Section 2 Contribution of Science and Technology to Global Issues

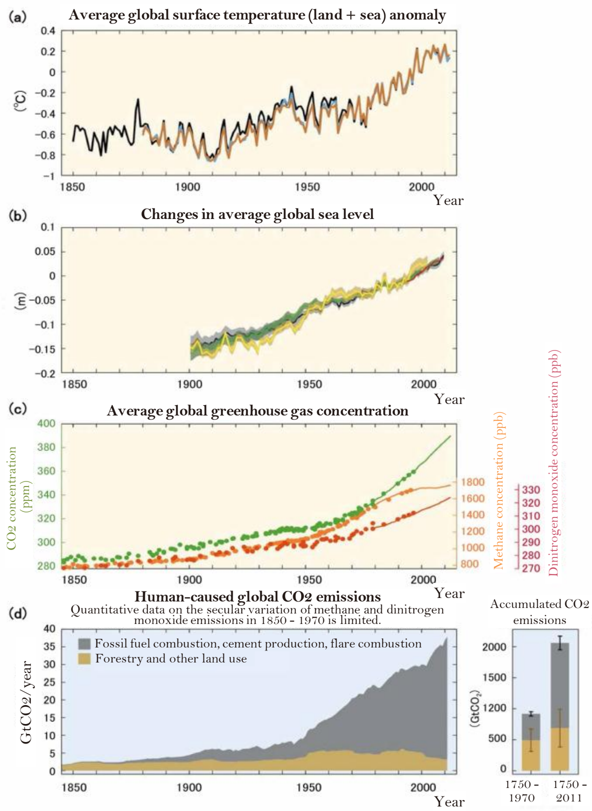
From the end of the 19th century to the 20th century, science and technology has rapidly advanced. Chemical industry, electrical industry and heavy industry and so on emerged and we have advanced forward to ages of mass production and mass consumption, when goods could be transported in bulk to distant locations for a short period, as physical distribution, including railways, cars and airplanes, developed. This accompanied the mass disposal of goods and mass consumption of energy, highlighting the risk of depletion of limited resources, global warming, the destruction of ecosystems and the crisis in the global environment.

Science and technology that changed our lives were explained in Section 1 of this chapter, but as well as changing our lives in terms of key daily lifestyle elements, science and technology are also crucial to solve global issues such as climate change, natural resource depletion and energy. There are significant expectations as to how science and technology can contribute to solve global issues. This section addresses the social contribution of science and technology in Japan domestically and internationally.

1 Contribution to Global Warming Countermeasures

○ Global warming state

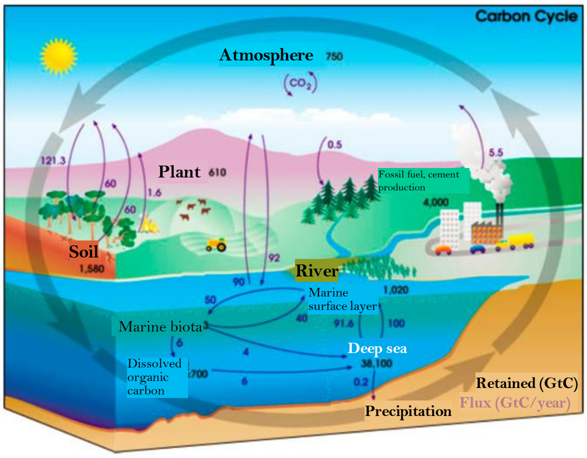
Climate changes caused by global warming are one of the most urgent problems which the world faces. The Intergovernmental Panel on Climate Change (IPCC)[1], awarded the Nobel Peace Prize in 2007, published the Synthesis Report of Fifth Assessment Report in 2014. The report said "Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems," and continued with a warning after presenting a deep insight, "Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems."



Data: IPCC Summary of the5th Evaluation Report for Decision-Maker
Translation: MEXT, METI, JMA, MOE

1 An organization founded by the World Meteorological Organization (WMO) and UN Environment Programme (UNEP) in 1988 to provide a comprehensive assessment of human-caused climate change, effect and adaptation and mitigation measures in scientific, technological and socioeconomic terms.

The atmosphere contains greenhouse gases, including carbon dioxide, methane and water vapor. Global warming is caused by the increased concentration of these gases in the atmosphere, which causes greenhouse effects. Carbon which composes typical greenhouse gases, carbon dioxide and methane circulates on Earth in various forms, in the air, plants, soil and sea. This phenomenon is called the "carbon circulation." Before the industrial revolution in the 18th century, the carbon circulation was balanced, but afterward, carbon dioxide in the atmosphere increased by about 40% due to the use of fossil fuels in human activities and the change of land use such as deforestation. The Fifth Assessment Report made several assumptions (scenarios) for future global warming countermeasures. Average global temperatures at the end of the 21st century increase in all scenarios. In the scenario assuming no more actions than present global warming countermeasures, it is predicted that an increase of global temperature will be about 4°C.



