Chapter 1 Change in Environment Surrounding Science and Technology of Japan

Yoichiro Nambu, Professor Emeritus at the University of Chicago, Makoto Kobayashi, Honorary Professor Emeritus at the High Energy Accelerator Research Organization (KEK), and Toshihide Masukawa, Professor Emeritus at the Kyoto University were awarded the 2008 Nobel Prize in Physics, and Osamu Shimomura, Professor Emeritus at the Boston University Medical School, and two other researchers received the Nobel Prize in Chemistry. Four researchers from Japan jointly winning the Nobel Prize was a splendid achievement and the first time that two or more Japanese have won the same prize. This achievement is the outcome of Japanese science and technology promoted continuously by the government hand-in-hand with the private sector shows the high level of Japanese research and development. The present reward was a source of great pleasure and pride, not only the researchers but the entire nation.

However, we are now facing a global economic crisis. In Japan, the labor force, the wellspring of the nation’s economic power, is rapidly shrinking due to the falling birthrate and the aging of the population. In addition, concerns about the global environmental, typified by global warming, have acted to restrain continued economic development.

Under these circumstances, Japan faces competition not only with its traditional rivals among the developed countries of the world but with emerging countries such as China and India, who have joined the global market offering extremely cheap labor and competent persons for research. To meet this challenge, the most promising course open to us is to create new value utilizing innovative S&T created as a result of high level of R&D, the type of R&D that led to the Nobel Prizes won by the four Japanese researchers this time around. That is, Japan should strive to maintain and strengthen its international competitiveness through innovative creation.

The global economic crisis has, however, had a significant impact on the situation and the nature of innovation itself is greatly changing. Japan is now experiencing a new movement of innovation. Japanese corporations have achieved a great deal of innovation under the so-called “individually controlled” or “vertically integrated” R&D system. However, the weight of university and R&D corporations[1] conducting basic research is increasing along with fiercer global competition. Moreover, a shift of production to emerging countries greatly impacts the competitiveness of Japan’s basic Monodzukuri, as seen in the electronics industry, which is the strength of the nation. Additionally, a new mode of innovation integrating knowledge and applying simulations to R&D has appeared. As a consequence, government involvement has become more important than ever. In addition, the international flow of competent persons for research has increased, and competition to acquire both has intensified with the open innovation as well as global innovation.

Chapter 1 analyzes changes in the environment related to Japan’s S&T, which is at the threshold of global transition.

1 It refers to the research and development corporation as used in the R&D-Capacity Strengthening Act [literal translation].

Column 1 Four Japanese Researchers Awarded the Nobel Prize in the Same Year

Yoichiro Nambu, Professor Emeritus at the University of Chicago (US citizenship), Makoto Kobayashi, Honorary Professor Emeritus at the High Energy Accelerator Research Organization (KEK), and Toshihide Masukawa, Professor Emeritus at the Kyoto University received the 2008 Nobel Prize in Physics, and Osamu Shimomura, Professor Emeritus at the Boston University Medical School, and two other researchers received the Nobel Prize in Chemistry. These awards come after a six-year absence of Japanese recipients. Their research is briefly described below.

Yoichiro Nambu
Professor Emeritus,
The University of Chicago
Photo: The University of Chicago

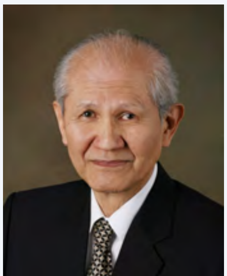
Dr. Nambu introduced the concept of the mechanism of spontaneous broken symmetry in subatomic physics as early as 1960 to explain the origin of mass. He also contributed to the establishment of the "standard theory", which provides a systematic explanation of three natural forces other than gravity; electromagnetic, strong, weak interactions. The basis of the "superstring theory" (see Chapter 1, Section 3), which is regarded as a key to constructing a theory accountable for the four natural forces including gravity, was also proposed by them.

Makoto Kobayashi
Honorary Professor
Emeritus, KEK
Photo: Japan Society for the Promotion of Science

Toshihide Masukawa
Professor Emeritus,
Kyoto University
Photo: Kyoto Sangyo University

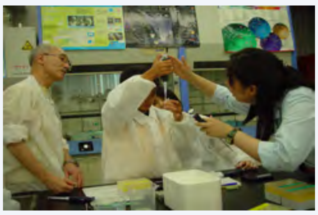
Dr. Kobayashi and Dr. Masukawa explained in published papers the broken symmetry between the particles composed of a substance and anti-particles having the opposite characteristics, and contributed to the establishment of standard theory with Dr. Nambu. This broken symmetry produced the differences in the numbers of particles and anti-particles, by which the earth, which consists of these substances, would have been created. The positron, the anti-particle of an electron, is used in Positron Emission Tomography (PET) for the diagnosis of cancer.

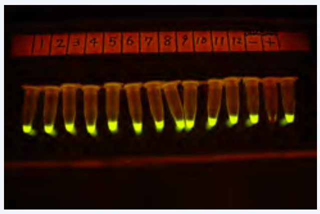
Dr. Shimomura succeeded in isolating Green Fluorescent Protein (GFP) from Aequorea victoria in 1962, and discovered that GFP emits a bright green glow when exposed to ultraviolet rays. GFP glows without a special enzyme, and it has no toxicity. GFP is now widely applied as a fluorescent marker to observe the location and behavior of protein in living cells based on the achievements of the US joint recipients of the Nobel Prize. This advance is expected to apply to the development of new anti-Alzheimer and anti-cancer drugs because the growth and destruction of neurons and the proliferation of cancer cells can be easily traced when labeled with GFP. His research on jellyfish might create big medical innovations never dreamed of before.



Osamu Shimomura
Professor Emeritus,
Boston University
Photo: Nagasaki University

Aequorea victoria
Photo: RIKEN





Experiment with GFP
Photo: Miraikan

1 New Trends of Innovation

In the past, Japan's economic growth was based on novel innovation with the clear target of catching up to the advanced European countries and the US through the improvement of products and production processes based on the introduction of overseas technology. Especially, the innovation which was achieved through the improvement of the production process, upgrade of equipment for example, is called process innovation, and contributed to the achievement of a superior Monodzukuri which supported high economic growth.

However, the foundation of the intra-corporate system of lifelong employment-based competent person development which supported the Japanese model of innovation has been wavering greatly in recent years. In addition, Japan is facing severe pressure from other Asian countries including South Korea, Taiwan, and China. Considering the recent approaching flow of science and innovation described below, Japan is poised to shift to the creation of the epoch-making products, to product innovation, utilizing high-level R&D capacity symbolized by last year's four Nobel Prize-winning researchers.

In addition, the vary nature of innovation is now changing greatly in the storm of fierce international competition. And Japanese corporations are faced with the need to create a new R&D system.

The current direction of innovation in Japan is outlined below.

Column 2 Definition of "Innovation"

The term of "innovation" was first defined by Joseph Alois Schumpeter (1883-1950), an Austrian economist. He described in his "The Theory of Economic Development" (1912) that in economic development, an internal factors like innovation rather than external factors like population growth and climate change play important roles in economic development. He insisted that the origin of economic growth should be the destruction of existing values and the creation of new values (creative destruction) by so-called entrepreneurs. He took as examples of innovations, (i) new product development through creative activity, (ii) the introduction of new production systems, (iii) the development of new markets, (iv) acquisition of new (supply sources of) resources, and (v) reform of organizations.

In the past in Japan, we tended to interpret the term "innovation" as technical innovation in the belief that innovation capable of changing economic society from its foundation is often the result of reformative science and technology. However, interest was directed to the impact of newly created value to economic society because innovation is created by the combination or integration of existing technologies of different areas, or the globalization of business management.

Based on these circumstances, the term of the creation of innovation was defined in the R&D-Capacity Strengthening Act [literal translation] enacted in July 2008 as "the creation of new values through the development or production of new products, the development or supply of new services, the introduction of a new system for production or marketing, the introduction of a new system to supply services, and the introduction of a new system for business management in order to effect significant change in economic society.

1 Open Innovation and Global Innovation

(1) Open innovation

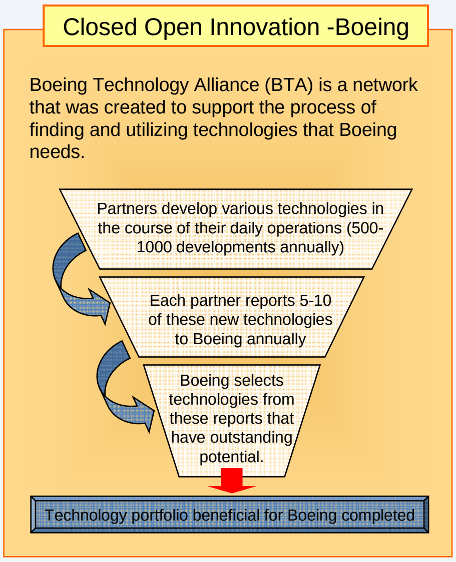
Japanese corporations had achieved many innovations not only in the area of product manufacturing but in R&D under the so-called "individually controlled" or "vertically integrated" R&D system adopted in their own or in the specified group of keiretsu subsidiaries.

However, it is now difficult for one corporation or group to complete all processes, from basic research to product development, by itself under recent environmental changes such as escalated global competition and increased R&D investment: It is required to narrow down the subjects of R&D and concentrate on them.

As a result, corporations tend to develop the core technology for products or services by themselves and pursue the development of peripheral technology and basic research with independent organizations. Especially in the US, the strategy to precede the opened R&D, involving many core institutions, has infiltrated the leading corporations. For example, it is well known that Intel Corporation, the manufacturer of a central processing unit (CPU), the core component of a personal computer, initiated the development of personal computers in cooperation with other corporations in many countries, including Taiwan. International Business Machines Corporation (IBM) has created an open academic research environment for advanced semiconductor technology, which requires enormous investment for R&D, with global corporations and academic institutions participating, including competitors, particularly in the popularly called Albany NanoTech[1] project. The Boeing Company has organized a network of partner corporations and groups called the "Boeing technology alliance" to identify and introduce the technology needed for Boeing (Figure 1-1-1).

