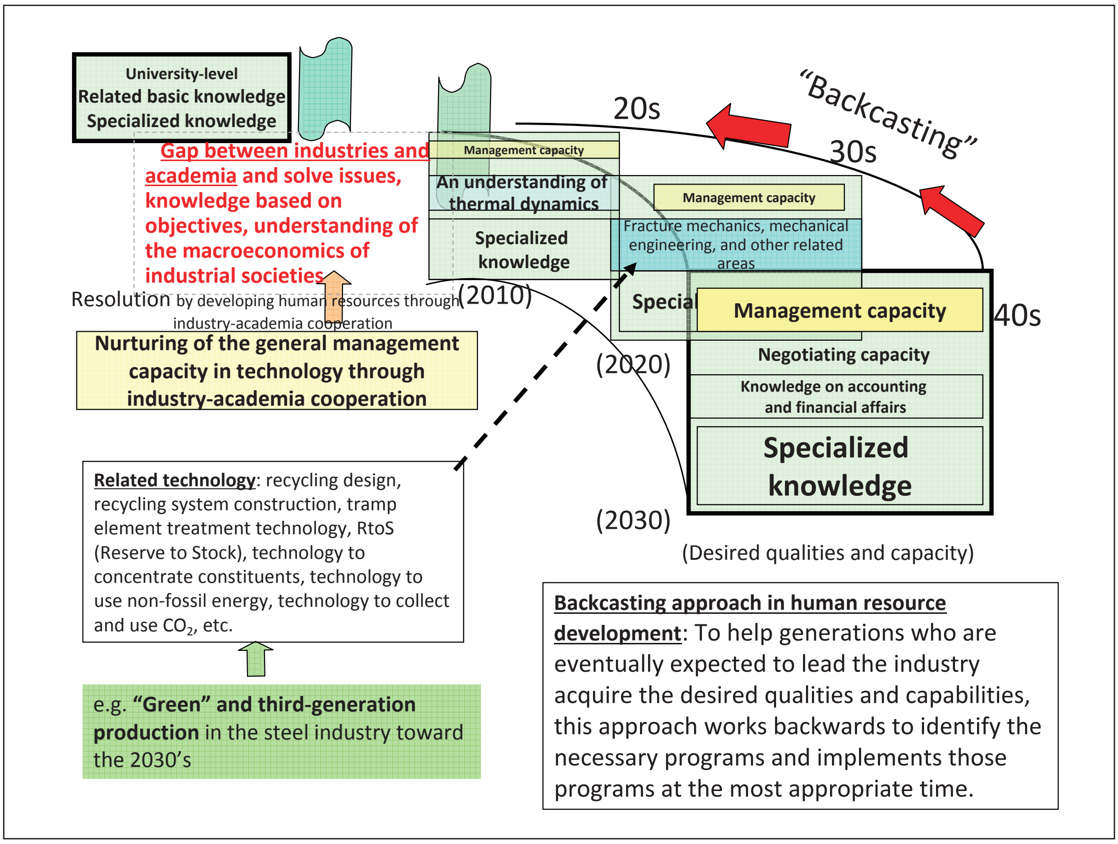

Figure 2 : Backcasting Approach in Human Resource Development

Prepared by the STFC

gap between the above-mentioned requirements and the curriculum taught in school up to college, we can also clarify what kind of human resource development programs the industry and academia need to create together.

Figure 2 also shows the gap between current college graduates and the professionals that the steel industry desires, assuming that such people will become key engineers in their 40s in 2030. Additionally, key engineers in 2030 will need to be able to comprehensively manage basic technology (such as establishing recycling systems and technology to treat tramp elements, concentrate constituents, and to collect and use CO_2) in order to respond to the need for green production and third generation steel production. As such, in addition to their specialized technical fields, they will need to promptly understand and master management of technology (MOT). MOT should be taught in college engineering classes rather than in post-college education. In particular, industry and academia need to work together to create a program that teaches the basics of MOT, such as how to identify and solve issues, as well as the macroeconomics of industrial societies. If the gap between industry and academia is closed, we can expect PhD graduates to work effectively immediately after they join the industry.

Below, I will discuss an industry-academia partnership to develop human resources in the steel industry field. I will also review existing and new efforts conducted by the steel industry. Additionally, I will consider how the gap between industry and academia is expected to be closed and what issues must be addressed to improve industrial competitiveness.

3 An argument about personnel training

3-1 Discussion of the Industry-Academia Partnership Project for Human Resource Development

In fiscal 2007, the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Economy, Trade and Industry launched the Industry-Academia Partnership Project for Human Resource Development, with the goal of achieving sustainable and dynamic growth in the Japanese economy and of making it possible for

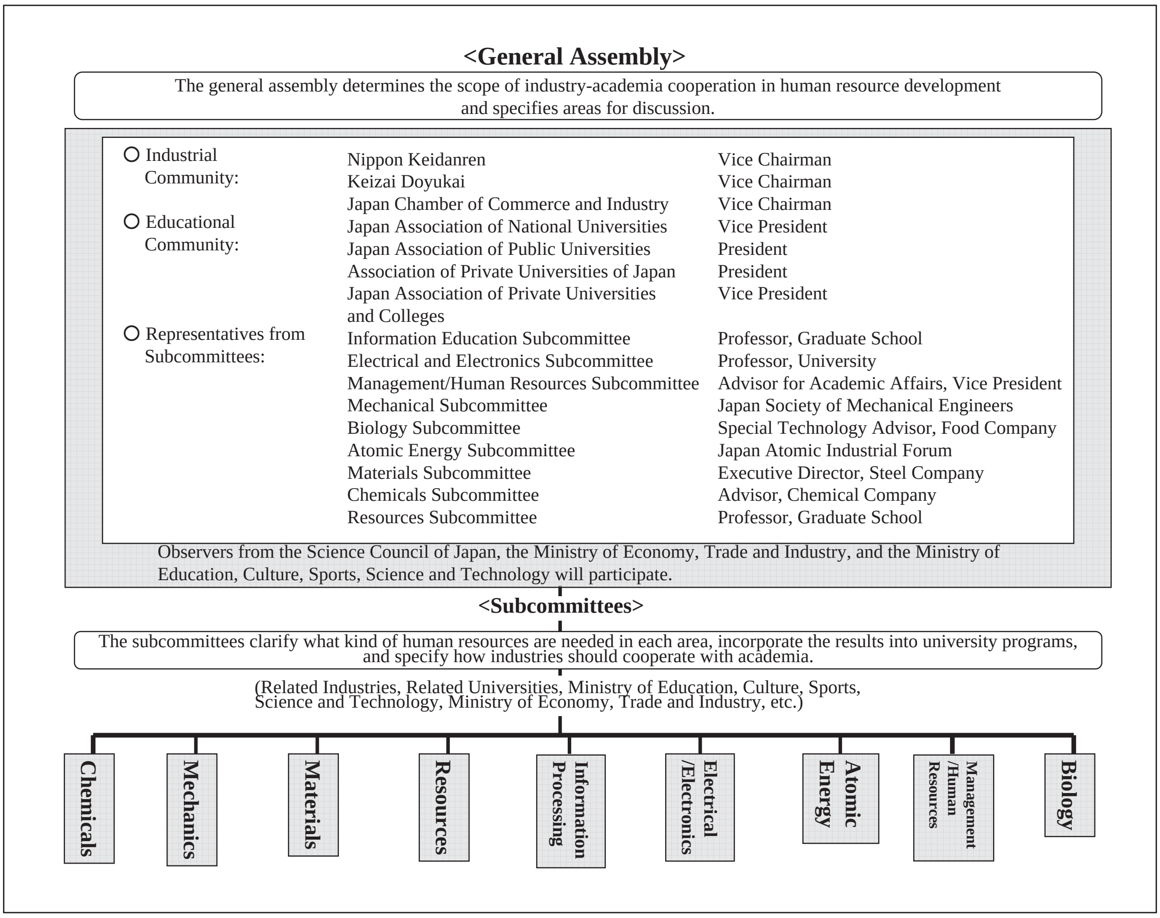

Figure 3 : Industry-Academia Partnership Project for Human Resource Development (General Assembly and Subcommittees)

Prepared by the STFC based on Reference[3]

the Japanese people to enjoy contented lives at ease.[3] This project targets nine industrial areas and explores industrial human resource development policies. Active exploration is underway with the materials field as one of these key areas (Figure 3). The materials subcommittee (the secretariat: Iron and Steel Institute of Japan) has been actively discussing issues as well as solutions in the industrial and educational communities, and has proposed concrete actions that industries and academia should take together.

The interim report states the following (summarized by this author based on Reference[3]).

Japan is a nation built on exporting internationally competitive products overseas. It is crucial to maintain a high and stable quality of materials as the basis for final products, and to develop technology toward innovative materials for the future.

As Figure 4 suggests, the ferrous and non-ferrous industries directly accounted for only 8% of all manufactured goods shipped. However, the competitiveness of mechanical products and automobiles and other transportation equipment also depends on ferrous and non-ferrous materials gualities. As such, the ferrous and non-ferrous industry is a key industrial area, supporting Japan's manufacturing. In particular, international competition in materials industries has become fiercer as the operations of automobile and electrical industries globalize. Thus, it is more important than ever to strengthen the research and development capacity for global advancement. Additionally, there is a greater need for resource-flexible and environment-friendly technology. It is especially essential for the ferrous and non-ferrous industries to aim to prevent global warming and to engage in other environmental activities, as they emit 40% of the total CO_2 emissions produced by industry. As the need for advanced technological development increases, the materials industry seeks excellent human resources who can maintain high-grade manufacturing technologies and overcome obstacles that are more challenging than ever before.

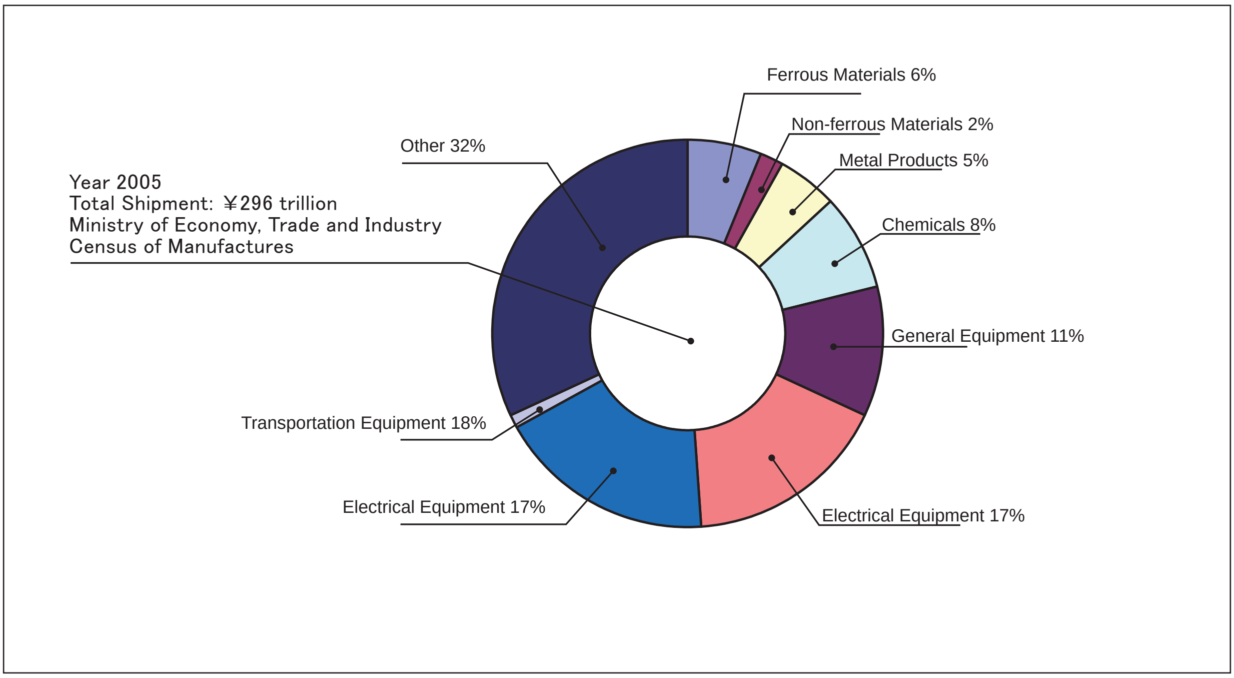

Figure 4 : Shipments of Japan's Major Manufacturers

Source: Reference[3]

A look at universities with materials technology departments reveals that the number of departments that teach metallurgy and other subjects concerning metal materials has been decreasing, and that the gap between the industry and universities has been increasing in terms of what should be taught in college. In addition, possibly due to insufficient PR, the number of students who want to study materials technology has been decreasing compared to other technological areas. Thus, some universities are having difficulty keeping these departments and majors. Materials technology is built on many different basic technologies. As such, it is difficult to achieve a one-to-one correspondence between industrial issues and scientific and technological issues. This is one reason that the materials field is so difficult for students and the general public to understand. So far, Japan's materials technology research has maintained its world-class status, but acquiring scientific research funding is becoming more difficult in some areas. As such, the progress of future research and development is becoming a concern. Now that national universities have become independent administrative institutions, assessments of university education and research depend more heavily on objective numeric data such as the rate of filling vacancies in graduate school, the number of articles submitted, and the number of presentations at international conferences.

Additionally, the number of job openings in materials industries has been influenced greatly by the changing economy. The number of new graduates hired by steel companies decreased substantially around 1993. If the number of new graduates hired around 1985 were to be represented by the value 1, this number hovered around 0.5 over the decade following 1993. According to a survey targeting major steel companies, the number of new employees who had studied materials technology was about 350, and more than 90% had master degrees. In light of these circumstances, now is not the time to abstractly discuss human resource development through industry-academia cooperation, but rather it is the time to consider concrete development policies.

Based on the above discussion at the materials subcommittee, an industry-academia partnership project for human resource development in the steel industry was proposed, and in 2008, it was adopted as the Industry-Academia Partnership Project for Human Resource Development by the Ministry of Economy, Trade and Industry.[4] The proposal was made by the Japan Research and Development Center for Metals in cooperation with steel companies and university teachers with the aim to formulate a sustainable industry-academia system following a three year trial period. The Project plans to build on the strengths of existing materials classes at universities and to create a consortium between universities in order to cover the necessary educational areas. Steel companies also plan to provide educational materials that reflect advanced technology to universities. Additional characteristics include a MOT program that covers the characteristics of the steel industry and includes case studies, and a new internship program incorporating suggestions from companies and providing students with relatively long-term opportunities for research and training through cooperation between universities and companies.

Cooperation and information sharing between industry and academia are essential in order to have university teachers better understand the current state of the industry and incorporate it into their classes. The existing human resource development programs in the steel industry target company engineers, but the above-mentioned proposal aims to develop full-fledged university education programs through industry-academia cooperation. It is expected to create effects that have not been realized through individual efforts by industry and academia. Furthermore, in order to stabilize the results of these efforts, the creation of educational materials and curricula as well as legal agreements and other infrastructures is necessary. For example, in order for industry and academia to accept the mutual flow of company employees, university teachers, and students, it is essential to establish a wide-ranging, concrete system covering insurance and intellectual property. To do so, support from the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Economy, Trade and Industry will be needed.

3-2 Discussion of Human Resource Development to Support Industrial Competitiveness in the Steel Industry

According to the Fundamental Issues Subcommittee of the Industrial Structure Advisory Council at the Ministry of Economy, Trade and Industry, the emphasis of Japan's industrial policies changed from "quickly promote key industries" to "let the market determine the key industries now that Japan has 'caught-up' economically and has become a developed country." The subcommittee also stated that the role of the government was to "maintain the market system and deregulate and abolish unnecessary regulations" and recognizes that Japan now faces issues such as declining birthrates and an aging population, bipolarization, and regulations concerning resources and the environment. The same subcommittee concluded that "Japan's environmental technology and strength coming from on-site monozukuri (manufacturing)" are the basic elements for its competitiveness, but that "Japan lacks the capacity to integrate and make the most of those elements and, thus, has not been sufficiently using them," and that, in order to overcome this situation, "Japan needs bold innovation and creativity gathered from every part of the country, that can change conventional technology and know-how." The subcommittee also pointed out that the japanese steel industry "should provide solutions services concerning environmental technology and attempt to both promote and find a way to receive compensation for them."[5]

However, the prices of ore and coal became 4.9 times higher between April 2000 and April 2008[6] and production decreased by 30% compared to the previous year due to the slowing economy in the latter half of 2008, and thus, the steel industry's profits have been declining. Additionally, to reach the goal of halving greenhouse gases by 2050, drastic reforms in the energy supply structure are required. Considering these circumstances, creativity that goes beyond conventional ideas is essential.

The steel industry has been active in investing in development. In fact, three steel companies ranked in the top 100 in a 2006 ranking of private research and development investment in Japan.[7] This research and development ranges widely from product development such as "design-in [Note 1]" with automakers to process development to reduce CO_2 emissions. Unlike the post World War II period, when nations promoted projects in pursuit of industrial competitiveness, it has been suggested that there will be more issues that can be solved only through open innovation, such as efforts to stop global warming. According to a report on the United States conducted by the Ministry of Economy, Trade and Industry, some experts suggested that "vertical cooperation was common in consortium projects in the United States and that the emphasis was on how companies in the same industry cooperate in research and create results."[8] To do so, it is essential to develop and secure human resources who can propose projects that respond to changes in the environment surrounding the industry.

It is true that the steel industry is often seen as symbolic of the old economy and that the number of students who choose to study in this field is declining. However, the steel industry has been conducting open innovation efforts and, through competitions and cooperation, has also been supporting Japan's industrial competitiveness since World War II. Of course, human resource development in the steel industry has emphasized technology, and individual persons and companies have been responsible for educating themselves and employees as engineers and researchers who can compete internationally. However, considering recent severe economic conditions, where the industry cannot even afford to conduct on-the-job-training (OJT),[Note 2] educating people to become engineers and researchers who can negotiate on the world stage is an important matter affecting more than a single industry, and as such, should be included in national policy. It is now necessary to define a desirable future and examine, in concrete terms, human resource development programs that include university education. It is also expected that by clarifying future requirements (namely, the relationships between age, knowledge, intelligence, etc.), job opportunities will increase for PhD graduates, who will be able to immediately start working effectively in the industry.

The Japanese steel industry is said to have matured and growing sluggishly. To maintain international competitiveness in the midst of the global economic downturn, the industry has been conducting in-house education and, in order to solve issues that are common throughout the industry, has been developing engineers. The Industry-Academia Partnership Project for Human Resource Development (Figure 3) groups together industries in related fields, but the steel industry has been working closely not only with the materials field but also with other fields. Thus, it is essential to discuss human resource development in the industry in a more cross-cutting manner than ever before.

4 Issues and Cases of Human Resource Development from the Perspective of Current Industrial Competitiveness

4-1 Issues in the Japanese Steel Industry

In 2007, the world's crude steel production surpassed 1.3 billion tons, of which Japan produced 130 million. Japan's overall production was almost equal to the amount produced by ArcelorMittal, the world's top producer. Looking at production by country, China's production has increased by more than 20% each year to reach around 500 million tons (Figure 5). There are several hundred steel companies in China, and these conditions are expected to continue at least until the 2010 World Expo in Shanghai.[9] China and ArcelorMittal are by far the largest producers among countries and companies, respectively. Due to the oligopoly situation, each company's price negotiation ability toward mine-suppliers is limited. The Japanese steel industry has its strength in high-quality steel, but it will be necessary to work with middle users such as automakers and the shipbuilding industry in order to maintain and improve industrial competitiveness. To achieve this, continuous technological and product development and innovation are required.

In 2008, the Japanese steel industry celebrated 150 years of modern iron making. On December 1st, 1858, Takato Oshima from the Nanbu domain (present-day Iwate prefecture) succeeded in the

[NOTE 1]
Design-in : Engineers from both the producer and the user sides communicate, beginning from the designing stage, to create products that have characteristic functions.

[NOTE 2]
Acquisition of knowledge, technology, skills, behaviors, etc. required for work as a result of teaching through actual work (from superiors and experienced workers to subordinates and less experienced workers).

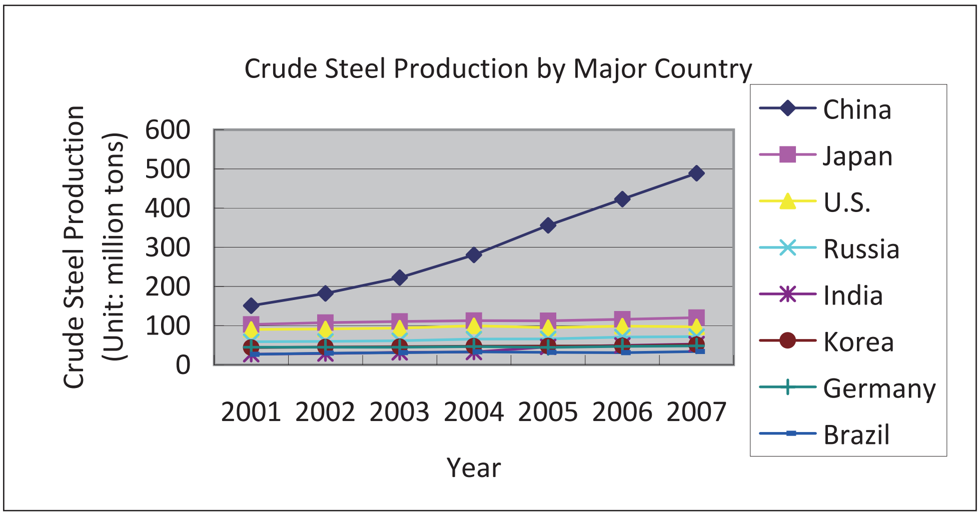

Figure 5 : Crude Steel Production by Major Countries

Prepared by the STFC based on Reference[10]

continuous production of pig iron using a Japanese-style blast furnace. To commemorate his success, December 1st is the anniversary of iron making in Japan. The success of the Japanese-style blast furnace was the result of continuous improvement efforts based on Japanese know-how, and did not just rely on the introduction of foreign technology. This point is reinforced by the fact that a foreign engineer employed by the Meiji government later failed in iron operations. Similar continuous innovation has been conducted throughout the history of the steel industry.

In his "Comparative Analysis of the Integrated Steel Companies in East Asia,"[11] Nozomu Kawabata characterized the first generation of the integrated steel making system by the location of ore and the second generation by the waterfront industrial areas in the 1960s and 1970s in Japan. He defined the third generation as "a production system that solves problems of mass production, establishes more flexible production, and substantially advances resource and environmental control." The current steel industries of Japan and the United States basically follow the pattern of the second generation (defined by Kawabata), typical of mass production, but also incorporate flexible multi-variety small-lot production, and thus, are considered to be second-and-a-half generation.

Due to the drastic economic downturn in the latter half of 2008, worldwide pig iron production from blast furnaces decreased compared to the previous months, except in China. Comparing August and December of 2008, production declined more than half in some countries (Figure 6). According to the "common sense" of furnace experts, changes in production had been normally limited to 10% per month. As such, the industry is experiencing a once-in-a-century situation. However, the potential global demand is steady. Thus, it is important from both the management and the technological perspective to secure production capacity while enduring the current decline in production. Technological development concerning the elasticity of production is also essential. The steel industry must regard the current situation as an opportunity to establish tools for elastic production and let young engineers take over in order to establish third-generation steel production.

If we consider the future environment surrounding the steel industry and focus on industrial competitiveness in 2030, then in order for Japan's manufacturing industries to survive through high value final products, it will be necessary to maintain either high quality that others cannot keep up with, or price competitiveness. Additionally, the worldwide average demand for steel is expected to be close to 250kg per person in 2030 (the same level as Korea at present). If demand goes up any higher, due to the drastic increase in the demand for steel to be used for machinery, the ratio of copper to be mixed into iron materials is expected to surpass 2.8%, producing a large amount of non-recyclable iron scrap.[12] Japan has established a materials sorting system using, for example, a shredding process,

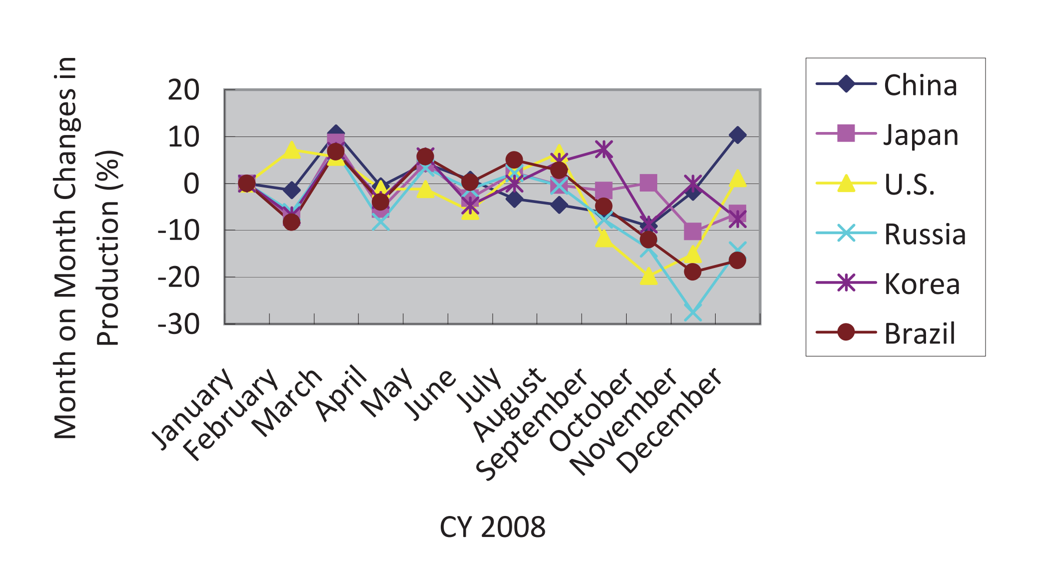

Figure 6 : Monthly Changes in Pig Iron Production from Blast Furnaces

Prepared by the STFC based on Reference[10]

but there are not yet sufficient technologies or systems to deal with copper-mixed scrap on the global level. Looking toward 2030, it is essential to technologically respond to the increase in factory scrap from overseas. Technologies currently being explored include technology to remove the undesirable effects of copper and other impurities (tramp elements) and other technology to actively use such impurities to improve the quality of materials. It is desirable for waste treatment to shift from the conventional disassembly-sorting-smelting process to RtoS (Reserve to Stock: disassembly, separation, concentration, and smelting).[2] To be competitive on the world stage in 2030, it is essential both to maintain a scrap-based control system and to establish a customized multi-variety production system.

The steel industry has increased its production, with the auto industry as its main user. However, to work with a variety of users in the future, shifting to green and third-generation steel production is essential, and the key words to do so are: minimum CO_2 emissions (a new iron making process, high-efficiency smelting, production of appropriate amounts in the appropriate places, under high pressure), low-quality materials (low iron content, low-quality coal, location near mine-suppliers, supply chain), low alloy-containing steel (minimum additives, new processing, element separation recycling), design for longevity (bridges, reinforcement for high-rise buildings, replacement, design for easy disassembly), material flow design (material circulation, element circulation, element cost), etc. In order for iron to continue to be a key material in 2030, it is necessary to integrate, based on materials-related technology, various scientific and technological fields, such as mechanical, electrical, and chemical engineering as well as plant design and financing. Temporarily reducing production is not sufficient to respond to the current economic downturn. Rather, it is important to take this opportunity to come up with technological and management ideas to realize elastic production systems.

4-2 Human Resources in the Japanese Steel Industry

High monozukuri (manufacturing) technology as well as high-quality materials that ensure reliability in final products supported the high economic growth of the post-war era, the stable growth that followed, and the industrial competitiveness fostered in those periods of growth. Steel products are symbolic of those high-quality materials. For example, the tensile strength of high tensile steel sheets (which are mainly used for automotive exterior panels) has been around 40 for about 40 years, but it is now over 70 in some panels (tensile strength: sample bar strength measured at the time when the bar breaks in a tensile stress test in units of kgf/mm^2). As a result, steel products strong enough to use in automobiles now weigh about

20% less,[13,14]contributing to fuel efficiency. The tensile strength of steel plates for ships has also improved, and larger container ships can be now built, sharply reducing transport costs. It is high quality materials that make technology possible, and people in the steel industry have played a key role by developing and manufacturing such high-quality materials. The efforts were made by a wide range of experts in not only material manufacturing technology, but also in welding, plasticity processing, and surface treatment technology or so.

One characteristic of Japanese industry is that manufacturers of materials and users of materials, such as automobile companies, share information and start working together from the design stages to develop materials. Cars are consumer products. As such, car companies tend to become the center of people's attention when we discuss the automobile industry. However, material companies cover materials and processing technology, and steel company engineers play a substantial role in the overall technology. Ohashi, et al.[15] defined user innovation [Note 3]as the way that users of introduced technology gain a thorough knowledge of products (or introduced equipment) by committing to the improvement of how they are used and their performance. Ohashi, et al. gives an example case where steel companies imported production technology of the basic oxygen furnace (BOF) from overseas, a dramatic development in the industry. At that time, BOF was facing some serous technological problems. Thus, it was essential to solve those problems before the technology could become used widely. It was a Japanese steel company that created the technology to solve these problems. This achievement was the result of a high level of expertise among on-site iron-making professionals.

However, for third-generation steel making, it is essential to aim to transcend conventional technology, and the Japanese steel industry needs to create an atmosphere of open innovation and to respond to cirumstances. To do so, the way we nurture engineers and developers in various areas over the next ten to twenty years is important, and this should be different from an extension of the existing production technology.

Some, from the perspective of production management, attempt to understand that the strength of the Japanese manufacturing industries comes from the post-war lifetime employment system and that Japanese in-house human resource development is a variation of McGregor's theory X.[16] This view is based on a social environment where human resources are relatively static. Currently, major steel companies are able to conduct in-house human resource development programs targeting specialists. However, small and medium-sized companies are having difficulty in passing on their technology to younger generations, and human resources are fluid. To respond to this situation, the Japanese steel industry has been conducting industry-wide basic technological development programs, taking advantage of the industry's culture of cooperation and competition nurtured during the period of reconstruction following World War II. In addition, it is also necessary to cultivate generalists who have expertise in responding to sudden changes in the socio-economic environment. It is hard for a single company to achieve this kind of human resource development. Thus, some companies, through the coordination of the Iron and Steel Institute of Japan, are aiming to conduct a joint program.

4-3 Human Resource Development Efforts by Industry Association

Here, I will introduce human resource development efforts being conducted by the steel industry association.

Human resource development programs conducted by the Iron and Steel Institute of Japan are planned and managed by a development

[NOTE 3]
In recent years, marketing methods that emphasize user innovation have been popular. Those methods include, for example, product line-ups based on data and requests from internet buyers (market development), or the involvement of (information) equipment users in development (of terminal equipment). Ohashi, et al. extended this concept.

committee comprised of people from both companies and universities. Development programs in Figure 7 include “steel engineering seminars,” “specialized steel engineering seminars,” and “advanced steel engineering seminars.” They are provided for a fee, and each program is basically operated on a for-profit basis. Currently, all programs are turning slight profits. This suggests that the programs meet the needs of the present generation and are well-received, including how they are managed.

A steel engineering seminar is held every year. It targets young individual members (including non-Japanese members) of the association, who are mostly in their 20s and have three-to-five-years of experience in the steel industry. Many engineers and researchers have participated over the years. The course aims, for example, to provide an employee whose college major was mechanical engineering or electrical engineering with an opportunity to relearn the basics of materials or metallurgy. The course can also be a good opportunity to meet people in the same field from different companies, and many people seem to keep in touch with each other and exchange ideas. Each time, there are some 150 participants. They attend lectures and engage in discussions while staying at a hotel in Zao for a week. On the last day, groups of participants make presentations based on earlier group discussions, and excellent presentations receive an award. The teachers come from both academia and industry (about half and half in number) and their term lasts for two years. The teaching experience becomes a valuable asset especially for company employees who are in their 40s and in management (mainly department chiefs). In other words, the seminar effectively trains not only the participants but also the teachers. Applicants usually apply through each company’s human resources department, and this proves that the programs are considered human resource development tools.

The specialized steel engineering seminars target engineers and researchers who have taken the steel engineering seminar and desire to learn more about specific areas. Each year, the human resource development committee of the association asks university professors to suggest themes

1) Steel engineering seminar (Zao seminar)

Target: Engineers and researchers who have several years of experience in the industry

Number of participants/duration/content: About 150 participants/one week retreat/three courses: iron making, steel making, and material and rolling

2) Specialized steel engineering seminar

Target: Those who have completed the steel engineering seminar

Number of participants/content: About ten participants in each course/taught by specialists from each specified field (actual subjects taught in 2007: cast structure control/high-temperature deformation and processing/properties of melted iron and slag/thin sheet press molding)

3) Advanced steel engineering seminar

Target: Mid-career employees (mainly section chiefs)

Number of participants/content: up to about ten participants each/three courses in iron making, steel making, and material and rolling, aiming to nurture human resources, mainly through discussions, who will eventually play key roles in the industry

(The 2008 seminar was conducted at the Kanagawa Science Park from October 23 to 25. Eight participants in iron making, eleven in steel making, and fifteen in materials. Keynote speech: Professor Kawabata from the Faculty of Economics, Tohoku University, “New Phase of the Steel Industry in East Asia.”)

Figure 7 : Human Resource Development Programs Conducted by the Iron and Steel Institute of Japan (Fiscal 2007)

Prepared by the STFC

for the seminar, and company employees who are interested in those themes can participate. More than ten applicants are required to hold the seminar, and company employees are appointed as organizers to conduct the seminar smoothly. The advanced steel engineering seminars target mid-career employees (mainly section chiefs in their 30s) who have taken the steel engineering seminar and are eventually expected to play a key role in engineering and related areas. During a two-night and three-day retreat, participants are divided into three groups (iron making, steel making, and materials [rolling]) and, according to predetermined themes, engage in discussions including those on technological perspectives. Without revealing their companies' intellectual property or know-how, the participants discuss future technological prospects in groups and each group gives a presentation at the end. More experienced company employees and associate professors in their 30s serve as discussion moderators.

The current human resource development programs being conducted by the Iron and Steel Institute of Japan have taken shape in accordance with the needs of the industry and universities' desire to teach practical knowledge. Moreover, thanks to countless efforts by those who recognize the importance of cooperation and who were involved in the management of the programs, continuous improvements have been made. However, it took over 30 years to reach this point, suggesting the difficulty of conducting a human resource development program. The current programs were not created based on the backcasting concept, but they now provide different learning opportunities for employees in their 20s, 30s, and 40s.

4-4 Proposing Solutions for Issues of Human Resource Development in the Steel Industry

In this section, I will use the backcasting approach shown in Figure 2 to examine the human resource development programs conducted by the Iron and Steel Institute of Japan in order to make further improvements.

Firstly, it is necessary to share, among the industry and academia, issues that concern how to maintain and improve the competitiveness of the industry between now and 2030. Next, we must picture human resources in the future who can promote the innovation necessary to respond to changing environments and to maintain and improve Japan's industrial competitiveness. To do so, we need to urgently consider industry-academia programs targeting young engineers and students in materials engineering or other areas in their 20s. For example, establishing technology to use recycled alloy steel and creating a system to minimize CO_2 emissions are essential. To realize this, developing elemental technology and cultivating technology to integrate such elemental technology as well as developing human resources who will play key roles in these activities are necessary. In engineering classes at universities, students should, at an early stage of their education, acquire MOT capabilities in addition to knowledge in their specialized fields. We should help students understand the actual state of the industry and introduce a MOT program to improve their overall capabilities. Students should learn, before they join a company, about project management, making them able to find issues, develop technology, and achieve goals.

At the Central Education Council of the Ministry of Education, Culture, Sports, Science and Technology, university-related professionals have been discussing how university education should be from a mid and long-term perspective. The council stated, "college graduates require high intellects to be able to compete internationally in a globalized world,"[17] and aims to improve the quality of college education. This author hopes that there will be further discussion involving various sectors in order to clarify the objectives of the human resource development much needed by society, and, using the backcasting approach, to conduct appropriate programs at appropriate times without being confined to the existing programs. For example, based on the result of industry-academia efforts, I hope that there will be discussion on closing the gap between industry and academia by, for instance, incorporating what has been taught at companies into university curricula. As discussed in Section 3, the Industry-Academia Partnership Project for Human Resource Development, conducted jointly by the Ministry of Education, Culture, Sports, Science ad Technology, and the Ministry of Economy, Trade and Industry, is providing new opportunities for industry-academia cooperation. I hope that this will become an opportunity to use the backcasting approach to discuss what human resources are needed in each industry or company and that we will take concrete action in order to maintain and improve Japan's industrial competitiveness, which can be achieved only through cooperation.