Schematic view of carbon circulation
Source: "Summary of IPCC Fifth Assessment Report" MOE

Scenario name	Countermeasure	Average (℃)	"Highly potential" prediction (℃)
RCP8.5	None	+3.7	+2.6～+4.8
RCP6.0	Low	+2.2	+1.4～+3.1
RCP4.5	Medium	+1.8	+1.1～+2.6
RCP2.6	Maximum	+1.0	+0.3～+1.7

Prediction of world average ground temperature rise at the end of the 21st century based on 1986 - 2005
Data: "Summary of IPCC Fifth Assessment Report" MOE

In Japan, phenomena which may be caused by global warming, such as damage to crops due to high-temperature injury, change of natural ecosystems and increase of drought and flooding risks have been observed. It is concerned that much further global warming will cause the quality loss of rice, the increase of the flood risk and the enlargement of distributional range of infectious disease vector in future.

There are two approaches to curb global warming: "Mitigation (emission reduction)" to restrict emissions of carbon dioxide and other greenhouse gases causing global warming and "Adaptation" to adjust our society and nature to the effects of global warming. Major science and technology to support "mitigation" include power generation and heat utilization using renewable energy such as solar light, wind, water, biomass and geothermal heat and developing and utilizing next-generation energy systems using hydrogen and fuel cells. Examples of "Adaptation" include flood and disaster control (e.g. evacuation systems and drainage functions) to increase the frequency of heavy rainfall and developing crops resistant to high temperatures.

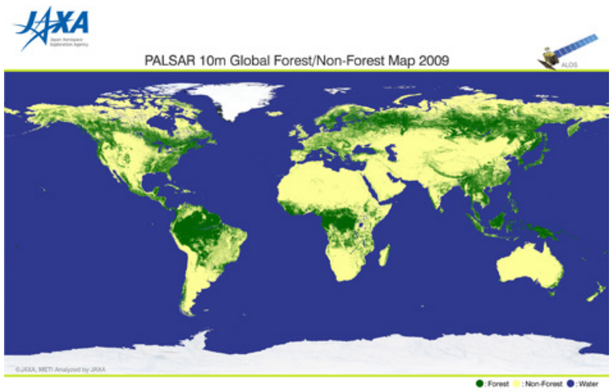
○ Contribution by global observation

Accurately understanding the current status of Earth is essential to find solutions and respond appropriately to global warming. Countries and organization worldwide observe the Earth, from satellites in space and observation stations on the ground and at sea to understand the current state of global warming. The Global Earth Observation System of Systems (GEOSS)[1] is an international system to share Earth observation data collected from these satellites and observing stations on the ground and at sea and the result of climate change prediction using accumulated data. The Group on Earth Observations (GEO) is an international framework to support GEOSS. 184 nations and organizations had joined GEO (as of February 2015), in which Japan plays a leading role as an executive committee member. GEOSS provides useful scientific knowledge, based on which member nations and organizations determine their policies, by consolidating observation data from various countries and conducting integration analysis of such data. GEOSS is a system allowing member nations and organizations to access and obtain easily the observation data and scientific knowledge owned by GEOSS. GEOSS defined the nine areas of disaster, health, energy, weather, water, climate, ecosystem, agriculture and biodiversity into societal benefit, setting goals in each case. Japan's contribution is found in the disaster, climate and water areas with the advanced land observation satellite "DAICHI" (ALOS) and the successor model "DAICHI-2" (ALOS-2), greenhouse gases observing satellite "IBUKI" (GOSAT) and marine observing ship "MIRAI."

<DAICHI (ALOS)>

"DAICHI" was launched in January 2006 as part of a JAXA project. It is one of the largest land observing satellites in the world (operation stopped in May 2011), performing detailed observation of land with three Earth-observing sensors, "Panchromatic Remote-sensing Instruments for Stereo Mapping (PRISM)" for reading topographical data on the land surface such as altitude, "Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2)" for observing land surface conditions and utilization of their lands and "Phased Array type L-band Synthetic Aperture Radar (PALSAR)" for enabling land observation day and night regardless of weather conditions

Forests absorb carbon dioxide and accumulate carbon through the photosynthesis. Deforestation therefore increases atmospheric carbon dioxide concentrations and accelerates global warming. In 2010, JAXA published a map sorting forested and non-forested areas worldwide, which is created at the resolution of 10 m based on picture data taken by DAICHI in 2009. The forest and non-forest map is composed of an enormous number of images, 86,000, taken by "DAICHI", but retaining quality as a large image without any trace of joint lines. Changes in the forested area are obvious when the images taken at regular intervals are compared. Comparing data on Amazon Para in 1996 and 2010 reveals a decrease in forested areas. Such a map is very useful, since it allows the general public to see changes in forested and non-forested areas at a glance, as well as national policy leaders and researchers, which raises