1 One of five Centers of Excellence that New York State founded at Albany University to support high-technology industry

Figure 1-1-1 Boeing Technology Alliance



Source: Washington Office, New Energy and Industrial Technology Development Organization

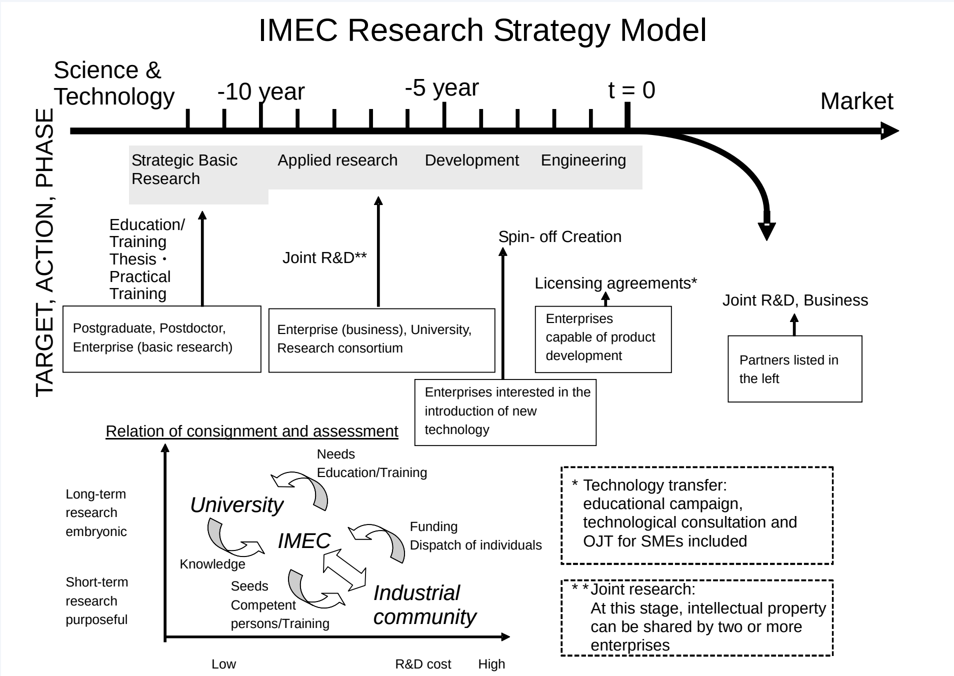
These corporations have strengthened cooperation with external research institutions. Therefore, the role of the public research institutions, including universities and governmental institutions, the primary sources of basic research, has become more important than ever. As seen in the Inter-university Microelectronics Center (IMEC), which is well known as the global base in the fields of nanoelectronics, in addition to the creation of simple outsourcing type innovation, a number of universities and corporations have worked together to generate a considerable synergistic effect at the R&D stage, including the stage of basic research, where information sharing and co-work with external institutions is possible (Figure 1-1-2). Additionally, in the fields of bio-technology and IT, venture enterprises engage in the R&D bridging the results of basic research obtained by public institutions and product development by large corporations, functioning to considerably reduce the risk of R&D by large corporations.

Figure 1-1-2 Inter-university Microelectronics Center (IMEC)

IMEC, famous as a typical case of excellent open innovation management, is a global base in the fields of nanoelectronics and nanotechnology founded in 1984 in Leuven of Belgium by the staff retired from the Katholieke Universiteit Leuven as a nonprofit organization independent of the government or the universities.

Its main academic activity is to bridge the results of the basic research obtained by the universities and the technology development delivered by the industrial corporations. Taking advantage of its good location, IMEC has recruited joint research partners globally, attracting many corporations from all over the world to participate in.

The concrete research programs include R1, non-competitive R&D phase which enable the sharing of information and collaboration with other partners, and R2, which is competitive research phase that is difficult to share with partners. In R1, a number of researchers at corporations and universities all over the world have worked together to generate a significant synergistic effect by sharing their results and information. In R2, the specified corporations and IMEC share information, and both open and closed type R&D are effectively selected on a case-by-case basis.

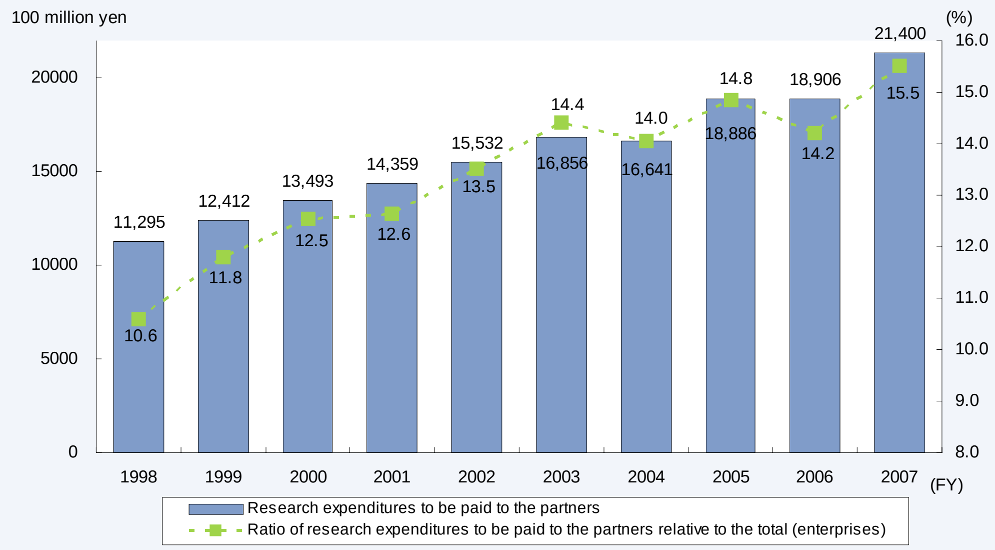


Source: Center for Research and Development Strategy, Japan Science and Technology Agency *Survey on Nanotechnology infrastructure investment strategies of major countries beneficial in establishing R&D bases in Japan* [literal translation]

In Japan, private corporations are increasing the quantity of R&D resources for the commission to universities and partners (Figure 1-1-3). Moreover, 80 % or more of those corporations are tied up with external institutions for cooperation in research, and the partnerships range from the domestic universities to overseas institutions (Figure 1-1-4). The number of corporations who wish to engage in joint research with external institutions in the future has grown larger than the number already involved in such partnerships, which suggests they are positive about joint research (Figure 1-1-5).

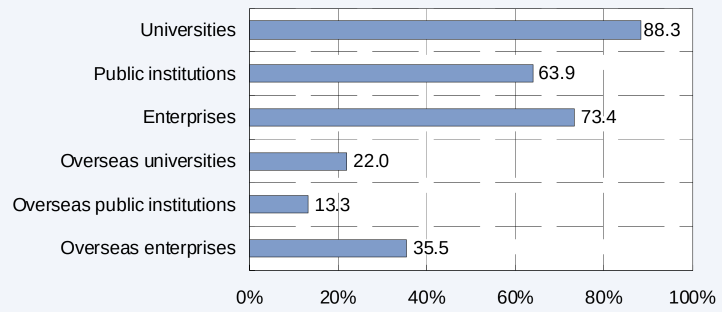
Even in the universities, the amount of the external capital received for joint research is increasing (Figure 1-1-6).

Figure 1-1-3 Ratio of Research Expenditures to Be Paid by Private Corporations to Partners (Domestic + Overseas)



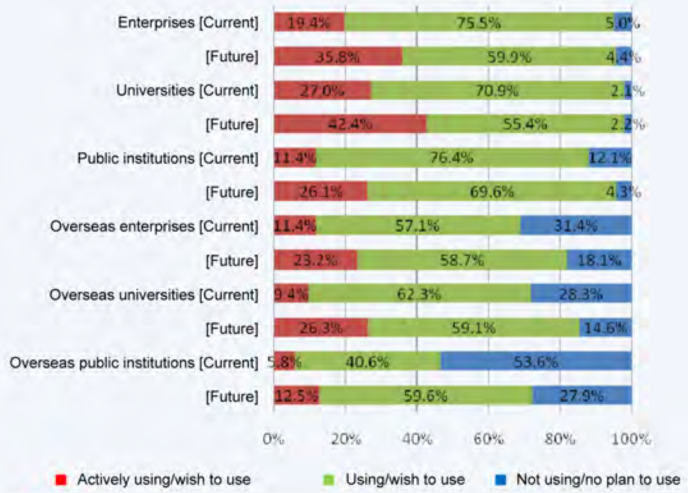
Source: Statistics Bureau, Ministry of Internal Affairs and Communications *Report on the Survey of Research and Development*

Figure 1-1-4 Ratio of Private Corporations Cooperating in Research with Domestic and Overseas Universities, Public Institutions and Corporations



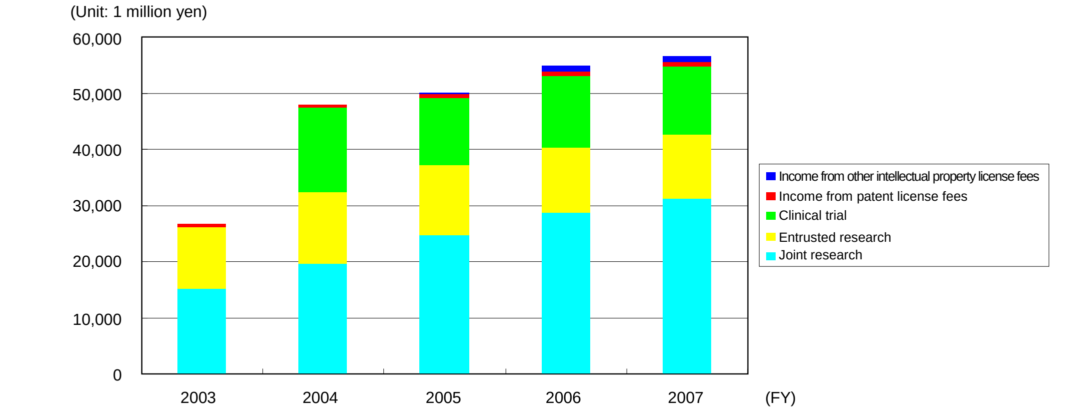
Source: MEXT *Survey on Research Activities at Private Corporations (FY2007)* [literal translation]

Figure 1-1-5 Possible Use of Joint Research at Private Corporations



Source: Prepared by Ministry of Economy, Trade and Industry

Figure 1-1-6 Trends in Research Funds Received by Universities from Private Corporations



Notes:

1. The income from other intellectual property lincese fees was not investigated in FY 2003 and 2004.
2. The clinical trial in FY 2003 was not investigated.

Source: MEXT *Survey on Industry-Academia-Government Cooperation Implementation Status* [literal translation]

The governmental and private research institutions in Japan should respond to the movement toward such an open innovation. Especially, as seen in IMEC, when R&D is carried out by the government hand-in-hand with the private sector, it is increasingly important to proceed in an open manner by which the synergic effect of many research institutions can be expected in non-profit, non-competitive fields including basic research, where the sharing of information and collaboration with external institutions are acceptable for the purpose of increasing the financial efficiency of R&D. On the other hand, in profit-oriented, competitive fields of applied research where such information sharing and collaboration are difficult, R&D should proceed in a closed manner, and skilful management such as strategic selection is required.

As pointed out above, Japanese corporations achieved many innovations under the so-called "individually controlled" or "vertically integrated" R&D system. They have become increasingly aware of the need for cooperation with universities in the era of open innovation has moved forward, as seen in Column 3. Therefore, the importance of the universities and R&D institutions, the core of basic research in Japan, is increasing rapidly, and public research institutions should also respond to this global innovation.