5 Conclusion

In this article, I have introduced human resource development programs being conducted by the steel industry in order to maintain and improve industrial competitiveness. I believe that these programs can be used as model cases for other industries. I have also looked at the industry-academia partnership programs being conducted by the Ministry of Education, Culture, Sports, Science and Technology and the Ministry of Economy, Trade and Industry, which aim to solve issues that cannot be solved by the industry or companies alone, in the hope that those efforts will close the gap between industries and academia. Currently, we are experiencing a global economic downturn. However, once the financial system is reformed, it is expected that the market will expand to respond to potential demand. Looking forward to 2030, the Japanese steel industry needs to realize third-generation iron making. That is to say, industry must both respond to environmental issues and establish production elasticity. In the future, globalization will not just mean a global flow of money but will also include both physical and mental aspects, which will transcend or even eliminate boundaries. As such, it is expected that each company or industry will not be able to develop human resources sufficiently by itself. Human resource development programs have been conducted through trial and error, but I hope that the backcasting approach will clarify issues and be used to establish, with public support, industry-academia programs that will effectively maintain and improve industrial competitiveness. MOT programs should not only be introduced at universities but also be constantly improved in order to meet the concrete needs of industry. Additionally, although I did not mention it in this article, I believe that there should be a public system in order to develop human resources in small and medium-sized companies who will be able to not only pass technology on to future generations but also work globaly from a management perspective.

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Profile

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Mr. Chida earned his PhD in Engineering with a major in ferrous metallurgy. After being dispatched to the Japan Association for the Advancement of Research Cooperation and at the Japan Science and Technology Agency (JST) and being a new technology agent for the Joint-research Project for Regional Intensive in Iwate Prefecture, he studied Management of Technology (MOT) and earned his degree with an emphasis on management of intellectual production. He was involved in the establishment of the New Technology Commercialization Center of Tohoku, and has been working for regional industry-academia-government cooperation for years.

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4

Steel Industry's Global Warming Measures and Sectoral Approaches

Akira Kojima
Affiliated Fellow

1 Introduction

The five-year first commitment period started in 2008 under the Kyoto Protocol for the United Nations Framework Convention on Climate Change, which was signed in 1996 and took effect in 2005. According to Japan's Kyoto Protocol Target Achievement Plan that was revised wholly on March 28, 2008, the nation's GHG emissions in FY 2005 increased by 7.7% from the standard year of FY 1990.[1] Even if forests' CO_2 absorption and the Kyoto Protocol's CDM[NOTE1] and Joint Implementation mechanisms are exploited, the government states that Japan will have to reduce emissions in FY 2010 by 0.8-1.8% from the standard year (Figure 1).

Japan's CO_2 emissions are shown in Figure 2. CO_2 emissions have declined in the industrial sector while increasing in the transportation, commercial and household sectors. Japan's overall CO_2 emissions have expanded. A major challenge for Japan is to reduce emissions in emission-expanding sectors.

Emissions in the industrial sector (covering the energy conversion and industrial sectors) are shown in Figure 3. The steel industry accounts for as much as 44%[2] of the industrial sector's total GHG emissions. Therefore, the steel industry's GHG emission reduction is significant for Japan's emission-cutting measures.

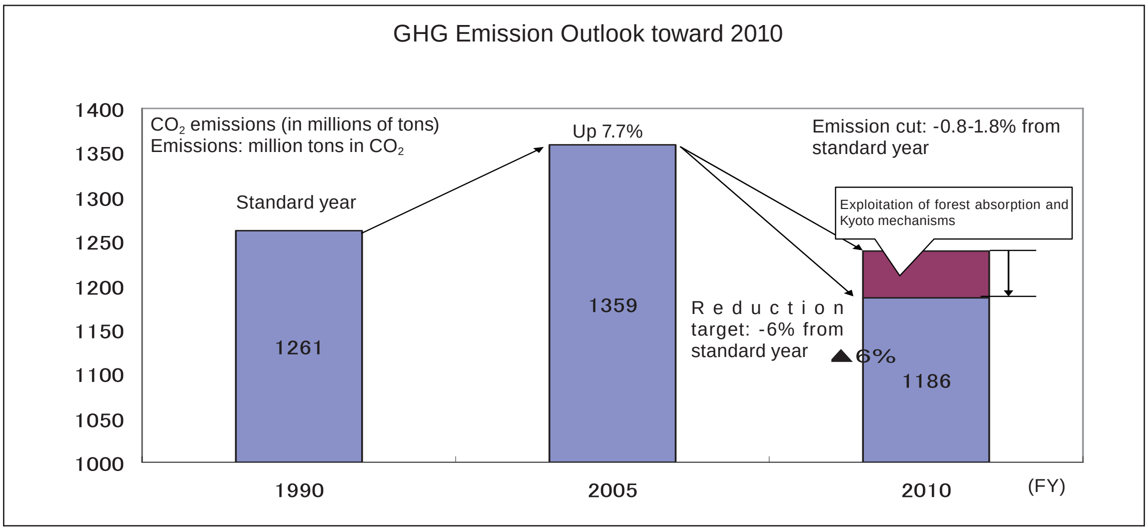

Figure 1 : Emission Outlook in Government's Kyoto Protocol Target Achievement Plan

Prepared by the STFC based on Reference[1]

[NOTE 1]
The Clean Development Mechanism (CDM) is designed to provide entities cooperating in GHG emission reductions in developing countries with emission credits meeting the reductions.

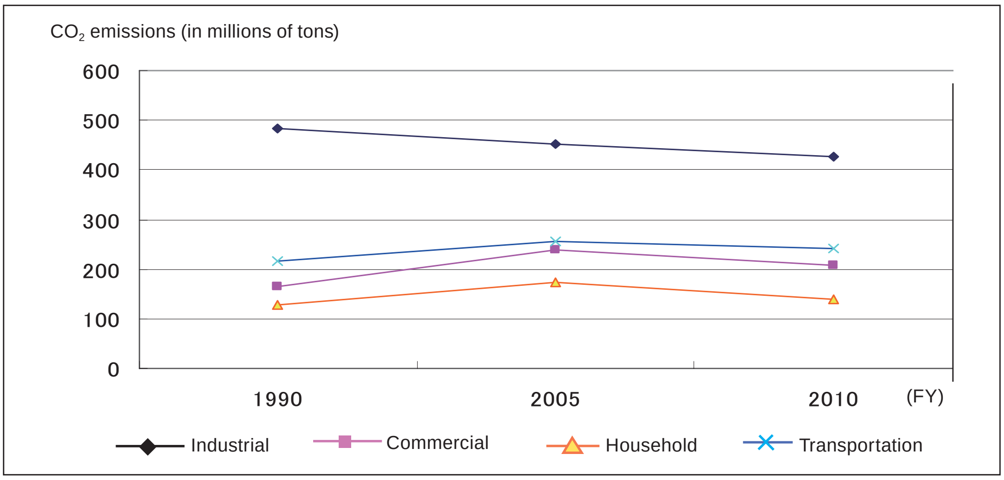

Figure 2 : Sector-by-Sector Energy-based CO_2 Emission Outlook

Prepared by the STFC based on Reference[1]

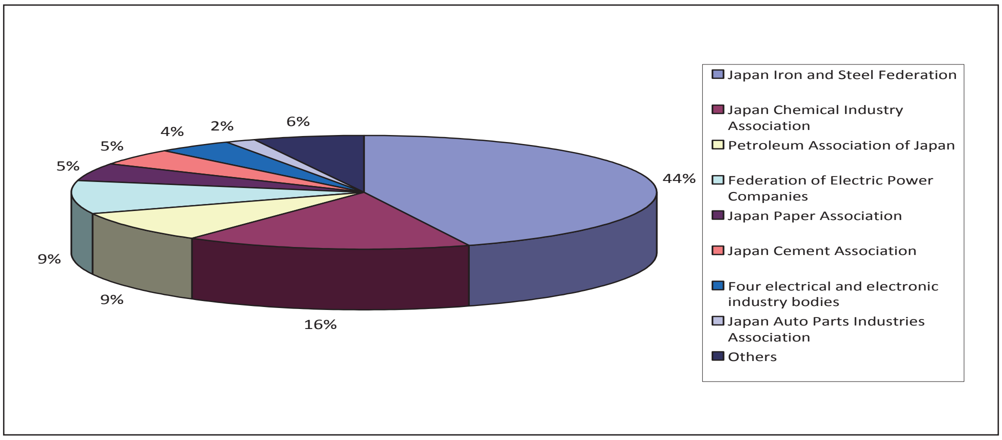

Figure 3 : Energy Conversion/Industrial Sector CO_2 Emission Share

Prepared by the STFC based on Reference[2]

2 Steel Production and GHG Emissions

The integrated steelmaking process to make steel materials from iron ore includes the generation of metallic iron through the reduction reaction, rolling and heat treatment steps, and the production of various steel products. The iron ore reduction reaction is indicated as $2F_{e2}O_3+3C \rightarrow 4F_e+3CO_2$ generating CO_2. The reduction reaction alone emits 0.59 ton of CO_2 per ton of steel output. In fact, however, the iron content of iron ore is limited to some 60%. Therefore, heat sources are required to melt iron ore including non-iron components and promote the reduction reaction. Furthermore, refining, processing and other steps are required for turning out steel products. Given fuel consumption on heating for these steps, CO_2 emissions per ton of steel products come to about 2 tons.

For real steel production, scrap iron is used substantially. In Japan, scrap iron accounts for 42% of materials for crude steel production (in 2007). Scrap iron is a precious iron material. An expansion in scrap iron's share of steelmaking materials can effectively contribute to reducing CO_2 emissions. But scrap iron output depends on regional steel accumulations and steel-processing industries. Impure substances contained in scrap iron becomes constraints on scrap iron uses. For automobile steel sheets, seamless steel pipes and other advanced steel products that Japanese steelmakers are good at producing, the materials standards are very tough. Scrap iron used for these products is limited.

Steel has been widely used as a basic material to support people's living and economic activities at home and abroad. Without steel, modern life cannot stand. Demand for the steel has increased in proportion to an expansion in economic operations in the world.

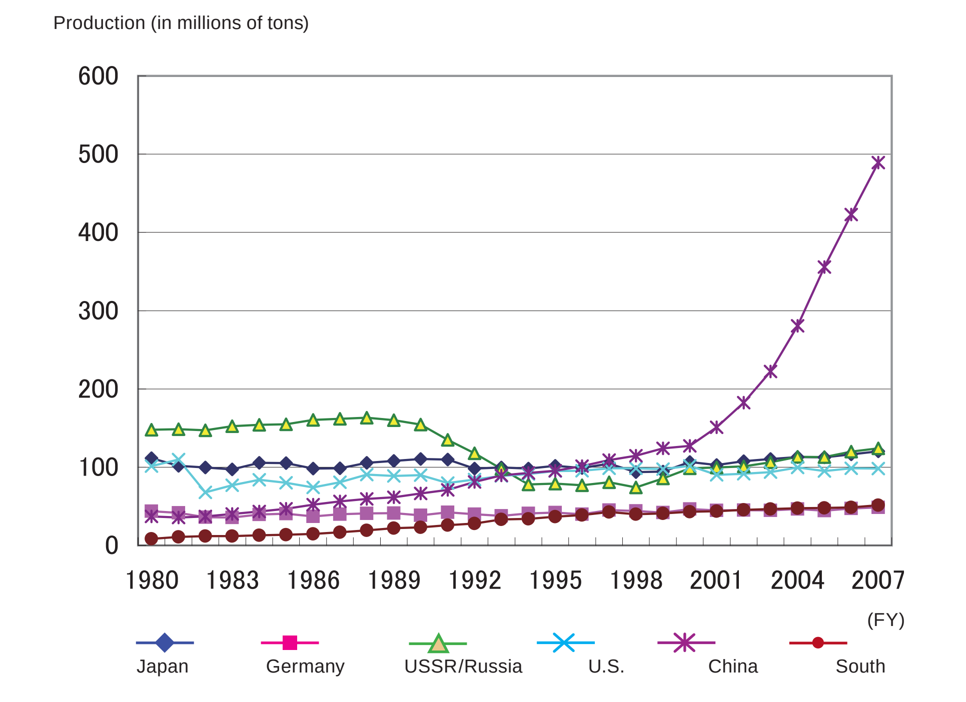

Figure 4 : Steel Production in Major Countries

Prepared by the STFC based on Reference[3]

Recent steel production in major countries is indicated in Figure 4.[3] Since 2000, steel production has increased globally on economic development mainly in the so-called BRICs countries. Particularly, China's explosive steel production expansion has attracted attention. China's recent annual expansion of 50 million tons in steel output could have required five of the representative integrated steel plants seen in Japan to be built in one year.

3 Kyoto Protocol and Sectoral Approaches

Since the Kyoto Protocol was signed, the situation involving GHG emissions has changed greatly. The United States as the world's largest GHG emitter pulled out of the Kyoto Protocol in 1998. China and other emerging countries have increased GHG emissions sharply, these have expanded the gap between countries subject to numerical GHG emission reduction targets and others. As shown in Figure 5, the 192 nations that have ratified the U.N. Framework Convention on Climate Change include the 39 countries that are specified in Annex I as subject to binding numerical commitments.

The United States as the world's largest GHG emitter and China which has been expanding steel production are left out of the numerical regulations. CO_2 emissions in the countries subject to the numerical targets accounted for an estimated 28% of global emissions in 2005.[5] While those are subject to numerical regulations, other countries accounting for 72% remain unregulated and are left to expand emissions. Under such situation, global emissions cannot be expected to decline. Numerical regulations that fail to cover very influential countries are described as less effective and unfair.

China and other countries that are left out of GHG emission regulations have been expanding their share of global steel production and steelmaking-related GHG emissions. The effects of GHG emission reduction measures in which these countries do not participate may be limited. Steel is traded widely in the world, as indicated by Table 1. Some countries shoulder costs for GHG emission reductions involving steelmaking, while others are free from such costs. Such situation could distort world steel trade. Countries with less GHG emission regulations may expand steel production in accordance with competitive condition gaps, leading to an increase in global GHG emissions. Such phenomenon is called as carbon leakage.

Carbon leakage is a problem with the carbon cap-and-trade system[NOTE2] planned under the Kyoto Protocol. This would be a major institutional

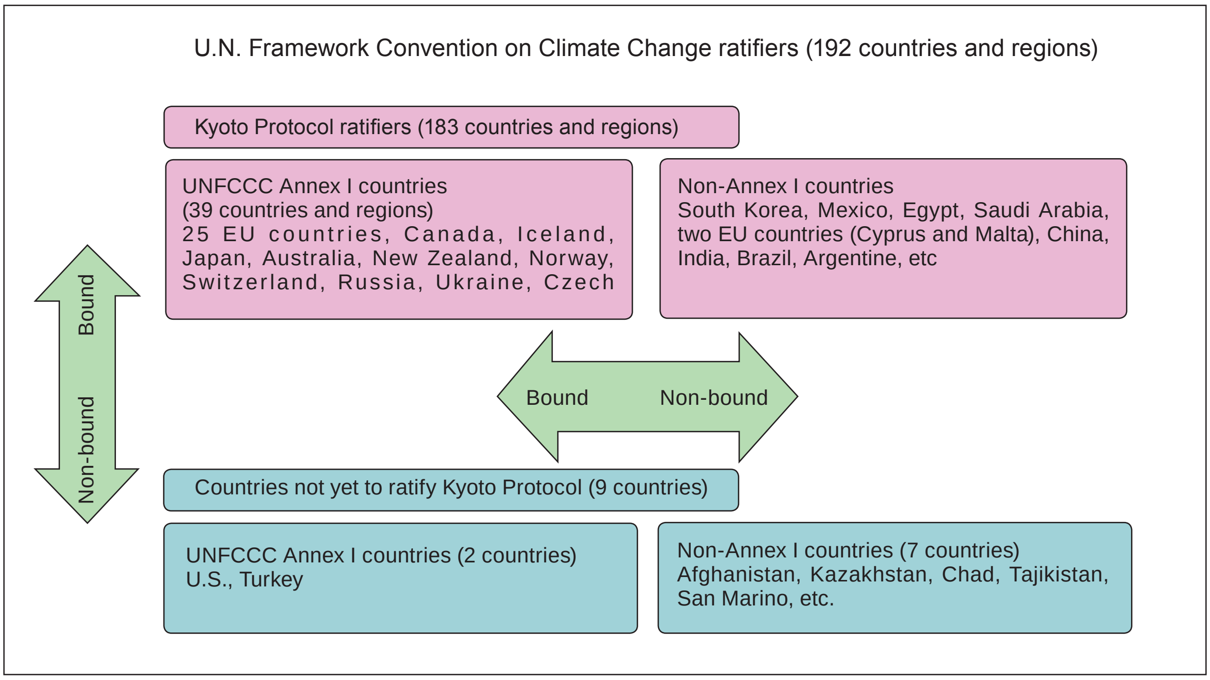

Figure 5 : Structure of Kyoto Protocol

Prepared by the STFC based on Reference[4]

Table 1 : Steel Exports from Major Countries (2007)

unit : Mt

Country	China	Japan	25 EU countries	Russia	Ukraine	Germany	Belgium*	France	South Korea
Exports	51.7	34.6	32.4 **	31.5	30.6	29.2	24.6	18.8	18.0

* Covering exports from Belgium and Luxembourg
** Excluding trade between the 25 EU countries

Prepared by the STFC based on Reference[3]

problem if countries subject to numerical regulations account for a small portion of global GHG emissions.

In order to solve the problem, steelmaking, thermal power generation, cement production and other major GHG-emitting industrial sectors may diffuse best available technologies through international cooperation to reduce specific GHG emissions on a global basis. Interests for such sectoral approaches are growing.

Sectoral approaches are designed to adopt advanced energy conservation and environmental technologies for GHG emission cuts in specific industrial sectors globally to reduce global emissions while avoiding the carbon leakage. At the G8 Hokkaido Toyako Summit in 2008, Japanese Prime Minister Yasuo Fukuda proposed the sectoral approaches. Japan has also proposed the approaches at international conferences on global warming. The sectoral approaches are realistic, emphasizing the diffusion of best available technologies. The global diffusion of available environmental and energy conservation technologies will work to promote technology development not only in industrial countries but also throughout the entire world. In the steelmaking sector, the World Steel Association comprising major steelmakers in the world is moving ahead with a sectoral approach. This will serve as a useful model for other sectors.

Before looking into details of the sectoral approaches, the next chapter introduces relevant efforts that the Japanese steel industry has tackled so far.

[NOTE 2]
The cap-and-trade system sets country-by-country GHG emission goals and allows countries to trade in emission credits and take advantage of emission cuts through cooperation with developing countries and joint implementation of projects to achieve their respective goals.

4 Japanese Steel industry's CO_2 Emission Reduction Efforts

In 1996, the Japan Business Federation, known as Nippon Keidanren, drew up a voluntary environmental action plan in which 29 industrial sectors participated (the number has increased to 36). In the steel industry, the Japan Iron and Steel Federation worked out a voluntary action plan . Each industry's voluntary action plan is positioned as important measures in the government's Kyoto Protocol Target Achievement Plan. Progress in each industry is examined at government advisory panels.

Following are details of the Japanese steel industry's voluntary action plan[6]:

(1) Energy conservation efforts for steelmaking processes

- On the assumption of annual crude steel production at 100 million tons, steelmakers will reduce energy consumption on steelmaking processes in FY 2010 by 10% from the standard year of FY 1990.
- Even if annual crude steel production exceeds 100 million tons, steelmakers will make efforts to achieve the target by taking advantage of the Kyoto mechanism.
- The above target should be achieved as a five-year average for FY 2008-2012.

(2) Contributions to energy conservation in society

- The industry will effectively utilize 1 million tons in exhaust plastics on the assumption of the development of a relevant collection system.
- Steelmakers will use products and byproducts for contributing to energy conservation in society.
- Steelmakers will contribute to energy conservation through international technology cooperation.
- Steelmakers will make efforts with neighboring communities for using untapped energy sources.
- Steelmakers will enhance emission reduction efforts in commercial, residential and transportation activities.

(3) Innovative technology development efforts

- Steelmakers will try to develop technology to separate and collect CO_2 from blast furnace gas.
- Steelmakers will try to develop technology to use hydrogen reformed from coke ovens for reducing iron ore.

The Japan Iron and Steel Federation's 10% energy consumption reduction target roughly amounts to a 9% CO_2 emission reduction target. According to data released by the federation in October 2008, CO_2 emissions in FY 2007 (from April 2007 to March 2008) posted a 1.8% drop from FY 1990. While crude steel production increased by 8.9% from 112 million tons to 122 million tons, the industry lowered specific energy consumption (energy input per unit of steel production) to achieve the net CO_2 emission cut.

The Japanese steel industry plans to achieve the 10% energy consumption reduction target for FY 2010 by stepping up energy conservation. The industry is considering utilizing the reduction of CO_2 emissions from the steelmaking processes and the Clean Development Mechanism under the Kyoto Protocol to achieve its CO_2 emission reduction target.

5 Energy Conservation in Each Steel Production Process

Energy conservation measures in the steel industry reduced energy consumption in FY 2007 by 290 PJ (petajoules) from FY 1990 while a crude steel production increase worked to boost consumption by 222 PJ. As a result, the industry's energy consumption in FY 2007 came to 2,458 PJ against 2,527 PJ in FY 1990.

Energy conservation in each steel production process was specified in the above-mentioned federation data released in July 2008.[7] The data indicate that steady energy conservation efforts in each process have been accumulated to achieve energy efficiency improvements.

Specifically, energy consumption in FY 2006 was cut by 111 PJ (29.4%) from FY 1990 through operational improvements to cut consumption of electricity, high-pressure air, steam and fuels, by 101 PJ (26.8%) through equipment-related energy efficiency improvements such as the installation of more efficient burners and the enhancement of efficiency for private electric power generaters and oxygen compressors, by 47 PJ (12.5%) through coke dry quenching (CDQ),[NOTE3] the introduction of top-pressure recovery turbines (TRTs)[NOTE4] and enhanced recovery of waste energy including byproduct gases and steam, and by 25 PJ (6.6%) through production process rationalization/continuation including direct rolling. Furthermore, the effective utilization of exhaust plastics worked to reduce energy consumption by 14 PJ (3.7%) (Table 2).

Figure 6 indicates energy consumption for steel production in Japan. Since energy consumption depends heavily on steel production volume, specific energy consumption (energy input per unit of steel production) can better reflect energy conservation efforts. As indicated in Figure 7, the steel industry's specific energy consumption stood at 89.5 in FY 2007 against 100 for FY 1990, posting a substantial decline.

It is noteworthy that the Japanese steel industry achieved the results in the period by accumulating various efforts. This is because the Japanese industry's specific energy consumption in 1990 was already the lowest in the world.

The Japanese steel industry has featured the maximum utilization of resources and energy. After World War II, Yataro Nishiyama, the first president of Kawasaki Steel Corp. (that has been taken over by JFE Steel Corp.), built an integrated coastal steel work

Table 2 : Factor-by-Factor Breakdown of Energy Consumption Decline and Increase

FY 1990 energy consumption (PJ: petajoule)		2,527	Percentage change
FY 2006 energy consumption		2,394	
FY 2006 (Change from FY 1990)		-133	-5.2%
Decline	Waste energy recovery	-47	-1.9%
	Enhancement of equipment efficiency	-101	-4.0%
	Production process rationalization/continuation	-25	-1.0%
	Operational improvements	-111	-4.4%
	Effective utilization of waste plastics	-14	-0.6%
	Other energy conservation measures	-80	-3.2%
	Subtotal	-377	-14.9%
Increase	Expansion of added values products	50	2.0%
	Enhancement of environmental measures	14	0.6%
	Recycling by-products and resources	8	0.3%
	Decline in quality of iron ore and other materials	95	3.8%
	Aging equipments	18	0.7%
	Other energy consumption-increasing factors	16	0.6%
	Subtotal	201	8.0%

Prepared by the STFC based on Reference[7]

[NOTE 3]
The CDQ (coke dry quenching) system quenches glowing coke with inert gas and collects steam with high-temperature gas to generate electricity.

[NOTE 4]
The TRT (top-pressure recovery turbine) reduces pressure on the blast furnace at its top and utilizes a pressure gap to generate electricity.

in Chiba. Since its successful operation, the Japanese industry has developed with many coastal steel works constructed. The key word for the industry in resources-poor Japan has been the maximum effective utilization of precious materials from abroad. The Japanese steel industry grew even more conscious of resources savings upon the 1973 oil crisis. When the second oil crisis in 1980 led to resources price spikes, the industry further enhanced energy conservation efforts to reform its structure. Energy conservation and GHG emission reductions are two sides of the same coin. In this sense, the Japanese steel industry has tackled the GHG problem since the 1970s. As a result of various efforts, the Japanese steel industry's specific energy consumption is lower than other countries, as indicated in Figure 8.[8]

In line with the fall in energy consumption for steel production, energy-based CO_2 emissions per unit steel output have declined, as indicated in Figure 9.

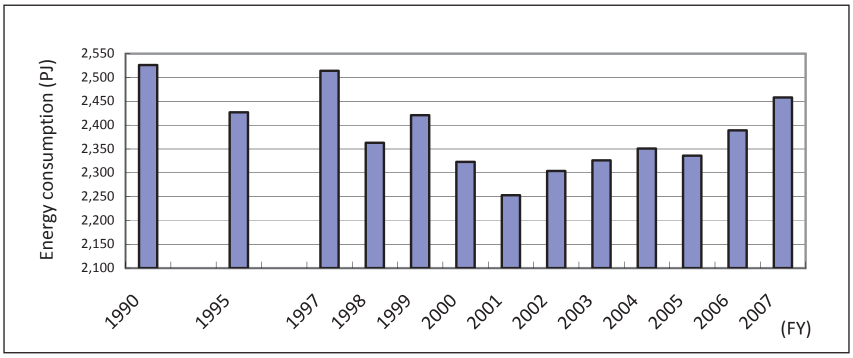

Figure 6 : Changes in Steel industry's Energy Consumption

Prepared by the STFC based on Reference[6]

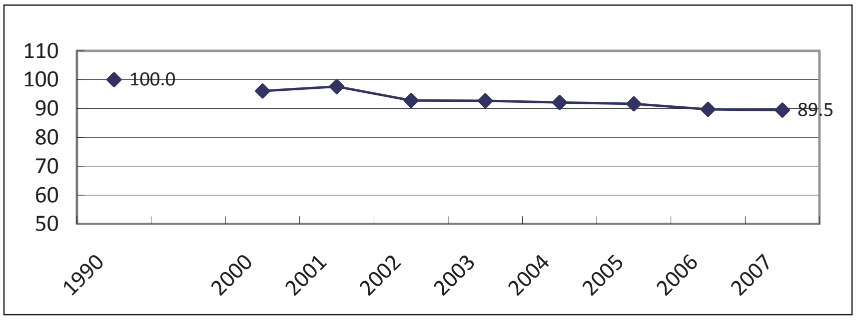

Figure 7 : Changes in Specific Energy Consumption for Steel Production (100 for FY 1990)

Prepared by the STFC based on Reference[6]

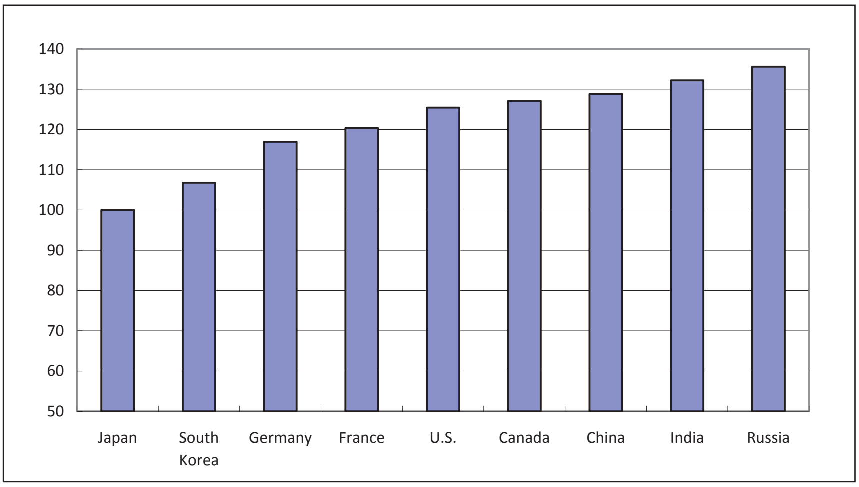

Figure 8 : Comparison of Specific Energy Consumption for Steel Production (integrated blast furnace steelmaking processes) in Major Countries in 2000 (100 for Japan)

Prepared by the STFC based on Reference[8]

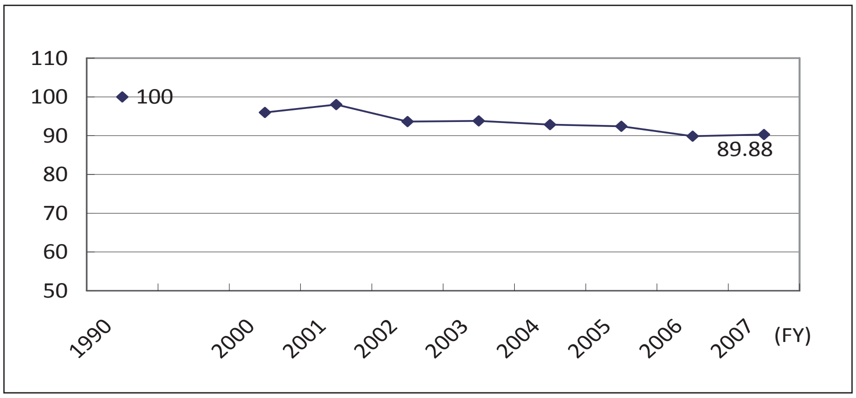

Figure 9 : Changes in Energy-based CO_2 Emissions per Unit of Steel Output (100 for FY 1990)

Prepared by the STFC based on Reference[6]

6 Japanese Steel industry's Future Measures

The Japanese steel industry has continuously been considering energy conservation and emission reduction measures toward 2010. According to the above information from the Japan Iron and Steel Federation, the industry is considering production process operation improvements including lower reducing agent rates for blast furnaces and enhanced controls on temperatures in steel processing; the enhancement of waste energy recovery including the expansion of TRTs, the introduction of CDQ equipments, the expansion of gas recovery and the recovery of heat from converters; equipment efficiency improvements including the introduction of more efficient oxygen equipments, the enhancement of private electric power generaters and motor efficiency, and the refurbishment of sintering plants, blast furnaces, blast and air-heating furnaces; and the expansion of exhaust plastics-hot stoves equipments. As of March 2007, the TRT diffusion rate reached 100%. The CDQ equipment diffusion rate stood at 85% then and is expected to reach 93% in March 2010.

These measures now under consideration are estimated to reduce energy consumption in 2010 by 3.2% from 1990. As of October 2007, about 65% of these measures were funded.

The Japanese steel industry has positioned the acquisition of emission credits under the Kyoto Mechanism as an auxiliary means to achieve its emission reduction target, promoting technological assistance for overseas steel industry energy conservation projects including CDQ exhaust heat recovery in China and sintering furnace exhaust heat recovery in the Philippines, as well as CDM projects including a chlorofluorocarbon disposal project in China.[6] The Japanese steel industry has purchased 59 million tons (11.8 million tons per year) of emission credits, including 41 million tons (8.2 million tons per year) registered at the U.N. CDM Executive Board. The purchases totaling 59 million tons amount to 5.7% of CO_2 emissions in 1990 and the registered 41 million tons to 4.0%.

The steel industry is attempting and will continue efforts to substantially reduce specific energy consumption with energy conservation technologies.

7 Development of Innovative Technologies to Further Reduce Emissions

The improvement and diffusion of best available technologies are expected to be effective as short-term measures to reduce CO_2 emissions in the steel industry. Since their effects come close to the limits, however, the industry will have to develop fundamentally innovative technologies for steelmaking processes in a long run.

The Japanese steel industry's voluntary action plan specifies (1) technology for separation and recovery of CO_2 from blast furnace gases and (2) technology for reduction of iron ore using hydrogen reformed from coke oven gas. Based on recent developments, the author would like to introduce the COURSE 50 (CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technologies for Cool Earth 50) project launched in FY 2008 for the development of innovative steelmaking process technologies and the SCOPE (Super Coke Oven for Productivity and Environment) 21 project under which a real coke oven was developed in 2008.

As steelmakers are required by customers to secure high reliability of products, their production process replacement usually takes a long time. Therefore, innovative technology development takes a long time. The Japanese steel industry has successfully developed the SCOPE 21 coke oven as explained below, attracting attention throughout the world.

(1) COURSE 50 (CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technologies for Cool Earth 50) Project

This project is a component of the government's Cool Earth 50 Program and started in FY 2008 to develop innovative steelmaking process technologies to reduce CO_2 emissions (Figure 10). These technologies will increase hydrogen in coke oven gas, use hydrogen for the iron ore reduction process and separate CO_2. These technologies will be combined with the CCS (CO_2 capture and storage) technology to reduce CO_2 emissions in steelmaking processes. The first phase of the project is planned to take five years. The project is designed to establish these technologies by 2030 through research and development efforts in and after the second phase. These technologies are expected to cut CO_2 emissions by 30% when they are put into practical use after 2030.

As well as Japanese steelmakers, their foreign counterparts are developing innovative technologies for steelmaking processes. They are considering information and technology exchanges through the World Steel Association, planning globally effective technology development.

(2) SCOPE (Super Coke Oven for Productivity and Environment) 21 Project

The SCOPE 21 project was implemented from 1996 to 2005 with support from the Ministry of Economy, Trade and Industry to develop technology to heat coal rapidly for enhancing the fusibility of materials, for making coke ovens more compact, for conserving energy and for raising productivity 2.4 times and the blending ratio of non-coking or slightly coking coal from 20% to 50% (Figure 11). Based on technology development achievements over the 10 years, a real plant was completed and went on stream at Oita Steelworks of Nippon Steel Corp. in May 2009. The plant is expected to consume 21% less energy and emit 400,000 tons less CO_2 annually than a conventional one.

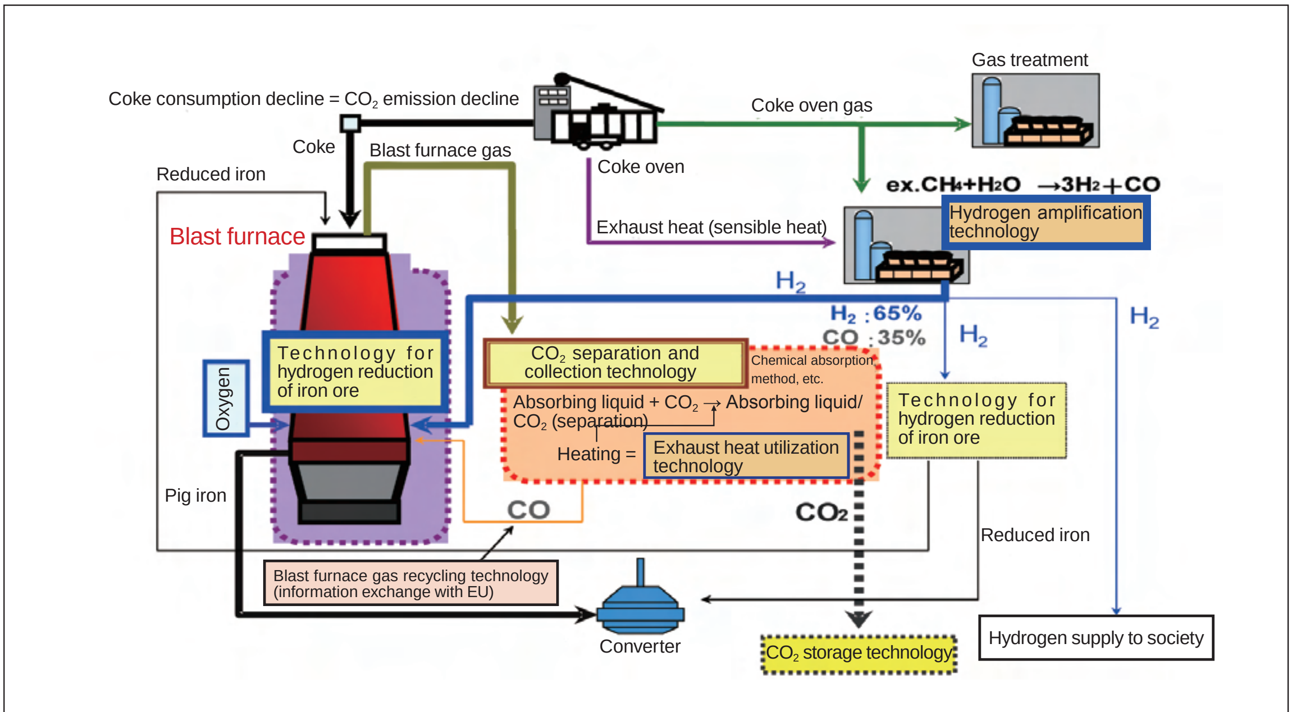

Figure 10 : Conceptual Illustration of COURSE 50 Innovative Steelmaking Process Technology Development Project

Source: Reference[9]

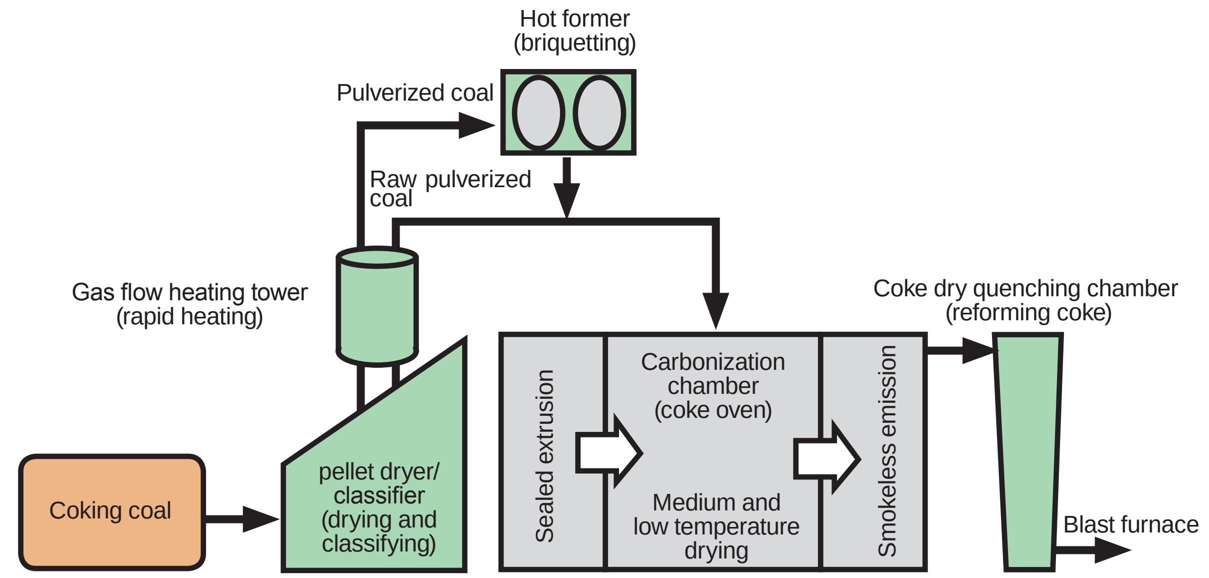

Figure 11 : Conceptual Illustration of SCOPE 21 Next-generation Coke-making Technology Process

Source: Reference[10]

8 Indirect CO_2 Emission Reduction

Steel products are widely used as basic industrial materials. Higher-performance steel products can be used to indirectly reduce CO_2 emissions in society. According to estimates by the Institute of Energy Economics, Japan, and the Japan Iron and Steel Federation, highly functional steel products[NOTE5] produced between FY 1990 and 2007 were used in Japan to cut 8.12 million tons in CO_2 emissions in FY 2007.

Blast furnace cement production using slag, a byproduct in the steel industry, can allow the cement industry to skip a calcination process that emits CO_2 on calcination of limestone ($CaCO_3$) and is required for conventional cement production. Blast furnace cement production can thus be expected to reduce CO_2 emissions in the cement production processes. Blast furnace cement production is estimated to have worked to cut 4.39 million tons in CO_2 emissions in the Japanese cement industry in FY 2007. If blast furnace cement exports (working to cut 4.72 million tons in emissions) are taken into account, total CO_2 emission cuts come to 9.11 million tons.

Furthermore, the steel industry accepts exhaust plastics and tires as an alternative reduction agent. This can contribute to reducing consumption of coal-based reduction agents to cut energy consumption and CO_2 emissions. But exhaust plastics and tires used for steelmaking were limited to 450,000 tons in FY 2005 and 370,000 tons in FY 2007. Regarding use of exhaust plastics under the Containers and Packaging Recycling Law, exhaust plastics supply to the steel industry is limited to 200,000 tons, far below the industry's plastics processing capacity of 400,000 tons, as local governments have not yet to establish exhaust plastics collection systems and collected exhaust plastics are massively used for material recycling. There are thus institutional problems to be solved. This is a key point for our future consideration of environmental problems.

Since around 2003, Japan has considered an eco-complex initiative to secure more effective use of

[NOTE 5]
Highly functional steel products include the following:
Heat-resistant steel sheets for boilers to raise steam temperatures and improve power generation efficiency; high-tensile steel sheets for automobiles to reduce vehicle weights and improve fuel efficiency; high-tensile steel sheets for ships to reduce ship weights; magnetic steel sheets for transformers to improve electromagnetic conversion efficiency; stainless steel sheets for trains to make painting free from maintenance requirements and reduce weights.

energy and reduce CO_2 emissions in society through inter-industry cooperation in which the steel industry would provide low-temperature exhaust heat to other industries like chemical and food manufacturers and accept exhaust materials from other industries. But the initiative has not worked well due to energy safety nets and other problems. Its implementation is limited to small-scale projects including some for liquor producers' use of steam from steelmakers. Japan should widely implement this initiative by developing heat transfer and storage and other technologies and solving social system constraints.

9 International Cooperation to Reduce Emissions

The Japanese steel industry has proceeded with international cooperation to diffuse its accumulated energy conservation technologies and know-how in the world to globally reduce CO_2 emissions from steelmakers.

The Japanese industry's bilateral cooperation includes a July 2005 Japan-China exchange meeting on advanced environment and energy conservation technologies for steelmaking. Based on an agreement at the meeting, bilateral workshops have been held for promoting technological cooperation.

The Asia-Pacific Partnership on Clean Development and Climate (APP)[NOTE6] consists of government and private sector representatives from Japan, China, India, South Korea, the United States, Australia and Canada to effectively promote technological cooperation in CO_2 emission reductions in the Asia-Pacific region.

As the APP participant countries' steel production accounts for 60% of the global total (against 40% for Kyoto Protocol Annex I countries), the utilization of energy and environment conservation technologies in these countries is expected to produce great effects.

At the APP's Steel Task Force, chaired by Japan, the participant countries have cooperated in compiling "State-of-the-Art Clean Technologies(SOACT) Handbook," covering steelmaking technologies that can contribute to reducing CO_2 emissions. The handbook is positioned as a guideline for future cooperation, specifying boundary conditions for

1 Preliminary material processing (sintering) technologies Sintering exhaust-gas recovery, sintering exhaust gas dust collection, activated coke filling (exhaust gas desulfurization and denitration), improved material supply, material adjustment, multi-slit burner, pelletizer
2 Coke making technologies New coke making technology (SCOPE 21), coke dry quenching (CDQ), coal moisture control (CMC)
3 Pig iron making (blast furnace and direct reduction) technologies Top-pressure recovery turbine (TRT), pulverized coal injection (PCI), blast furnace gas dust collection, pig bed dust collection, slag deodorization, direct reduction
4 Steelmaking technologies Automated converter operation, converter gas cooling system, converter gas heat recovery
5 Recycling and waste reduction Slag recycling, dust recycling system by the rotary hearth furnace
6 Common technologies Regeneration burner
7 General energy conservation and environmental measurement technologies Energy monitoring and control system, cogeneration, efficient slag utilization, hydrogen production, steelmaking slag carbonation

Figure 12 : Japanese-proposed Technologies Cited in SOACT Handbook

Prepared by the STFC based on Reference[11]

[NOTE 6]
The APP represents the Asia-Pacific Partnership on Clean Development and Climate.

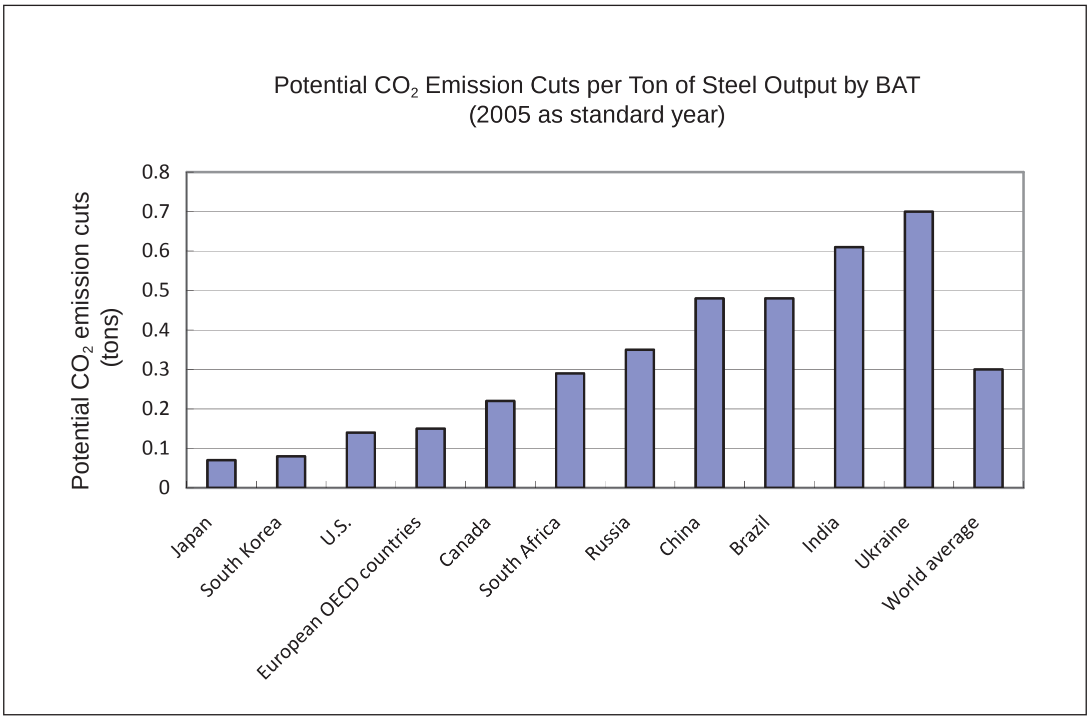

Figure 13 : IEA-estimated Potential CO_2 Emission Cuts by Best Available Technologies

Prepared by the STFC based on Reference[12]

application of technologies and estimated potential CO_2 emission reductions through technological cooperation. Japanese experts have assessed steel plants in other participant countries. The SOACT Handbook covers a wide range of technologies for each steelmaking process. Japan has proposed 27 of the 64 environmental and energy technologies taken up in the handbook (see Figure 12 for Japanese-proposed technologies).[11]

Potential CO_2 emission cuts using best available technologies in steelmaking have been considered at the APP and estimated at 127 million tons a year. The APP method is expected to become a sectoral approach model.

The International Energy Agency (IEA) has estimated potential country-by-country CO_2 emission cuts per ton of steel output through the utilization of best available technologies in steelmaking throughout the entire world. It has estimated the total global reduction at 0.3 tons per ton of steel output.[12] A simple calculation using steel output indicates that the world could cut 340 million tons in CO_2 emissions against 1.14 billion tons in steel output in 2005. Given 1.34 billion tons in global steel output in 2007, best available technologies for 2005 could reduce 400 million tons in CO_2 emissions in 2007 (Figure 13).

The IEA has analyzed best available technologies and cited improvements in blast furnace operation technologies, coke oven gas recovery, coke dry quenching, blast furnace gas recovery improvements, blast furnace gas power generation efficiency improvements and rolling process improvements as particularly effective steelmaking technologies.

10 Efforts by World Steel Association

The World Steel Association consisting of about 180 major steelmakers in the world (accounting for 75% of steel output in the world other than China and 20% of output in China) has proactively tackled the global warming problem. The association has advocated a global sectoral approach, citing the reduction of emissions per unit of steel production as a realistic measure.

In October 2007, the association, then called the International Iron and Steel Institute, made comments as summarized as follows[13]:

- Leaders of the world steel industry have endorsed a global approach as the best way to help address climate change, and will establish a globally common approach and conduct the collection and reporting of CO_2 emissions data by major steel plants in the world.
- Cap-and-trade policies are not effective in reducing CO_2 emissions. Constraining production from the

best emission performing plants is not the solution for a globally competitive steel industry.

- An effective approach for the steel industry requires the participation of all major steel producing countries and a focus on improving emissions per unit of production. In the near term, the steel industry's main contribution will be in the wider application of current best practice and technology. For the longer-term, the steel industry is investing in research on the development of breakthrough new steelmaking technologies.

In line with such policy, the World Steel Association launched the collection of data in April 2008 in a bid to reduce CO_2 emissions from steelmakers under the Global Steel Sectoral Approach (GSSA).

11 Future Discussions on Global Warming and Sectoral Approaches

The year 2009 is important for deciding on a framework after the Kyoto Protocol to address global warming. Important meetings are scheduled for the year, including a conference of relevant countries in Bonn in June, Group of Eight summit in Italy and the COP15 meeting (the 15th conference of Parties to the UNFCCC) in Copenhagen in December. At the 2008 Toyako G8 summit, then Japanese Prime Minister Yasuo Fukuda in the Chair's Summary said, "Sectoral approaches are useful tools among others for achieving national emission reduction objectives." [14] The usefulness of sectoral approaches as advocated by Japan should be recognized more and more in the world.

Steelmakers at home and abroad have made efforts as discussed above. They emit massive CO_2 and have no choice but to seriously address the emissions. As noted by the World Steel Association, steel products are traded widely in the world. Considerations should be given to preventing fair world trade in steel products from being distorted.

The sectoral approaches to reduce CO_2 emissions in major sectors by diffusing advanced technologies may be realistic and effective. At a time when technologies play a key role in preventing global warming, one of the globally common principles should be a framework for future emission reductions that should be designed to reward those trying to develop and improve technologies. This may stimulate further technology improvements. Such framework may encourage steel researchers and engineers to redouble efforts to reduce CO_2 emissions from the steel industry. As well as short-term CO_2 emission reductions by best available technologies, the long-term development of innovative steelmaking technologies is a mission that steelmakers in the world should mobilize their full resources to tackle as an ultimate solution. As an advanced steelmaking country, Japan has a great role to play in this respect.

This report introduced steelmakers' GHG emission reduction efforts and the sectoral approaches including the global sector specific approach as advocated by the World Steel Association. In the future, sectoral approaches may have to be analyzed as a framework for promoting technology development.

Acknowledgement

In compiling this report, I used a massive amount of information from websites of the Ministry of the Environment, the Ministry of Economy, Trade and Industry, the Ministry of Foreign Affairs, the Japan Iron and Steel Federation and the World Steel Association. I thank these entities for making such information available.

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Profile

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The author serves as executive director of the Iron and Steel Institute of Japan, which was founded in 1915 for the development of steelmaking technologies through industry-academia cooperation.
The author is engaged in steel administration, and small and medium enterprise technology administration.
Industry-academia cooperation is indispensable for human resources development and technology research for Japan's development.
The author would like to emphasize the Japanese steel industry's top technological capabilities in the world, which are low-profile but support Japan's industrial world.

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5

High Thermal Insulation Technology Contributing to Residential Energy Saving

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1 Introduction

In November 2007, the Fourth Assessment Report by the IPCC (Intergovernmental Panel on Climate Change)[1] presented that the reduction of energy consumption in housing, office buildings and other buildings is a key policy for mitigating global warming. This proposal is based on the fact that promotion to reduce energy consumption in this field was inadequate up to the present. In addition to this, number of buildings in globe is likely to increase in the future with progressing population growth and city's expansion of worldwide. In June 2008, the IEA (International Energy Agency), in its report "Energy Policies of IEA Countries-Japan 2008 Review",[2] stated that the Japanese energy policies based on technical development and voluntary approach in industrial sector benefited appropriateness and leadership. However, they also suggest that especially in the housing sector, the voluntary approach leaves room for efficiency improvements.

Japan has been primarily promoting energy saving policies for household electrical appliances in residences by establishing the top-runner standard. Consequently, Japan's energy saving technologies, heat pump for heating, air-conditioning, and hot water heating, inverter control and solar panels, became most advanced in the world. It is also widely recognized that these approach make reduction of environment burdens and economic growth good balance.

On the other hand, Europe promotes reduction of residential energy consumption from different viewpoint compared with Japan. Thermal insulation techniques in Europe, which mainly developed in cold weather regions that are in high demand for heating, has been evolving over a period of more than thirty years since the Oil Crises of the 1970s. Interestingly, ultimate goal of the thermal insulation techniques in Europe is to eliminate essential necessity about heating appliances[3] and is in contrast to the Japanese policy, which has promoted energy saving in home electrical appliances.

This report particularly introduces high thermal insulation technologies trend as well as the basic concept and outlook of residential energy savings in various countries. Finally, it also discusses Japanese policies to strengthen and directions of technical development to be needed.

2 Residential CO_2 emissions and related policies

2-1 Outline of residential energy consumption

In general, energy consumption for heating holds a large percentage of energy consumption by households in the developed countries. Energy consumption for heating in wintertime accounts for 50 to 80 percent of total annual energy consumption excluding Japan and Australia (Figure 1). If hot water is also included, the percentage of energy consumed as a heat source is even larger. On the other hand, residential energy consumption in Japan is relatively small compared with other countries, but looking at the percentage of energy consumption by region, conditions are various (Figure 2). In Sapporo of northern Japan, energy consumption for heating is large at over 50 percent of total energy consumption. Total energy consumption in Sapporo is nearly double of that in subtropical Naha, this difference comes from heating usage. In regions besides Sapporo, energy consumption for heating accounts for about 20 percent of every region

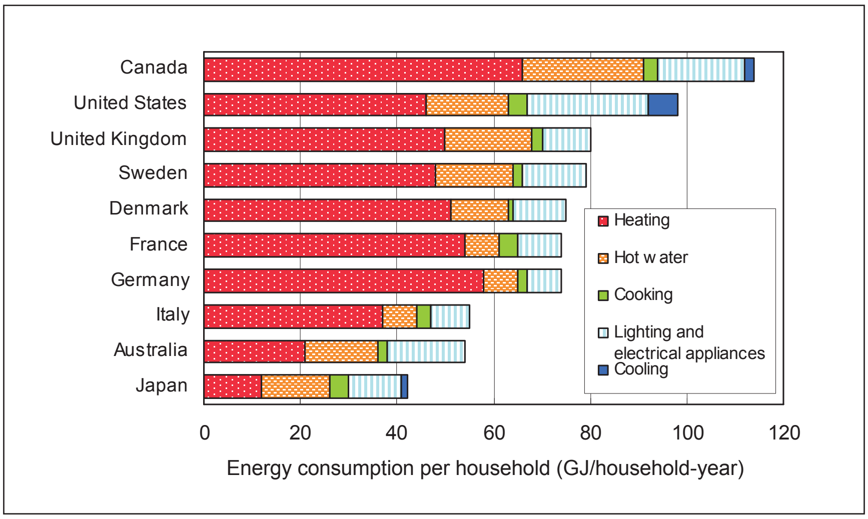


Figure 1 : Residential energy consumption (country comparison, 2001)

Prepared by the STFC based on Reference[4]

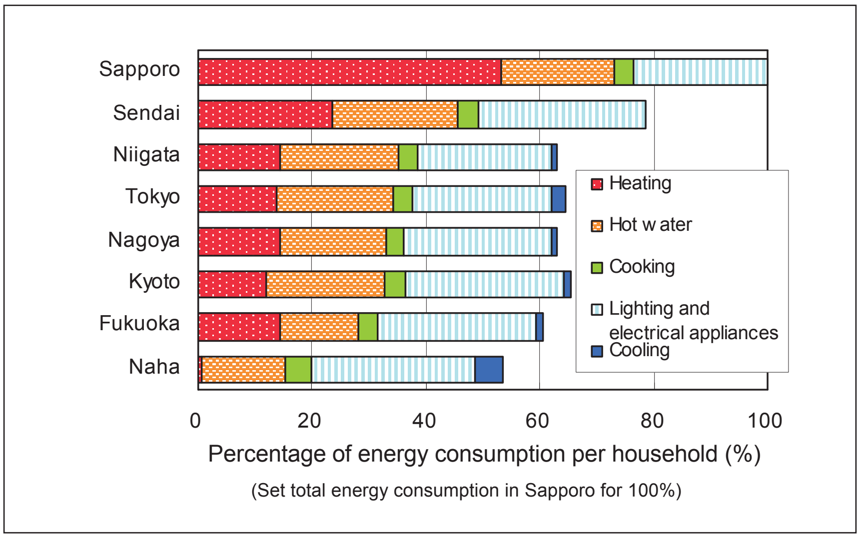


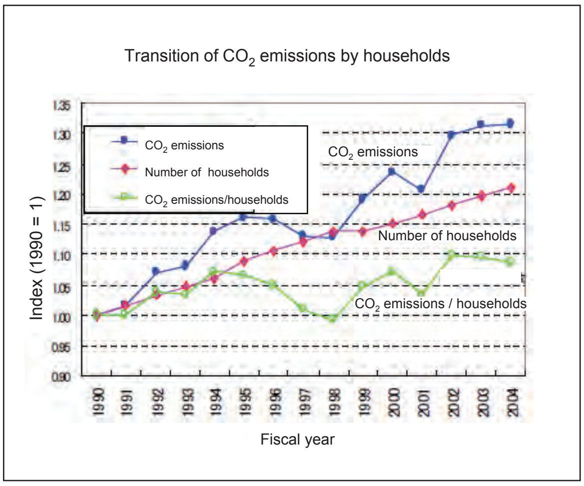
Figure 2 : Residential energy consumption by application (comparison of eight cities in Japan)

Prepared by the STFC based on Reference[4]

except Naha. These facts suggest the importance of reducing energy consumption for heating in winter season.

One thing that should be considered on residential energy consumption in Japan is the fact that total energy consumption per household has been continuously increasing. According to Figure 3, CO_2 emissions (equivalent to energy consumption) are increasing rather than the growth in the number of households. Looking at trend in residential energy consumption by application, heating-use and power-use (lighting, personal computers, televisions, etc.) are especially increasing. This trend corresponds to transition about ownership of home electrical appliances by households, such as room air-conditioners and DVD players, as shown in Figure 4.

In Japan, the climate is relatively warm in winter season and local heating way in house was common as Japanese culture. That is the reason why Japan's energy consumption for heating is smaller than other countries. In Europe and the United States, it became general custom to live in a comfortable space uniformly heated throughout the whole house even in winter by a central heating system. On the other hand, in Japanese custom, it was general to heat only a few rooms to necessary by placing heating unit every room space. From the viewpoint of energy consumption, Japan seemed to be superior. However, even in Japan, considering that increasing of heating appliances for room and residents would require an "affluent and healthy life" on the same level with the western countries, energy consumption will likely increase.



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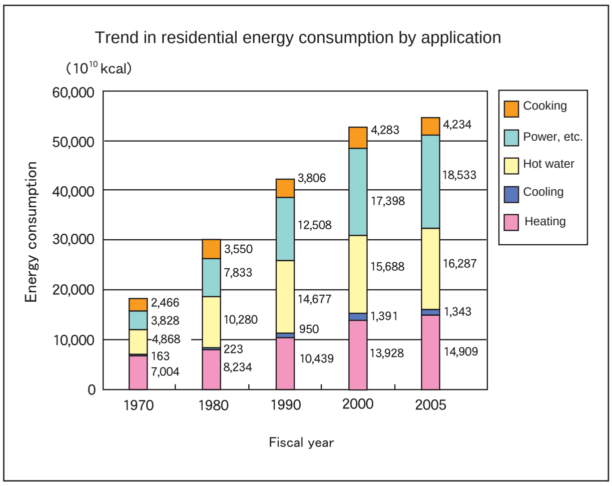

Source: Reference [5]

Figure 3 : Residential energy consumption (country comparison, 2001)

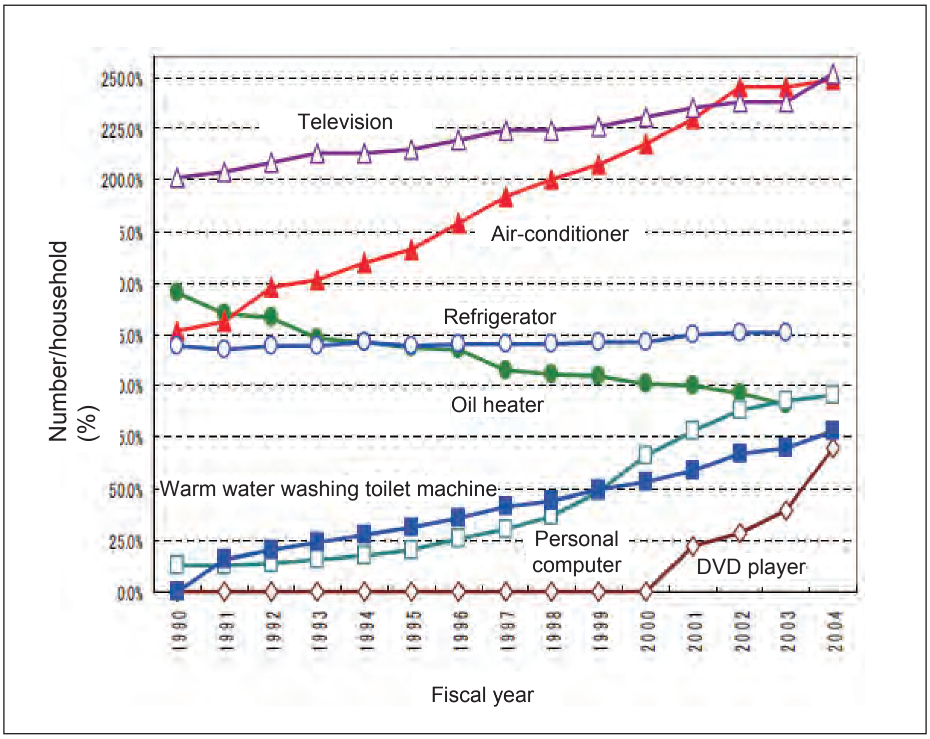

Figure 4 : Ownership of home electrical appliances by households in Japan

Source: Reference [5]

From the viewpoint outlined above, this report discusses trends on technology and policies to reduce winter energy consumption for heating that holds a key position in the residential energy consumption.

2-2 Residential energy conservation policies of various countries

2-2-1 Outline of energy conservation policies

Table 1 shows an outline about the examples of energy conservation standards for housing, which have been implemented in several countries. The energy conservation standards by all the countries listed here are based on energy conservation standards, which had been established or revised after the Oil Crises of the 1970s. In the United States, many states implement their own energy conservation codes based on individual state's judgment. Except for several states, the code obliges housing to apply these energy conservation standards.

In the EU, the "Energy Performance of Buildings Directive (EPBD)" was brought into force on January 4, 2003, and presents guidelines that housing in EU member nations must hold residential energy consumption performance. Based on the

Table 1 : Examples of energy conservation standards for housing

Country	Current energy conservation standard	Outline	History of revision
United States	"Model Energy Code" (MEC) 1995 Edition, The Council of American Building Officials	Established as a reference model for study of energy conservation standards to be determined by individual states.	Established in Dec. 1977. Revised in 1983, 1992, and 1995. Integrated in 1998 as "IECC98."
	"2006 International Energy Conservation Code (IECC)"	Energy conservation standard established under the leadership of the US Department of Energy and many states currently ratify the code. Provides acceptable criterion for residential total energy, heat transmission coefficients by part, average heat transmission coefficient of the building envelop, etc. Establishment and implementation of actual standards is referred to the individual state governments.	Established in 1998. Revised in 2003 and 2006.
United Kingdom	"The Building Regulations 2000 : Conservation of fuel and power in dwellings" (L1A: New dwellings, L1B: Existing dwellings; 2006 Edition)	Fulfilled under Building Regulations. Specifies acceptable criterion for heat transmission coefficients by part, average heat transmission coefficient of the building envelop, energy consumption coefficients per unit of floor area, etc. Intends to both new construction and existing dwellings.	Established in 1965. Revised in 1974, 1981, 1990, 1995, 2000, 2002, and 2006.
Germany	Energy Saving Ordinance : "Energieeinsparungsgesetz - EnEG 2005"	Law on energy conservation in buildings. Announced three ordinances concerning thermal insulation, heating, and hot water heating equipment, respectively.	Established in 1976. Revised in 1980 and 2001; the 2009 Edition is currently in the revision process.
	Energy Saving Ordinance : "Energieeinsparverordnung - EnEV 2007"	Standardization of the above-mentioned ordinances. Regulates actual energy consumption of buildings. The energy consumption standard (detached houses) for heating has been strengthening by three times from 200 kWh/m^2-year in 1977 when the standards were established to 70 kWh/m^2-year in the revision of 2002. This is called the "Low energy house standard."	Established in 1977. Revised in 1984, 1995, 2002, and 2007; the 2009 Edition is currently in the revision process.
Japan	"Act on the Rational use of Energy"	Comprehensive law specifying improvement of energy use in factories, transportation, buildings, etc. is the basis for the current energy conservation standards in Japan.	Established in June 1979. Revised in 1993, 1998, 2002, and 2005.
	"Standards for Owner's Judgment of Rationalization of Energy Use in Housing," "Design and Execution Guidelines for Rationalization of Energy Use in Housing."	Energy conservation standards provided under the above-mentioned law. Established six regional areas corresponding to annual use of heating and cooling and specifies acceptable criterion and construction methods corresponding to those areas for heat transmission coefficients by part, average heat transmission coefficient on building envelope, and energy consumption coefficients per unit of floor area, etc. Obliges to report for new construction, expansion, large-scale renovation and improvements of residences and other buildings with floor areas of 2000m^2 or more.	Established in 1980. Revised in 1992, 1998, and 2006.

Prepared by the STFC based on Reference[6-14]

EPBD, the member nations have created domestic systems and begun starting implementation. In particular, Germany has been promoting a similar system earlier before the above-mentioned directive by the EU had started. In 2002, previous energy conservation law had been revised to EnEV 2002 (a government ordinance in connection with thermal insulation and equipment for energy conservation in buildings). This ordinance specifies not only standards for structures and equipment for warm keeping in new construction and renovation, but also usage of certified heating equipment and prohibition, after 2006, on the use of heating equipment installed up to 1978. On October 1, 2007, the revised ordinance EnEV 2007 was brought into force and obliged to show an "Energy Performance Certificate" certificate (see 2-2-2 for details) when buying and selling residential housing and buildings constructed before 1965. From January 1, 2009, a new requirement that newly constructed buildings must hold an Energy Performance Certificate will be bound. As for non-residential buildings, the same policy will start on July 1, 2009.

In Japan, "Act on the Rational Use of Energy" had established in 1979, energy conservation standards for buildings was brought into force. Energy conservation standard revised in 2006 specifies that owners of office buildings and administrators of multi-unit residential buildings, with floor space of 2000m^2 or more, must report measures for energy savings. However, for general residences with an area of less than 2000m^2, this policy is limited to voluntary obligation. Since energy conservation standard with only limited force seems to be rare in the advanced nations, strengthening and improvement of this point should be expected.

2-2-2 Trends in Germany toward improvement of residential energy consumption

When purchasing an automobile, it is general to consider so-called "fuel economy" as a material for comparative study so that the consumer can check in advance the running cost, other maintenance costs, and environmental burden. In case that the "fuel economy" does not exist, even if the various individual performance specifications on the engine, air-conditioner, audio system, etc. is provided to consumer, it would be difficult to understand the actual final energy consumption as a whole vehicle. The concept of the "Energy Performance Certificate" corresponds to a residential version of automotive "fuel economy," in that annual energy consumption is showed as a numerical value per unit of floor space. Germany's "Energy Performance Certificate" is a

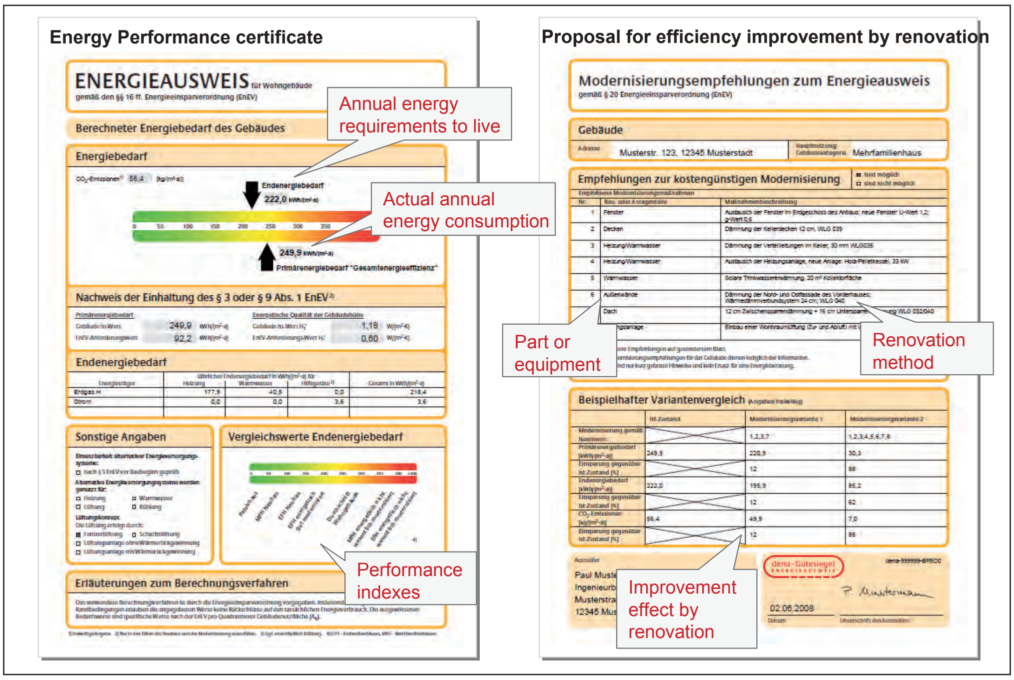

Figure 5 : Energy Performance certificates used in Germany

Prepared by the STFC based on Reference[15]

system that was brought into force in advance of the EU's "Energy Performance of Buildings Directive" (discussed in section 2-2-1) and aims at grasping and efficiently reducing final total energy consumption from residences.

Under this system, the owners and managers of buildings must hold an "Energy Performance Certificate". The Certificates are issued by persons who possesses qualifications certified by a supervisory body.[15] The conditions for acquiring the qualification to issue this certificate are regulated in detail, and include the university curriculum, business experience, etc. In order to fulfill the enforcement of this system, several thousands of qualified persons had been training in Germany.

This certificate comprises two parts, "Actual current energy consumption" and "Efficiency improvement by renovation" (Figure 5). In the part of "Actual current energy consumption", the energy consumption is considered by calculation not only required for maintaining the specified room temperature and heating hot water, but also adjusted for the cost of energy from mining to transportation, up to the supply of primary energy such as electricity, gas, etc. For example, if the building uses private power generation by solar panels, it is possible to visualize the amount of reduction in real energy consumption. Thus, this is a system that encourages the selection of more efficient primary energy. In the part regarding "Efficiency improvement by renovation," concrete proposals are described, even in the case of newly constructed residence. These include structural parts of the residence, such as windows, walls, doors, etc., and types of equipment, such as hot water and heating systems.

2-2-3 An experiment to create low energy city block

In the EU, a large-scale experiment has begun obtaining the amount of actual energy consumption when residents live in low energy housing by test at the city block unit. This is called the "POLYCITY"[16] Project and is extremely large-scale under the "CONCERTO"[17] initiative, which supports innovative energy policy in the EU as a whole. The sites of the project are currently being newly constructed at three locations in Germany (Ostfildern, Stuttgart), Italy (Arquata, Torino) and Spain (Credanyola, Barcelona), but data collection has partially begun. The collected energy consumption data are accumulated, and they will also be posted on a website. In the project, demonstration results of the energy conservation, not only by the individual building unit but also by the city block unit, which has flexible energy usage among different buildings, are expected. Since the site includes office buildings and power generating facilities besides housing, the project will be expected to comprehensively manage total energy supply and demand at the city block unit as an extremely interesting social test.

3 Situation of CO_2 reduction in housing

3-1 Basic concept of residential CO_2 reduction

Formulation shown in Figure 6, which is defined in this report to quantitatively evaluate the current status of residential energy consumption in Japan, is a concept model of energy consumption. To reduce energy consumption (equivalents CO_2 emissions) of heating and hot water supply in housing, it is necessary to consider three factors: (1) “Energy saving in warm keeping of building,” (2) “Higher efficiency in heating equipment,” and (3) “Reduction of CO_2 emission in supplied primary energy.” This report explains the significance and current status in Japan of each factor in the following.