Column 3 "Expectations and Responsibility of Industry for Basic Research" (Council on Competitiveness-Nippon)

The Council on Competitiveness-Nippon (COCN) composed of representatives of industries interested in the reinforcement of Japanese industrial competitiveness published *Expectations and Responsibility of Industry for Basic Research* [literal translation] on March 6, 2009.

The report discusses the open innovation with an emphasis on the increasing difficulty being faced by the private sectors in carrying out the entire spectrum of R&D, from basics to developments, because the shortening of R&D periods and synchronization of advanced research and product development are now progressing as a result of increasing global competition. Moreover, the report indicates the importance of innovative research which constructs priority issues in future application, and finds truly innovative solutions, going back to the basics, and makes an appeal for the establishment of a forum for leading researchers with different specialties from the public and private sectors to share their expertise. The report shows recent awareness on the side of Japanese corporations in the age of open innovation. In addition, COCN suggests the following to promote basic research:

(1) It is necessary to adhere to the initial goal of the total amount of R&D investment in the Third Science and Technology Basic Plan, and to design an effective funding system that ensures a seamless fund for research from basics to applications.

(2) Innovative research should be the core of basic research and strengthened. To accomplish this, a forum is needed to promote open discussion via industry-academia-government cooperation.

(3) The "Innovation Center for Fusion of Advanced Technologies" should be the base for innovative research, and serious discussion should be focused on effective management.

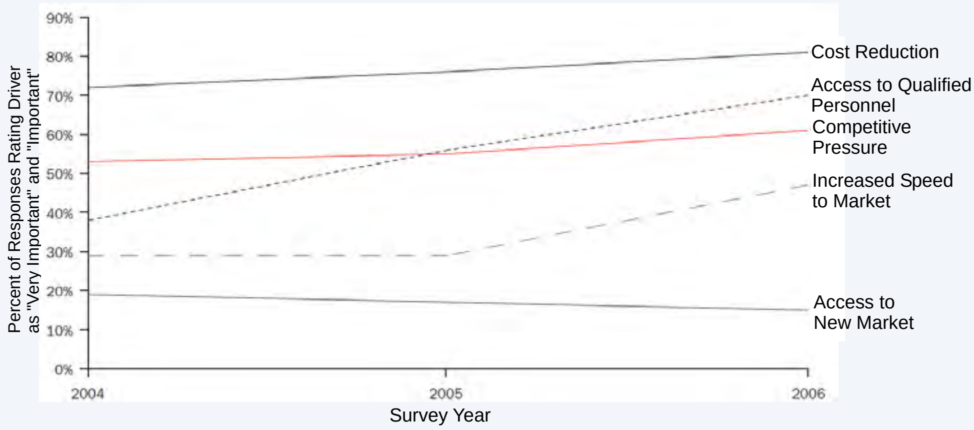
(4) It is important to cultivate “connoisseurs” capable of understanding the meaning of academic results and coming up with conceptual ideas that link to actual needs.

(5) Excessive dependence on outcome indexes in the evaluation of advanced research is a concern. Industry and academia should share consciousness and focus on university management with well-balanced research and education. The cultivation of competent persons, people-to-people exchange, and revitalization of contribution-based course should be promoted more actively along with flexible cooperation between industry and academia.

(2) Global innovation

The movement to develop business as well as R&D globally has progressed in parallel with global innovation. According to the report *Here or There*? issued by the National Academies in 2006, approximately 90% of the 200 or more multinational corporations who participated in this survey has assigned its R&D function to overseas countries, and for 20%, more than half the number of technicians are working in overseas countries. Moreover, as an advantage of operations in overseas countries, the existence of competent persons as well as the conventional reduction of personnel costs, etc. has been emphasized (Figure 1-1-7).

Figure 1-1-7 The Key Reasons Offshoring Has Evolved Beyond Cost Reduction



Sources: Duke University/Archstone Consulting *Offshoring Research Network 2004 and 2005 Surveys*; Duke University/Booz Allen Hamilton *Offshoring Research Network 2006 Survey*

In the US as well, universities are actively incorporating overseas corporations as R&D resources, responding to the globalization of R&D in their corporations. For example, Massachusetts Institute of Technology (MIT) launches the Industrial Liaison Program (ILP) to promote industry-academia cooperation which includes overseas corporations. In this program, the Industrial Liaison Officer selects the faculty or research team suitable for the needs of ILP members, and provides support for them. Many Japanese corporations participate in this program (Table 1-1-8).

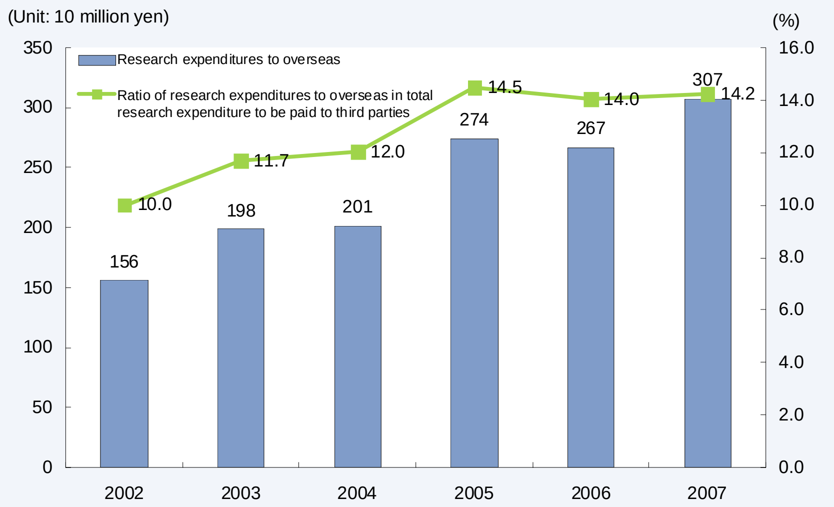
Table 1-1-8 Member Corporations Participating in the MIT Industrial Liaison Program (Example)

Japanese enterprises	Mitsubishi Electric	Alstom S.A. (France)
Alps Electric	Mitsubishi Materials	BT Group (UK)
Dai Nippon Printing	Murata Manufacturing	Compania Vale Do Rio Doce (Brazil)
Daikin Industries	NEC	Endesa, S.A. (Spain)
DENSO	NIKON	Fiat S.p.A. (Italy)
EBARA	NTT	Industrial Bank of Taiwan (Taiwan)
Fuji Electronics	Nissan Motor	Kuwait Petroleum (Kuwait)
Fuji Heavy Industries	SANYO	Royal Phillips Electronics (Netherlands)
Fujitsu	SHARP	Saab A.B. (Sweden)
Hitachi	TEIJIN	Royal Dutch Shell plc (Netherlands)
HONDA	Tokyo Electron	Tata Steel (India)
HOYA	TOYOTA	Telecom New Zealand
KOMATSU	**Overseas enterprises**	Veolia Environment (France)
Mitsubishi Chemical	Agria (Belgium)	Volkswagen (Germany)

Source: Prepared by Washington Office, New Energy and Industrial Technology Development Organization based on the Massachusetts Institute of Technology website

Japanese corporations are increasing research funding to finance external organizations, and the amount of fund almost doubled in the five–year period from 2002 to 2007 (Figure 1-1-9). In addition, the amount of technological trade, which indicates the offer or acceptance of technology such as patents to or from overseas countries, has shown a tendency to increase every year.

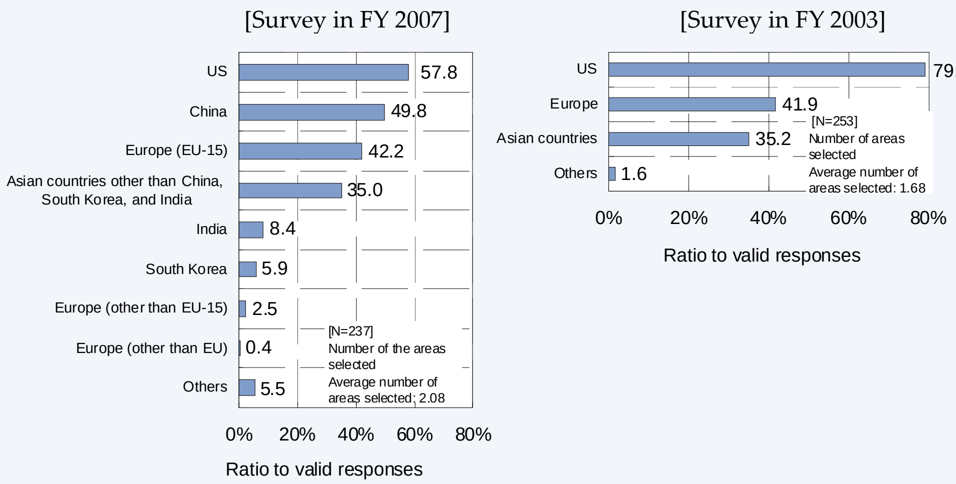
Figure 1-1-9 Increase of Research Expenditures to Overseas



Source: Statistics Bureau, Ministry of Internal Affairs and Communications *Report on the Survey of Research and Development*

With respect to the overseas research bases, half of the corporations with capital of 50 billion yen or more report that they have R&D bases overseas. The increase of bases in China is especially significant (Figure 1-1-10).

Figure 1-1-10 Overseas Areas with R&D Base Located



Source: MEXT *Survey on Research Activities at Private Corporations (FY2007)* [literal translation]

Under this trend of global innovation, both Japanese and overseas corporations are expanding their own research activities on a global scale via R&D bases. The activity has not been necessarily performed in their home country.

Therefore, public and private Japanese research institutions have been required to obtain or maintain their position as international research bases by strengthening their R&D capacity.

2 Shift of Production Process to Emerging Countries through the Development of Modularization

Japanese corporations were skillful in process innovation, focusing on the improvement of the production process. In addition to this, the precise coordination of many processes and parts, "suriawase" (integration) techniques, as seen in the typical production processes in the automobile industry, is often pointed out as a reason for Japanese predominance in manufacturing.

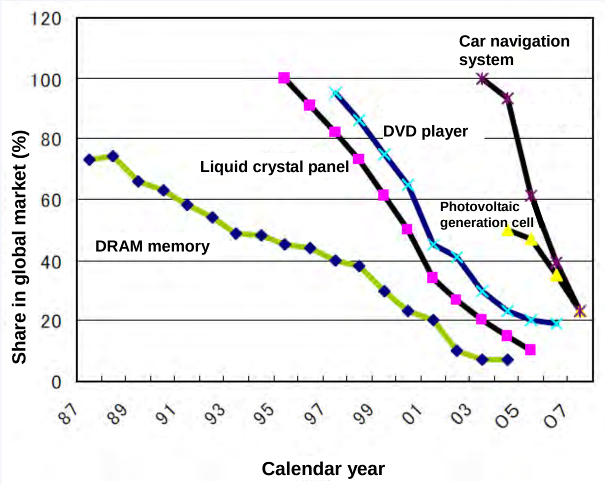
However, the phenomenon of modularization, which does not require such "suriawase" techniques, using instead a combination of standardized general-purpose parts, is now progressing, particularly in the assembly of personal computers, cellular phones, and electronics. In the 1980's, IBM allowed its personal computer to be assembled using the combination of general-purpose parts. As a result, assembly processes could not be differentiated with technical competitiveness. Moreover, as the supply of parts became more dependent on the external corporations, the technical kernel of the personal computer shifted to individual component parts, including operating system and CPU.