3-2 Energy saving in warm keeping of building

In Figure 6, (1) “Energy saving in warm keeping of building” is defined as the percentage of heating value supplied from heating equipment in order to maintain the living space temperature constant. Heat in a living space escapes via the building envelop (outer surface of a building), which faces the outside air and ground surface, and this becomes heat loss. Therefore, with using low-heat-flow materials at the walls, windows, and other parts of the building envelop, the heat loss and the heat supply requirement as essential heat source reduce. That is, the ideal building structure should look like a Vacuum Flask enables to keep room temperature constant. Figure 7 shows a comparison on heat loss coefficient[NOTE 1] in Japan and the United States and European countries, which is specified as one of energy conservation standard for thermal insulation performance. All countries establish energy conservation standards corresponding to the climatic conditions in respective region, and oblige stricter standards with colder regions. The standard in Japan for cold climate region corresponding to Sapporo seems to be the same level as those of other countries. But the standards for south areas from Tohoku (northeastern Japan) and for extremely cold areas like Kushiro (coastal city in eastern Hokkaido) are easier compared with other countries. Consequently, the standards and implementation in Japan are obviously behind than other countries.

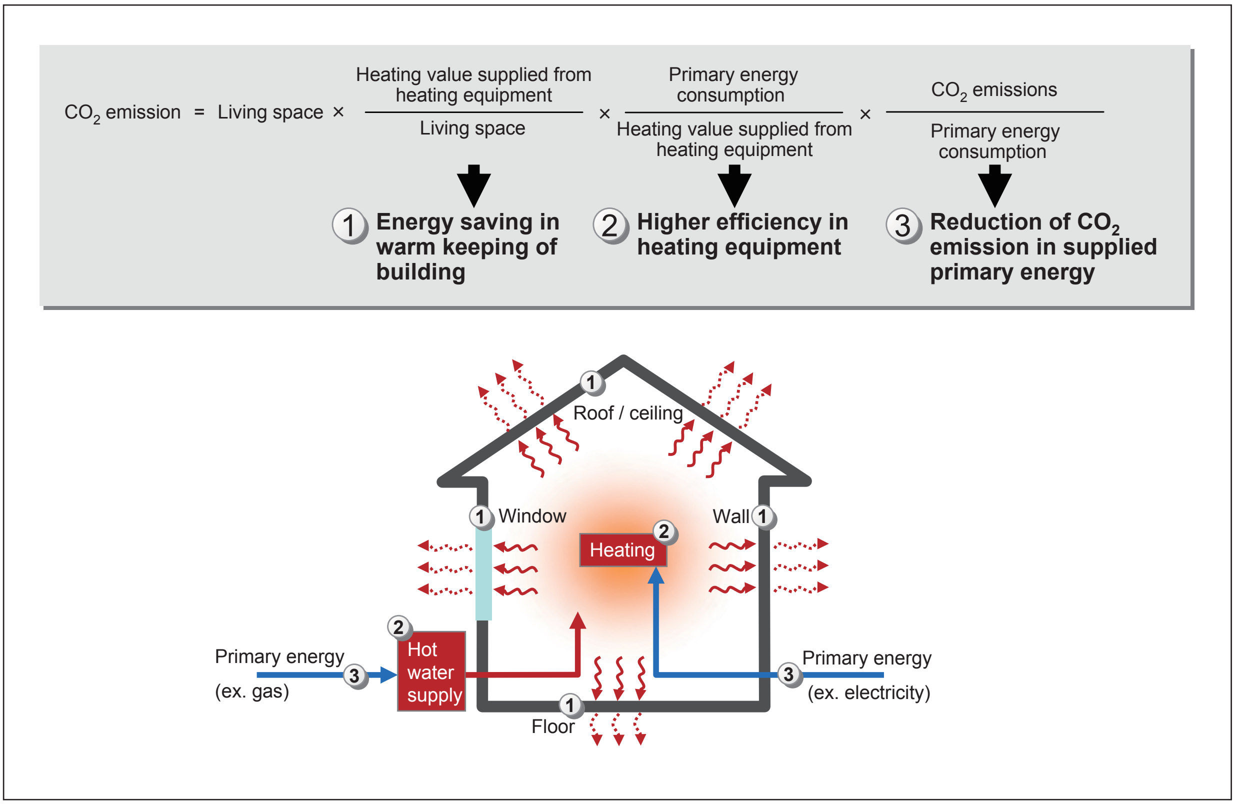

Figure 6 : Concept of residential energy saving

Prepared by the STFC

Figure 8 shows a comparison on coefficient of heat transmission[NOTE 3] in order to understand the thermal insulation performance of windows as positioned key components in the building envelop. The standard in southern France, which is a warm region with a Mediterranean climate, is almost the same as that in Hokkaido in northern Japan. Moreover, the standards in Germany and northern Europe, which have cold climates, are stricter twice than that in Japan. In countries that have strict energy conservation standards, since it is difficult to meet regulations with single-layer windows, multi-layered insulating glass is generally used. Table 2 shows the penetration rate of the insulating glass. The European nations obliges

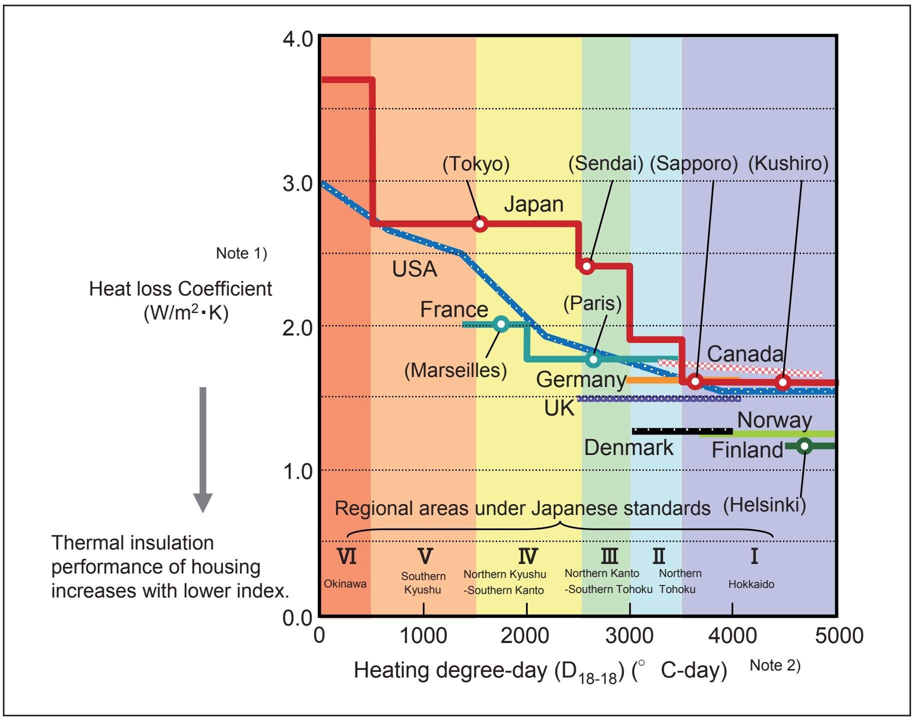

Figure 7 : Comparison of residential energy conservation standards (heat loss coefficient)

Prepared by the STFC based on Reference[6]

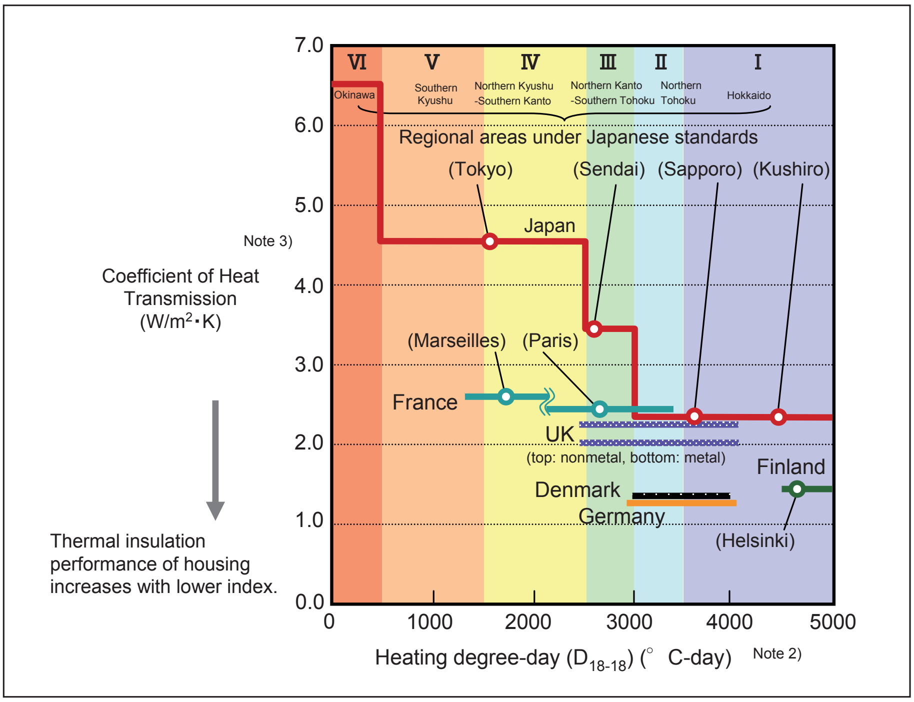

Figure 8 : Comparison of energy conservation standards for windows (heat transmission coefficient)

Prepared by the STFC based on Reference[6]

Table 2 : Penetration of insulating glass windows

Country	Penetration of insulating windows (%)	
	Newly constructed housing	Existing housing
Finland	100	100
Germany	100	73
Sweden	100	100
Netherland	100	57
Denmark	100	99
Luxembourg	100	59
Austria	100	100
Portugal	17	11
United Kingdom	100	64
United States	90	90
Japan	31 (90*1)	2 (6*1)

*1: Result from survey in 2007. (1998; survey by the Flat Glass Manufacturers Association of Japan)

Prepared by the STFC based on Reference[18,19]

[NOTE 1] Heat loss coefficient :
Generally called as “Q value,” expresses the thermal insulation performance of a whole house unit as with numerical value. The Q value is calculated from dividing heat loss, which obtained by calculating the sum of the heat escaping via walls, ceilings, floors, windows, and other parts, by the floor area. The thermal insulation performance of house increases with decreasing the Q value. The unit is $W/m^2 \cdot K$.

[NOTE 2] Heating degree-day ($D_{18\text{-}18}$) :
A heating days is defined as a day when the average daily temperature falls below 18°C, the heating degree-day is calculated the temperature difference between the average daily temperature and 18°C. For example, in case of the average daily temperature is 17°C, this is called a 1 degree-day (°C day). This index is generally expressed as accumulated value over the year (season).

[NOTE 3] Coefficient of heat transmission :
Generally called as “U value,” expresses the thermal insulation performance of parts and components in building envelope with numerical value. The U value is calculated from material thermal conductivity used in the part and its thickness, etc. but the area of the part or component is not considered. The thermal insulation performance of house increases with decreasing the U value. The unit is $W/m^2 \cdot K$.

buildings to apply the insulating glass, as a result, penetration rate of 100 percent has been achieved. In Japan, the penetration has been rapidly increasing recent years in newly constructed housing, but is still extremely low level in existing housing.

As described above on (1) “Energy saving in warm keeping of building”, the standards and implementation in Japan are obviously behind than other foreign countries.

3-3 Higher efficiency in heating equipment

In Figure 6, (2) “Higher efficiency in heating equipment” is defined as the ratio with the heating value supplied from heating equipment and primary energy consumption to run the equipment such as electricity and gas. Japan has currently an advantage in this field, for example, heat pump technologies for heating, air-conditioning, and hot water heating and energy saving in products by using inverter control, etc., energy conservation policy based on the top-runner system has motivated to establish the situation. In the international comparison of heat pump efficiency shown in Figure 9, Japan’s COP (Coefficient of Performance) is extremely high efficiency at exceeding 6, compared with that of heat pump air-conditioners in North America and Europe at 2.2 to 3.8. The figure about transition of efficiency improvement also shows that COP has been constantly improving since the top-runner system was introduced in 1999. By applying this technology, heat pump-type boiler using CO_2 as a refrigerant has rapidly progressed in efficiency improvement. A COP has improved by

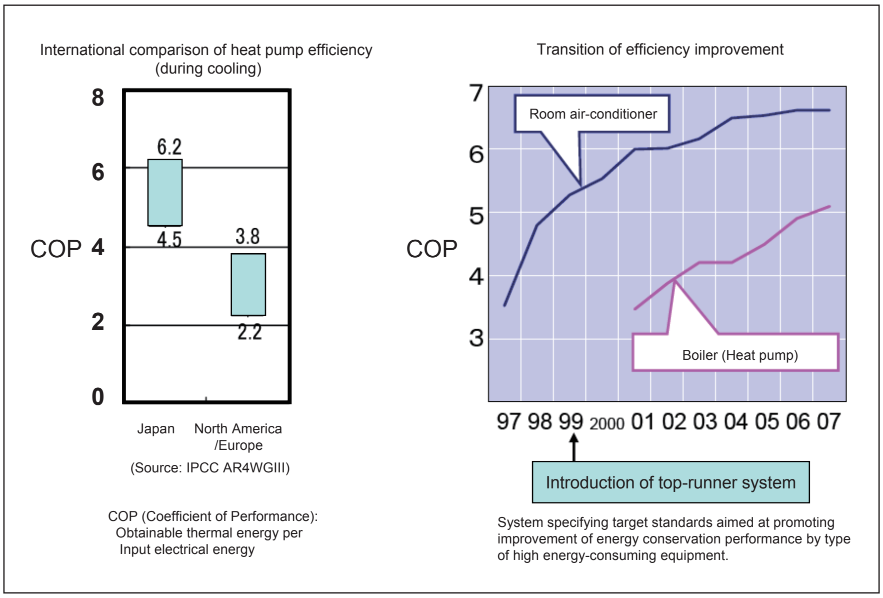

Figure 9 : International comparison and transition in heat pump efficiency

Source: Reference [20]

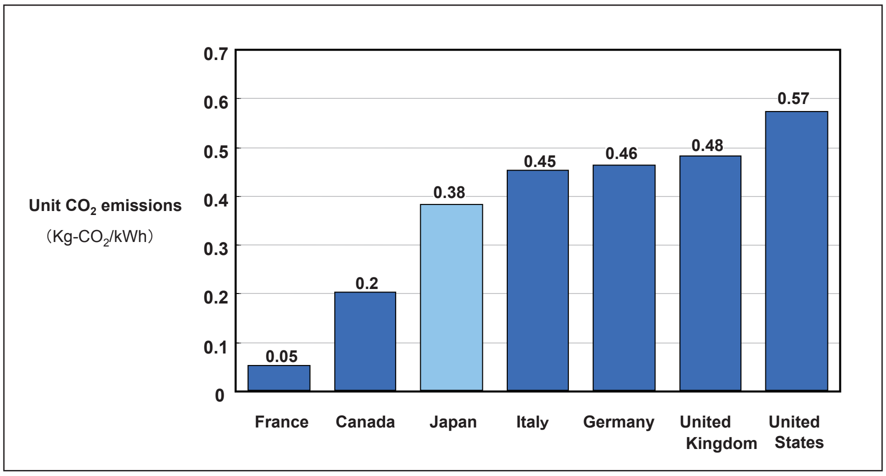

Figure 10 : Comparison of unit CO_2 emissions in electric power

Prepared by the STFC based on Reference[22]

40 percent in recent 5 years and unit penetration has increased by a million in 6 years.

3-4 CO_2 reduction in supplied primary energy

In Figure 6, (3) "Reduction of CO_2 emission in supplied primary energy" is defined as the amount of CO_2 emissions to be spent over the whole process from energy production and supply until using primary energy in housing, such as electricity or gas. This factor is so-called "unit CO_2 emissions of primary energy." For example, in electric power, France, which the nuclear power generation ratio is extremely high at 82 percent, is in the lowest emissions level. Canada, which has high hydro power generation ratio of 58 percent, is the low emissions too (Figure 10). In Japan, although the nuclear power generation ratio and the hydro power generation ratio is not so high as these two countries, CO_2 emissions level is relatively superior by utilizing limited nuclear power (nuclear power generation ratio: 29 percent) and developing high efficiency thermal power generating technologies.[21] Ideally, the residents should choose the primary energy with the lowest unit CO_2 emission from electricity, gas, etc. However, it would be the realistic way to select the optimum energy by considering combinations of energy sources and the equipment mentioned in the above (2). If the residents install private power generation by renewable energy on buildings such as solar panels, further improvement in this factor will be expected.

3-5 Points of focus

In order to reduce energy consumption accompanying heating in winter, a well-balanced improvement with both (1) "Energy saving in warm keeping of building" and (2) "Higher efficiency in heating equipment" should initially be considered. Although replacing old heating equipment to new one with excellent energy saving performance is important, heating unit capacity will not necessarily decrease and operating efficiency of the equipment will deteriorate unless the thermal properties of buildings are improved. From this viewpoint, what Japan should focus is to promote policies and technical development for reducing essential energy to maintain room temperature comfortable by concentrating on (1) "Energy saving in warm keeping of building". By focusing on thermal insulation technologies in the following Chapter 4, this report explains how practical technologies for reducing heat loss are progressing.

4 Technology Trends on Energy saving in warm keeping of building

4-1 Thermal insulation technologies for windows

According to the estimation based on the house model under the 1992 standard, 48 percent of heat during heating in winter escapes outdoors via openings such as windows and doors, and 71 percent of heat enter from outdoors during cooling in summer.[23] This is because the thermal insulation performance of openings is inferior to that of other parts such as walls, floors, and ceilings. Figure 11 shows the fact that the thermal properties of the materials used in openings is poor. For example, the thermal conductivity of the glass and aluminum used in windows is prodigiously higher than the wood and glass wool used in walls. This is why strengthening thermal insulation in windows and doors have strongly been required. In addition to this, average window area per housing unit in Japan is large at level of 1.2 times to that in Germany and 1.9 times to that in France.[24] Japanese likely prefer taking natural sunshine and breeze into house inside.

Although opening parts include some components such as entrance doors, etc as well as windows, this report particularly explains about windows (Figure 12) that remarkably affect on energy consumption of housing and are used in many place of housing.

(1) Window frames

In window frames, once steel was used and aluminum has been widely used so far. When aluminum is used in a window frame, the thermal insulation performance becomes worse. This is because, since the thermal conductivity of aluminum is prodigiously higher than those of wood and resin and is also higher than that of glass, as shown in Figure 11, the heat loss caused by intensive heat flow at aluminum window frames from indoors to outdoors occurs. In order to reduce the heat loss, composite structures, in which resin is partially used in aluminum window frames, have been developed. At present, window frames made of mono-resin are gradually coming into the mainstream. On the other hand, in countries like Sweden that holds abundant wood resources, window structure with all-wooden

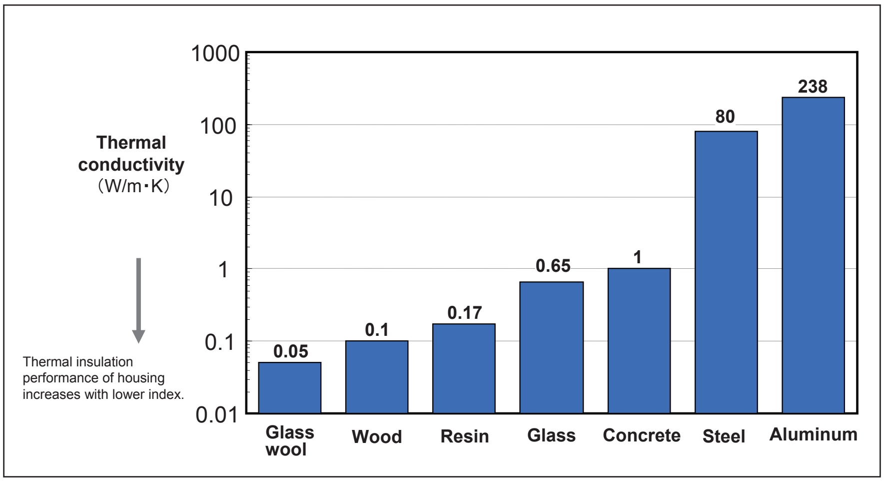

Figure 11 : Thermal properties of representative materials used in housing

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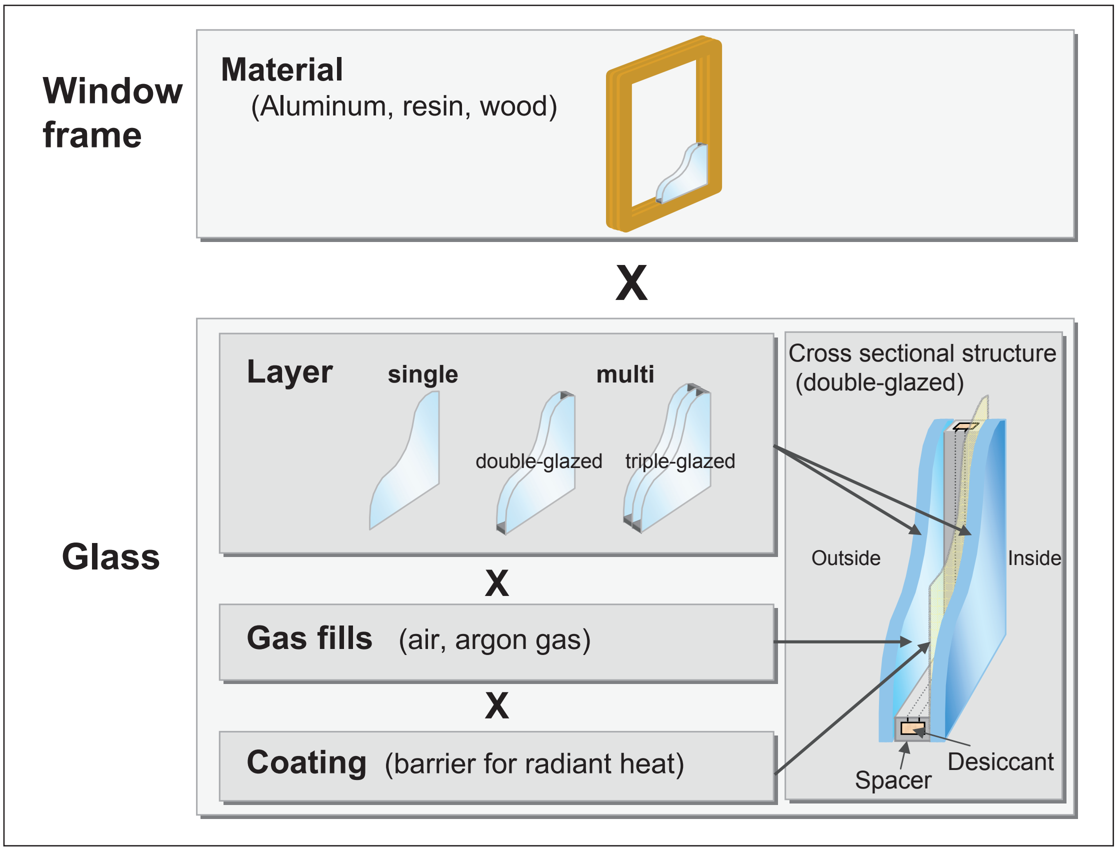

Figure 12 : Structure example of thermal insulation technologies for windows

Prepared by the STFC

frames have independently developed. In any cases, the thermal properties like resin or wood should initially be considered to qualify for window frame materials.

(2) Glass (Layer and Gas fills)

As previously mentioned, in countries that have strict energy conservation standards, multi-layered insulating glass is generally used in order to meet their regulations. The multi-layered insulating glass is a window with double-glazed or triple-glazed glass and a space formed between each glass. The space is formed by sandwiching a spacer with a desiccant, using the both glass. By inserting a space (air layer) with one-digit lower thermal conductivity (0.023W/m・K) than that of glass (0.65W/m・K), it become possible to reduce the heat loss to flow via the glass surface from indoors to outdoors. The effectiveness of this measure will gain with increasing the number of glass layers (number of air layers), but the cost will become expensive too. In recent years, products filled with argon gas (thermal conductivity: 0.018W/m・K), which has even lower heat transmission than air, have been commercialized.

(3) Glass (Coating)

In indoor environment, the temperatures people can sense is influenced a lot by not only the direct temperature of the air and heating equipment but also radiant heat generating on the surfaces of objects such as heaters, walls, and furniture. A Glass that is designed to reflect the indoor radiant heat and not to escape the heat to the outside is called “Low-E (low emissibility) glass.” The coating film for Low-E is made of metals and it appears extremely thin and transparent. By reflecting wavelengths generated on indoor heaters and other objects with this glass, the thermal insulation performance of windows improves by 1.5 to 2 times. On the other hand, since the wavelengths of sunlight can pass through the window in this film, it enables to utilize sunlight as actual effective heating source for room in wintertime.

(4) Window Structure

Products of windows available in the market have various levels of thermal insulation performance, depending on the structure with combination of parts and materials as shown in Figure 13. This figure obviously tells what a superior performance

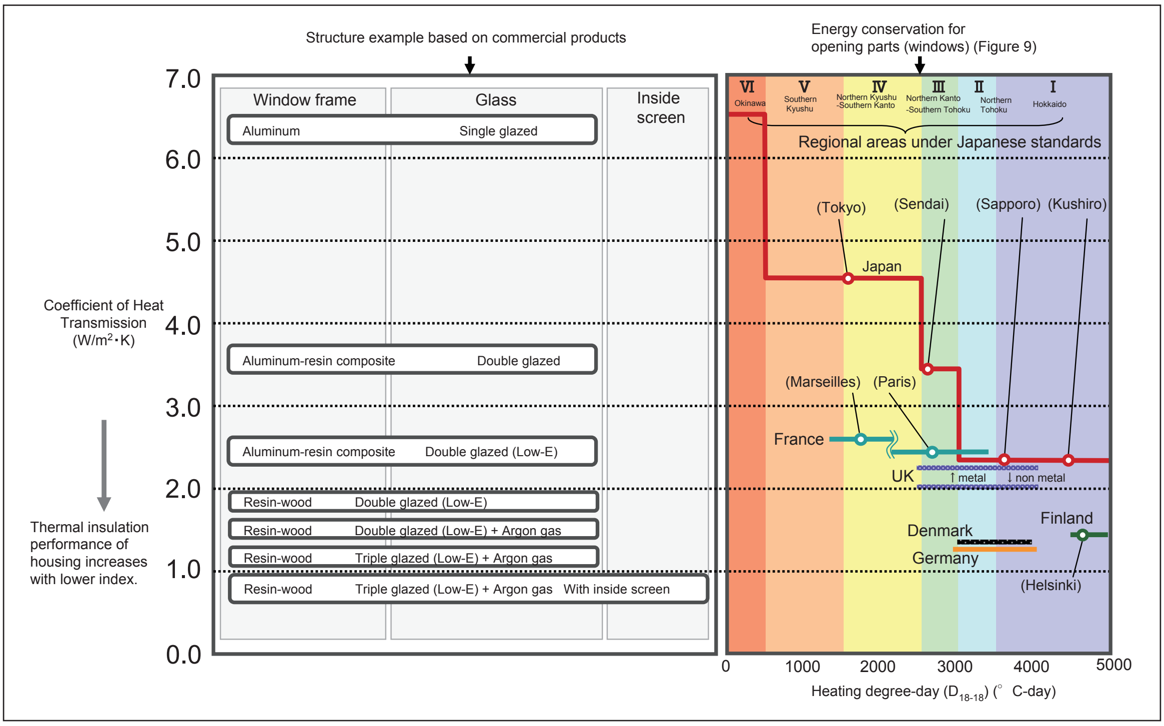

Figure 13 : Structure example of thermal insulation windows contributing to energy saving in opening parts

Prepared by the STFC based on Reference[26]

the high thermal insulation windows have, compared to the conventional window structure with aluminum frame and single glazed glass. As discussed in section 3-2, in Europe, energy conservation standard requires conditions for structure and specifications of windows to meet their regulations in each country. It is roughly estimated that CO_2 reduction effect by replacing glass from single-glazed into double-glazed with Low-E is 350 (kg-CO_2/year-house unit) in Tokyo or Osaka and is 800 in the city of Morioka in northeastern Japan, even if the window structure is conventional aluminum flame.[25] This effect corresponds to a reduction of 10 to 20 percent in annual heating energy.

4-2 Thermal insulation technologies for walls

Since walls are generally constructed with materials such as wood or glass wool, which have lower heat conductivity compared to glass and metal used in opening parts, their thermal insulation performance is high. However, as the walls accounts for large percentage of the area against a whole surface of housings, the thermal insulation structure of the walls will widely affect on total heat loss. The housing structures generally used in Japan has various types, such as wooden, prefabricated, steel moment frame, reinforced concrete, etc. From wooden housing, which has excellent thermal insulation performance, this report introduces the following thermal insulation construction methods recently applied in Japan for wood-framed construction like two by four construction.

Figure 14 is an example of high thermal insulation construction method for wall based on general wood-frame construction. A ventilation layer is placed on the indoor side of the exterior wall material, and a moisture protecting and air sealing sheet is inserted on the back side of indoor gypsum board. The ventilation layer enables to prevent heat loss from passing through the exterior wall from indoors, by circulating air, which is closer to room temperature rather than outdoors. In addition to this, the ventilation layer plays to discharge the humid air accumulated in inside of the wall structure. As a harmful effect by increasing thermal insulation performance, dew condensation must be considered. In case that heat transfer is cut by inserting or placing with high thermal insulating materials, a sharp temperature gradient is likely to cause at boundary surface contacting the thermal insulation materials. As a result, condensation will occur if the atmospheric humidity is high. Condensation not only degrades durability of the housing by causing corrosion of the components, but also has influence on health as causing mold. In order to prevent these harmful effects, control technology of humidity inside of the wall structure corresponds to high thermal insulation era becomes quite important. The moisture protecting and air sealing sheet, on the back side of the indoor gypsum board wall, is placed as a countermeasure for this. This sheet prevents the moist air caused at indoors from passing through the gypsum board and penetrating to inside of the thermal insulation material. In addition to this, by the effect of sealing invisible clearance at connecting part of wall materials, heat loss will reduce. Due to this wall structure, the thermal insulation performance gained high level at coefficient of heat transmission of 0.4 (W/m^2・K). Thermal insulation performance of a whole housing based on this wall structure achieved twice at heat loss coefficient of 1.3 (W/m^2・K), compared to that the general wood-frame construction method reached.[27] These values are on a level to meet the energy conservation standards in northern Europe.

Figure 15 shows an example of high thermal insulation construction method using internal wall insulation and external wall insulation based on general wood-frame construction. Essentially, key wards of "internal wall insulation" and "external wall insulation" were used as a technical term meaning how to cover the concrete wall with insulation materials, but the term is becoming general ward in recent

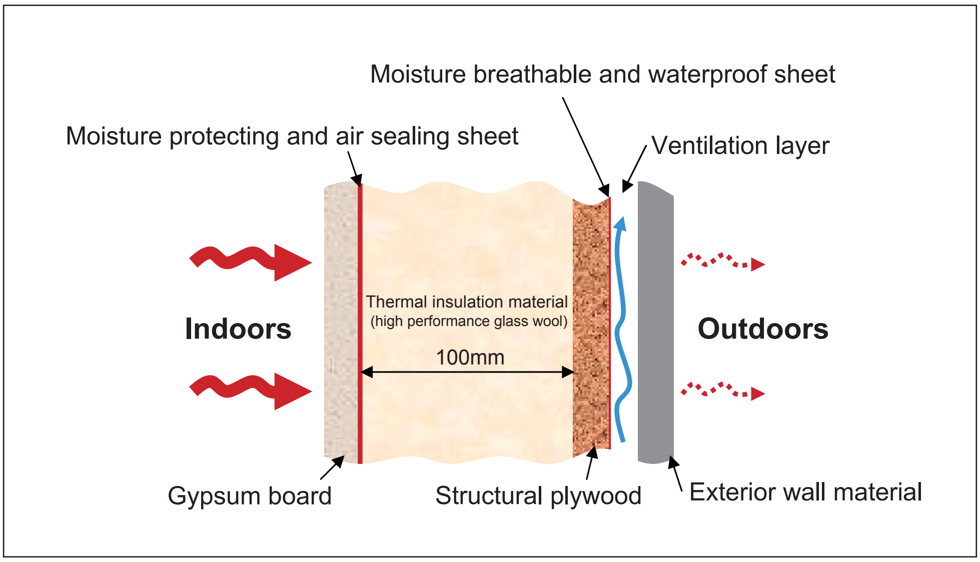

Figure 14 : Example of high thermal insulation construction method for wall

Prepared by the STFC based on Reference[27]

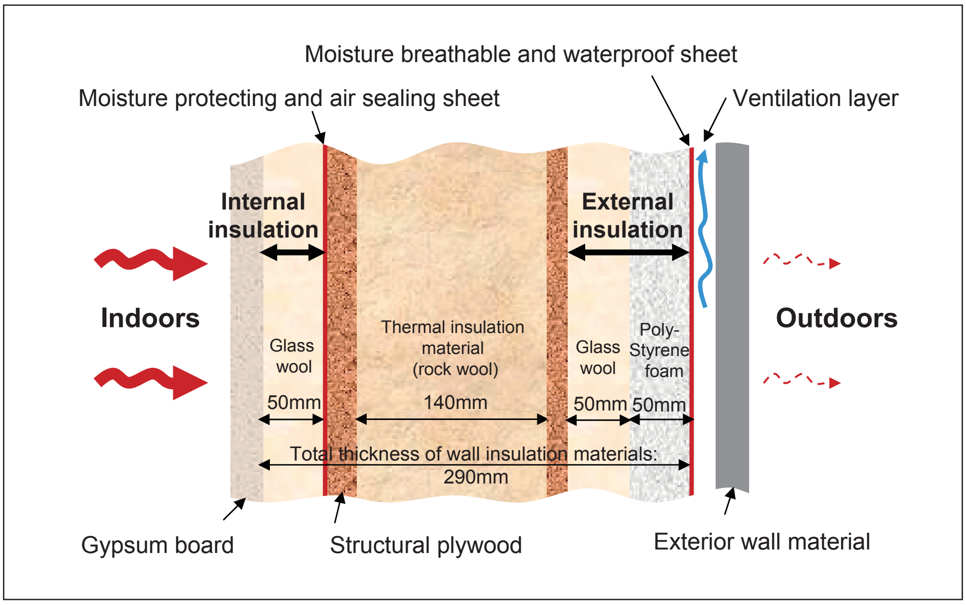

Figure 15 : Example of high thermal insulation construction method for internal and external wall insulation

Prepared by the STFC based on Reference[28]

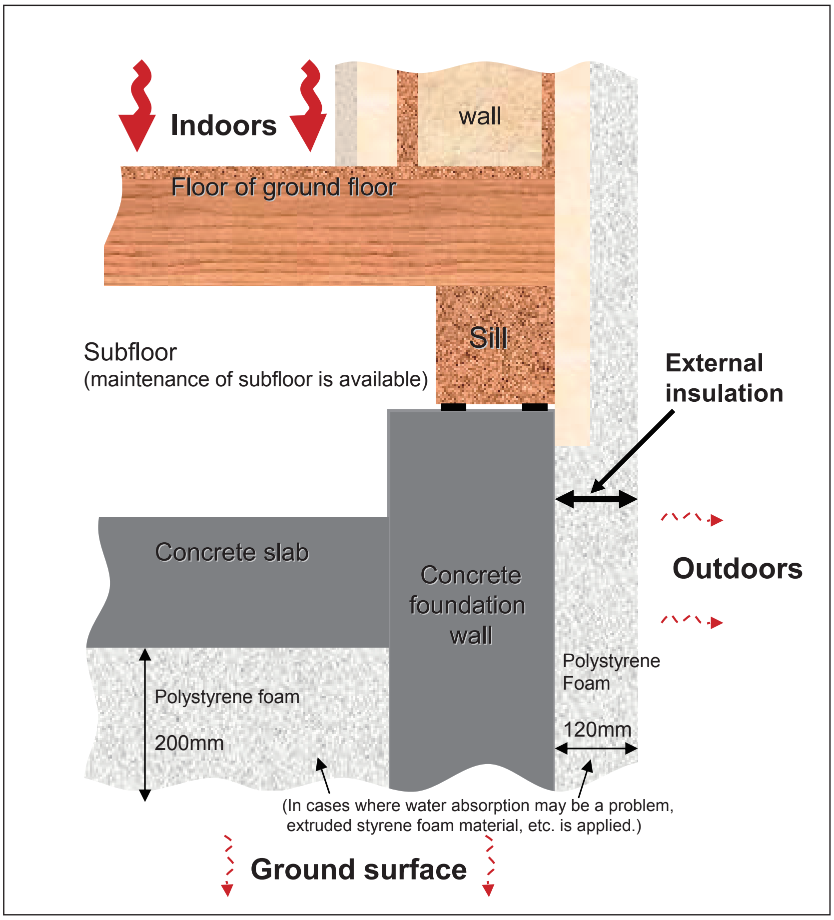

Figure 16 : Example of high thermal insulation construction method for foundations

Prepared by the STFC based on Reference[28]

years. Therefore, this report uses the ward here as a general expression. As for the external wall insulation, insulation material with a thickness of 100mm (polystyrene: 50mm, glass wool: 50mm) is applied to the indoor side of the exterior wall. For the internal wall insulation, insulation material with a thickness of 50mm (glass wool: 50mm) is applied to the back side of the gypsum board. Since the moisture protecting and air sealing sheet is placed on the outdoor side of the internal wall insulation, the sheet enables to prevent the moist air from penetrating to inside of the thermal insulation material (rock wool), like previous example shown in Figure 16. With this wall structure, the thermal insulation performance gained very high level at coefficient of heat transmission of 0.13 ($W/m^2 \cdot K$).