Such modularization is percolating through the entire electronics industry, including digital consumer electronics. Therefore, the assembly process has been moved to countries where the manufacturing costs are low, and, the technical kernels of products and the target of innovation shifted to standardized general-purpose parts and materials to comprise them. As a result, the horizontal and international specialization has progressed, as seen in the example of the planning and designing processes being separated from the assembly process for electronic products. Japanese corporations who have not fully responded to such changes are loosing a significant market share.

Moreover, horizontal specialization and modularization is observed in the field of component parts as well as in final products. For example, semiconductors are relatively easy to produce in emerging countries such as China if the materials, including silicon wafers, and manufacturing devices are available.

The decrease in market share due to modularization is observed in products using liquid crystal panels, photovoltaic generation cells, and car navigation devices, all of which are deliverables of the product innovation achieved in Japan. The decrease in market share due to modularization is also observed in the manufacture of DVD players, while approximately 90% of the related patents of the product are held by Japanese corporations (Figure 1-1-11).

Figure 1-1-11 Trends in Japanese Private Corporations' Share in Modularized Products



Source: Prof. Koichi Ogawa, The University of Tokyo *New Standardization and Business Strategy as Japanese Style Innovation (11)* [literal translation]

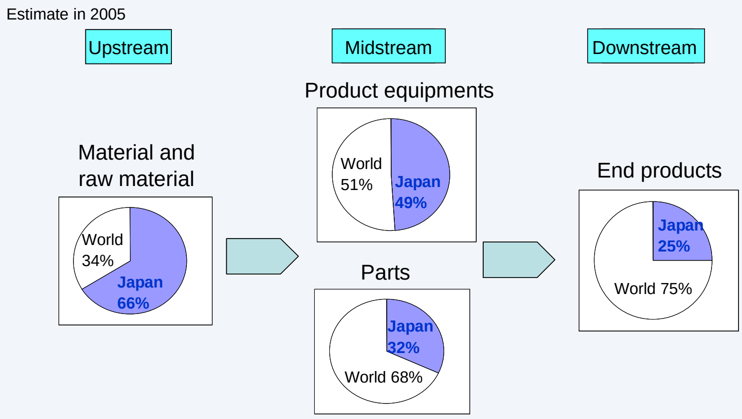
Across the manufacturing industries, Japanese corporations are loosing their market share for end-products other than automobiles and copy machines, which require sophisticated “suriawase” techniques in the production process.

On the other hand, Chinese and Taiwanese corporations who are skillful in responding to the horizontal specialization for business use the results of innovations obtained by the European and the US corporations effectively. They have increased their market share of electronics products significantly, and have achieved high profit margins. Additionally, some European and the US corporations have increased their share significantly by effectively combining their skill at planning and design with the manufacturing capacities of Chinese and Taiwanese manufacturers through skillful global business cooperation.

However, Japanese corporations have a very high share in the areas of parts, materials, and manufacturing devices, etc., (hereafter, "materials”) which require a high level of technology and “suriawase” techniques. There are for instance many products for which Japanese corporations have an overwhelming global share, such as silicon wafers, essential for the manufacture of semiconductors and glass boards for liquid crystal panels. In the information appliances industry, where Japan once enjoyed a high degree of global competitiveness, the share of end-products is now 25%, while upstream materials represent a market share of 60 % or higher (Figure 1-1-12).

As a result, a polarization of competitiveness is emerging in which market share for end-products is decreasing while the share for materials continues to be dominated by Japan.

Figure 1-1-12 World Shares of Upstream/Midstream/Downstream Home Information Appliance Industries



Source: MEXT; Ministry of Health, Labour and Welfare; and Ministry of Economy, Trade and Industry *White Paper on Monodzukuri 2006*

Therefore, in the face of such developing modularization, Japanese corporations should continue with R&D while observing technology for core materials which play a pivotal role in the business model of products. Based on this, they should focus on strengthening technology management in order to lead R&D and the development of business in the global market, while incorporating other research institutions.

3 Changes in the State of R&D Including the Approach of Science and Innovation, and the Application of Simulation and Mathematics

The conventional technology is reaching the limit of its innovation vis-a-vis the recent global increase of science linkage[1], and the need to apply scientific results to product development has increased. As a result, the scientific results have become more closely related to product development (Figure 1-1-13).

For example, in the report *Expectations and Responsibility of Industry for Basic Research* in Column 3, it is noted that miniaturization of the semiconductor integrated circuit will reach the level of 10 nanometers in 2020, and will reach at a substantial limit in the near future. The limit attainment of IT basic technology is pointed out as one of the five risks which Japan faced. It is emphasized that a breakthrough to a higher level of basic IT technology is essential.

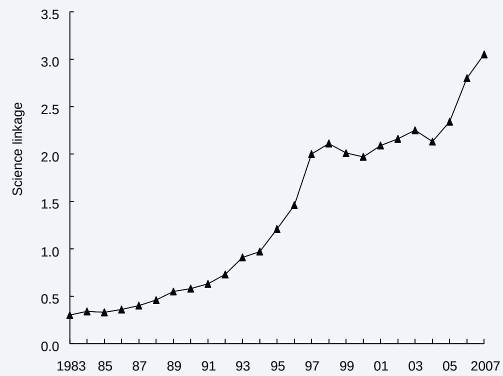
In addition, one industry group, the science-based industry, where scientific discovery and results are more closely linked to product development than in other industries, is increasing its presence, as seen in the pharmaceutical and software industries. However, it cannot be said that Japan maintains strong global competitiveness in the science-based industry. For example, Japan shows an excess of pharmaceutical and software imports from the US. Japan has fallen far behind the US which positively addressed industrial promotion from the early 1980's.

As previously described, the strength of Monodzukuri in Japan had greatly depended on

1 Expressed as the frequency with which each patent is cited to in academic papers.

superior process innovation. However, a strengthening of the system to achieve goals, a return to basic science, and the positive utilization of the results of basic research obtained by universities and R&D institutions are essential to maintain the international competitiveness of Monodzukuri and the science-based industry.

Figure 1-1-13 Increase of Science Linkage in the US Patents



Source: National Institute of Science and Technology Policy *Science and Technology Indicators - Data updated in 2007 for 5th edition*

Additionally, recent advancements in IT technology and mathematics have made it possible to clarify complicated natural phenomena. For example, the phenomenon of climate change, which was difficult to predict due to the massive amount of data, is now becoming easier to predict accurately through the development of computer science technology such as supercomputers. The Council on Competitiveness also reports that employing computational models will reduce development costs, certification costs, re-engineering costs, design cycle time, and improve performance and efficiency while reducing waste such as emissions, noise, and raw material use. They also noted that the application of simulations generated by supercomputers to the research and development of aircraft, automobiles, biotechnology, and energy technology serves as a key to innovation in the future[1].

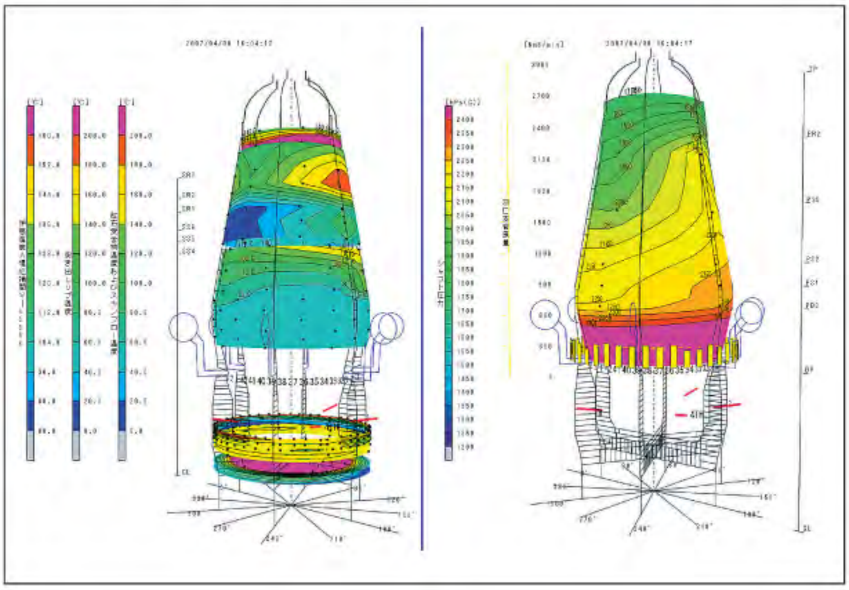
Moreover, mathematics has been applied to various phases of Monodzukuri and services in addition to IT and simulation. For example, the status within the blast furnaces at ironworks was quantitatively determined using mathematical models to improve quality and productivity (Figure 1-1-14).

1 *U.S. Manufacturing-Global Leadership Through Modeling and Simulation* (March, 2009)

Figure 1-1-14 Mathematical Model for Inside of Blast Furnaces in Ironworks

In the blast furnace, iron ore reacts with coke at a high temperature, and the oxygen contained in the iron ore is removed to extract iron. However, it is necessary to properly understand the conditions inside the furnace and to optimize the process of removing oxygen from iron ore in order to increase manufacturing efficiency. At the Nippon Steel Corporation, the distribution of temperature, pressure, and gas in the blast furnace are expressed numerically by means of temperature and pressure sensors installed in the furnace because conditions inside the furnace cannot be observed directly. Visualizing the conditions inside the furnace in three dimensions by analyzing a large amount of information obtained by measurement every second using the mathematical model becomes possible, and it contributes to the stable operation of the blast furnace.

Image displayed by 3D-VENUS



Source: Nippon Steel Corporation

The application of mathematics to the field of finance significantly affected business development in the financial industry, and established a new academic field known as financial engineering. Therefore, application of advanced mathematics to the real world is resulting in big innovation. The importance of advanced mathematics is increasing even in the basic academic sciences. Highly advanced mathematics is applied to the study of superstring theory in physics, which has been focused on as a major candidate to explain the control of the four interactions, namely electromagnetic interaction, strong interaction, weak interaction and gravitational interaction between subatomic particles.

In this connection, Japan should promote R&D using the new tool, supercomputer-assisted computing technology and applied mathematics, in the future.

4 Innovation Increased through Intellectual Integration and Combination

Intellectual integration played an important role in the great discoveries and inventions of the 20th century. Recently, the tendency to induce innovation through intellectual integration and combination has increased more than ever.

Innovation through the integration of Monodzukuri and service or the combination of S&T

and excellent ideas/concepts has been noted in particular. In fact, in the area of personal computers, a new business which integrated Monodzukuri and the advanced distribution was appeared as seen in Dell Inc. Apple Inc.'s iPod is a combination of product and IT service, a product beyond the conventional concept of Monodzukuri.