Figure 16 shows an example of high thermal insulation construction method for foundations. As for the external wall insulation for foundations, insulation material with a thickness of 120mm is covered to the outer side of the concrete foundation wall. In addition to this, insulation material with a thickness of 200mm is placed between the ground surface and the concrete slab. The thermal conductivity of concrete used in foundation is approximately 10 times greater than that of wood, and concrete easier transmits heat (Figure 11). This thermal insulation construction enables to prevent from the foundation temperature become the same as outside atmospheric temperature. Due to this effect, heat loss caused by heat flow from wooden structure to concrete foundation will reduce. The construction methods with examples shown in Figure 15 and Figure 16 achieved three times at heat loss coefficient of 0.8($W/m^2 \cdot K$), compared to that the general wood-frame construction method reached. As these examples shows, the high thermal insulation housing in Japan, which will meet strict energy conservation standards applied in northern Europe, is progressing in the practical stage.

4-3 Countermeasures to improve thermal insulation performance: Airtightness and heat bridge

In many countries including Japan, airtightness indexes for improving thermal insulation performance are specified in the energy conservation standards for housing. The airtightness index is a value obtained by dividing the total area of tiny clearance existing on building envelope such as exterior walls, ceilings, floors, and windows by the floor area of the building, and is called the C value (equivalent opening area). In general, heat loss increases with increasing the C value, because outside cool air flows into the wall structure inside and the heated indoor air flows to the outside through the clearance. This C value is only obtained by field measurement of invisible clearance, and is greatly influenced by how to construct. Actual countermeasure for airtightness requires quite careful design and construction treatment, such as, how to seal the clearance in electrical outlets and wiring inside walls, how to precisely cut and shape the thermal insulating materials to tightly enclose in wood frames. As mentioned in the previous section, the moisture protecting and air sealing sheet are placed to enhance airtightness performance too.

Another factor to improve thermal insulation performance is heat bridge. A heat bridge is a phenomenon that heat flows between housing inside and outside atmosphere, it occurs at balcony, roof and wall, etc, via the structure parts connecting both inside and outside. Essential countermeasures for heat bridge is to physically intercept the route of heat transmission in the part. Concrete measures used in Europe are, for example, independent installation of the balcony by separating from the housing itself and minimization of the roof installation parts. These measures are still not familiar in Japan where the earthquake frequency happens, but it should essentially be considered to establish effective way in the future.

4-4 High performing insulating materials

In recent development of thermal insulation materials, the performance gained high level at the thermal conductivity of 0.02 (W/m・K) [29], while the thermal conductivity of conventional glass wool is 0.05 (W/m・K) (Figure 11). One of main direction of high performing insulating material technologies is to establish the independent foam structure that no bubble cell connects each other in resin bulk. By recent manufacturing technologies, such as bubble cell minimization and foaming gas injection, thinner thermal insulation layers has been progressing. Due to this effect, it enables to save the filling space of insulation materials only at 40 percent against the thickness with the glass wool (under equivalent performance). Since the material is like a hard board, it cannot be used as soft materials to fill up, but it will likely be suitable for use as an insulating film when used with exterior wall panels, etc. It also has another potential for application as a heat bridge shield, such as an insulating film to cover the steel frame surface in steel moment frame construction.

4-5 Germany's passive house: the ultimate level of thermal insulation standard

Germany has promoted energy saving house under an energy conservation policy for the consumer sector since the Oil Crises of the 1970s. In the historical process, researchers had challenged to explore zero energy house. It is recognized that the past experimental challenge formed strict energy saving standard in today's Germany. Germany's current "low energy house standard" legally requires that annual energy consumption accompanying heating of the house (detached house) is 70 (kWh/m^2・year) or less (Table 1). Furthermore, party has been discussing what a stricter standard should look like after 2009. In Germany, there are some voluntary stricter standards besides current legal standard, such as, the "3 liter house" (derived from fuel consumption of boiler) and the strictest the "passive house."[30] A "passive house" is defined as a house that uses no more than 15 (kWh/m^2・year) of annual energy consumption for heating (detached house). This performance level means the house practically does not need heating equipment even in wintertime. According to Germany's Passive House Institute,[30] the number of registered actual buildings examples on "passive house" reached more than 1,000 units, mainly constructed in Germany. In addition, the number of house unit including apartment house of multi-unit residential buildings already exceeded 6,000 at 2005. The trends toward "passive house," which will suggest ideal buildings vision in thermal insulation performance to us, will likely be a remarkable driving force for establishing the future energy conservation standard.

5 Energy conservation policy and technology development for future housing in Japan

Table 3 shows idea what a desirable policy and technology should look like in the future. The figure summarizes the directions of idea in policies and technologies using box A through D.

Table 3 : Directions of desirable policies and technology

	Newly constructed housing	Existing housing
Existing technologies	**A** *Policies* -Strengthening of energy conservation standards with mandatory compliance. -Elimination of application procedures for preferential treatment. *Technologies* -Standardization for thermal insulation system technologies.	**C** *Policies* -Strengthening of energy conservation standards. -Strengthening of renovation penetration. *Technologies* -Standardization of renovation technologies.
New technologies	**B** *Policies* -Support for the following technologies. *Technology* -Establishment of “Japanese” high thermal insulation technologies suited for Japanese distinctive conditions; · Earthquake resistance · Windows enable to shield solar heat as well as thermal insulation	**D** *Policies* -Support for the following technologies. *Technologies* -Establishment of future renovation technologies. · Modularization of parts and components

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A. Measure to newly constructed housing with existing technologies

In the policy side, making residential energy conservation levels similar to those in other foreign countries should initially be considered. In addition, it is necessary for Japan to discuss about establishing further stricter standards to be the leader of low carbon society in the future. To make these ensure as effective measures, it is vital to switch to mandatory standards. The discussion will also need approach from other side of financial incentive including preferential tax treatment, etc. In the technology side, many kinds of parts and components to suit for high thermal insulation performance are already available. Thus, by adapting these to the housing construction widely in Japan, we can expect to realize the high thermal insulation housing to meet high thermal performance requirements assuming in the near future. However, this does not mean that all designers and construction contractors understand thermal insulation technology, and furthermore, energy conservation is still not a high priority for building owners. The above situation formed the points to measure that are standardization and promotion of thermal insulation system technologies and improvement in appealing it for building owners. For this, various efforts, such as leadership of the government as well as improvements by parties concerned in building construction, would be needed. In terms of incentive for building owners, NEDO (New Energy and Industrial Technology Development Organization) has been implementing the policies, such as promotion for introducing highly-efficiency equipments and subsidy program in thermal insulation renovation,[31] but the procedures and process are troublesome. By considering reduction the price of the thermal insulation parts and components with preferential treatment based on the thermal insulation performance rating system that have begun implemented in window parts, we can expect more easier system and procedures that does not need application by building owner in the future. There are also some room for discussion about new preferential treatment in tax and building area regulation, which does not include the space used for energy saving in the building area, etc.

B. Measure to newly constructed housing with new technologies

In Japan, tough buildings used steel frame and metal a lot, which was prepared for natural disasters of earthquake and typhoon, has developed and become general. The housing used metal like this necessarily become disadvantageous in thermal insulation performance because the heat flowing in the metal structure tends to increase. However, thermal insulation construction methods, which physically intercept the route of heat transmission between metal flame and outside atmosphere, have been developing in recent years. There is a case that accomplished high level at heat loss coefficient of less than 1.0($W/m^2 \cdot K$) as practical technology.[32] What to aim new housing idea, which satisfies both high thermal insulation performance and tough structure for earthquake by further promotion of these technologies, will be the distinctive way Japan should approach.

Essentially, the areas in Europe, where high thermal insulation technologies for housing have developed so far, does not necessarily need air-conditioning equipment for cooling because of colder climate. Because the climate in Japan is hot and humid in summer compared with areas like this, we require the air-conditioning equipment for both heating and cooling. Thus, in addition to wintertime performance of thermal insulation and warm keeping, summertime performance of sun shading and cool keeping are also becoming important. The performance of cool keeping improves with increasing the performance of thermal insulation at the same time, but the improvement in performance of sun shading will require modifying other individual measures. In Europe, product of sturdy motorized metal sun-screen installed to the building outside space, which respond the sun shading problem, are recently being introduced to many buildings. Shielding solar heat at outside of the buildings is so efficient rather than at inside that the method have progressed. When considering application in Japan, however, heavy wind due to typhoon will likely become a major problem. Japan has traditional excellent culture of hanging screen “Sudare” and rain shutter “Amado”, but these are detachable when using. It will be vital to have features that cannot break by heavy wind. Today, Japan acknowledges the importance of establishing the future original window to highly meet both requirements of thermal insulation and sun shading derived from Japanese climate condition. To sooner create concrete versatile window structure based on the concept, which was listed in the Technology Strategy Map 2008[33] presented by Ministry of Economy, Trade and Industry (METI), would be quite important policy for Japan.

C. Measure to existing housing with existing technologies

In the policy side, regulation based on residential energy conservation standards should initially be applied to existing housing, as done in the foreign countries. In Europe, where obliges existing housing to meet the regulations, renovation construction for old buildings using thermal insulation for exterior wall are implementing, except for the buildings registered as World Heritage Site. In Japan, the number of existing housing amount about 47 million units, which is overwhelmingly large compared with that of newly constructed housing at about 1.2 million units in recent years. As it is generally thought that replacing all the existing housing to the newly constructed housing needs 40 years, it is clear that drastic strengthening of renovation will strongly be required for the existing housing. However, cheaper renovation method without large-scale construction exists even today, renovation parts, which enable to exchange only window glass from single-glazed to multi-glazed glass, are still available in the market. Above discussion formed remaining issue that government should promptly steer is to makes a promotion plan by gathering parties, such as renovation parts manufacturers and contractors.

D. Measure to existing housing with new technologies

In order to realize efficient renovation to current existing housings, new technology development is desired, which realize cheaper renovation and shorten construction term by establishment of modularization enables quick exchanging parts and components. On the other hand, it is also necessary to consider new renovation technology for the future existing housing which will have been constructed in the coming years. Since the housing structures is becoming sturdier and longer life recently, the need for replacement of new windows and doors updating to higher thermal insulation performance after the house constructed would increase in the future. In this case, by standardization based on investigation about what parts and components should be designed for easier exchange in advance, reduction of wasteful demolition will be expected.

6 Conclusion

In order to be a leader of Low-Carbon Society era in the future using the advantage of high efficient heating equipment technology Japan has cultivated, promotion to progress high thermal insulation housing technology should initially be considered to focus. For this, the establishment of strict energy conservation standards, which meets long term vision and the support for technical development to correspond the requirements, will be urgent issues Japan should implement. Japan’s condition that housing exists is extremely special, for example, cold climate in winter, hot and humid in summer, and earthquakes and typhoons are frequent. To establish Japan's low energy house, which suit for particular situation Japan has, it will be necessary to develop new thermal insulation system technologies which incorporate unique technologies as well as catching up with the technologies developed in Europe. Japan is a country that has various housing construction method. When we develop and promote the thermal insulation technology in Japan like this, standardization of the system technologies beyond framework based on existing circle of housing construction method and academia will be the key action. If we carry out in practice what Japan should implement from the present, it is expected that housing environment in Japan will have improved beyond all recognition after one to two decades.

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Promotion of Field-verified Studies on Sediment Transport Systems Covering Mountains, Rivers, and Coasts

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1 Introduction

Some 70% of the land of Japan is mountainous, and a substantial amount of sediment is produced each year due to the erosion and collapse of mountain slopes and other causes. The sediment is transported through rivers. Rivers have periodically overflowed and deposited sediment in river basins during floods, and at river mouths and in coastal areas, sediment has repeatedly been deposited and carried away due to the motions of waves and currents. Existing plains, river-mouth deltas, and sand and gravel beaches were formed through such sediment movement. Formerly, how to control the riverbed aggradation and prevent flooding were important issues. However, it is true that the ample supply of sediment has contributed to the formation of Japan's rich natural landscapes that boast coastlines of white sand and green pines and to the maintenance of ecological diversity.

Since around 1960, when Japan entered a period of high economic growth, many dams have been built to control floods, generate electricity, and secure water for various uses. Large dams blocked the passage of sediment down rivers, and in the basins where sediment yield is great, a considerable amount of sediment is deposited in dam reservoirs. Additionally, a substantial amount of sand and gravel have been extracted from rivers and the sea to be used as concrete aggregate, reducing the supply of sediment into the sea, and moveover, many ports and other coastal structures have been built, blocking littoral sediment transport[NOTE 1].

These conditions cause dams to function less effectively, cause riverbed degradation in the areas downstream from dams, and the erosion of sandy beaches at the mouths of rivers and along coasts, and create many other problems by disrupting the balance of sediment transport systems[NOTE 2].

In consideration of these conditions, the Integrated Sediment Management Subcommittee of the Council of Rivers at the Ministry of Land, Infrastructure, Transport and Tourism submitted a report in July 1998, demanding efforts toward the integrated management of the entire sediment transport systems. Additionally, the Third Phase of the Science and Technology Basic Plan (launched in 2006) covers "technology to estimate the actualities of sediment transport in the total sediment transport systems, sediment management technology, and technology to assess the effect of an individual sediment management on the entire sediment transport systems" as an important science and technology strategy in the area of social infrastructure framework.

[NOTE 1] Littoral sediment transport :
The movement of bottom sediment (sand) caused by the motions of waves and currents. The Japanese word (hyōsa) also refers to drifting sand itself.

[NOTE 2] Sediment transport system :
The integrated system of sediment transport extending from river sources to the coast including the area of longshore sendiment transport if that sediment source is from the river.

To solve or mitigate the undesirable problems existing in the present sediment transport systems, it is essential to take action such as sediment releasing from dams, that fulfills an appropriate sediment blance throughout the systems satisfying the aims of flood control, water usage and environment simultaneously. Until recently, however, we had only considered how to block the outflow of sediment from upstream basins for the sake of disaster prevention and had not considered ways to supply the necessary amount of sediment to downstream basins. Thus, there are no integrated institutions to consider entire sediment transport systems covering mountains, rivers, and the sea. Moreover, our understanding of sediment transport is insufficient because sediment moves through wide areas and longtime span in a complex manner and this movement is difficult to measure. Therefore, we have not yet established the technology to assess, for instance, the bad or good effects of sediment releasing from dams on downstream basins and the sea, nor have we created the technology to appropriately control sediment transport.

This report gives an overview of increasingly serious sediment problems surrounding sediment transport systems and technology and research trends directed at tackling these problems. It also expresses what is needed in order to conduct sediment management in an integrated manner, in consideration of entire sediment transport systems.

2 Problems Existing in Sediment Transport Systems in Japan

2-1 Characteristics of Sediment Runoff from Mountains

Japan is located in the Pacific Ring of Fire and experiences many earthquakes and much volcanic activity. There are mountains throughout the country and the geological structures are often fragile. The bedrocks have been fractured and hydrothermally altered due to the intrusion of volcanic rocks and these bedrocks readily collapse as a result of continuous infiltration, freezing, and dissolution of rainwater as well as bedrock creep. In addition, severe climatic conditions such as typhoons, rain fronts, and atmospheric depressions cause heavy rains, and thus, a great amount of sediment is produced in the mountains. The average sediment production is estimated to be about 200 million m^3 per year.[1] Sediment production varies by region; it is active along the Itoigawa-Shizuoka Tectonic Line and other regions containing fragile geological structures, and about half of the production occurs in the Chūbu and Hokuriku regions (in the central and northeastern parts of the main island of Honshū).

Dividing mountain ranges cut through the Japanese archipelago like a backbone, and short steep rivers flow directly into plains and to the sea. Sediment of various particle sizes produced in the mountains is continuously transported downriver and, periodically, in large quantities by floods. In the process, rivers repeatedly overflow and sediment is deposited in many places and then moves again. The deposit of relatively large gravel and sand has created alluvial fans where rivers flow into the plains from steep mountain regions. Small sand and nutrient salts contained in fine soil particles have been deposited in flatlands to create plains and river-mouth deltas. Additionally, the supply of sediment from rivers has formed tidal flats and sandy coasts.

Thus, sediment from mountains has played an important role in creating and maintaining Japan's landscape and has nurtured regional climates and ecosystems. At the same time, however, sediment has been a threat to human life.

2-2 History of the Situations of Sediment Transport Systems

2-2-1 Before the Period of High Economic Growth

Before and during the Edo period (1603-1867), mountain forests deteriorated due to logging to supply wood for construction and fuel purposes. A substantial amount of sediment flowed into rivers and consequently riverbeds rose, causing frequent flooding. During the Meiji period (1868-1912), engineers from overseas hired by the govement began to plant trees and conduct other erosion control projects in order to reduce the amount of sediment outflow. Development of new farmland was also active. Continuous levees instead of open levees [NOTE 3] were adopted when developing farmlands in alluvial plains, leading to the reduction of marshes, which retained water from rivers and contributed to flood control. Inevitably, these areas were vulnerable to floods and frequently damaged by flooding. Considerable sediment yield continued until the 1960s and contributed to frequent and major flooding.[2]

2-2-2 After the Period of High Economic Growth

After World War II, many homes were built on floodplains. Frequent flooding caused by typhoons and heavy frontal rains attacked these areas causing many deaths, and the Japanese people strongly desired to create flood-resistant rivers.[3] Thus, river levees have been strengthened and trees have been planted on mountainsides as a part of erasion control works. It was also necessary to secure water for agricultural use in order to increase food output, to secure clean drinking water in order to protect the people in cities from cholera, dysentery, and other epidemics, and to build large hydroelectric plants in order to respond to rapid increase in the demand for energy.[4]

Consequently, beginning around the 1960s, many large dams were constructed to control flood, generate hydroelectric power, and secure water for municipal, industrial use and so on. These dams reduce the danger of flooding and protect people's lives and property. They have also extended intensive land use, greatly contributing to the development of industry. Hydroelectric power production was about 95 billion kwh per year as of 2006, a little less than 10% of the total demand for electricity. It is an important resource that can be produced 100% domestically and that does not emit CO_2.[5] Large dams are usually designed to store, along with water, 100 years' worth of sediment in reservoirs in accordance with the country's guidance for reservoir planning. Therefore, except for fine soil particles that flow through the dams, most sediment coming from upper river basins is captured and deposited in dam reservoirs. Additionally, many check (sabo) dams have been built to control erosion and to store sediment from deteriorating mountains and mountain streams.

Figure 1 shows an outline of sediment transport from the mountains to the rivers and to the sea. About 100 million cubic meters of sediment is deposited in dam reservoirs and other structures that cut across rivers annually, halving the average yearly supply (production) of sediment going down rivers. There are about 2,700 dams of 15m or higher, of which 877 dams can store a million cubic meters or more of water, such

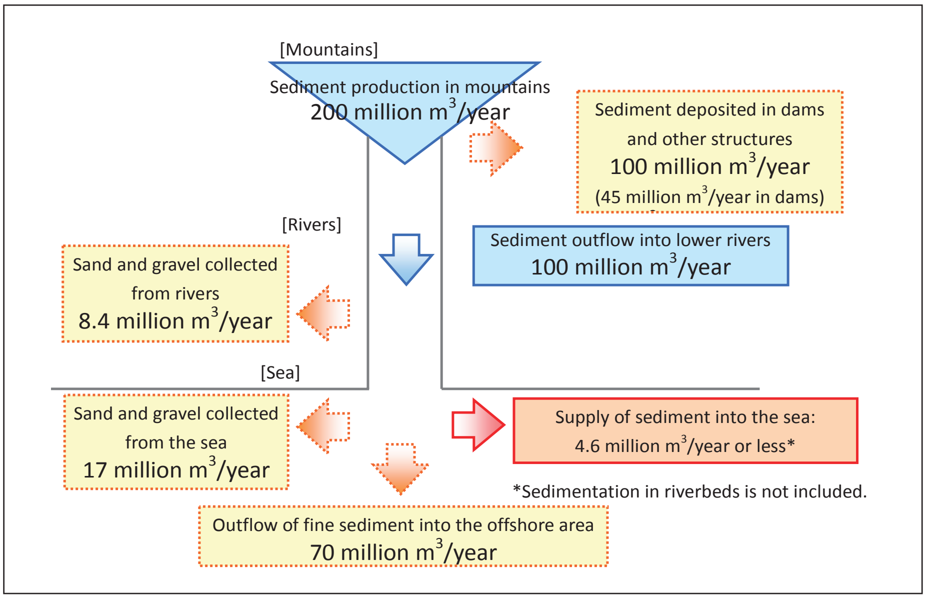

Figure 1 : Outline of Sediment Production and Amount of Sediment Outflow in Japan

Prepared by the STFC based on Reference[1]

[NOTE 3] Open levees :
Openings are made in levees for relatively steep rivers. These openings both temporarily let some water out of levees to reduce the force of floods and allow the deposit of rich soil on farmland to improve the land. They also let overflow from levees and floods from tributary streams run into rivers.

dams are compulsorily required to report the amount of sedimentation. A total of about 1.3 billion cubic meters of sediment had been deposited in these 877 dams as of 2005.[1] Especially in river basins where the sediment outflow is great, dam reservoirs can capture a substantial amount of sediment transported down at the time of flood, and by such a function, these dams have lowered the elevation of the riverbeds of once unmanageable rivers downstream, and contributed to considerably enchance the safety of rivers by increasing discharge capacity.

In addition, since the period of high economic growth, a great amount of sand and gravel have been extracted from rivers and the sea to make concrete aggregate, greatly altering sediment transport systems. The amount of sediment collected from rivers once reached 130 million m^3 in 1966. However, strict regulation reduced the amount to 22 million m^3 in 1989 and to 8.4 million m^3 in 2004. There has also been a trend to ban the collection of sediment from the sea, and the amount collected in 2004 was 17 million m^3. Additionally, ports and other large coastal structures greatly influence sediment transport along coasts. Most amount of sediment deposited in navigation routes and anchorages does not drift back to sandy shores and is disposed offshore or in inland areas.

2-3 Problems Caused by Imbalance in Sediment Transport Systems

Figure 2 shows the characteristics of sediment transport through rivers, i.e.,sediment deposition in dam reservoirs, problems typical of sediment transport systems such as the coarsening (armoring

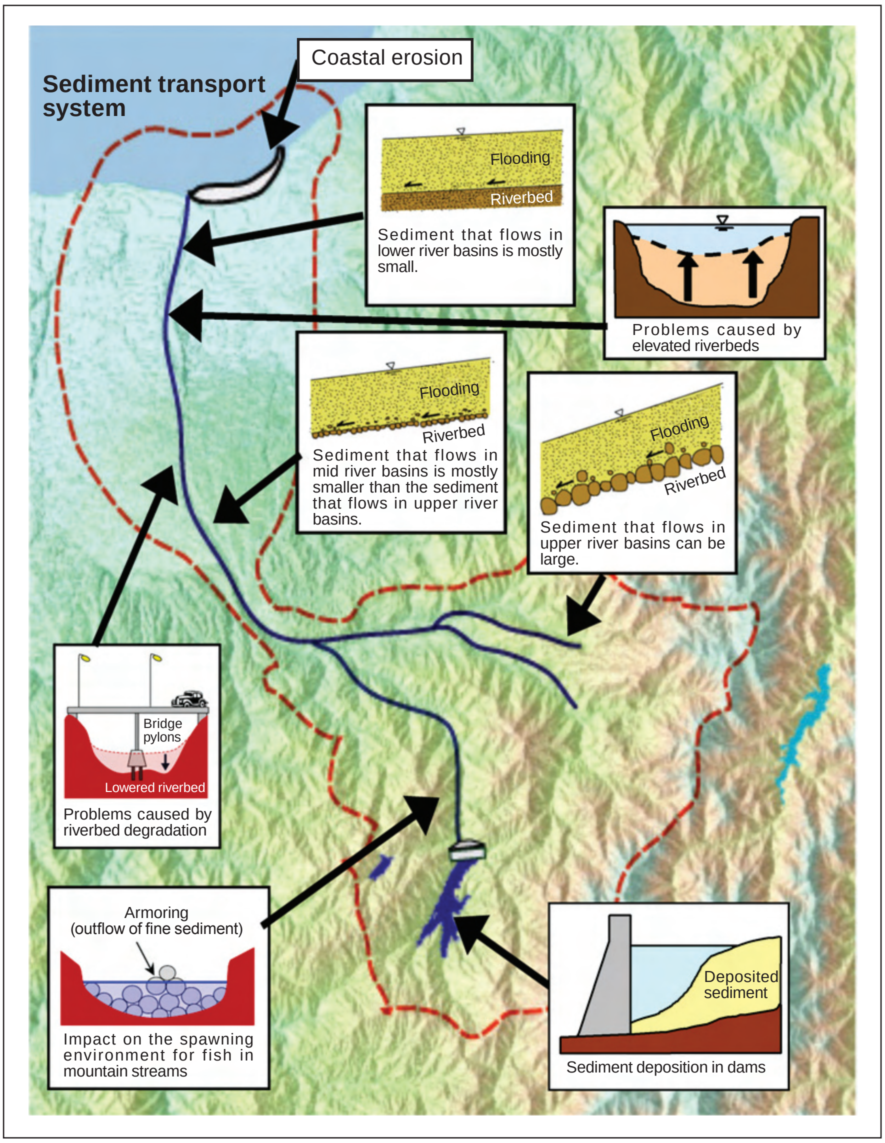

Figure 2 : Characteristics of sediment transport through rivers and outline of the sediment problem

Source: Reference[6]

phenomenon) of the top layer of riverbeds, lowered riverbeds downstream from dams, elevated riverbeds in lower river basins, and coastal erosion. It should be noted that the nature and extent of problems greatly depend on how much of each problem is natural or artificial.

2-3-1 Sediment Deposition in Dam Reservoirs

Dam reservoirs are normally designed to have a capacity to store 100 years' worth of sediment in the deepest parts close to the dams, but sediment flowing from the upper rivers is often deposited in areas of effective storage capacity near the entrances to the reservoirs (Figure 3). Thus, deposited sediment reduces the effective capacity to store water as was intended by the reservoir planning, deteriorating the functions of reservoirs (such as flood control, providing drinking water, and power generation), and elevates riverbeds near the entrances to reservoirs, increasing the risk of overflow during floods. If sediment deposition proceeds, dams' ancillary facilities such as water release and water intake facilities might be affected.

Looking at dams with a water storage capacity of 1 million m^3 or more in the Chūbu region, where sediment production is active, 30% or more of the dams' overall capacity was filled with sediment in 27 dams (34% of total number) in 2005.[1] Looking at dams throughout Japan, 140 dams (16%) had already accumulated their intended quantities of sediment. Due to recent rapid depopulation in intermediate and mountainous areas, mountain forests have been managed insufficiently, reducing the capability to stop landslides. Thus, future increase in sediment production may make the situation worse.

In large reservoirs that have low water turnover rates, a great amount of fine soil particles of about 10μm or smaller remains suspended in the reservoirs for long periods, making the downstream water murky for a long time.[7] Additionally, nitrogen, phosphorous, and other nutrient salts can remain in the reservoirs in high concentrations for long hours, creating conditions for excessive reproduction of algae that causes the generation of blue-green algae and algal blooms, harming water quality through eutrophication.[7]

2-3-2 Riverbed Degradations in Middle and Lower River Basins

Due to riverbeds degradations caused by the sediment blockage by dams and the excessive extraction of sand and gravel from rivers, there are cases where the foundations of revetments and bridge piers are scoured and intake weirs for agricultural water and tap water do not function properly in middle and lower river basins. It has also been pointed out that the decreased supply of sediment from upper rivers by the effect of dams lets fine sand on the bed be carried away, causing the coarsening of riverbed, and that lowered grinding effect on riverbed gravel by the less active sediment transport slows the regrowth of attached algae. These conditions have an impact on the habitat for aquatic life.[8] In addition, the decreased flow rates and number of floods due to the operation of dams make the sand bars unmovable in lower rivers,

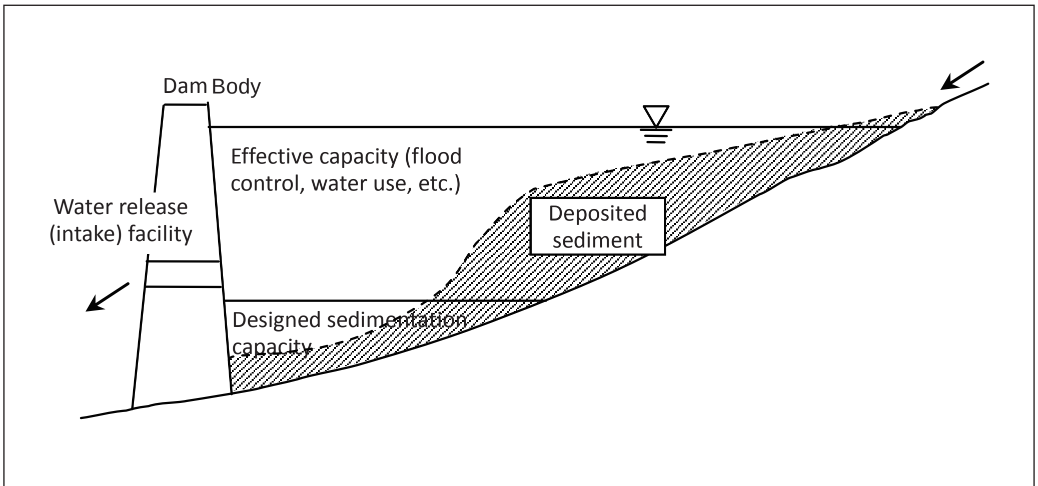

Figure 3 : Relationship between the Sedimentation Capacity of Dam Reservoirs and the Shape of Sedimentation

Prepared by the STFC

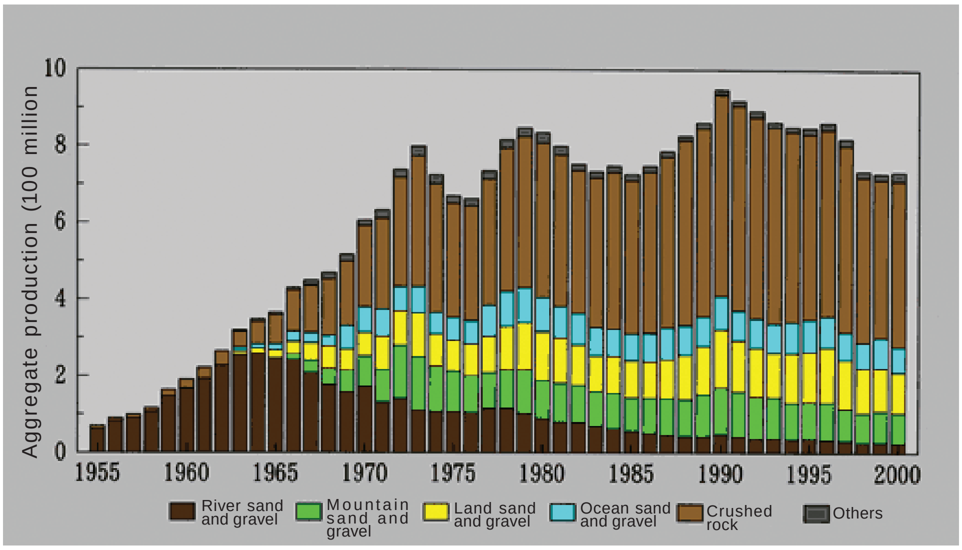

Figure 4 : Changes in Aggregate Production in Japan

Source: Reference[9]

creating a stable colony of vegetation like willow. This affects the previous natural distribution of plants and reduces the discharge capacity of rivers at times of major floods.[1]

Due to concerns about the adverse effects of sand and gravel mining from rivers, such extraction has been strictly regulated in recent years. However, riverbeds in some parts of lower river reach have become elevated in the absence of large dams up steam, increasing the risk of flooding. Such regulations sometimes extended even to the inside of reservoirs, resulting in a shortage of usable sand and gravel. Consequently, a substantial amount of rock has been cut from mountains to be crushed (Figure 4), devastating the beautiful natural landscape.

2-3-3 Erosion of Estuaries and Sand and Gravel Beaches

The erosion of estuaries and sand and gravel beaches has been proceeding because of the reduced supply of sediment from upper river basins, extraction of sand and gravel from riverbeds and the sea, and the blocking of sediment movement along coasts due to the construction of ports and other coastal structures.[10] Since the early 20th century, an average of about 160ha of sand and gravel beaches have been lost annually,[11] and it has been pointed out that this situation affects the coast's ability to mitigate tidal waves (a disaster prevention function), the self-cleansing process of sea water, the environment for fish larvae growth, and the egg-laying environment of sea turtles.

To stop coastal erosion, concrete structures such as wave-absorbing blocks and detached breakwaters have been built in many places. However, these stopgap erosion prevention methods can create additional problems by, for example, accelerating erosion in other areas.[12] These structures are also huge eyesores in the beautiful natural landscape along sandy coasts. Figure 5 compares the Enshū-Nada coast in 1987 and 2005. As seen in the picture on the left (from 1987), to prevent erosion of the beach caused by the decreased supply of sediment from the Tenryu River, a series of breakwaters was constructed between the Tenryu River and the Magome River (in the center of the picture). The breakwater captures sediment moving along the nearby coast and has stopped erosion in this area. However, less sand is now supplied to the Nakatajima Dune (in the lower part of the picture), and as seen in the picture taken in 2005, the coast of the dune has eroded remarkably.

Japan has 35,000km of coastline and the total length of coastal protection facilities had already reached about 9,500km by 2005. Considering that these facilities last for 50 years, a 200km length of these facilities need to be repaired or updated every year, which is a great burden to place on future generations.

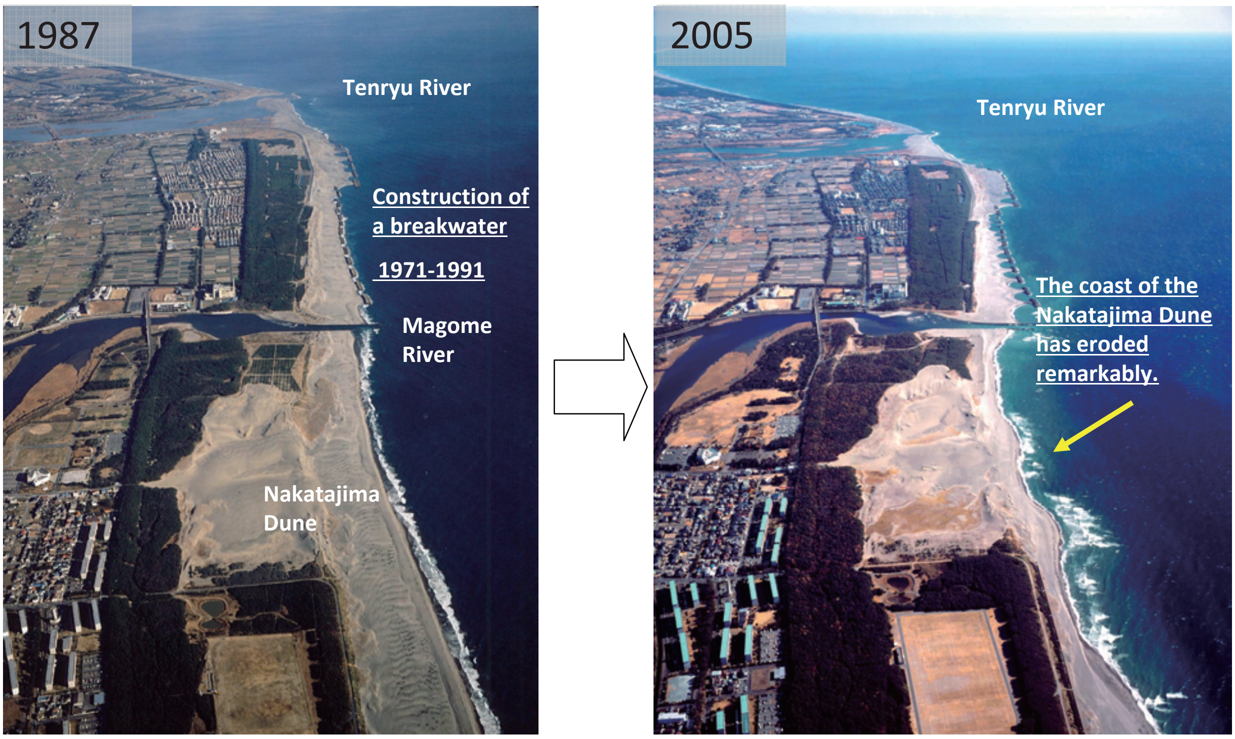

Figure 5 : Erosion of the Enshu-Nada Coast

Reference[13] was partially modified by the STFC

3 Technology to Solve Problems Surrounding Sediment Transport Systems and Study Trends

3-1 Shift to Integrated Sediment Management Policies

In order to make the most of river and coastal resources and to protect the public from disasters, various anti-erosion structures, reservoirs, levees, revetments, weirs, coastal dikes, and breakwaters have been built in the hopes of controlling natural phenomena. These efforts have successfully fulfilled their original purposes. However, they have also created adverse effects on other parts of the sediment transport system, and as time goes by, various problems have become apparent. In response to this situation, the Integrated Sediment Management Subcommittee of the Council of Rivers at the Ministry of Land, Infrastructure, Transport and Tourism submitted a report entitled “Integrated Sediment Management of the Sediment Transport Systems” (in July 1998). The report introduced the concept of a sediment transport system, which includes areas extending from the sources of river basins to the coasts. It revised the conventional idea of sediment management that focuses on measures to stop sediment outflow and emphasized the importance of allowing appropriate sediment movement throughout the system. In response to the report, the Ministry of Land, Infrastructure, Transport and Tourism began to take action that takes into consideration integrated sediment management covering both river basins and the sea, which aims to, based on the characteristics of each river and coast, prevent disasters caused by sediment transport, while preserving the ecosystem, landscape, and environment and making proper use of rivers and coasts.[14]

The River Act was revised in 1997 to include the environment aspect in addition to previous flood control and water use aspects. The Coast Act was also revised in 1999 in an aim to conserve coasts in a balanced way taking into consideration the environment and use in addition to the protection of human life and property.