In addition, cases in which the opportunity for innovation belongs to a customer are currently increasing. With diversified customer's needs, not only end-products but intermediate products are also required to respond exactly to such needs, otherwise it would be difficult to acquire market share. Therefore, how we should respond to the information from the customer at each step of R&D is important.

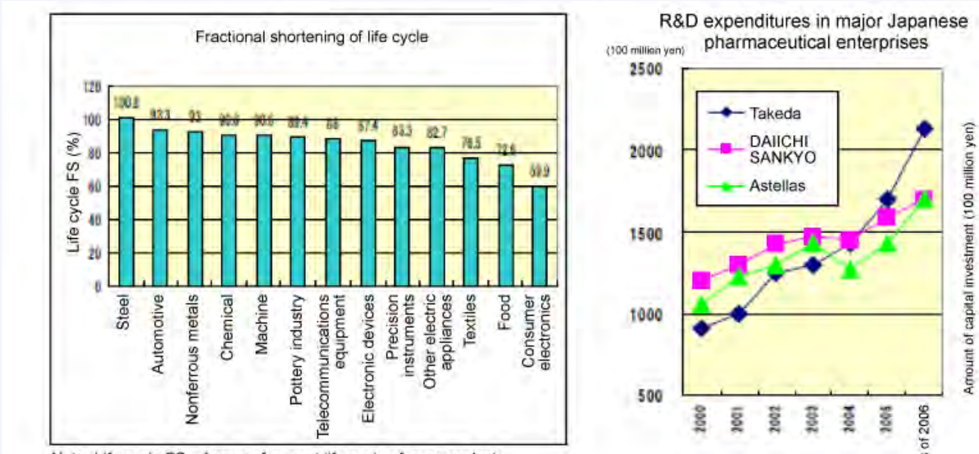
Accordingly, it is important that we also create innovation through Monodzukuri/services and intellectual integration/combination exceeding the boundaries between arts and sciences. Concretely, it is essential to improve technical management capacity capable of integrating technology and ideas/concepts and business models including marketing, in addition to the promotion of interdisciplinary research, including the service science and engineering described below.

5 Large Scaled R&D Investment and Increased Government Involvement

Borderless industry reorganization was advanced in response to increasingly fierce global competition, and a global huge corporation appeared. As a result, the life cycle of a product was shortened, and the amount of R&D investment was scaled up (Figure 1-1-15). When the top-ranking corporations in terms of R&D investment in Japan were compared with corporations overseas, it was found that investment was almost equal in the automotive industry. On the other hand, both R&D investment and sales amount were found to be significantly different in the pharmaceutical industry which included global huge corporations. Moreover, as seen in the information, electricity, and electronics industries, overseas corporations tend towards exclusive business deployment, while Japanese corporations tend to expand their business multilaterally. Therefore, when a specific product and technical field are compared, the amount of R&D investment is higher than Japanese corporations (Figure 1-1-16).

Recently, S&T in fields with a competitive advantage are promoted together with government and private sector in some overseas countries. For example, the US government has made huge R&D investments in the biotechnological fields, including pharmaceuticals, though the US pharmaceutical corporations have an excellent reputation for overwhelming scale and industrial competitiveness. In fact, the budget of the National Institutes of Health (NIH), which plays the central role in government investment in the biotechnological field doubled from 13.1 billion to 26.4 billion dollars during a period of only five years, from 1988 to 2003. The budget for FY 2008 is approximately 39 billion dollars, including the supplementary budget; it is comparable with the total Japanese S&T expenditure.

Figure 1-1-15 Shortening of Product Life Cycles and Increase of R&D Cost

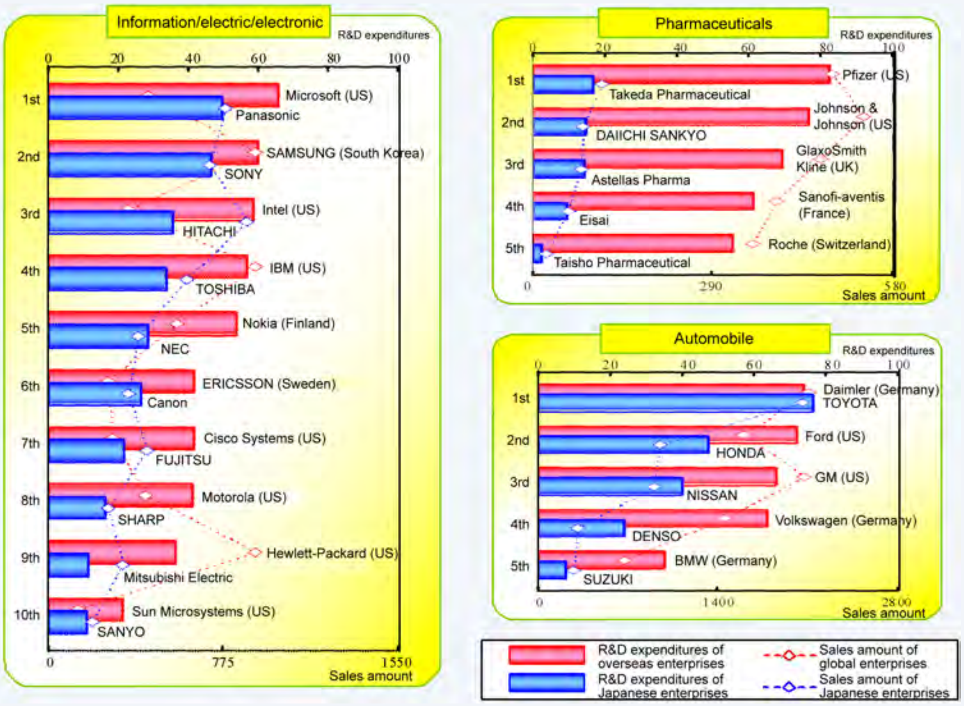


Note: Life cycle FS = [years of current life cycle of core products (mean by industrial field)]/[years of life cycle of core products 5 years before (mean by industrial field)]

Sources: [Left] MEXT; Ministry of Health, Labour and Welfare; and Ministry of Economy, Trade and Industry *White paper on Monodzukuri 2007*

[Right] Office of Pharmaceutical Industry Research *Future Vision of Pharmaceutical Industry: Industry's missions and challenges toward 2015*

Figure 1-1-16 Comparison of the Leading Domestic and Overseas Corporations in R&D Investment, by Type of Business



Unit: 100 million US dollars

Source: Prepared by Ministry of Economy, Trade and Industry based on *S&P Global 1200* (2006)

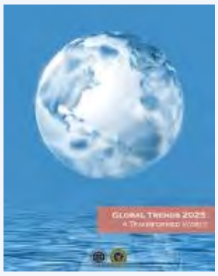
The customized manufacture of semiconductors became a big business in Taiwan, occupying more than the half of the world's market share. One factor in this success is the presence of governmental institutions, including the Industrial Technology Research Institute (ITRI). ITRI has moved their R&D results to corporations and gets involved in their R&D activities. As a result, many spin-offs have been seen. Taiwan Semiconductor Manufacturing Company Limited (TSMC), the world's largest customized manufacturer of semiconductors, is also a spin-off from ITRI. In addition to these advantages, competitive domination has been facilitated through tax incentives to the high-tech industry in this country.

In the light of increasingly fierce international competition, the establishment of large-scale globalized corporations through borderless corporate realignment, a significant increase in R&D investment by these corporations, and the movement to promote S&T together with government and private sectors in the fields maintaining competitive domination will be accelerated and expanded. The report *Global Trends 2025: A Transformed World*, prepared by the National Intelligence Council (NIC) in November 2008 describes that the system of economic management that gives a prominent role to the state is called ‘state capitalism,’ and that “China, India, and Russia are not following the Western liberal model … but instead using a different model, ‘state capitalism.’ … Other rising powers—South Korea, Taiwan, and Singapore—also used state capitalism to develop their economies.” Additionally, after the international economic and financial crises hit, the US and the UK which tended to place an emphasis on the market economy and which have been reluctant to intervene in economic activity, strengthened government participation in the economic activity, as seen in the injection of funds to financial institutions and the huge amount of R&D investment under the American Recovery and Reinvestment Act which created supplementary budget in 2009.

Therefore, Japan should also immediately construct a framework for the promotion of S&T in fields maintaining competitive domination in cooperation between the government and the industry.

Column 4 "Global Trends 2025: A Transformed World" (Summary)

On November 2008, the National Intelligence Council (NIC) prepared the report *Global Trends 2025: A Transformed World*, which analyzes the world situation in 2025 macroscopically. It is summarized as below.



- By 2025, the international system will be a global multipolar one with gaps in national power continuing to narrow between developed and developing countries.
- Although the United States is likely to remain the single most powerful actor, the United States' relative strength—even in the military realm—will decline and US leverage will become more constrained.
- Growth projections for the BRICs indicate they will collectively match the original G-7's share of global GDP by 2040-2050. China is poised to have more impact on the world over the next 20 years than any other country.
- India probably will continue to enjoy relatively rapid economic growth and will strive for a multipolar world in which New Delhi is one of the poles.
- China, India, and Russia are not following the Western liberal model, but instead are using a different model, "state capitalism." Other rising powers - South Korea, Taiwan, and Singapore - also used state capitalism.
- Europe and Japan will continue to far outdistance the emerging powers of China and India in per capita wealth, but they will struggle to maintain robust growth rates because the size of their working-age populations will decrease.
- Resource issues will gain prominence on the international agenda, and demand is projected to outstrip easily available supplies over the next decade or so. As a result of this, the world will be in the midst of a fundamental energy transition away from oil toward natural gas, coal and other alternatives.
- The World Bank estimates that demand for food will rise by 50 % by 2030.
- Climate change is expected to exacerbate resource scarcities, and a number of regions in developing countries will begin to suffer water scarcity and loss of agricultural production.
- New technologies could provide solutions, such as viable alternatives to fossil fuels or means to overcome food and water constraints. However, all current technologies are inadequate for replacing the traditional energy architecture on the scale needed.

2 Increased International Mobility of Research Personnel and Intensified Competition for Talent

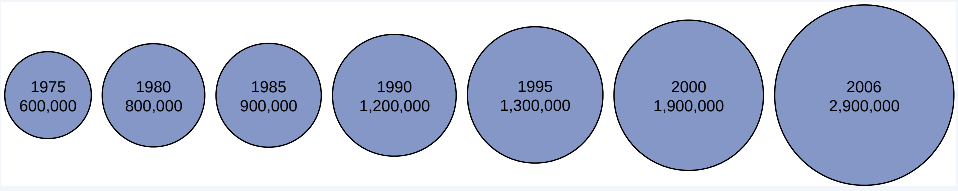
1 Increased International Mobility of Research Personnel and Intensified Competition for Talent

In parallel with the progress in the open innovation and global innovation, it became easy for researchers to move across national borders to work in other countries. Moreover, the overseas students who may be engaged in research also increased to such a degree that their international mobility became the norm (Figure 1-1-17). Though the biggest flow is from the Asian countries, the US has received more overseas students than Japan, which is much closer to Asia geographically (Figure 1-1-18).