3-2 Study Trends in Technology Concerning Sediment Transport Systems in Japan

3-2-1 Studies on Sediment Transport

As a part of efforts to improve integrated sediment management technology, some field investigations to understand the actual sediment transport phenomena been conducted in the areas where the effects of imbalance in sediment delivery have been remarkable in recent years.

(1) Studies on Sediment Movement in Rivers

In the Tenryū River, the particle size distributions of sediment in the Sakuma dam reservoir and of sediment in the lower river channel are being compared in order to assess, if in the future sediment were flushed from the dam, what size particles flow into the offshore sea, what sediment contributes to the formation of the beach, and what sediment may be deposited in the lower river and need to be properly controlled to prevent flooding.[15]

In the Abe River, the amount of sediment transport is being measured and correlated with the water discharge in order to estimate the amount of sediment movement by particle sizes at each flood. About 72% of the sediment transported to the lowest part of the river at the time of flood was made up of sediment (0.1-10mm) that is effective in the formation of beaches, and that sediment was also deposited in the upper riverbed and was needed to be continuously removed to keep the river safe.[16] We have the technology to observe geographical changes and discharges of suspended sediment, but it is still difficult to measure the discharge of large particles which may be deposited in riverbeds and cause flooding.[16]

In the Yahagi River, study is being made into the effects of changes in the supply of sediment from the dam on benthic organisms. The sediment concentration is small in the tailwater, and the percentage of sand and small gravel is low in the riverbed. In contrast, zooplankton proliferates propagated in the reservoir and they flows downstream. These habitat change has clearly influenced benthic organisms, but the effects tend to be alleviated in the lower river basin due to the confluence of tributary streams.[17]

(2) Studies on Sediment Movement in the Sea

At the river mouth of the Abe River, geographical changes in the river mouth terraces have been studied via survey data. More specifically, studies have been conducted on the development of the river mouth terrace due to sediment inflow from the river during a flood and on the sediment supply to the beach by the deformation of terrace due to wave action.[18]

In the area around Enshū-Nada, where the Tenryū River flows into the sea, studies on the historycal change of the beach have been conducted, based on a combination of old maps, aerial photos, and survey data from ground-penetrating radar. The mineral substances of the sediment in the mountains, the river, and the beach are analyzed to understand the broad-based origin of sediment. In addition, in order to understand sediment movement in the sea, efforts have been made to develop technologies such as new ultrasonic survey technology and technology to monitor the long-term and broad-based ocean floor topography change by acquiring data of whitebait's fishfinder from fishery cooperative associations. These efforts are conducted by the collaborations of universities, the private sector, the Ministry of Land, Infrastructure, Transport and Tourism, and prefectural and local governments under the project entitled “dynamic sediment management and coastal disaster prevention using advanced technology(Enshū-Nada Project)” within the framework of the Special Coordination Funds for Promoting Science and Technology (a research and development program for resolving critical issues), and the project has attracted attention from researchers studying sediment transport systems.[13]

At the Kanazawa coast, where the Tedori River flows into the sea, and at the Hyūga-Nada coast in the eastern part of Miyazaki prefecture, fluorescent sand tracer experiments, mineral analyses, and sediment transport surveys using bathymetry have been conducted. These studies have made clear the sediment loss to offshore areas and sediment transport over the capes.[19]

3-2-2 Technology to Predict Sediment Runoff from Mountain Areas

The Takase dam in the Shinano River system has the largest annual sediment deposit per basin area in Japan. Based on surveys on geographical changes using aerial photographs that have been taken for years and observation data concerning the repetition of erosion and deposition on bare slopes, the electric power company that manages the dam has been working collaborating with universities to understand the characteristics of sediment production on the slopes and sediment runoff processes including temporal sediment storage on the slopes and on the riverbeds.

These studies made clear the relationship between rainfall conditions and sediment runoff,[20] and a numerical simulation model of sediment runoff enabling the tracing of particles motion by several size ranks has been presented.[21]

3-2-3 Technology to Release Sediment from Dams

In the past, sediment in large dam reservoirs has been removed primarily by digging or dredging. In recent years, however, according to the characteristics of the particular river basin and the dam's facilities, various technologies for releasing sediment have been explored as shown in Figure 6.[22] Sediment in a large number of dams constructed during the period of high economic growth needs to be managed to ensure the sustainable proper functioning of the dams. Studies have begun on the asset management of dams relating to the relationship between the life cycle costs and the service standards focusing on sediment management.[23] Efforts to release sediment downstream from large dams and check dams have also begun.

(1) By-pass Tunnel

At the Asahi dam in the Shingū River system[24] and the Miwa dam in the Tenryū River system,[25] water tunnels have been built connecting upstream reservoirs to the areas downstream of the dams, and efforts have been made to develop and operate a system to bypass the sediment flowing into the reservoirs at the time of flood. As Figure 7 shows, a check dam was built upstream from the reservoir, leading sediment-loading floods into the tunnel and downstream from the dam. This system has greatly improved the turbidity that had been an issue for a long time and has controlled the sedimentation problems in the reservoir. The system has resulted in the reappearance of clean sand on the riverbed downstream from the dam and has been well-received by the local residents. However, the sediment from the Asahi dam flows into and is deposited in the next dam below. As such, sediment transport is not being continuously managed throughout the river. In addition, the tunnel lining is corroded by the sediment transport and need to be repaired every year.

(2) Sediment Flushing

The Dashidaira dam and the Unazuki dam in the Kurobe River system have begun efforts to empty the reservoirs in a coordinated manner and to flush sediment deposited in the reservoirs from the sediment flushing gates using the force of running water (Figure 8). The amount of sediment flushed is between 20,000m^3 and 1.72 million m^3 per flushing. This method has been used for small dams but not for large dams because it takes time to refill a large reservoir after flushing and because it makes difficult to maintain the dam's power-generating

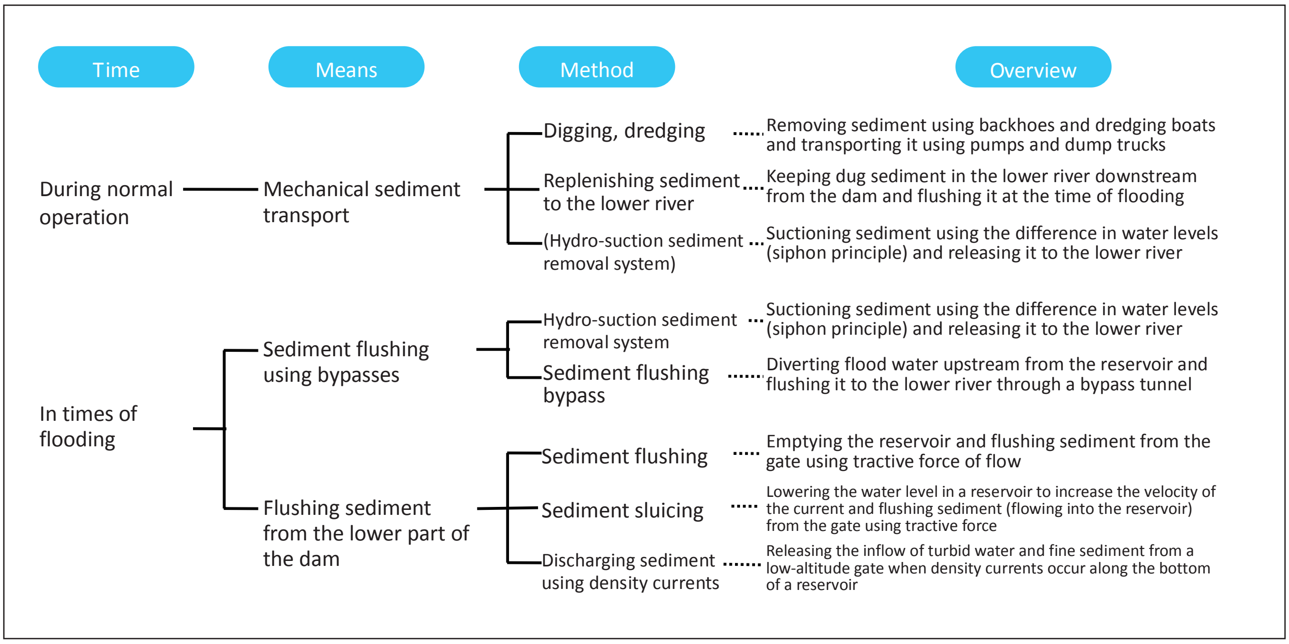

Figure 6 : Technologies to Flush Sediment from Dams

Prepared by the STFC based on Reference[1]

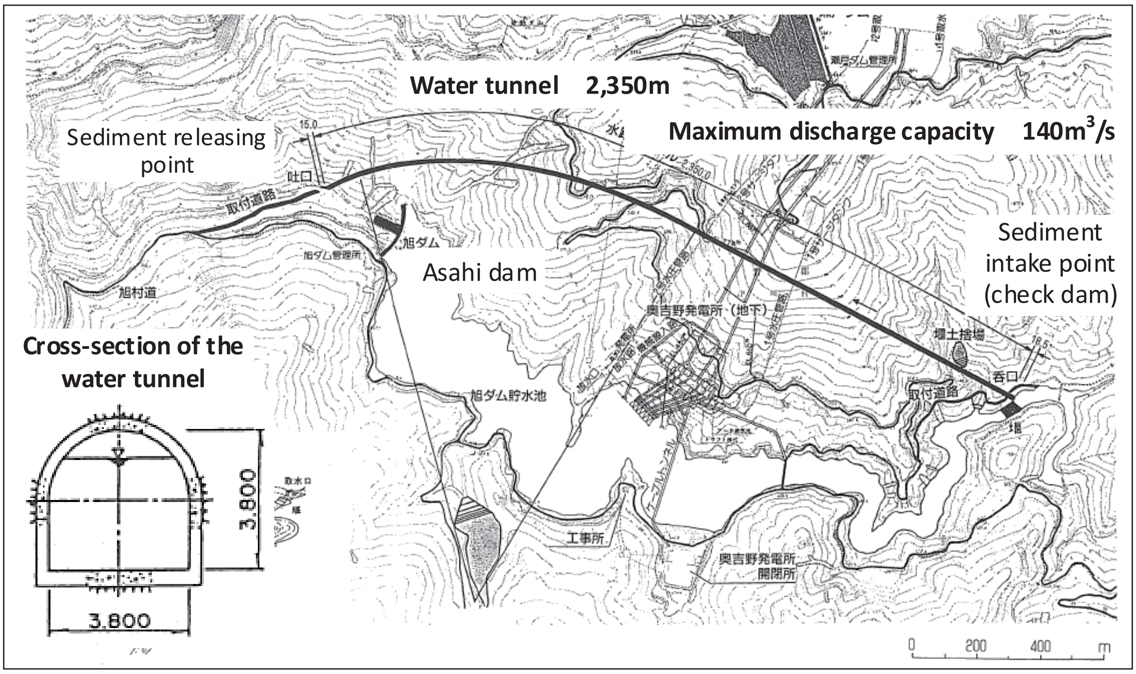

Figure 7 : Map of Flushing Bypass for the Asahi Dam

Reference[24] was partially modified by STFC

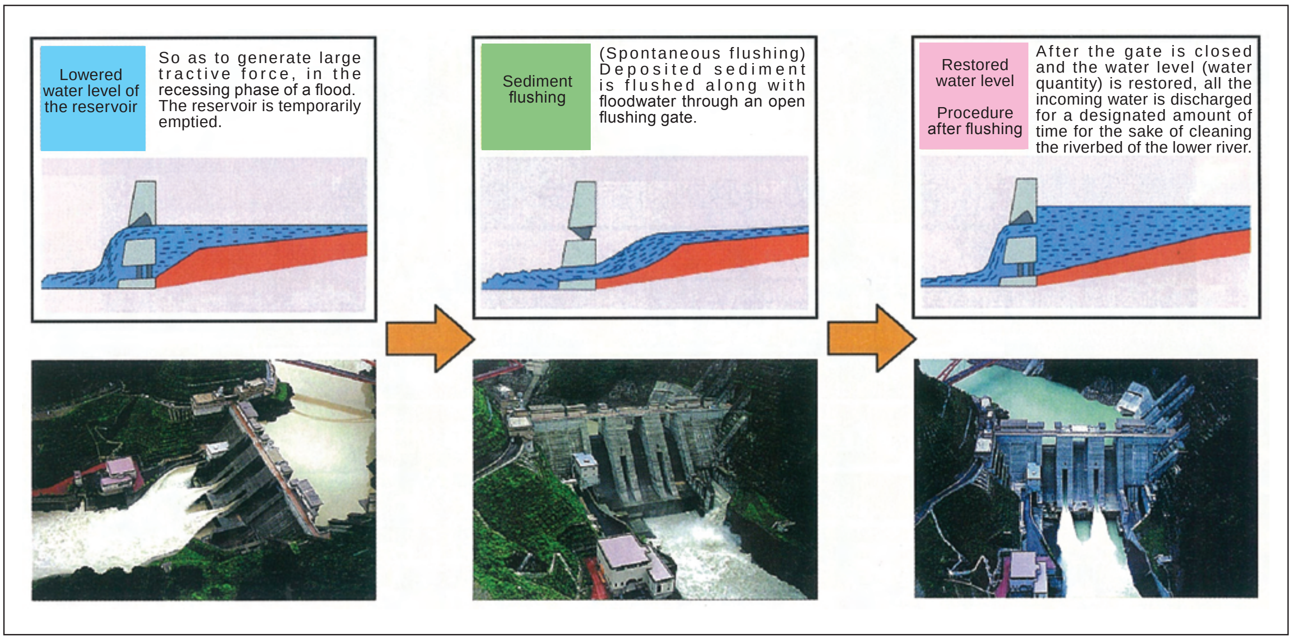

Figure 8 : Sediment Flushing at the Dashidaira Dam

Source: Water Resources Environment Technology Center

functions. However, it was easy to introduce this method at these dams because the risk relating to refilling the reservoirs is low due to the large volume of water flow compared to the capacities of the reservoirs and because the impact of sediment flushing on the riverbed downstream is relatively small due to the steepness of the river downstream from the dams and the short distance to the Japan Sea (only some tens of kilometers).

The flushed water quality deteriorates when sediment is flushed after being deposited in a reservoir for a long period of time. Thus, sediment flushing has been conducted as freguently as possible at times of flood, and turbidity and dissolved oxygen levels in the river and the sea have been monitored while looking at the impact of sediment flushing on the lower river basin.[26]

(3) Open Type Check Dams and Open Type Dams Exclusively Used for Flood Control

Check dams have been built to stop sediment and prevent from sediment disasters downstreem. In recent years, check dams assembled from steel pipes or concrete dams having slit(s) have been built to stop sediment only at times when sediment outflow is great and to let sediment rundown into lower river basins at times when water and sediment outflow is small (Figure 9).

Some open type dams having no gate have been built to control flood. These dams do not ordinarily store any water, but when a flood occurs, the dams adjust the water discharge by letting some water run through and storing some water behind the dam. The naturally stored water is discharged naturally immediately after the flood. These dams can spontaneously let sediment flowing from upstream run down at the time of succeeding small scale floods and control the sedimentation in the reservoir and so maintain the continuity of sediment transport (Figure 10).

(4) Replenishing Sediment to Rivers

In recent years, in order to maintain the function of dams and to improve the environment for the ecosystem in the rivers downstream from dams, efforts have begun to keep some dredged sediment as an embankment in riverbeds downstream from dams and flush it downstream in times of flood (Figure 11). As of 2008, some 21 dams nationwide had tried this method and other dams have also been examining the possibility of implementing it. The main characteristic of this method is that it does not require the construction of large facilities. However, the amount of sediment being stored has been limited, ranging from several hundreds of cubic meters to several tens of thousands of cubic meters each time. To implement this method, consideration has to be given to environmental problems in the lower river basins, to the occurrence of turbid water, and to safety risks due to sediment deposition in the channel. Concrete means are being explored, taking into consideration the particle sizes of sediment, such as the scale of flood suitable for the safe implementation, and appropriate ways to place sediment in riverbeds.[29] Local residents are

Figure 9 : Open Type Check Dam Made from Steel Pipes

Source: Reference[27]

Figure 10 : Open Type Dam to Control Flooding (upper side of a dam)

Source: Reference[28]

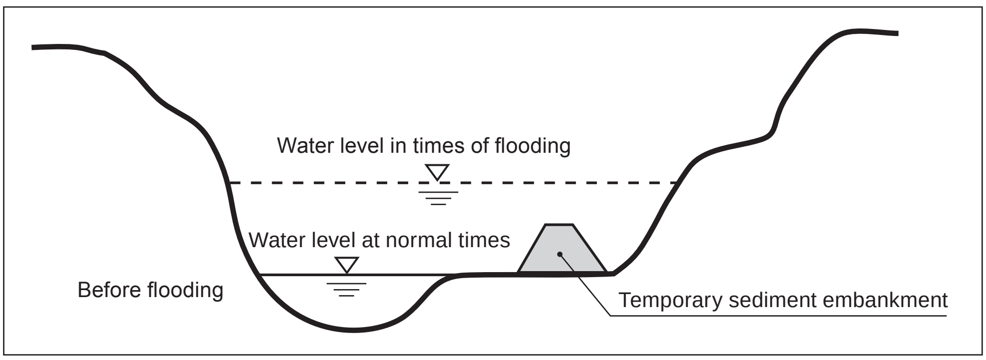

Figure 11 : Replenishing Sediment (deposited in reservoirs) to Rivers by Storing It in Riverbeds

Source: Professor Tetsuya Sumi, Kyoto University often against the occurrence of turbid water. However, monitoring efforts before and after instances of this method's implementation have shown that it has had the effect of improvements in riverbed formation, riverbed materials, benthic organisms, and algae, and there are cases where local residents have welcomed this method.

3-2-4 Technology for the Effective Use of Sediment

In the past, sediment has been collected mainly from the inlets of reservoirs for use in concrete aggregate. However, due to issues concerning transportation costs, quality control, and laws and regulations, sediment has not been used properly.

Figure 12 shows characteristics of sediment deposited in reservoirs by location. In recent years, in addition to the conventional use of sediment, demonstration tests have been conducted to use sediment (high-density iron humate) deposited at the bottom of a lake (located proximate to a dam) to restore seeweeds withering phenomenon of a beach and to allow marine algae to grow.[31] Field studies have also been conducted on an easy way to separate sediment located in different parts of a reservoir by particle size and to return it to the river.[32]

3-2-5 Technology for Predicting Riverbed Variations

Sediment is comprised of mixture ranging from small to large particles, and it is essential to develop numerical models to estimate the amount of erosion and sedimentation in riverbed considering such wide range of particle sizes. To properly maintain and manage rivers taking account of changes in sediment transport, it is necessary to fully consider that riverbeds change remarkably during floods, but there has not yet been sufficient analysis that does so. Currently, studies are being conducted to improve the reliability of analysis for riverbed variations and water surface profiles at the time of flood by considering the mutual influence between the flow and riverbed fluctuations based on experimental data at the site.[33]

3-2-6 Technology for Predicting Coastal Deformations

Studies have also been conducted to understand the process of deposition and erosion of estuary or beach composed of sediment mixture under the effects of geography and coastal structures based on data concerning geographical changes, particle sizes, and waves. In the aforementioned Enshu-Nada Project, efforts are being made to develop

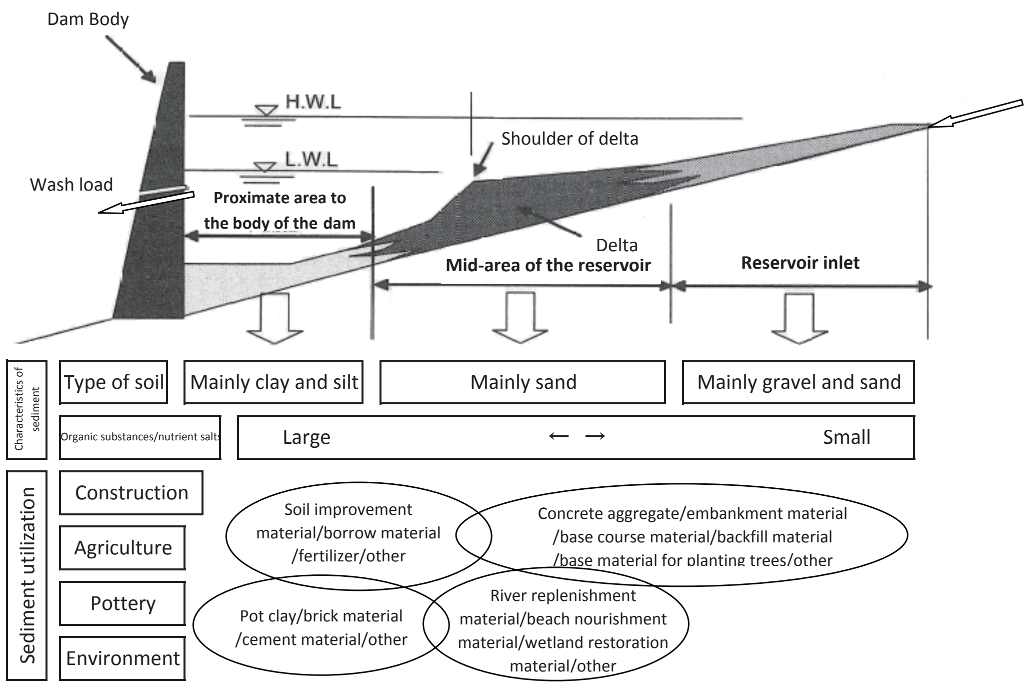

Figure 12 : Characteristics of Sediment Deposited in a Reservoir by Location

Created by STFC based on Reference[30]

a high-precision model to predict geographical changes based on the survey results of wide-area sediment movement, the sediment transport mechanism from river mouths to coasts. By combining the technology to monitor the actual sediment movement and the technology to predict geographical changes, the project aims to create an adaptable sediment management technology that can flexibly and continuously respond to sediment movement and geographical changes.[13] In addition, at Hasaki Beach on the Kashima-Nada coast, efforts are being made to develop a simulation model to understand the distribution of on-offshore sediment transport and ocean-floor changes using observation data (taken continuously for 20 years), for example, on waves, current speeds, sediment concentration, and changes in the ocean-floor.[34] Furthermore, based on lab experiments, efforts are being made to develop a three-dimensional beach transformation model targeting harbors used for thermal and nuclear power generation, in which mixed particle-size sediment is cousidered.[35]

3-2-7 Sand Bypass/Sand Recycling

To mitigate coastal erosion due to the effects of coastal structures, a sand bypass system is being used to restore the continuity of longshore sediment transport by artificially transporting sediment blocked by and deposited near the upstream side of these structures to the opposite side of the structures (Figure 13). To nourish eroded beaches, a sand recycling system is also being used to put sediment deposited back to the area where erosion occurs. In the Sendai River sediment transport system, to maintain the Tottori Sand Dunes and Hakuto Beach from the expansion of erosion, the river authority, the port and fisheries authority, and the coast authority have been working together to carry sediment dredged from the river mouth, seaway, and the anchorage to the eroded coast.[36] At the Fukude Port located east of the Tenryū River, to protect the port function against deterioration due to substantial sediment deposition transported from the Tenryū River as well as to stop the erosion of Asaba Beach, located at the downstream side of the port, waves, a sand bypass system (that uses a pipeline to permanently transport sand) is under construction now. In implementing these efforts, studies are being conducted on the changes in coastal geography and particle sizes of bottom sediment on the effects on the living environment for, for example, benthic organisms, plankton, loggerhead turtles, and white bait, as well as on the abrasion of pipe of the sand transport system.[37]

3-3 Overseas Trends

3-3-1 Sediment Releasing from Dam Reservoirs

(1) Europe

In the Water Framework Directive (2000), the European Commission set forth a policy to preserve the quality and quantity of continuous sediment transport targeting international rivers in Europe from the perspective of integrated sediment management. Sediment flushing has been used as a primary method while considering effects on the lives and property of the people, ecosystems and the environment in the lower river basins.[38-40] In Switzerland, sediment flushing has been clearly

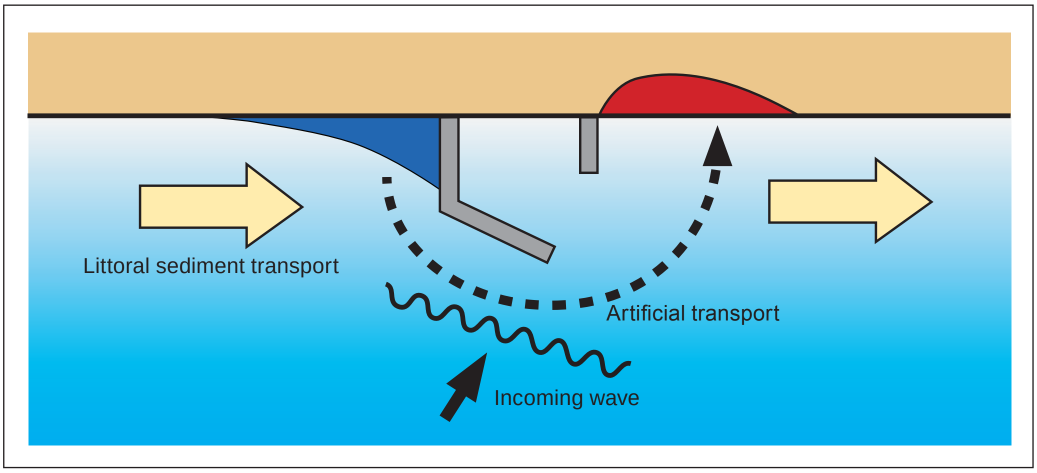

Figure 13 : Sand Bypass System

Source: Reference[37]

systematized: federal guidelines have been issued for the planning and management of sediment flushing, and the implementation times and methods must be approved by cantons. In France, flushing have been made to meet water quality standards in the lower river basins by taking account of the timing of flushing in the upper river in Switzerland.

(2) China

In China, dams used to be designed with the intention of holding 100 years' worth of sediment. However, after a substantial amount of sediment was deposited in the Sanmenxia Dam (completed in 1957; height: 106m) during a short period of time, sediment flowing into dams is now basically passed into lower river basins. Because sediment in the Yellow River and the Yangtze River is made up of fine particles, the water levels of the reservoirs are kept low during flood seasons to increase the current speeds and to allow incoming sediment to pass through more readily. This effort decreases the amount of hydroelectric power generation, but China uses nature to conduct sediment releasing based on the ideas of "storing the clear and discharging the turbid" namely "still water for navigation and torrential water for sediment discharge."

(3) United States

Most dam reservoirs in the United States are very large, and sedimentation is not a big issue. To deal with scouring in lower rivers, sediment is transported using heavy equipment.[41]

3-3-2 Response to Coastal Erosion

(1) Europe

In the Netherlands, consideration is being given to the protection of the coast against the sea level rise due to global warming, and a policy has been made to protect the coastline by nourishing the beaches instead of by building structures.[42]

(2) United States

The congressional declaration of policy in the Coastal Zone Management Act states that "it is the national policy to preserve, protect, develop, and where possible, to restore or enhance the resources of the Nation's coastal zone for this and succeeding generations." This looks at the objectives of coastal zone management from a wide perspective and aims to conduct both development and preservation in a balanced manner. State laws have more specific stipulations to protect the value of their coasts. For example, Florida law states that since port facilities can block longshore sediment transport, sediment (dredged for the purpose of maintenance) should be supplied to the lower side of the sediment movement and annual sediment transport should be ensured.

Coastal erosion has also been a serious problem in the United States. Before the 1960s, many structures were built to deal with the problem, but since the 1970s, beach nourishment has been the main method to solve the problem of erosion.[42]

4 Solving Problems Surrounding the Sediment Transport System: Issues and Methods

4-1 Issues Surrounding Japan's Sediment Transport System

In Japan, a substantial amount of sediment is produced in the mountains, and the supply of sediment to the rivers and to the coasts has maintained the balance of the land and the ecosystems. Sediment found in the reservoirs in China's Yellow and the Yangtze Rivers is mostly made up of very fine particles. In contrast, sediment found in Japan is made up of particles of different sizes, and thus, special consideration is needed when it comes to disaster prevention and the environment.

To solve problems related to the sediment transport system, it is essential to ensure the continuity of sediment transport and to restore mechanisms for supplying sediment to various place in a balanced manner. However, various structures exist in every part of Japan's sediment transport systems, and society is built on the functioning of these structures. Thus, it is not realistic to try to completely restore nature to how it was. For example, it is necessary to fully consider that the removal of a large dam reservoir may cause adverse effects on the lower river basin. Therefore, to soundly manage the sediment transport system for the future, it is not appropriate to discharge all sediment, but it is essential, first, to consider regional characteristics and protect the lives and property of local residents, and next, to enable the sustainable use of resources and to maintain diverse ecosystems and a rich natural environment.

However, our understanding of sediment transport is insufficient because sediment moves through wide areas and in a complex manner due to frequent typhoons and heavy rains as well as because it is difficult to measure this movement. In particular, since many different regions, administrations, and scientific and technological fields are involved, we very much lack continuous and wide ranged field data covering the entire sediment transport system. This point makes it difficult to improve the reliability of specific technology. We have not yet established the technology to assess and control the higher risk of flood and the influence on the ecosystems that may be caused by riverbeds aggradations due to possible future enhanced sediment discharge from upstream. Nor have we created the technology to predict the effects of improvement in coastal erosion due to the supply of sediment from rivers. Problems concerning the sediment transport system affect wide areas and for longtime, we cannot find fundamental solutions (that consider safety, the proper use of the resources, and the environment in a balanced manner) through mere regional and stopgap efforts conducted by individual administrations and studies of narrow special areas.[12,43] Some ten years have passed since the necessity of integrated sediment management efforts were emphasized, but we still have a long way to go before we can systemize management technology and take actual action that covers the total sediment transport system.

4-2 Solutions

(1) Understanding the Actual Conditions

First of all, it is essential to look at the total sediment transport system to precisely diagnose the current problems, where they are occurring, their causes and effects, and the extent of their impact by monitoring and accurately understanding sediment movement from the sources of rivers to the coasts. Next, it is necessary to clarify goals for improvement in terms of required amounts and particle sizes for sediment transport in each area, and to come up with an appropriate sediment supply system in order to solve or alleviate problems in consideration of disaster prevention, proper use of sediment, and the environment. Based on such information, we need to verify and improve the specific technologies for handling sediment transport systems. Sediment hydraulics which studies sediment transport has been primarily based on experimental research in labs. Thus, our understandings are not sufficient when it comes to predicting how sediment will be supplied from upper river basins and to assessing the impact of the distribution of different sediment sizes on geographical changes. This author hopes that the existing technologies will be examined and improved and that the reliability of the technologies will increase by the fulfillment of reliable field data. In addition, it is essential to improve upon the system for researchers to effectively share and use data. Sediment production and outflow in mountains vary greatly depending on the characteristics of the river basins, i.e., geological conditions, the weather, and hydrological conditions. Sediment movement in rivers and the sea also changes remarkably both temporally and spatially, and geography, hydrological and meteorological conditions, and sediment sizes are all correlated. It is necessary to develop new sediment transport observation technology based on advanced technology, to improve the observation system, and to conduct continuous efforts to understand the actual conditions both under normal and abnormal weather conditions.

(2) Integration of all the concernd Parties and the Road Map for the consistent Field-verified studies

It is not easy to establish an optimal integrated method when different bodies are managing different parts of the sediment transport system using different management systems. It is essential for administrations and local interested parties extending from the mountains to the sea, and researchers in the field of sediment transport systems to work together and pool their knowledge in order to implement consistent verification studies. The road map or the flow chart of consistent field-verified studies aiming to the implementation of balanced and sound sediment transport systems may be given as Figure 14.

(3) Sampling Typical Sediment Transport Systems and Establishing Goals for Improvement

It should be effective to, first, choose Typical sediment transport systems where problems have become apparent and where the necessity to improve the situation has been recognized, and, to then, intensively invest research resources into these

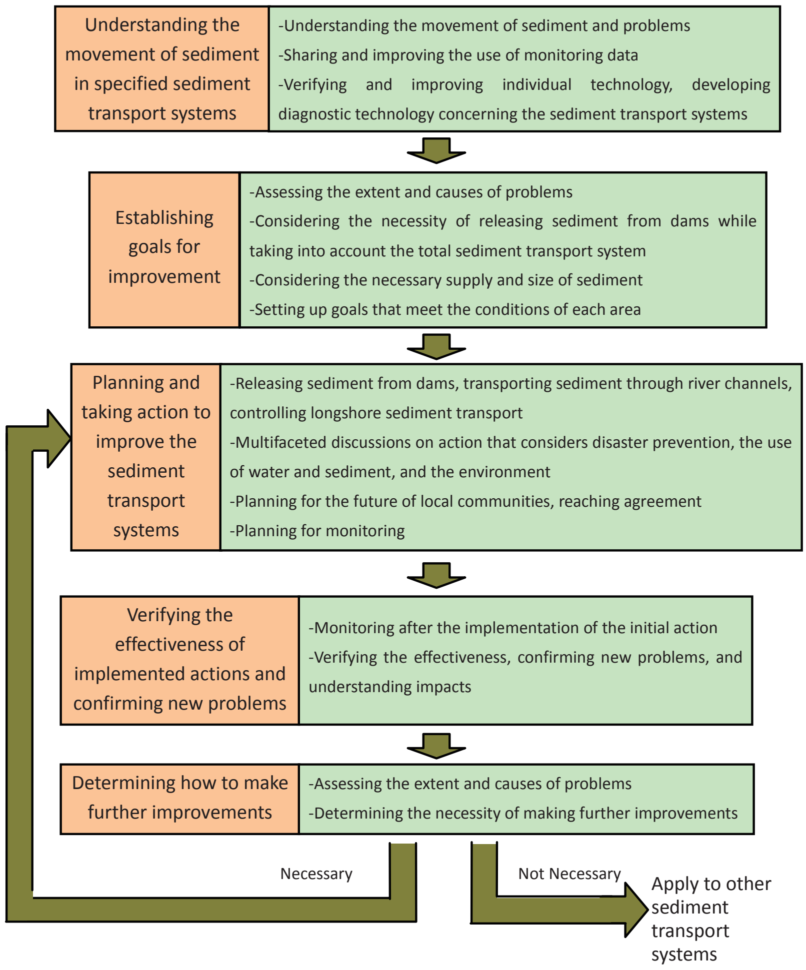

Figure 14 : Flow of Consistent Ffield-verified Studies on Issues Concerning the Sediment Transport Systems

Prepared by the STFC

systems and promote problem-solving studies.

When setting up goals for improvement in the chosen sediment transport systems, it is necessary to assess the causes and effects of these unfavorable problems, and, then, to make some alternative implemental plans for improvement of the impact on the desaster prevention, water utilization and the desirable ecosystems. In particular, it is important to focus on sediment management in view of the particle sizes. Disasters might occur if sediment is discharged as-is from mountains. Thus, full consideration needs to be given to the effective treatment of sediment deposited in reservoirs and riverbeds in mid- and lower-river basins by the operation of some artifical measures. This author hopes that goals will be established by looking at entire regions including the mountains, rivers, and sea, and that such information will be disclosed, and that open discussion involving various fields will be conducted.

(4) Establishing a New Concept of Sediment Delivery

Provided sediment should be released from a dam to improve the situation of a sediment transport system, one should, in advance, consider the effect to the risk of flooding, to the water utilization, to the ecosystems, and to the environment, dwe to sediment deposition in lower river reach, and one should, then, choose the method that guarantee a sustainable balanced sediment Transport system. The amount of sediment yield and the particle sizes are different greatly from one sediment transport systems to another. Therefore, we need to assess both positive and negative aspects of storing sediment in eservoirs for respective sediment transport systems, and reflecting such an assessment, we must choose suitable technologies to controll sediment delivery to reservoirs, lower rivers, and the sea. Depending on the conditions of each site, we also need to explore a new method that combines various methods to discharge sediment from dams, including sediment sluicing.

Through this kind of examining process, it is also important to harness nature. We may try to restore the landscape and ecosystems by returning sediment movement closer to its natural state by, for instance, allowing rivers, previously protected and constrained by dams and levees, to inundate to a certain extent so that sediment is deposited at the time of flooding, for example, at the change of a river gradient or at the junction of tributary streams. To do so, it become necessary to expand the river zones and, where sediment deposition is great, it will be necessary to restore wetlands and farmlands. As the population of Japan will decline remarkably, I hope that efforts will be made to make the effective use of sediment easier and to increase food self-sufficiency and to consider the rich natural environment is an important resource. These effort would be helpful to the revitalization of future local communities. This way of thinking will also help to reduce disaster risk under extremely abnormal weather.

(5) Establishing a Study Forum

As discussed earlier, to solve various problems concerning sediment transport systems, there is a limit to regional and stopgap efforts by individual bodies. Since the problems involve a wide range of communities, administrations, and scientific and technological fields, it is essential to have a common understanding of entire sediment transport systems. Therefore, it is needed to conduct joint research on solutions, and to form agreements between related parties. It is desirable to establish a study forum that will develop the field of sediment transport systems academically. That accademic field should cover not only the dynamic aspect of sediment movement but also it should cover ecosystems and the environment. It is also desirable to promote comprehensive activities that go beyond the boundaries of different administrations, in charge of regions ranging from mountains to rivers to the sea, and academic fields and to create a forum that tries to reflect their efforts on the establishment of an integrated sediment management system.

To break through the status quo, it is necessary to secure the funding required to promote research as well as to have young people such as graduate students actively participate in field work. Thurs, the depth of human resources for long-term and multi-faceted verification studies will be increased. It is also desirable for researchers to have the strong will to gather knowledge by transcending the boundaries of different interested parties.

5 Conclusion

There is a concern that a substantial outflow of sediment and large-scale coastal erosion may occur due to unprecedented and great changes in natural phenomena caused by global warming such as increases in abnormal rainfall and a rising sea level. The phenomenon of sediment outflow from mountains discussed in this report will continue in the future, and therefore, will be an important issue both for the present and future generations. In order to explore sustainable measures that make it possible to live in harmony with nature, relating with the issues of sediment, it is important to reassess the existing hard measures on social infrastructure and preservation costs of these structures based on the mechanisms of sediment transport as well as from a long-term perspective.

Compared to other developed countries, Japan's geomorphic changes are more substantial. In addition, dividing mountain ranges cut across the land like a backbone and short steep rivers flowing directly into plains and the sea are both a blessing and a threat. To appropriately preserve the land for the future, it is desirable to establish new and efficient individual technologies and an integrated management system for the improvement of sediment transport systems. The fruit of such efforts can contribute to other Asian countries and so on that have similar natural conditions.

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[NOTE] :
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Profile

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Before assuming his current positions, Motoyuki Inoue engaged in various technological duties and research at Tepco, including construction, maintenance, operation and management of hydraulic power plants, thermal power plants. He has also been active in working with universities, the Institute for Science of Labour, JAPIC, and JABEE.
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7

R&D Activities for Aeronautics S&T in Japan, the United States and Europe

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1 Introduction

The YS-11 twin-engine, turboprop small passenger plane was developed in the late 1950s to the early 1960s as the first Japanese-developed passenger aircraft since the end of World War II. However, a decision to halt its production was made in December 1971[1,2] because of weak sales and huge losses. A total of 182 YS-11 units were manufactured before the production was halted in 1974, and the last of them retired from commercial airline service on September 30, 2006. After the development of YS-11, there were no national projects to develop civil aircraft until the late 1990s.

Although Japan is internationally competitive with regard to household electric appliances, electronics equipment and transport equipment such as cars, railways and vessels, Japanese industry's role in civil aircraft manufacturing has been limited as a supplier of subsystems and components of airframes and engines in international development projects with U.S. and European aircraft manufacturers.[1] Since the beginning of this century, Honda Motor Co. and Mitsubishi Heavy Industries Ltd. (MHI) have announced plans to enter the civil aircraft market, through a small business jet called HondaJet in the case of Honda, and a small passenger jetliner called the Mitsubishi Regional Jet (MRJ) in the case of (MHI). The market for medium- and large-size passenger aircraft with a passenger capacity of 100 or more and with a flying range of more than 5,000 kilometers is dominated by the duopoly of Boeing Co. of the United States and Airbus of Europe. The market for regional jets with a passenger capacity of around 100 and a flying range of a few thousand kilometers is controlled by Bombardier of Canada and Embraer of Brazil, while Sukhoi of Russia, with its SSJ jet, and Commercial Aircraft Corporation of China Ltd., with its ARJ21, as well as Mitsubishi Heavy Industries Ltd, with its MRJ, are planning to enter this market.[3] The MRJ's entry into the market will be far from easy. There is an argument stating that as Japan lacks total aircraft integration technology, it is necessary for all parties involved in the Japanese aeronautical sector to work together to promote the development of the MRJ.[4] We hope that the development of the MRJ and HondaJet will help to foster the international competitiveness of Japan's aeronautical industry.

This report first describes global warming-related developments, which have been a recent focus of attention, in relation to aeronautical technology. It then studies how Japan should promote R&D programs in the future based on the investigation and analysis of environmental R&D programs in Japan, the United States and Europe that aim to develop environment-friendly aircraft with reduced greenhouse gas emissions and noise levels, for example.

2 Global Warming-related Developments

As shown in Figure 1, a jet engine emits a variety of gases and substances generated as a result of the high-temperature, high-pressure combustion of compressed air and fuel.[5] The Intergovernmental Panel on Climate Change, which was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environmental Programmed (UNEP), issued a special report on the

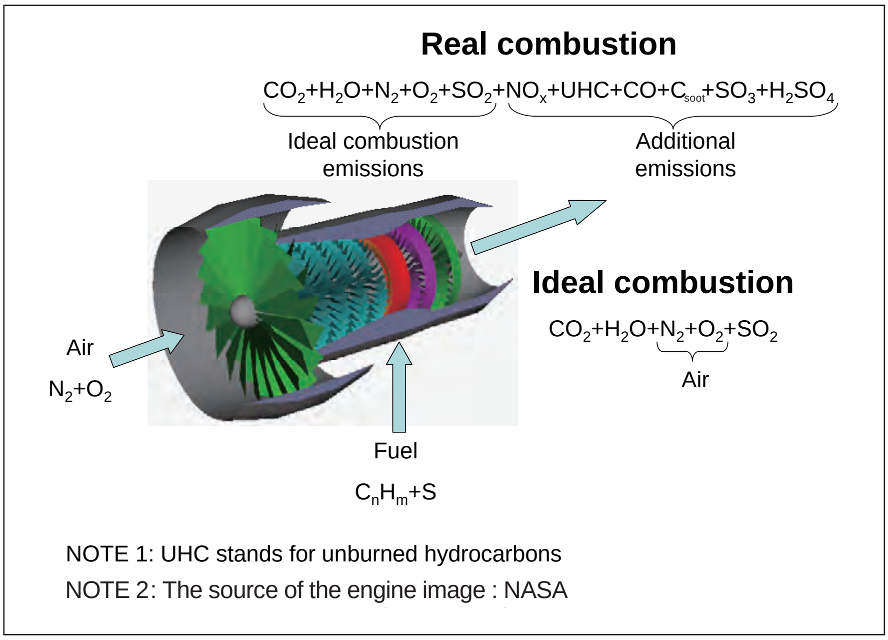


Figure 1 : Ideal and real combustion processes for jet engines

Source: Reference[5]

impact of aircraft emissions on global warming in 1999 in response to a request from the International Civil Aviation Organization (ICAO).[6]

As shown in Table 1, major climate-influencing factors include carbon dioxide (CO_2), which is a major greenhouse gas; nitrogen oxides (NO_X), which generate tropospheric ozone and reduce methane; and water vapor (H_2O) which leads to the formation of contrails and cirrus clouds; and soot and aerosol particles.[7] It should be noted that the combustion of 1kg of fuel emits 3,160g of CO_2, 1,290g of H_2O, up to 15g of nitrogen oxides and up to 1g of other gases and substances.[8]

Regarding the global warming effects of aircraft emissions, the radioactive forcing of contrails is estimated at 0.02W/m^2, while a range of 0 to 0.04 W/m^2 is estimated for cirrus clouds as there are factors that are not well understood. Radiative forcing is an index that expresses a change in the energy equilibrium between the ground surface and atmosphere due to changes in various factors, including changes in the concentration of greenhouse gases, as the rate of energy change per unit area at the tropopause, which represents the atmospheric boundary between the troposphere and the stratosphere. Radioactive forcing is expressed as a positive figure when it has the effect of warming the ground surface and as a negative figure when it has the effect of cooling it.[9] IPCC's fourth report, issued in 2007, evaluated the impact of aviation on global warming.[10] The report estimated that the amount of CO_2 emissions from global aviation increased by a factor of 1.5, to approximately 480MtCO_2 in 2000 from approximately 330MtCO_2 in 1990, accounting for around 2% of overall anthropogenic CO_2 emissions. The report warned that in the absence of additional measures, projected annual improvements in aircraft fuel efficiency of the order of 1–2% will be largely surpassed by traffic growth of around 5% each year, leading to a projected increase in emissions of 3–4% per year. The report estimated the radiative forcing of contrails at approximately 0.01W/m^2, about half the level estimated in the special report issued in 1999 (although as a figure for 1992). This discrepancy is attributable to an improvement in satellite-based cloud observation technology and an advance in studies on cloud radiative forcing. Meanwhile, the report did not provide an assessment of the radiative forcing of cirrus clouds on the grounds that relevant mechanisms are not well understood by modern science. It should be noted that various evaluation results have been published with regard to the impact of cirrus clouds on global warming.[11]

Under the Kyoto Protocol, international aviation, unlike domestic aviation, is not included among the sectors/source categories listed in Annex A. Therefore, greenhouse gas emissions resulting from international aviation are not subject to the obligation for the limitation or reduction of

Table 1 : Climate Change Impacts of Aviation Emissions

Climate Effect	Nature of Impact	Scientific Understanding
CO_2 generation	• Lasts in the atmosphere for dozens or hundreds of years or even up to thousands of years • Has the same impact wherever it is emitted. • The effect is global.	"Good" There is widespread acceptance that research has provided a robust understanding of the scale and climate impacts of aviation-related CO_2.
Tropospheric ozone generation	• Emissions of NO_X during cruising generate tropospheric ozone (which can cause climate warming). The extent of the ozone effect also depends on altitude, location and atmospheric conditions. • The lifetime of ozone is several weeks. • The warming effects are regional rather than global.	"Fair" There is uncertainty over the extent of the impact. The IPCC notes that changes in tropospheric ozone levels are mainly in the Northern Hemisphere, while those of methane are global in extent. Given this, the net regional radiative effects do not cancel.
Methane reduction	• Emissions of NO_X result in the reduction of ambient levels of methane (from other sources) in the atmosphere, which results in cooling. • The lifetime is around 8-12 years. • The effects are global.	
Contrails and cirrus cloud formation	• Contrails only form at altitude in very cold, humid atmospheric conditions. Ambient temperature and the level of ice-supersaturation regulate the lifetime of a contrail, which may vary from seconds to hours. Contrails may in turn lead to the formation of cirrus clouds. • The warming effects are highly dependent on altitude, location and atmospheric conditions. The extent of enhanced cirrus that arises from aircraft contrails and particle emissions is not well quantified, although there is some evidence of a correlation between cirrus trends and air traffic.	"Fair" for contrails, but "poor" for cirrus clouds Generally, the role of clouds, including cirrus, in climate change is one of the least understood aspects.
Soot and aerosols	• Effects are more pronounced at altitude than at ground level. • Soot traps outgoing infrared radiation and has a small warming effect. • Sulphate aerosols reflect solar radiation and have a cooling effect. • The lifetime of both is brief. The effects are regional.	Understanding is "Fair"

Source: Reference[7]

greenhouse gas emissions by the parties to the protocol that are listed in Annex I, and so such emissions are not automatically covered by emissions trading as defined under Article 17 of the Kyoto Protocol.[12] However, Article 2.2 stipulates that, "The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases" resulting from aviation, working through the International Civil Aviation Organization (ICAO). In light of this, ICAO is considering the establishment of a governmental or private-sector emissions trading system. It should be noted that ICAO's Committee on Aviation Environmental Protection (CAEP) set standards for the emissions of gases harmful to humans, such as carbon monoxide (CO), hydrocarbons (HCs) and nitrogen oxides (NO_X) during the landing-takeoff (LTO) cycle as well as for noise levels, and these standards have been strengthened over time.

On January 1, 2005, the European Union launched the EU Emission Trading Scheme (EU-ETS), which handles emissions of CO_2, one of the greenhouse gases listed in the Kyoto Protocol. The EU-ETS completed the first phase, which was regarded as a trial period, at the end of 2007, and it is now in the second phase, which spans the period between January 2008 and the end of 2012, coinciding with the commitment period under the Kyoto Protocol.

The European Commission, looking beyond the Kyoto Protocol, has strengthened European efforts to fight against global warming and proposed to (1) reduce the amount of greenhouse gas emissions by 20% (by 30% if an international agreement is reached) by 2020 compared with 1990 and (2) set an EU-wide emissions cap, rather than caps for individual EU member states, in order to reach the EU target of a 20% share of renewable energy in overall energy consumption by 2020 and include allowances for the emissions of greenhouse gases other than CO_2 in the EU-ETS. After undergoing some revisions, this proposal was approved in December 2008 by the European Council and the European Parliament.[13] As a result of the approval, starting in 2012, greenhouse gas emissions from flights arriving in and taking off from airports in the EU region are expected to be covered by the EU-ETS regardless of whether the flights are intra-EU ones or not.[14,15] Commercial air carriers, but not the government agencies of the EU states, will be in principle subject to the regulation, with each carrier administered by the supervisory body of one member state. However, carriers based in countries that take measures similar to the EU approach may be exempted from the regulation. Only CO_2 emissions will be subject to the regulation. For each carrier, the baseline emissions amount will be calculated in accordance with the revenue-ton-kilometers (passengers and cargo expressed in weight multiplied by the distance flown) based on the annual average of overall emissions from its flights arriving at and taking off from airports in the EU region. Aviation emissions will be capped at 97% of the emissions amount thus calculated in 2012 and at 95% between 2013 and 2020. Each carrier will be allotted 85% of the cap for free, with the remaining 15% to be auctioned. To simplify procedures, operators of small aircraft will be excluded from the EU-ETS.

According to Sustainable Aviation, a U.K. environmental organization, the amount of CO_2 emissions from U.K. air transportation in Britain will increase by a factor of around three by 2050 compared with 2000 on the assumption of no improvement in technology (at constant technology level).[16] On the assumption of air traffic management improvements, the development of advanced technologies related to the Air Transportation System (ATS) based on the Strategic Research Agenda set by the Advisory Council for Aeronautics Research in Europe (ACARE) and low-carbon alternative fuels as well as post-ACARE ATS technologies, Sustainable Aviation estimates that CO_2 emissions will peak around 2020 and could be reduced to 2000 levels by around 2050. As the EU-ETS is expected to be applied in principle to emissions from commercial flights arriving at and

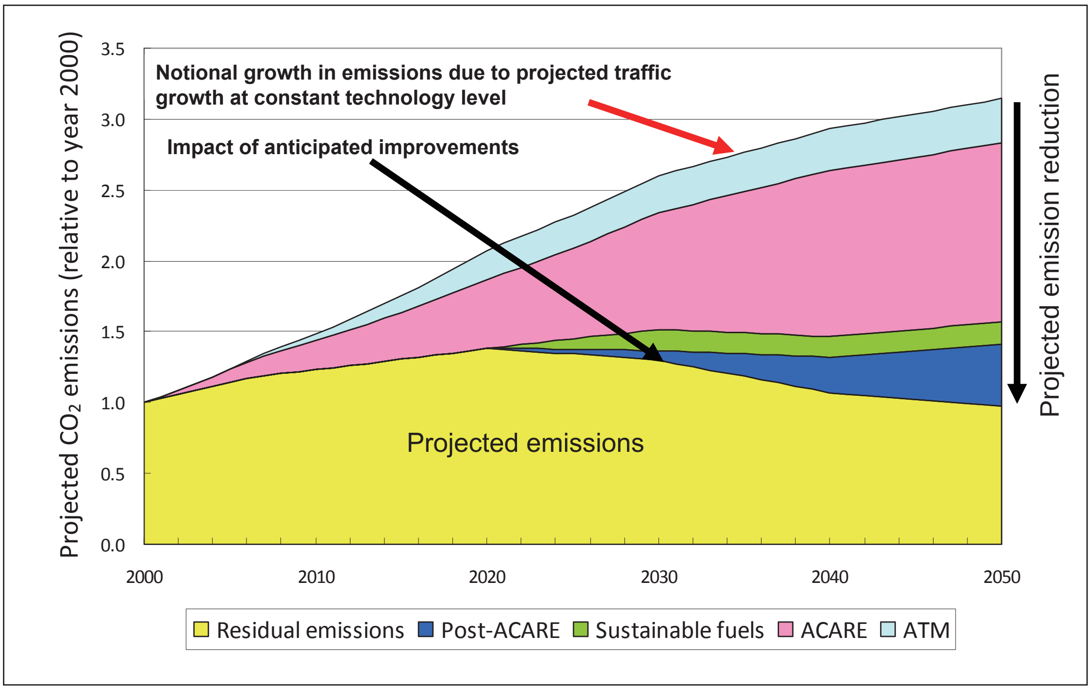


Figure 2 : Projected future emissions of CO_2 from U.K. aviation (relative to year 2000)

Source: Reference[16]

taking off from airports in the EU region starting in 2012, demand for environment-friendly aircraft with significantly reduced emissions of CO_2 and other greenhouse gases is likely to grow in the future.

3 R&D Activities in Japan and Abroad

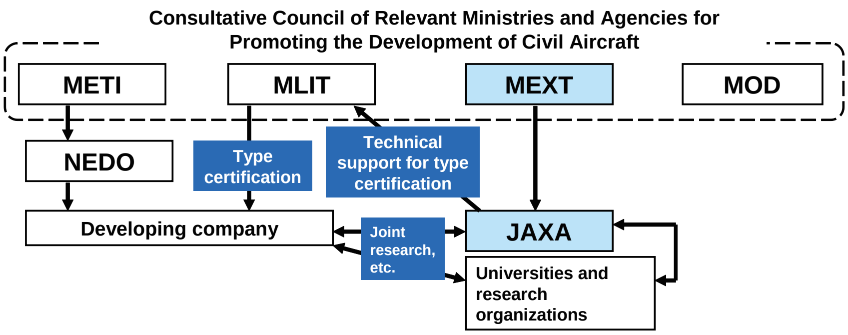
3-1 Japan

The Sector-by-Sector Promotion Strategy,[17] which was adopted on March 28, 2006, by the Council for Science and Technology Policy based on the 3rd Science and Technology Basic Plan, has seleted "domestic aircraft technologies that meet new demand" and "new preventive safety technologies related to traffic and transportation" as priority strategic technologies that require intensive investment, citing both as technologies for adapting to new society within the traffic and transportation system technologies that suit new society in the field of social infrastructure. The technical scope of the domestic aircraft technologies that meet new demand is specified as "prototype development and corresponding technology development selected from the total aircraft integration technologies that could realize aircraft and engines meeting new demands, R&D for quiet supersonic experimental aircraft, and inventions of, and processing technologies for, composite materials that maintain and strengthen Japan's international competitiveness." As for the reason for selecting these technologies, the strategy states that because "it is essential for Japan to secure its unique domestic technical capabilities that it has so far acquired through its participation in international join development projects, strategic priorities shall be placed on the total aircraft integration technologies and the improvement of supporting element technologies…(and) the technologies… for meeting future higher speed needs." The scope of new preventive traffic and transportation safety technologies is specified as "IT-based air traffic management technologies, including four-dimensional (three dimensions in space and one dimension in time) traffic management that will enable safe high-density flights, flight support technologies for small aircraft and all-weather, high density flight technologies." The reason given for selecting these technologies is that "with due consideration of future growth in air traffic demand, it is necessary to place priorities on promoting the use of new technologies necessary for ensuring preventive safety."

(1) Total Aircraft Integration Technologies

With regard to the total aircraft and engine integration, which is included among domestic aircraft technologies that meet new demand, the Research and Development of Environment-Friendly, High-Performance Small Aircraft[18] and the Research and Development of Environment-Friendly Small Aircraft Engine (the Eco Engine Project)[19] have been underway since fiscal 2003 as projects managed by the New Energy and Industrial Technology Development Organization (NEDO), which is under the jurisdiction of the Ministry Economy, Trade and Industry (METI). The outline of the framework for the implementation of these projects is as described in Figure 3.[20,21]

The Japan Aerospace Exploration Agency (JAXA), one of whose supervising government ministries is the Ministry of Education, Culture, Sports, Science and Technology (MEXT), stated, under its first mid-term plan (October 1, 2003 to March 31, 2008), that it was its goal to "participate as joint research activities in, as well as provide active technical assistance and access to large facilities to" the Research and Development of Environment-Friendly, High-Performance Small Aircraft project and the Research and Development of Environment-Friendly Small Aircraft Engine project." Furthermore, under its second mid-tem plan (April 1, 2008 to March 31, 2013), it states that it is its goal that "JAXA will conduct advanced and fundamental aeronautical science and technology R&D activities focused on strategically prioritized S&T provided for in the third Science and Technology Basic Plan. Specifically, JAXA will conduct highly value-added and technically differentiating R&D activities for high performance indigenous passenger aircraft and the Clean Engine as R&D activities contributing to aircraft and engine advancement." JAXA, pursuant to the above stated goals, has been conducting advanced R&D activities such as the "Clean Engine" project that will develop by around 2012 an engine whose goal is to be more environment-friendly than the Eco Engine, which will be developed by around 2010, and the "High Performance Indigenous Aircraft"



Project Name	JAXA, universities and research organizations (roles)
Research and Development of Environment-Friendly, High-Performance Small Aircraft	• JAXA (Joint research with the developing company: Development and evaluation of advanced aerodynamic design technology, evaluation of advanced materials and processing and molding technologies, cockpit evaluation, evaluation of control systems.) • Tohoku University (Joint research with the developing company: Aerodynamic analysis and development of airframe configuration design technology)
Research and Development of Environment-Friendly Small Aircraft Engine	• JAXA (Transfer of technology with high value added to the developing company, support for design and development, joint research concerning the "eco-engine" and the "clean engine" with the developing company, implementation of development tests on behalf of the developing company) • National Institute for Materials Science, Tohoku University, Tokyo University of Agriculture and Technology and Waseda University (Joint research with the developing company concerning the "eco-engine" and the "clean engine"
NOTE: Type certification is under consideration with regard to the Research and Development of Environment-Friendly, High-Performance Small Aircraft project.	

Figure 3 : Outline of the Framework of NEDO's Project Implementation

Source: Reference[18~21]

whose goal is to further reduce noise and improve fuel efficiency, safety and passenger comfort as well as technically assisting these NEDO projects. In addition, it has provided its wind tunnel testing and computational fluid dynamics (CFD) facilities, which are among the largest such facilities in Japan, for use in these projects, and it also plans to build a jet flying test bed (FTB), which enables operating-environment assessment of equipment.[24]

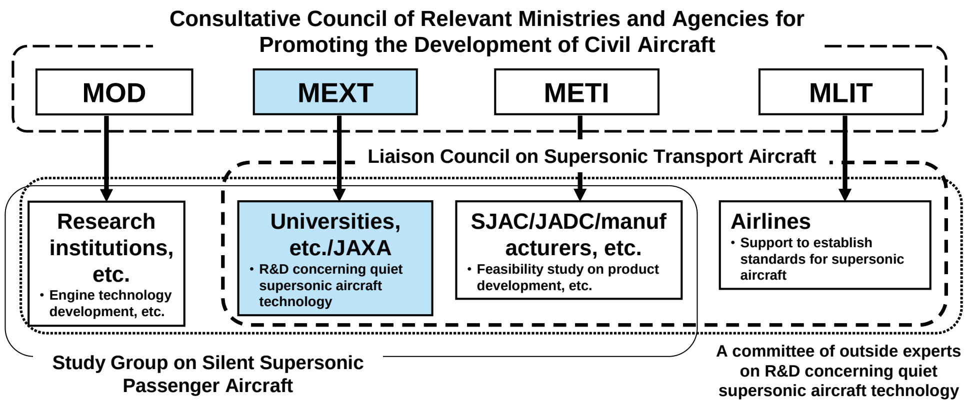
As for small jet aircraft technology being developed under the Research and Development of Environment-Friendly, High-Performance Small Aircraft project, Mitsubishi Heavy Industries Ltd. (MHI) decided on March 28, 2008, to commercialize it as the "Mitsubishi Regional Jet" (MRJ), which will be the first Japanese-developed civil passenger aircraft in approximately 40 years since YS-11. On April 1, 2008, MHI established Mitsubishi Aircraft Corporation, which is responsible for the commercialization of the MRJ.[25]

It should be noted that for the MRJ to be operated as a civil aircraft in Japan, it will need a type certification from the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and JAXA will provide technical support to the ministry in this regard.

(2) Quiet Supersonic Experimental Aircraft

Unlike military aircraft, for which only several minutes of supersonic flight is required at a time, Concorde, which was developed jointly by the United Kingdom and France and which was the only supersonic passenger aircraft in the world, was required to fly at supersonic speeds for several hours. Consequently, the necessary weigh reduction, aerodynamic designs and fuel efficiency posed development challenges. Moreover, Concorde was allowed to land at and take off from only a limited number of airports because of its noise level, higher than that of subsonic aircraft, and was prohibited from flying over land at supersonic speeds because of its sonic booms.[26,27]

As shown in Figure 4, JAXA, in cooperation with relevant agencies, is engaging in the quiet supersonic aircraft technology R&D project, which aims to achieve both environmental friendliness, including the reduction of sonic booms, which will be the key to the realization of SST, and fuel efficiency improvement based on weight reduction and aerodynamic drag reduction in addition to reducing noise during the landing and take-off cycle, with a view to participating in a future international SST (supersonic transport) development project on an equal footing.



(1) Liaison Council on Supersonic Transport Aircraft: Established in January 2008 to bring together relevant public and private organizations to discuss ultimate goals, the division of roles and how to collaborate with each other. Comprised of five domestic relevant organizations. Members: Japan Aircraft Development Corporation (JADC), Engineering Research Association for Supersonic Transport Propulsion System (ESPR), Japanese Aerospace Engines Corporation (JAEC), Society of Japanese Aerospace Companies (SJAC) and Japan Aerospace Exploration Agency (JAXA) Observers: Ministry of Economy, Trade and Industry (MLIT), Ministry of Education, Culture, Sports, Science and Technology (MEXT), and Ministry of Land, Infrastructure, Transport and Tourism (MLIT), academic experts and airlines
(2) A committee of external experts on R&D concerning quiet supersonic aircraft technology: An external advisory committee to JAXA established in September 2007 to efficiently promote R&D concerning quiet supersonic aircraft technology. Comprised of experts from aircraft manufacturers, airlines and think tanks, among other organizations. Members: Two members from the academic circles, three from aviation-related organizations, two from airlines, one from a think tank and four from manufacturers Observers: Ministry of Education, Culture, Sports and Science and Technology (MEXT), Ministry of Economy, Trade and Industry (METI) and Ministry of Defense (MOD:Air Systems Research Center).
(3) Study Group on Silent Supersonic Passenger Aircraft: A study group that was established in October 2005 under the Japan Society for Aeronautical and Space Sciences

Figure 4 : Framework for Implementation of R&D concerning Quiet Supersonic Aircraft Technology

Source: Reference[26]

JAXA has been conducting supersonic aircraft technology R&D activities since 1997. The first stage of JAXA's R&D was intended to acquire design techniques necessary for achieving aerodynamic drag reduction, including the computational fluid dynamics (CFD) inverse design techniquls. Unlike conventional design techniques, which involve iteration between the design evaluations through wind tunnel tests and CFD analysis and the design modifications based on the differences between the evaluation results and the goal, the CFD inverse design techniques determine the shape of the wing based on the assumed goal of achieving the pressure distribution that realizes natural laminar flow. In the first stage of the R&D, JAXA successfully conducted a flight demonstration of a rocket-powered small supersonic experimental airplane launched by a booster rocket, and the successful demonstration flight confirmed the validity of the CFD inverse design techniques.[28]

JAXA has entered into the second phase since 2006 to conduct flight demonstrations using jet-powered and fully autonomous unmanned experimental aircraft to resolve the noise problem by halving the sonic boom level as well as to reduce the aerodynamic drag. As shown in Table 2, JAXA is conducting R&D activities for the experimental aircraft and associated flight test plans, and plans to start the full scale development in fiscal 2010, after a phase-up decision by an mid-term evaluation in fiscal 2009, to conduct flight demonstrations around the mid-2010s.[26] Regarding a study on the supersonic experimental aircraft design, the multidisciplinary design optimization approach has been developed and it is expected to contribute to not only the design of supersonic aircraft but also that of subsonic aircraft.[27] The multidisciplinary design optimization approach produces an aircraft design by going further than the CFD inverse design and dealing with problems involving a number of disciplines, including structural mechanics, aerodynamics and aero acoustics, in an integrated manner.

Also underway is a concept study on a hypersonic aircraft, which would fly at a cruising speed of around Mach 5 and cross the Pacific in about two hours. Since an engine for hypersonic aircraft produces propulsion force through the combustion of fuel and air taken in from the

Table 2 : Broad Schedule of R&D concerning Quiet Supersonic Aircraft Technology

Fiscal year	2006	2007	2008	2009	2010	2011	2012	Around the mid-2010s
I. Major milestones		▽ Preliminary evaluation		▽ mid-term evaluation	Concept of small SST with a halved sonic boom intensity	▲	Concept ofenvironment-friendly small SST	Performance target achievement evaluation of small SST
II. Technological targets								
(1) Halving of the sonic boom intensity: 0.5psf or less					▽ Analysis-based evaluation			▽ Achievement evaluation based on flight tests and analysis
(2) Noise during take-offs and landings: Conforming to ICAO Chapter 4							▽ Achievement evaluation based on element tests and analysis	▽ Achievement evaluation based on ground tests and analysis
(3) Lift-to-drag ratio during cruising: 8.0 or more							▽ Analysis-based evaluation	▽ Achievement evaluation based on ground tests and analysis
(4) Structural weight: 15% reduction compared with an all-metal airframe							▽ Evaluation based on partial structural prototyping	▽ Analysis-based achievement evaluation
III. Development of a flight test system for quiet supersonic experimental aircraft and flight tests								
(1) Development of a flight test system for quiet supersonic experimental aircraft	Concept study	Concept study	Design study	▽ Completion of a preliminary desing; Design study	▽ Completion of a detailed design; Development	Development	▽ Completion of development; Development	
(2) Flight tests of quiet supersonic experimental aircraft			Study on flight test plans, etc.	Study on flight test plans, etc.	Drafting of detailed flight test plans, etc.	Drafting of detailed flight test plans, etc.		▽Start of flight tests; Flight tests

Source: Reference[26]

atmosphere, unlike a rocket engine, and thus enables the reduction of on-board propellant mass, the concept of using this engine for the first stage of a space transportation system is also under consideration.[28]

3-2 Europe

(1) European Aeronautics: A Vision for 2020 and the Advisory Council for Aeronautics Research in Europe (ACARE)

A report entitled "European Aeronautics: A Vision for 2020" (hereinafter referred to as the "European Aeronautics Vision 2020") was issued in January 2001.[29] The report proposed, as goals to be achieved through partnership among government, industry and academic sectors, (1)"Responding to society's needs" to advance and strengthen quality and affordability, safety, environment, and air traffic management (ATM) aspects, as well as (2)"Securing global leadership" to maintain and strengthen the European aeronautics industry's world top-level international competitiveness, and (3)"Establishing supportive public policy and regulation" to adopt more flexible approaches to adapt to market changes, to strengthen public R&D activities, to facilitate greater integration of European, national and private research programs, to ensure education policies that nurture human resources for aeronautics, to encourage human resource mobility among EU nations, to promote electronic networks and eCommerce, and to strengthen relationships with the International Civil Aviation Organization (ICAO) and other international institutions that affect European air transportation activities.

The establishment of the Advisory Council for Aeronautics Research in Europe (ACARE) as a European Technology Platform (ETP) was also recommended in order to coordinate the interests of the parties involved in the aeronautics sector.[29,30] ACARE conducted a study on the prioritization of civil air transport R&D subjects that should be realized by 2020 to respond to society's needs as prescribed in the European Aeronautics Vision 2020 and drew up the Strategic Research Agenda (SRA). As shown in Figure 5, a report issued in October 2002 identified the five challenges (quality and affordability, safety, environment, European Air Transport System efficiency and security), with security included among the five challenges following the multiple terrorist attacks using hijacked aircraft that occurred in the United States in September 2001. A report issued in October 2004 identified six high-level target concepts (very low cost, ultra green, customer-orientedness, time efficiency, advanced security and air transport of the future) as the second SRA.[31]

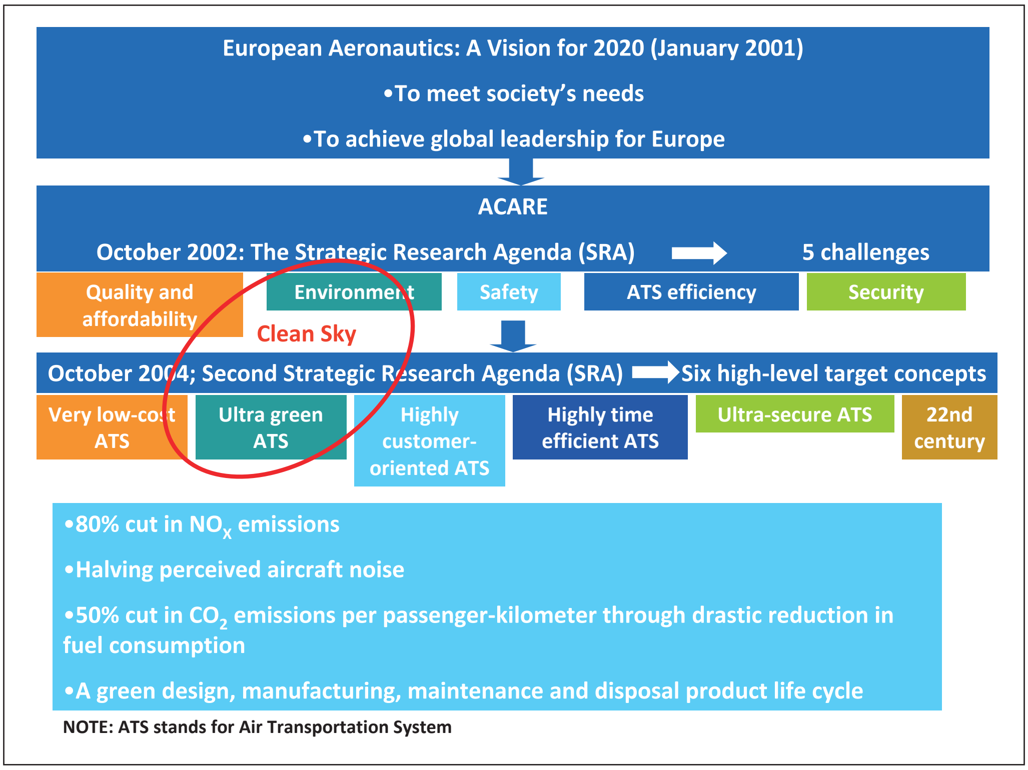


Figure 5 : Strategic Research Agenda for European Aeronautics

Source: Reference[31]

(2) Seventh Framework Programme for EU Research and Development

As shown in Table 3, the seventh framework programme for EU research and development (FP7) has adopted (1) the greening of air transport, (2) increasing time efficiency, (3) ensuring customer satisfaction and safety, (4) improving cost efficiency, (5) protecting aircraft and passengers and (6) pioneering the air transport of the future as challenges to be tackled in the field of aeronautics, based on ACARE's recommendations.[32,33]

R&D activities are classified according to their technology readiness levels. (1) Level 1 covers upstream research and technology development activities from basic research to validation at component or subsystem level through analytical and/or experimental means in the appropriate environment, while (2) Level 2 covers downstream research and technology development activities up to higher technology readiness, centered on the multidisciplinary integration and validation of technologies and operations at a system level in the appropriate environment (large scale flight and/or ground test beds and/or simulators). (3) Level 3 covers research and technology development activities up to the highest technology readiness, in a fully integrated system of systems in the appropriate operational environment.