In light of this situation, many countries, including emerging countries, are actively promoting receiving strategies and environmental improvement in order to attract high-talent personnel to their countries. The US which has attracted high-talent personnel from around the world is no exception, and is now considering expanding receiving to maintain its pool of researchers and technical personnel. Moreover, in the emerging countries, including China and India, which have lost competent persons to the US and Europe, the movement is gaining momentum to recall and acquire them from other countries for the creation of innovation in their home countries. In addition, there exist countries like Singapore which has actively addressed the maintenance of living environments and the acquisition of high-talent personnel from abroad.

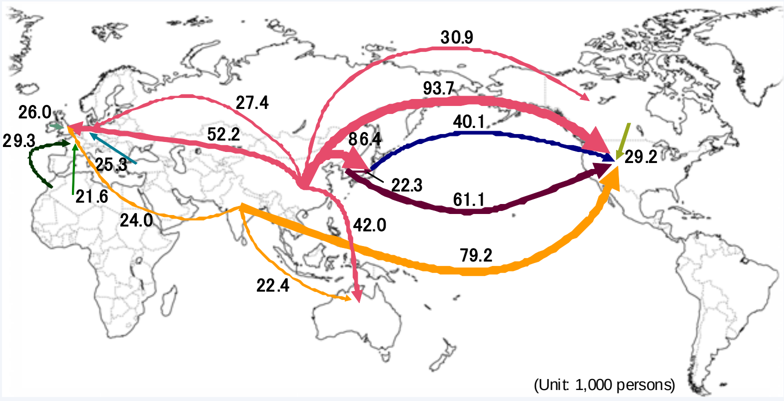
As mentioned above, with the recently increasing international movement of competent persons, the competition to attract excellent researchers and overseas students for the future creation of innovation is intensifying.

Figure 1-1-17 Long-term Increase in Number of Overseas Students in Higher Education



Source: Prepared by MEXT based on *OECD Education at a Glance*

Figure 1-1-18 Movement of Overseas Students between Regions (2006)



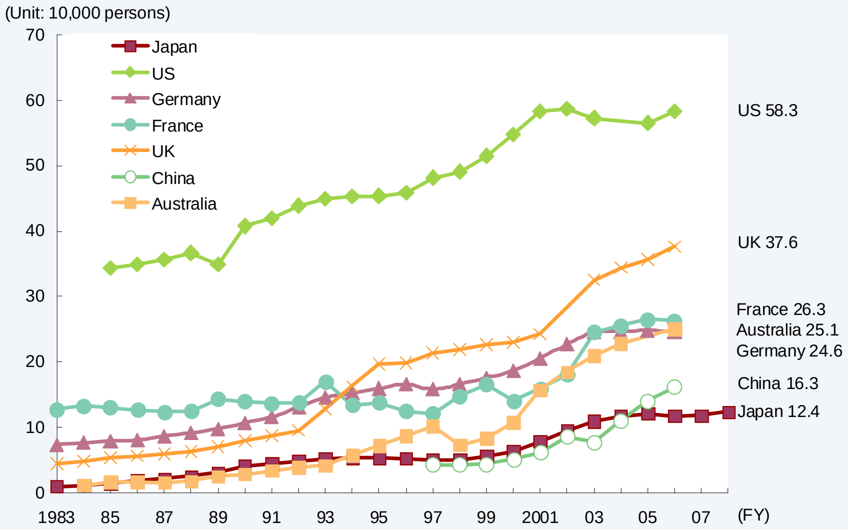
Note: Only figures greater than 20,000 students are presented.
Source: Prepared by MEXT based on *OECD Online Education Database*

2 State of Receiving Researchers in Japan

Securing high-talent personnel as researchers from internal and external sources is extremely important in the maintenance and strengthening of Japan's R&D capacity. The necessity for acquiring capable researchers from around the world is particularly increasing along with the shifts towards an aging society with a declining birthrate. Receiving researchers from abroad promotes the activation of research through friendly competition among individuals with diverse values and cultural backgrounds. Development of systematic exchange between the conventional parent and host organizations is also expected.

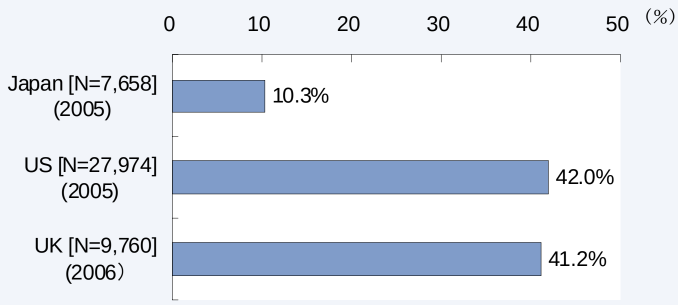
Receiving overseas students is important from the viewpoint of cultivating future researchers. However, the number of overseas students received in Japan remains flat compared with other major advanced countries, although the objectives of the FY 2003 Plan to Accept 100,000 Foreign Students were achieved (Figure 1-1-19). Moreover, the ratio of the foreign nationals in Japan to those who earned S&E doctoral degrees remained at about 10 % compared with about 40% in the US and the UK (Figure 1-1-20).

Figure 1-1-19 Trends in Number of Overseas Students Received in Major Advanced Countries



Sources: US: IIE *OPEN DOORS* (1994-2006), and *UNESCO Statistical Yearbook*
UK: HESA *STUDENTS in Higher Education Institutions* (1997-2001, 2003-2006), and *UNESCO Statistical Yearbook (1983-1996)*
Germany: Federal Statistical Office (1997-2006) and *UNESCO Statistical Yearbook (1983-1996)*
France: Ministère de l'Education Nationale (1998-2006) and *UNESCO Statistical Yearbook (1983-1995)*
Australia: DEST (2004), AEI (1998-2000, 2003, and 2005-2006), and *UNESCO Statistical Yearbook (1984-1997)*
China: Ministry of Education of the People's Republic of China
Japan: Student Exchange Division, MEXT (1983-2003); Japan Student Services Organization (2004-2008)

Figure 1-1-20 Ratio of S&E Doctoral Degrees Earned by Foreign Students, by Selected Industrialized Country

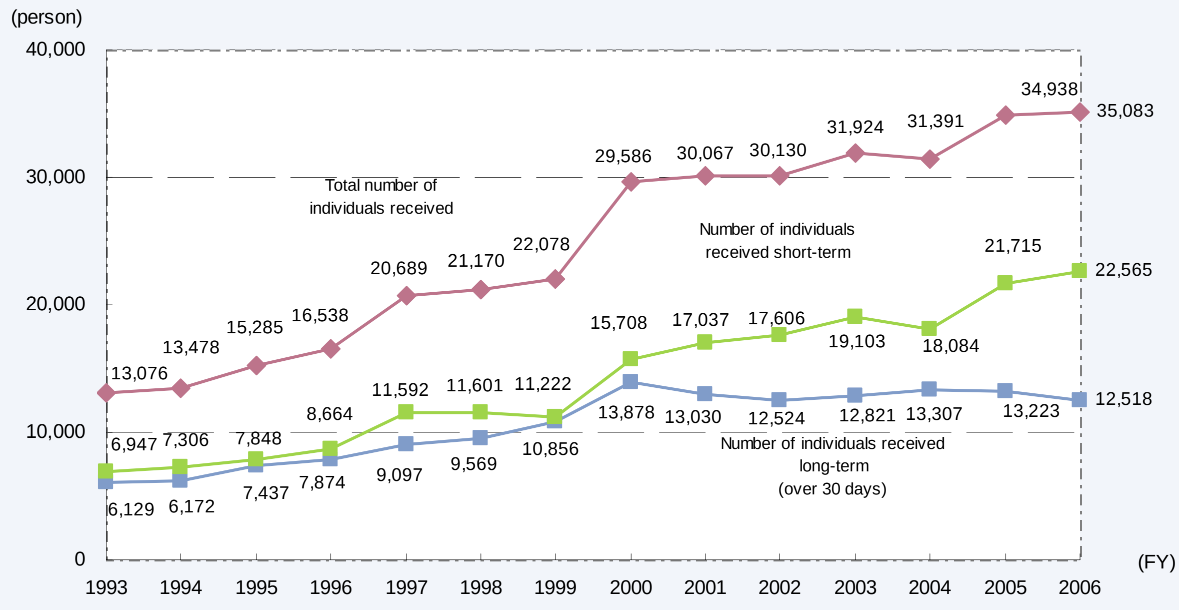


Note: The value "N" in each bar is the total number of S&E doctoral degree recipients.
Source: Prepared by MEXT based on National Science Foundation *Science and Engineering Indicators 2008* Appendix table 2-49

The number of overseas researchers received at universities in Japan shows a tendency towards increase in terms of the total number of researchers received. Short term receiving within 30 days is the largest, which indicates that long-term one in the expectation of more realistic research activity and researcher exchange does not increase (Figure 1-1-21)[1].

Thus, the numbers of overseas students and long-term researchers from abroad received remains flat in Japan. Therefore, universities and R&D corporations should actively receive overseas students and researchers diverse values and backgrounds by conducting distinctive and attractive research.

Figure 1-1-21 Trends in Number of Researchers Received, by Period



3 Current International Mobility of Japanese Researchers

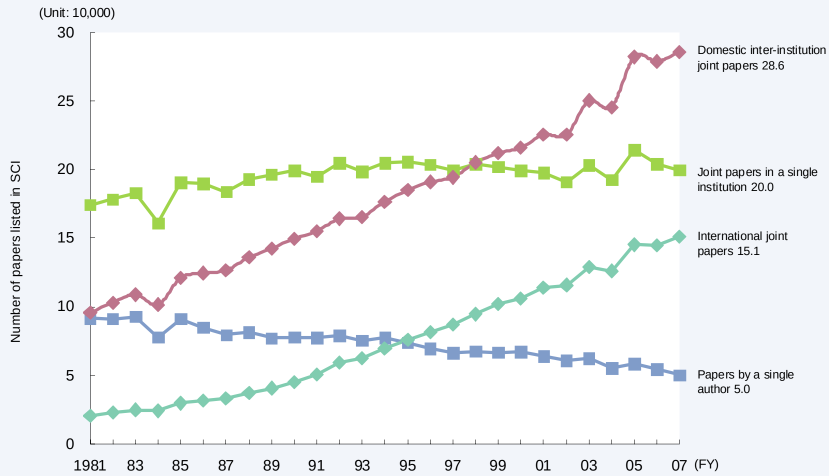
With the increased informatization and international mobility of researchers, publications and patent applications have increased internationally. The number of academic papers written by co-authors in a single institution tends to remain flat, while papers written jointly by the authors of domestic institutions or domestic and international institutions have steadily increased (Figure 1-1-22). Recent research, especially, is often reported jointly by top-level research institutions, and a borderless network of famous researchers is developing.