Among the ongoing Level 3 research and development projects are the Clean Sky Joint Technology Initiative (JTI) and the Single European Sky ATM Research (SESAR), which are implemented outside the framework of ordinary research and development activities under the FP7.

(3) Clean Sky JTI

The Clean Sky initiative conducts advanced technology development and demonstration that will lead to product development in order to significantly reduce the environmental impact of aviation, such as emissions of CO_2, NO_X and noise, through partnerships among the government, industry and academic secters based on the European Aeronautics Vision 2020 and ACARE's recommendations. As shown in Figure 6, with regard to the vehicle development, the Clean Sky initiative conducts element technology development and integrated technology demonstration (ITD) using prototypes for (1) smart fixed-wing aircraft which is equipped with open rotors capable of drastically improving energy efficiency and which realizes ideal natural laminar flow corresponding to flying speed and (2) green regional aircraft, which realizes a significant reduction of emissions of air pollutants and noise near airports and (3) green rotorcraft, which has

Table 3 : Aeronautical R&D activities under FP7

1. Greening of air transport • Areas: Green aircraft, ecological production and maintenance, green air transport operations • To reduce the environmental impact of air transportation by halving CO_2 emissions per passenger-kilometer, reducing NO_x emissions by 80% and halving the perceived noise by 2020 compared with 2001. • To enhance green engine technologies, including alternative fuels technology as well as improved vehicle efficiency of fixed-wing and rotary wing aircraft, new intelligent low-weight structures, and improved aerodynamics. • Issues such as improved aircraft operations at the airport, air traffic management, and green manufacturing, maintenance and recycling processes will be included.
2. Increasing time efficiency • Areas: Aircraft systems and equipment for improved aircraft throughput and time efficient air transport operations • To improve punctuality (to enable 99% of flights to arrive and depart within 15 minutes of their scheduled arrival/departure time) in all weather conditions and significantly reduce the time spent in travel-related procedures (to under 15 minutes for short-haul flights and to under 30 minutes for long-haul flights) at airports while maintaining safety in order to accommodate future growth in air traffic, which could increase three-fold. • To develop and implement an innovative air traffic management (ATM) system within the context of the SESAR initiative, by integrating air, ground and space components, together with traffic flow management and more aircraft autonomy. • Design aspects of aircraft to improve handling of passengers and cargo, novel solutions for efficient airport use and connecting air transport to the overall transport system will also be addressed.
3. Ensuring customer satisfaction and safety • Areas: Passenger-friendly cabin (expansion of the range of in-flight services and improvement in passenger comfort) and passenger-friendly air transport operations, aircraft safety and ATM operational safety • To significantly increase passenger choice and schedule flexibility and to reduce the accident rate to a fifth of the current rate. • To achieve a substantial improvement in the elimination of and recovery from human error and mitigate the consequences of accidents.
4. Improving cost efficiency • Areas: Aircraft development cost, aircraft operational cost and ATM operational cost • To improve the whole business process, from conceptual design to product development, manufacturing and in-service operations, including the integration of the supply chain, and reduce travel charges by reducing the aircraft development, the time to market and aircraft operating costs by 50% and the ATM operational costs by 20% by 2020 compared with 2001.
5. Protection of aircraft and passengers • Areas: Aircraft security and operational security • To prevent hostile action of any kind to incur injury, loss, damage or disruption to travelers or citizens. • To eliminate hazards of hostile on-board or external actions against aircraft and air transportation systems.
6. Pioneering the air transport of the future • Areas: Breakthrough and emerging technologies and step changes in air transport operation • To produce pioneering ideas and create future-oriented technologies, particularly through efforts by universities and research organizations, in order to meet society's needs that may arise in the second half of this century.

Source: Reference[32,33]

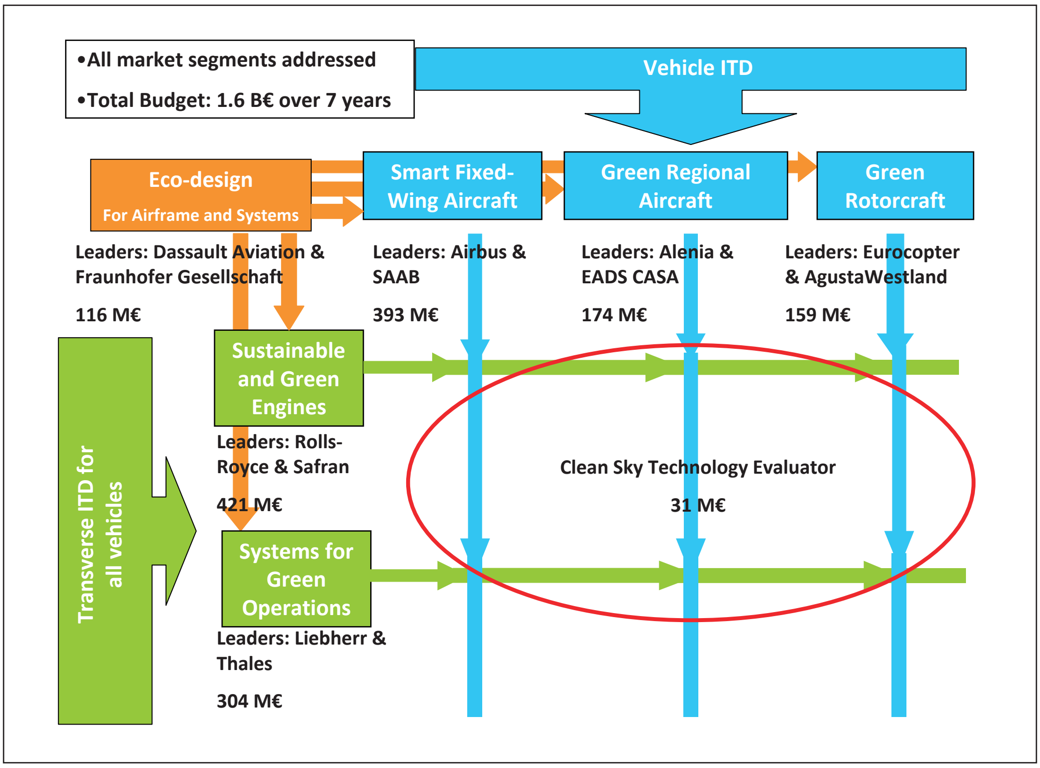


Figure 6 : Integrated Technology Demonstration Projects under the Clean Sky Initiative

Source: Reference[34]

■TRL7 : System prototype demonstration in an operational environment

■TRL6 : Full System/subsystem validation in a relevant environment

■TRL5 : Component and/or basic subsystem validation in a relevant environment

■TRL4 : Component and/or basic subsystem validation in a laboratory environment

■TRL3 : Analytical and experimental critical function and/or proof-of concept

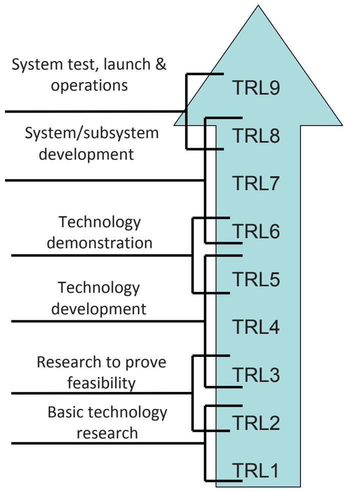


Figure 7 : Technology Readiness Levels (TRLS) and R&D phases

Source: Reference[35]

similar environment-friendly features to those of green regional aircraft. With regard to the transverse ITP for all vehicles, the Clean Sky initiative conducts element technology development and integrated technology demonstration using prototypes for (4) sustainable and green engines indispensable to the development of smart fixed-wing aircraft, green regional aircraft and green rotorcraft and (5) systems for green operations, which reduce energy consumption through the application of electrical auxiliary power units and hydraulic systems and the optimization of flight trajectories to mitigate the environmental impact near airpots as well as during cruising. With regard to the airframe and systems, the initiative develops element technologies and conducts integrated technology demonstration using prototypes for (6) the eco-design that aims to reduce the environmental impact throughout the overall life cycle of aircraft from design to manufacturing to dismantling.[34]

A total of approximately 1.6 billion euros are budgeted for the Clean Sky initiative over the seven-year period between 2008 and 2014, with half of the funds being provided by the European Commission and the other half by the participating companies. Individual IDT projects are led by major European companies. Small and medium-size aeronautics companies in Europe participate in IDT projects through calls for proposals or calls for tenders. As shown in Figure 7, the Clean Sky initiative aims to achieve a technology readiness level of TRL6 or higher to enable product development.[35]

3-3 United States

(1) The U.S. Federal Government's Policy

The National Science and Technology Council (NSTC) was established on November 23, 1993, as a cabinet-level council within the executive branch to coordinate science and technology policy. The NSTC is chaired by the President, and its membership consists of the Vice President, the Director of the Office of Science and Technology Policy (OSTP), Cabinet Secretaries and Agency Heads with significant science and technology responsibilities, and other executive branch officials.[36] An Executive Order entitled the"National Aeronautics Research and Development Policy," approved by the President in December 2006, was the U.S. federal government's first policy for aeronautics research and development for the period leading to 2020. The Aeronautics Science and Technology Subcommittee (AS&T) of the NSTC's Committee on Technology (COT) drew up the "National Plan for Aeronautics Research and Development and Related Infrastructure" in December 2007 in accordance with the provisions of this policy.[37]

As shown in Table 4, the National Plan set goals, and near-term, mid-term and far-term objectives regarding four fields of aeronautical research and development — (1) mobility, (2) national security and homeland defense, (3) aviation safety, and (4) energy and environment — as well as listed plans for research, development, test and evaluation (RDT&E) infrastracture.

As will be mentioned in Section 4-1 (1), "I. Mobility" of Table 4 set the goal of dealing with an expected significant increase in traffic volume by substantially improving the functions and performance of the air traffic management system through the introduction of the Next Generation Air Transportation System (NextGen). "IV. Energy and Environment" set the goal of developing alternative fuels derived from domestic sources and reducing the environmental impact of aviation through a significant improvement in energy efficiency.

The National Aeronautics Research and Development Policy also prescribes the division of roles between federal government agencies. The policy stipulates that whereas the Department of Defense (DOD), the Federal Aviation Administration (FAA), the National Science Foundation, the Department of Homeland Security (DHS) and the Department of Commerce (DOC) should conduct R&D within their own jurisdictions, the National Aeronautics and Space Administration (NASA) should maintain broad fundamental research efforts, including those essential for human and robotic missions, to preserve the intellectual stewardship and mastery of aeronautics core competencies to retain the nation's world-class aeronautics expertise.[36]

(2) NASA's Aeronautics Research and Development Activities

Under its long-term plan, NASA seeks to implement programs while maintaining the right balance between science, manned space exploration and aeronautics, and intends for aeronautics to develop knowledge in basic research fields as well as to conduct technology development to improve aircraft safety and deal with an increase in air traffic.[38] Goals that should be achieved in the field of aeronautics include (1) developing by 2016 tools, techniques and technologies to improve both conventional and new aircraft safety under the Next Generation Air Transportation System (NextGen), which is scheduled to start operation around 2025 for the air traffic management (ATM), (2) developing by 2016 advanced technologies that satisfy the requirements for the traffic volume and mobility of the NextGen while maintaining safety, (3) developing by 2016 the multi-disciplinary analysis and optimization (MDAO) approach, which will enable quantitative evaluation of the performance of various configurations of aircraft at all speeds from subsonic to supersonic and to hypersonic speeds, and (4) ensure continued provision of NASA's strategically important wind tunnel test facilities and ground test facilities.

Table 4 : Goals of U.S. National Plans concerning Aircraft Development and Related Facilities

I. Mobility Goal 1: Develop reduced aircraft separation in trajectory- and performance-based operations Goal 2: Develop increased National Airspace System capacity by managing NAS resources and air traffic flow contingencies Goal 3: Reduce the adverse impacts of weather on air traffic management decisions Goal 4: Maximize arrivals and departures at airports and in metroplex areas Goal 5: Develop expanded aircraft capabilities to take advantage of increased air transportation system performance
II. National Security and Homeland Defense Goal 1: Demonstrate increased cruise lift - to - drag and innovative airframe structural concepts for highly efficient high-altitude flight and for mobility aircraft Goal 2: Develop improved lift, range, and mission capability for rotorcraft Goal 3: Demonstrate reduced gas turbine specific fuel consumption Goal 4: Demonstrate increased power generation and thermal management capacity for aircraft Goal 5: Demonstrate sustained, controlled, hypersonic flight
III. Aviation Safety Goal 1: Develop technologies to reduce accidents and incidents through enhanced vehicle design, structure, and subsystems Goal 2: Develop technologies to reduce accidents and incidents through enhanced aerospace vehicle operations on the ground and in the air Goal 3: Demonstrate enhanced passenger and crew survivability in the event of an accident
IV. Energy and Environment Goal 1: Enable new aviation fuels derived from diverse and domestic resources to improve fuel supply security and price stability Goal 2: Advance development of technologies and operations to enable significant increases in the energy efficiency of the aviation system Goal 3: Advance development of technologies and operational procedures to decrease the significant environmental impacts of the aviation system

Source: Reference[37]

NASA's Aeronautics Research Mission Directorate (ARMD) aims to achieve the goals under the long-term plan with four pillars of fundamental aeronautics, aviation safety, air traffic and aeronautics test facilities.[39] ARMD's activities cover (1) with regard to the air traffic, research necessary for the NextGen , (2) with regard to the aviation safety, research concerning preventive safety for both conventional and new aircraft under the existing ATM and the NextGen, (3) with regard to the aeronautics test facilities, maintenance and improvement of the test facilities and equipment necessary for the United States, including the development of new test equipment and techniques, and (4) with regard to the fundamental aeronautics, advanced research aimed at discovering the principles of flight applicable to any atmosphere, on the Earth or other planets of the Solar System, and at any speed .

Regarding the fundamental aeronautics, R&D projects concerning subsonic fixed wing aircraft, subsonic rotary wing aircraft, supersonic aircraft and hypersonic aircraft are underway.[40] The subsonic fixed-wing aircraft and the supersonic aircraft are classified into the first generation (N+1), the second generation (N+2) and the third generation (N+3), which could enter into service around 2015, around 2020 and around 2030-35, respectively, with R&D goals set for each generation. Another notable thing is that in the hypersonic aircraft research, concept studies are underway concerning a Two-Stage To Orbit (TSTO) space transportation system, which uses an air-breathing hypersonic engine for its first stage and concerning the entry, descent, and landing (EDL) of a large structure weighing approximately 30 tons, which may be used for future human space exploration. In these research activities, tools for the multi-disciplinary analysis and optimization (MDAO) that enables efficient design trade-offs are also under development. ARMD is cooperating with Pratt & Whitney in ground tests of the geared turbofan engine, which is fuel efficient and is planned to be installed onboard the MRJ, and with Boeing Co. in flight tests for X-48B, an experimental blended wing body (BWB) airplane. In addition, ARMD has been implementing the NASA Research Announcement (NRA) program since fiscal 2006 in order to maintain and strengthen U.S. aeronautics industry's capabilities in the field of basic research. In fiscal 2008, research contracts were awarded under the NRA program to six industry teams to study advanced concepts for subsonic and supersonic aircraft that could enter into service around 2030 to 2035. Environmental friendliness is included among the major subjects of the study, and the total value of the contracts, whose term was approximately 18 months, was $12.4 million.[41]

4 Comparative Analysis of Research and Development Activities

4-1 Moves toward Environmental Friendliness

As shown in Table 5,[42] short- and medium-term technological measures to mitigate air transportation's environmental impact include retrofits[43] of winglets that reduce atomosrpheric drag caused by wingtip vortexes, the development of plant-derived and other alternative fuels[44] to oil-derived kerosene, and, in the long term, the introduction of new environment-friendly aircraft will become essential. Regarding operations, it will be important in the short- to medium-term to introduce a next-generation air traffic management (ATM) system, in addition to replacing the conventional landing method, which involves the repeated alternations of gliding and powered flights, with the continuous descent approach (CDA).

As we mentioned in Chapter 2, achieving environmental friendliness is becoming an increasingly urgent issue for air transportation amid the concern about an increase in the environmental impact of aviation expressed by the IPCC and the expected enforcement that emissions from flights taking off and landing at airports within the EU region will in principle be subject to the EU Emission Trading Scheme (EU-ETS) starting in 2012. Against this background, as we described in Chapter 3, Japan, the United States and Europe are implementing R&D programs to make air transportation environment-friendly through government-industry-academia collaboration. Below, we will explain the Japanese, U.S. and European R&D activities that demand particular attention.

Table 5 : Environmental mitigation strategies concerning air transportation

	Mitigation strategy	Environmental impact			Relative economic cost or benefit	Timeframe	Impact
		Noise	Air quality	Global climate			
Technology	Source shielding	+	N/A	×	− $ (Cost)	Short	Existing aircraft
Technology	Retrofits (e.g. winglets)	N/A	N/A	++	− $ (Setup cost) + $$ (Fuel benefit)	Short	Existing aircraft
Technology	Alternative fuels	N/A	+	++	− $$ (Cost)	Medium	Existing aircraft?
Technology	All-new designs	++	++	++	− $$$ (Setup cost) + $$ (Fuel benefit)	Long	New fleet
Operations	CDA	+	+	N/A	− $ (Fuel benefit)	Short	Airport
Operations	De-rated thrust	+	+/ −	N/A	+ $ (Benefit)	Short	Aircraft
Operations	Steep approach	+	+	N/A	− $ (Cost)	Medium	Airport
Operations	ATM efficiency	+	+	+	− $$ (Setup cost) + $ (Fuel benefit)	Medium	System

Source: Reference[42]

(1) Next-Generation Air Traffic Management (ATM) System

According to some estimates,[45] air traffic volume will almost double by around 2025 compared with around 2000. It will be difficult to deal with such an increase through a conventional air traffic system based on voice communications between aircraft and ground controllers using ground-based radar systems. In order to resolve air traffic congestion problems such as delayed arrivals and take-offs at airports and slow flights, it will be essential to introduce an air traffic system that enables exchanges of information and data, such as weather forecasts and the location and speed of neighboring aircraft, between pilots and ground controllers like the Internet, using navigation satellites such as GPS. The United States is developing the Next Generation Air Transportation System (NextGen), and is aiming to start operating the system around 2025.[46]

The European Union is implementing the Single European Sky ATM Research Programme (SESAR) under the Single European Sky (SES) policy, which will organize airspace uniformly, rather than dividing it into compartmentalized air traffic control areas, with a view to realizing the new air traffic control system around 2020.[47] In Japan, the Ministry of Land, Infrastructure, Transport and Tourism is engaged in a similar project using the MT-SAT multi-purpose satellite as well as an R&D project to develop DREAMS (the Distributed and Revolutionary Efficient Air-traffic Management System) is being conducted, which will enable autonomous navigation for small aircraft, in light of the unique circumstances of Japan.[48]

The introduction of such next-generation ATM systems is expected to reduce CO_2 emissions per passenger-kilometer by approximately 10%.[47] In order to further reduce CO_2 emissions as well as aircraft noise around airports and air pollutions caused by nitrogen oxides and unburned hydrocarbons, it will be essential to introduce environment-friendly aircraft with significantly lower gas emissions and noise compared with conventional aircraft.

(2) Technology Essential for Environment-Friendly Aircraft

The flying range per unit of energy consumed is obtained through the formula below. Va/c represents the aircraft speed, (L/D) the lift-to-drag ratio, TSFC the energy consumption rate per rated thrust, and W the aircraft weight, which is the total of the dry weight (W_0), the payload weight (W_{PL}) and the fuel weight (W_{Fuel}).

$$-dR/dW = Va/c \times (L/D)/TSFC/W$$

As indicated by the above formula, a) reduction of the aircraft weight, b) an improvement in the engine efficiency, c) an improvement in the lift-to-drag ratio (L/D) and d) an increase in the energy intensity per unit of fuel mass will be the key to reducing emissions of greenhouse gases such as CO_2 by increasing the flying range per unit energy consumed.[49]

a) Reduction of the Aircraft Weight

As shown by the case of B787,[50] the use of carbon fiber reinforced plastic (CFRP), which is light and strong, is effective in reducing the aircraft weight. However, as CFRP is usually comprised of layers of a semi-cured sheet-like composite material called pre-preg, its manufacturing involves many processes and requires an expensive manufacturing chamber called an autoclave, which uses high temperature and pressure, resulting in high manufacturing costs.[51,52] The Japan Aerospace Exploration Agency (JAXA) is conducting research concerning the application of the vacuum assisted resin transfer molding method (VaRTM) to the manufacturing of aircraft structure materials. The VaRTM method, which does not require either pre-pregs or an autoclave, injects into the mold fibers that are layered and formed into the prescribed shape through vacuuming, leading to a significant cost reduction. Through many years of research, including the prototyping of a 6 m long wing structure , know-how about testing techniques and safety evaluation standards has been acquired. As a result, it has been decided that the MRJ will use CFRP manufactured through the VaRTM method as the material for its tail in addition to using CFRP manufactured through the conventional manufacturing method as the material for the wings. The use of CFRP manufactured through the VaRTM method in an experimental quiet supersonic aircraft mentioned in Section 3-1-(2) is also under consideration.

b) Improvement in the Engine Efficiency

The thrust (F) generated by a jet engine is as shown in the formula below. Δm represents the mass of the fluid emitted by the jet engine per unit time, V_{jet} the speed of the jet stream and $V_{a/c}$ the aircraft speed. The fuel consumption is proportional to the square of V_{jet} (fuel consumption $\propto V_{jet}^2$)

$$F = \Delta m \text{ x } (V_{jet}-V_{a/c})$$

The mass of CO_2 emitted by a jet engine is proportional to the fuel mass consumed. As the fuel consumption mass is proportional to the square of V_{jet} while the thrust (F) is proportional to Δm and (V_{jet}-$V_{a/c}$), increasing the thrust, F by increasing in Δm is more fuel-efficient and contributes more to the reduction of CO_2 emissions than doing so by increasing V_{jet}, which leads to increasing the fuel consumption. Therefore, the turbofan engine, which increases the mass of air that flows outside the combustion chamber relative to the mass of air that flows into it, has become popular.[53] Although the bypass ratio, which represents the ratio of the volume of air that flows outside the combustion chamber to the volume of air that flows into it has been expanded, the advantage of a higher bypass ratio is becoming smaller because of an increase in aerodynamic drag caused by an expansion of the cross-section area of the engine and an increase in the weight caused by an expansion of the nacelle size. Consequently, a new approach is being explored. The geared turbofan engine, being developed by Pratt & Whitney of the United States is designed to ensure that both the low-wind-speed turbine and the fan rotate at the optimum speed by placing a reduction gear between the two. Also under R&D is an open rotor, whose turbine rotor blade is not covered by a nacelle so as to increase the bypass ratio. With regard to the open rotor, there are a variety of problems that must be resolved, including safety problems such as the risk of a broken rotor damaging the fuselage due to the absence of a protective cover, difficulty in assembly and maintenance and the louder big noise produced by the uncovered rotor. Under the Clean Sky initiative, efforts are underway to resolve these problems.

c) Improvement in the Lift-to-Drag Ratio

In order to improve the lift-to-drag ratio, it is necessary to limit the generation of vortex and realize natural laminar flow around the aircraft. Therefore, in the integrated technology demonstration of the Smart Fixed-Wing Aircraft under the Clean Sky initiative, R&D is underway in order to realize appropriate natural laminar flow around the wing according to the aircraft speed. As it is impossible to achieve a significant improvement in the lift-to-drag ratio based on the conventional fuselage-wing configuration (the combination of a cylinder-shaped fuselage and wings), some people think that an innovative airframe configuration needs to be adopted. Therefore, configurations such as the flying wing (FW) and the blended wing body (BWB) are under consideration. Since fiscal 2007, NASA has been conducting flight tests of a scale mode of the X-48B experimental aircraft, shown in Figure 8, in cooperation with the U.S. Air Force and Boeing Co.[54] These configurations are expected to not only lead to an increase in the passenger capacity but also reduce noise by enabling the installation of engines above the airframe.[55]

Figure 8 : X-48B Undergoing a Flight Test

Source: NASA

d) Alternative Fuels

Currently, kerosene is superior to any other fuel in terms of the energy intensity per unit mass fuel. Although hydrogen has the potential to replace kerosene as the main aviation fuel, there is a cost problem, because not only aircraft must be modified to adapt to the hydrogen fuel but also ground facilities must be reconstructed accordingly.[55] As indicated by the case of the United States described in Section 3-3-(1), the introduction of alternative fuels is deemed to be essential in order to secure a stable supply of fuels. Therefore, drop-in fuels that are compatible with existing aircraft and ground facilities are under development.[56] In addition to the gas-to-liquid (GTL) technology, the biomass-to-liquid (BTL) technology is promising in terms of reducing CO_2 emissions.[57] However since, the use of edible plant as fuel materials is controversial, a composite fuel of an algae-based biofuel and kerosene is under development.[44,58]

4-2 Comparison of Japanese, U.S. and European Research Targets

(1) Subsonic Passenger Aircraft

Table 6 shows a comparison of the targets for the reduction of environmental impact in the Japanese, U.S. and European R&D projects for the development of subsonic aircraft. It should be noted that the Japanese targets are those for the engines alone. While it is simple to compare the Japanese projects and the U.S. and European projects with regard to NO_X emissions, which derive exclusively from engines, a simple comparison regarding noise is impossible, because landing gears are the main source of noise during landings and take-offs, for example. It should be noted that the Advisory Council for Aeronautics Research in Europe (ACARE) sets the airframe contribution to the targeted reduction of CO_2 emissions at approximately 20 to 25%, the engine contribution at 15 to 20% and the ATM contribution at 5 to 10%.[59] Improving fuel efficiency through high-temperature, high pressure combustion processes involves a trade-off in terms of emissions, as the processes reduce CO_2 emissions but increase NOx emissions.[55] The Japan Aerospace Exploration Agency (JAXA) is developing a “clean engine” using the lean premixed combustion system, which mixes fuel with a sufficient amount of air for perfect combustion in advance in order to significantly reduce NOx emissions.[60] As shown in Table 14, this project is expected to achieve a performance comparable to the U.S. and European projects. We hope that further R&D efforts will lead to a market launch of a Japanese-developed environment-friendly engine that is internationally competitive.

(2) Supersonic Passenger Aircraft

Table 7 shows a comparison of the targets of the Japanese and U.S. projects for the development of supersonic passenger aircraft. As we mentioned in Section 3-1-(2), significant reduction in sonic booms generated by supersonic flights will be the key to the development of supersonic passenger aircraft.

Table 6 : Comparison of Japanese, U.S. and European Targets for Environmental Impact Mitigation concerning Subsonic Passenger Aircraft

Country/region	Japan		Europe	U.S.		
Name	Eco-engine	Clean engine	ACARE	N+1	N+2	N+3
Target Year	2010	2012	2020	2015	2020	2030-35
Noise Margin NOTE 1	-20 dB	-23 dB	-30 dB	-32 dB	-42 dB	NOTE 4
LTO NO_X Emissions NOTE 2	-50%	-80%	-80%	-65%	-78%	-78% or more
CO_2 Emissions	-10%	-15%	-50% NOTE 3	-33%	-40%	-70% or more

NOTE 1: Margin relative to ICAO Chapter 4
NOTE 2: Margin relative to the ICAO CAEP4 standard
NOTE 3: Including the expected reduction amount through SESAR
NOTE 4: 55LDN (day-night average sound level)

Source: Reference[21,30,32,40]

Table 7 : Comparison of Japanese, U.S. and European Targets concerning Supersonic Passenger Aircraft Development

Country	U.K./France	Japan	U.S.		
Name	Concorde	Quiet supersonic experimental aircraft	N+1	N+2	N+3
Target Year	1976	Around the mid-2010s	2015	2020	2030~35
Cruising Speed	M2.05	> M1.4	M1.6~1.8	M1.6~1.8	M1.6~1.8 NOTE 5
Flying Range (NM) NOTE 1	3,550	N/A	4,000	4,000	6,000
Passenger Capacity	100	N/A (Unmanned)	6-20	35-70	100-200
Sonic Boom	2~3 psf NOTE 6	< 0.5 psf	NOTE 7	NOTE 7	NOTE 8
Noise Margin NOTE 2	N/A	-αdB	0dB	0~-10dB	-10~-20dB
NO_X EI NOTE 3	Approx.20	N/A	(comparable to subsonic aircraft)	< 10	< 5
Fuel Efficiency NOTE 4	Approx. 2	N/A	1.0	3.0	3.5~4.5

NOTE 1: 1 NM = 1.85km
NOTE 2: Margin relative to ICAO Chapter 4
NOTE 3: NO_X emission index: Volume of nitrogen oxide emissions per unit fuel consumption during cruise. Expressed in the unit of "gNO_X/kg fuel."
NOTE 4: Passenger number times mile/lb fuel
NOTE 5: Value during a low-boom flight. The value is M2.0 when there is no restriction on flight conditions.
NOTE 6: A unit expressing pressure intensity in terms of "$lb/ft.^2$" 1 psf=47.88Pa
NOTE 7: 65-79PLdB (specified in terms of the level of noise perceptible to the human ear, rather than the level of "perceived loudness," which represents physical pressure; affected by the rise time and sound spectrum of the sonic boom)
NOTE 8: The value is 65-70PLdB during a low-boom flight and 75-80PLdB when there is no restriction on flight conditions.

Source: Reference[21,30,32,40]

JAXA plans to conduct a flight test of such aircraft around the mid 2010s, with a view to significantly reducing sonic booms compared with Concorde. The plan has drawn the attention of NASA, leading to joint research activities concerning the sonic boom reduction by JAXA and NASA.[61] We hope that Japan will develop its own supersonic aircraft technology, thus acquiring the ability to participate in a future international development project on an equal footing. It should be noted that ICAO is considering environmental standards for supersonic passenger aircraft.[62]

4-3 Basic Research / Technology Development and Product Development

Under the Seventh Framework Programme (FP7) of the European Union (EU), R&D activities are broadly classified by targeted technical readiness levels into the "basic technology research and feasibility studs" (TRL1-3), "the technology development" (TRL3-5) and "the technology demonstration" (TRL5-6). Under the Clean Sky Joint Technology Initiative in particular, technology development and demonstration activities are underway through government-industry-academia collaboration outside the framework of ordinary FP7-related R&D projects, with a view to achieving TRL6 or higher, which will enable product developments. The European aeronautics industry will thus pursue the product development based on the achievements of the technology development and demonstration under the Clean Sky initiative.

The U.S. Government Accountability Office (GAO) has issued recommendations aimed at

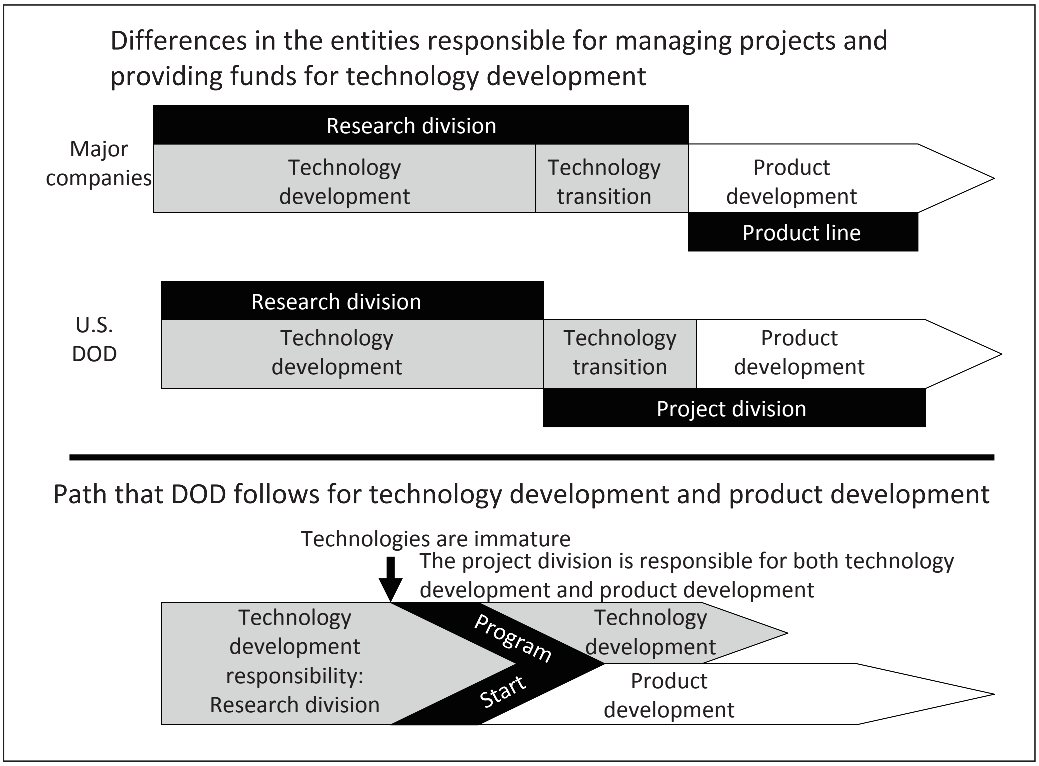


Figure 8 : GAO's Comparison of Technology and Product Development Approaches

Source: Reference[65]

resolving problems that have often occurred at the Department of Defense (DOD), such as development cost overruns, schedule delays and performance shortfalls, by comparing private-sector companies' R&D practices based on the technology readiness level (TRL) approach and the R&D practices adopted by DOD and NASA. Recently, GAO pointed out that problems such as cost overruns, schedule delays and performance shortfalls often occur in the process of technology transition, which is the point of transition from technology development to product development, because, as shown in Figure 8, technologies, including those not ready for transition, are moved too early from the research division to the project division in the absence of specific requirements for transition set by the project division.[65] It argued that as in the case of development by private-sector companies, the research division, rather than the project division, should continue the technology development until technologies become ready for application to the product development, with specific requirements set for transition.

Under the current circumstances of Japan's aeronautics industry, it is of course necessary that relevant organizations work together in all stages of R&D concerning the environment-friendly small aircraft through government-industry-academia collaboration. However, it is desirable that in the future, Japan's aeronautical technology development capability will be strengthened according to a roadmap and specific interface requirements agreed upon by the interested parties by utilizing the whole R&D cycle involving basic research by universities and research organizations, technology development and demonstration by R&D agencies such as the Japan Aerospace Exploration Agency (JAXA) and product development and data feedback by the aeronautics industry based on aircraft production and operations.

5 Conclusion

While Japan leads the world in environmental technology, it is lagging in civil aircraft development, as is shown by the fact that development has just started for a Japanese small passenger jet aircraft that will be the first passenger plane to be developed in Japan in 40 years since YS-11. Japan should make increased contributions to the fight against global warming in the field of air transportation by enhancing its aeronautical technology development capability. In the United States and Europe, medium- and long-term aeronautical projects, including the development of supersonic passenger aircraft, are underway, with targets set for the year 2020 and beyond. We believe that it is important for Japan, too, to implement medium- and long-term projects. The benefits of an advance in aeronautics science and technology are not limited to activities within Earth's atmosphere. NASA is studying the concept of (1) the Two Stage To Orbit (TSTO) space transportation system, which uses an air-breathing hypersonic aircraft instead of a rocket as the first stage and a rocket-propelled shuttle as the second stage, and (2) the entry, descent, and landing (EDL) of a large structure weighing approximately 30 tons in Mars' thin atmosphere as a future concept study for supersonic and hypersonic R&D. The development of aeronautics S&T will expand the frontier of our activities beyond the Earth's atmosphere to its orbital space and to other planets like Mars.

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