Promoting the domestic and international mobility of researchers to increase opportunities for work in various locations is an important theme for the development of researchers with creative vision who are able to work actively within the network of international researchers. For example, the researchers who engaged in research activities abroad tend to conduct international

1 National, public and private universities and experimental research institution are surveyed. The dispatched in this survey is identified as a researcher employed by one of these institutions with experience abroad for research, the accepted is a foreign national employed (including part-time staff) at one of these institutions as a teacher or researcher, or an expert who visited or was invited to Japan to participate in joint research, an academic conference, a lecture presentation, or an academic symposium. The researcher defined here is a professor, assistant professor, assistant, or lecturer (including part-time staff) who was employed by one of these institutions, or a laboratory worker contracted by them.

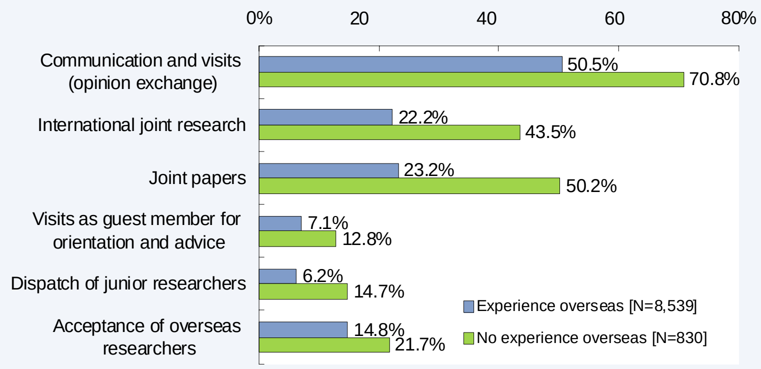
joint research and co-publish international academic papers more frequently compared with those without such experience. Therefore, international research will be important in increasing researchers' sense of international participation and in improving their academic level. (Figure 1-1-23, Figure 1-1-24)[1].

Figure 1-1-22 Trends in Styles of Joint Papers in Natural Sciences



SCI: Science Citation Index (JDreamII)
Source: National Institute of Science and Technology Policy *Science and Technology Indicators - Data updated in 2007 for 5th edition (Report No. 155)*

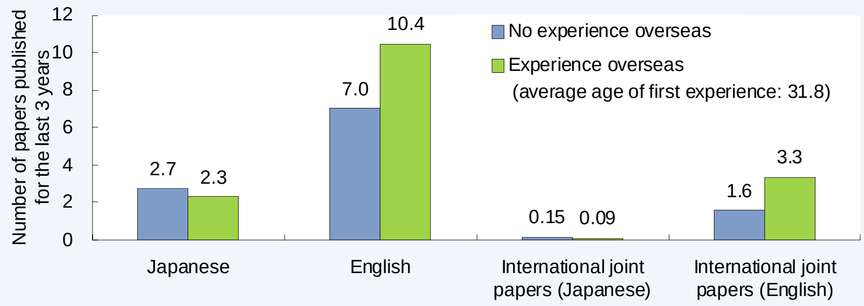
Figure 1-1-23 Presence or Absence of Experience Overseas of the Researchers, and International Activities for the Past Three Years (Multiple Answers)



Note: "N" refers to the number of valid answers.
Source: National Institute of Science and Technology Policy *Survey on Human Resources for Science and Technology (NISTEP REPORT No. 123)*

1 The institutions surveyed include domestic national, public, and private universities with doctoral programs in the natural sciences and inter-university research institutes (248 institutions) in addition to independent administrative institutions, national research institutions and public experimental research institutions, etc. engaging in research in the natural sciences (601 institutions). Researchers engaged at these institutions were investigated. A total of 15,250 questionnaires were distributed, and respondents were 9369 (RR: 61.4%).

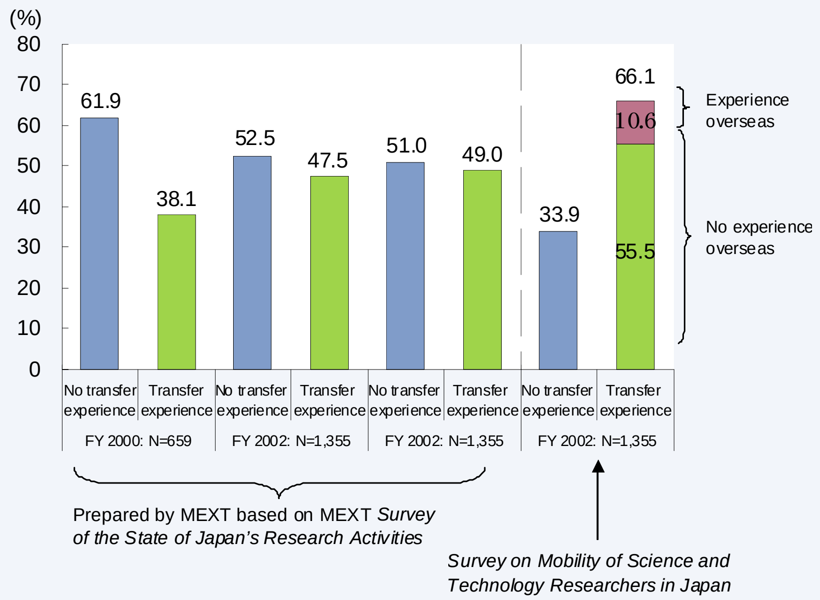
Figure 1-1-24 Presence or Absence of Experience Overseas of Researchers, and Productivity of Academic Papers for Past Three Years



Source: National Institute of Science and Technology Policy *Survey on Human Resources for Science and Technology (NISTEP REPORT No. 123)*

In regard to the domestic and international mobility of Japanese researchers, the percentage of researchers with experience of domestic or international movement is 66.1%, an increase over past results. However, the ratio of the researchers with no experience overseas remains at 10.6% of them (Figure 1-1-25)[1]. The percentage of researchers who plan to conduct research abroad in the near future is only 2.0%, a number lower than in the past, which clearly indicates that Japanese researchers are introverted Figure 1-1-26.

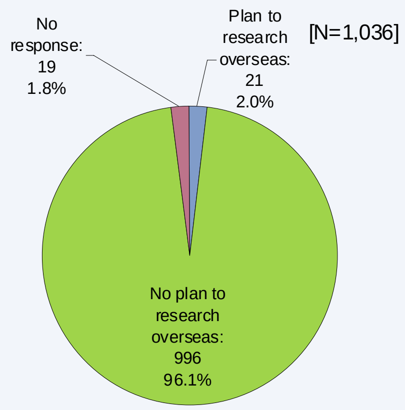
Figure 1-1-25 Presence or Absence of Transfer Experience and Work Experience Overseas



Note: Fiscal year is the time investigated.
Source: National Institute of Science and Technology Policy and MEXT *Survey on Mobility of Science and Technology Researchers in Japan (Report No. 163)*

1 The first and second authors of the academic papers listed in 2005 in JSTPlus (generic name of the academic literature database file contained in the JST Online Information Systems offered by Japan Science and Technology Agency) were regarded as researchers, and 2000 among these were extracted at random for stratification at a ratio of 30% for universities, 15% for public research institutions, and 5% for other institutions. Effective responses were 1036 with RR 51.8%.

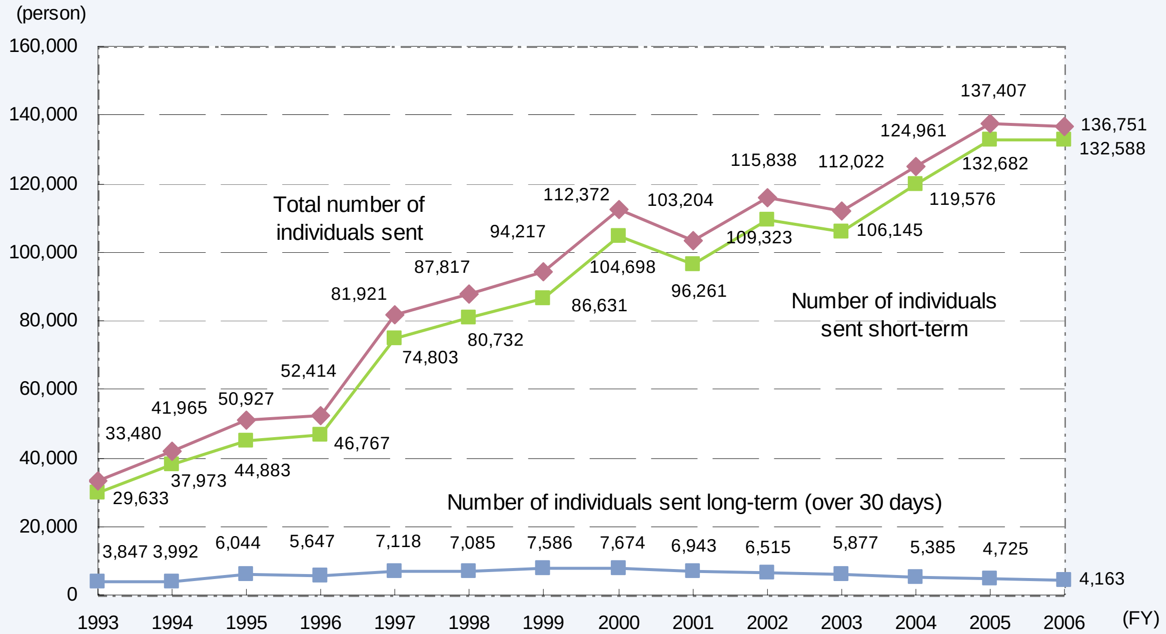
Figure 1-1-26 Presence or Absence of Plan to Research Overseas in the Near Future



Note: "N" refers to a total number of responders.
Source: National Institute of Science and Technology Policy and MEXT *Survey on Mobility of Science and Technology Researchers in Japan (Report No. 163)*

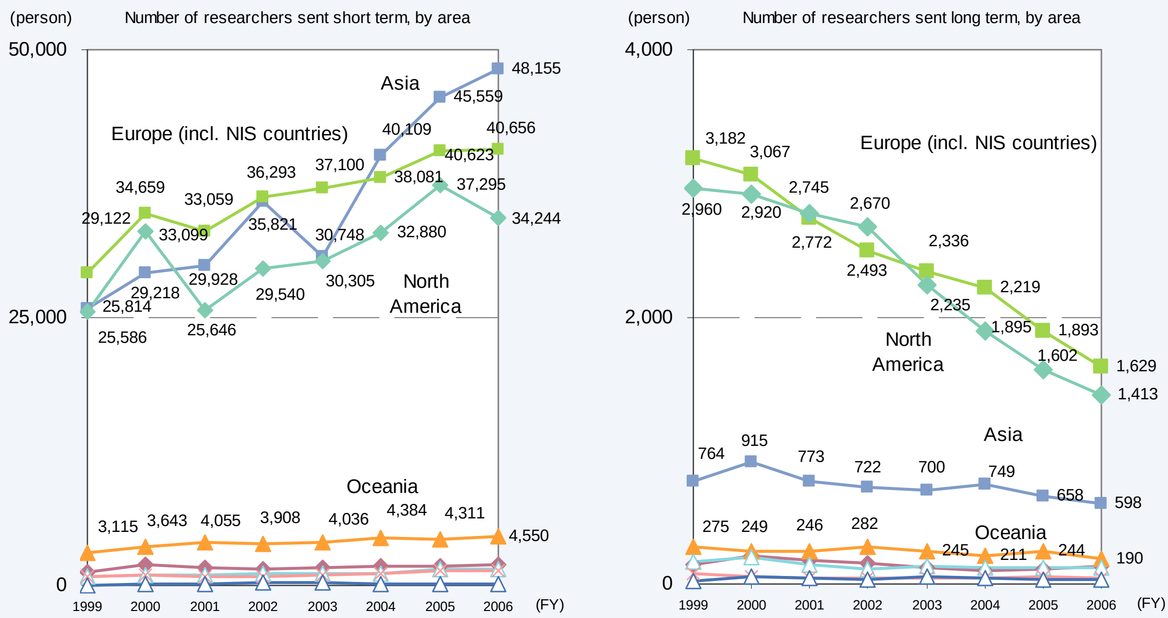
The total number of Japanese researchers sent to overseas countries tends to increase. However, the majority are short-term stays within 30 days. The researchers sent for long-term stays with the expectation of engaging in full-scale research activity and researcher exchange remain low and show a recent decrease (Figure 1-1-27). By region, the increase in short-term researchers sent to Asia and the decrease in long-term period of stay in Europe or the US are significant (Figure 1-1-28).

Figure 1-1-27 Trends in Number of Researchers Sent, by Period (Short and Long Term)



Prepared by MEXT

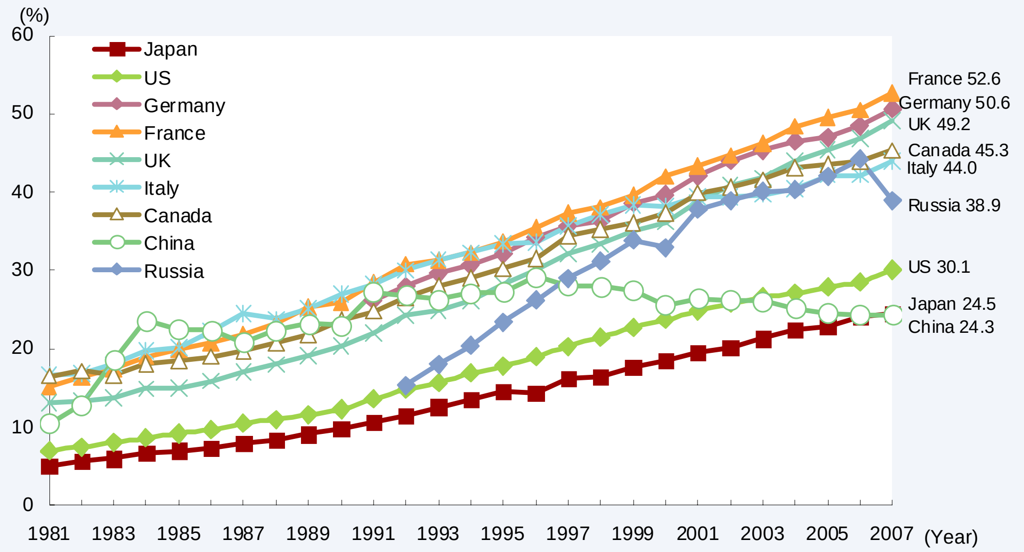
Figure 1-1-28 Trends in Number of Researchers Sent, by Area



Prepared by MEXT

In addition, the ratio of international joint papers in Japan is still lower than that in other major countries (Figure 1-1-29).

Figure 1-1-29 Trends in Ratio of International Joint Papers in Japan and Overseas

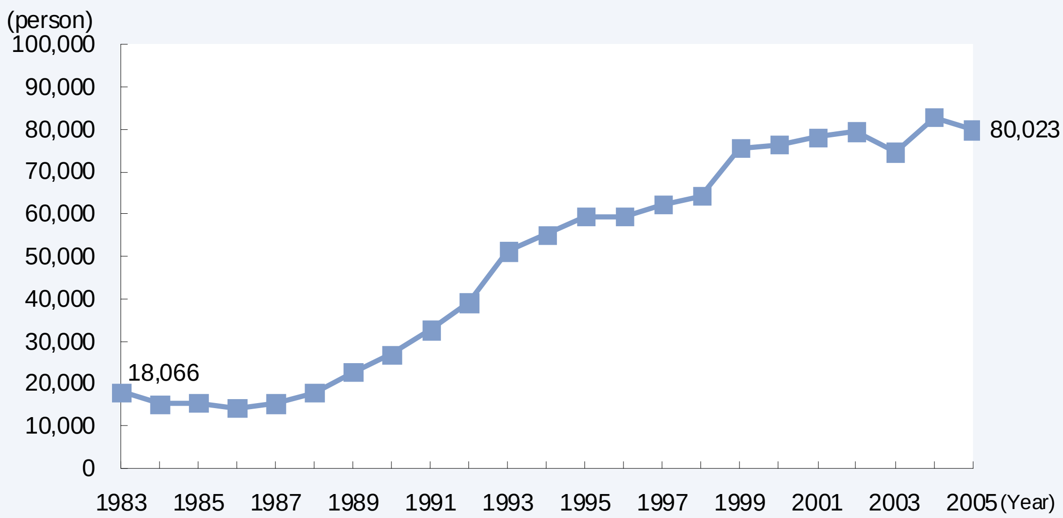


Source: National Institute of Science and Technology Policy *Science and Technology Indicators - Data updated in 2007 for 5th edition (Report No. 155)*

There is a trend towards introversion not only in researchers but students. The number of Japanese students studying abroad tended to increase prior to 1999, while it has remained flat in recent years (Figure 1-1-30). As described above, approximately 40 % of those who received S&E

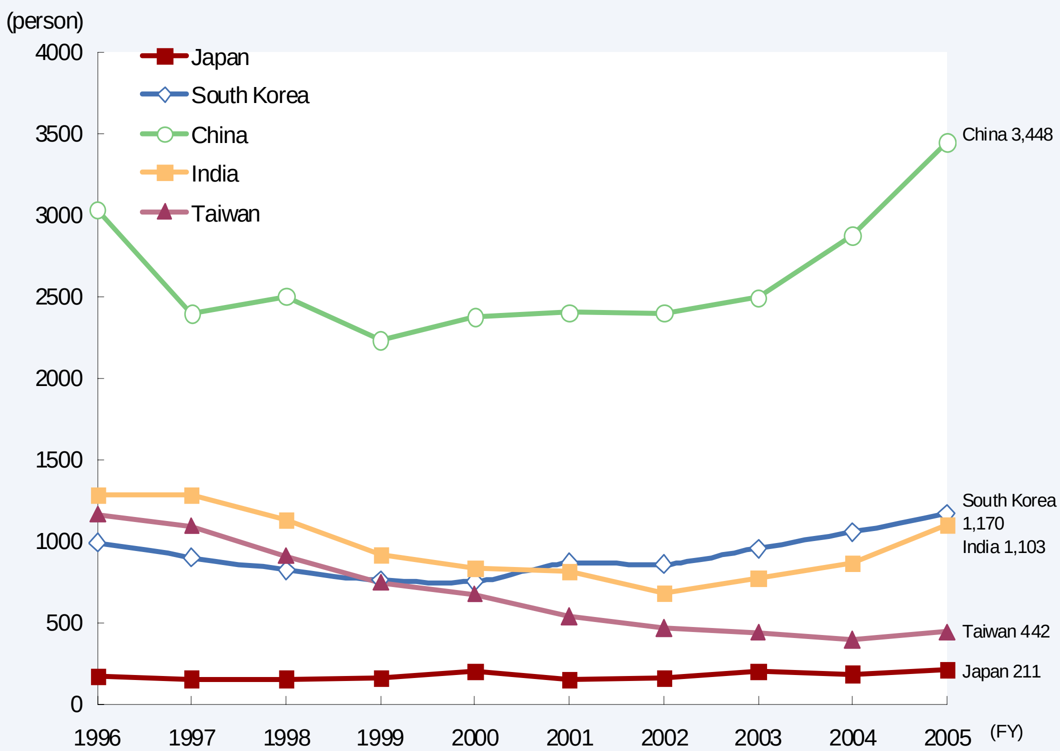
doctorates in the US are foreign nationals. These include around 200 Japanese remaining flat, while Koreans' or Indians' number is five times or greater; and Chinese, 15 times greater the number of Japanese doctorates awarded. These numbers are increasing every year (Figure 1-1-31).

Figure 1-1-30 Trends in Number of Japanese Students Studying Abroad



Source: Prepared by MEXT

Figure 1-1-31 Trends in Number of Asian Researchers S&E Doctorates Awarded in the US



Source: Prepared by MEXT based on National Science Foundation *Doctorates awarded 1996-2005*

Therefore, the numbers of transfer or dispatch of Japanese researchers overseas remains flat. There is a fear that Japanese researchers might be left out of the global network of researchers in a trend of increased international mobility.

3 Ideal Direction of Future Science and Technology

When examining the state of S&T policies, the role to be played by S&T is the first issue to be considered.

Finding solutions to global problems related to energy and environment having the potential to seriously impact the sustained development of the world economy is an important factor in ensuring the continuing survival of all human beings, and breakthroughs in S&T are indispensable in the search for such solutions. Japan must make use of its excellent energy and environmental technology to play a leading role in international society while ramping up efforts to enhance its technical capacity and global competitiveness.

Japan is also required to support the development of core industries that have strong global competitiveness and that contribute to the creation of new jobs and wealth in order to make a rich and fulfilling life possible for all its citizens. Monodzukuri can be called the mainstay of such industry. Recently, however, Japan has witnessed a major change in Monodzukuri the spread of modularization, which highlights the need to promote S&T to meet the new needs of Monodzukuri. Moreover, it is important to promote S&T for the advancement of the service industry, which accounts for approximately 70% of GDP and which is expected to be a future growth sector. As a result, an industry in next-generation needs to be created, which can be expected to create a large economic ripple effect comparable to the present automobile or electronics industries, and will lead to the creation of employment.

In addition, we should meet the diverse needs of the people, not only in the pursuit of material wealth but in the pursuit of a safe and secure society, and an improved quality of life. Science and technology are expected to make significant contributions in these areas.

All of this requires the establishment of a new R&D system through the implementation of appropriate measures such as the reinforcement of basic science capability that will become a wellspring of innovation and the creation of a globally attractive research environment open to all.