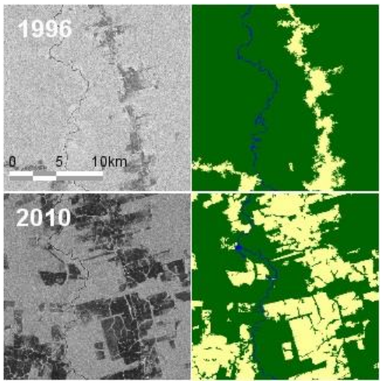


2009 Global Forest Map (green indicates forests)
Source: JAXA

1 A project started according to the heightened recognition of the importance of Earth observation. During the G8 Evian Summit in 2003, the former Prime Minister Junichiro Koizumi made a proposal to hold the 2nd Earth Observation Summit the following year in Tokyo, targeting the creation of framework documentation. Later, at the 3rd Earth Observation Summit in 2005, the "Global Earth Observation System of Systems 10-Year Implementation Plan" was adopted and the foundation of the GEO was agreed as an international framework to support GEOSS.

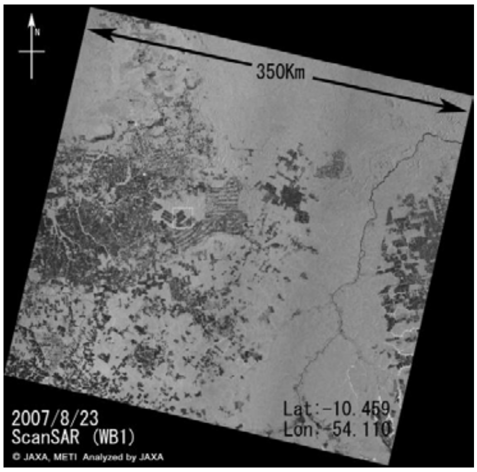
everyone's concern over global warming and boosts awareness to take action.

The following case is another example of data from "DAICHI" helping curb global warming: In 2007, JAXA made an agreement for a joint study with the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), which monitors illegal logging in Brazil and which distributed observation data of Amazon collected from "DAICHI". IBAMA developed a technique to identify deforested areas by comparing past data through technical aid of the Japan International Cooperation Agency (JICA) and implemented a system to take illegal logging groups into custody in cooperation with the Federal Police. The deforested area in Brazil drastically decreased from 14,000 km² in 2006 to 13,000 km² in 2008 and to 7,000 km² in 2009. This owed much to "DAICHI", which improved its function to monitor and deter illegal logging by taking forest images with all-weather sensor PALSAR, day and night year-round, including during the monsoon season, which covers more than half the year.



Comparison of Amazon Para in 1996 and 2010
Left images were taken by satellite and those on the right indicate forested and non-forested areas.
Data in 1996 was acquired from the "Earth Resources Satellite 1."
Source: JAXA

PALSAR IBAMA Made Arrests
IBAMA tightened control at the start of rainy season.
February 14, 2011



A typical image delivered to IBAMA (black parts are logged forest areas)
Source: JAXA

Now, the advanced land observation satellite "DAICHI-2", which took over "DAICHI" in 2014, supports disaster response by immediately distributing information on affected areas observed from space at the time of major disasters, including earthquakes and floods in Japan and Asia, as well as monitoring changes in forests. Four days after the Great East Japan Earthquake, the Tohoku region was blessed with fine weather and "DAICHI" revealed tsunami damage at the coasts of affected areas by only 10-minute observation. Helicopters were banned from flying over the TEPCO Fukushima Daiichi Nuclear Power Station just after the Earthquake and only satellites could observe the vicinity of the plant. "DAICHI" delivered images of land before and after the disaster to the disaster response personnel of the government and municipalities to help them estimate the damage in these areas and locate flooded areas and areas with rubble in the search of missing persons. It also supports various aspects of society, including maintaining and managing national land with national land information and ensuring safe voyage in the Sea of Okhotsk during winter by regularly monitoring the distribution of sea ice.

<IBUKI (GOSAT)>

The Greenhouse gases Observing SATellite (GOSAT) "IBUKI," launched in January 2009, is a world-first satellite for observing the concentration of carbon dioxide and methane from space. It is a joint project of JAXA, the National Institute for Environmental Studies (NIES) and MOE, each of which performs a share of the work. JAXA develops, launches and operates observing sensors and satellites. NIES is mainly responsible for high-order processing and distribution of data and MOE promotes the utilization of data.

Measures to drastically reduce global greenhouse gas emissions should be taken based on scientific information on the causes of emissions and the mechanisms for absorption and emission of greenhouse gases. The concentration distribution of greenhouse gases is observed at ground observation points and airplanes, but the number of observation points remains insufficient and they are unevenly located. In contract, "IBUKI" is capable of measuring concentration distribution of greenhouse gases regularly, once every three days, almost worldwide and estimating the absorbed and emitted amount of carbon dioxide and total methane balance more accurately. Data from IBUKI is opened to governments and research organizations worldwide to facilitate effective policy making to curb global warming in future.

Analysis of data obtained by the Greenhouse Gases Observing Satellite "IBUKI" for three years from June 2009 to December 2012 in big cities and surrounding areas revealed that carbon dioxide concentration in big cities tended to be higher than surrounding areas worldwide. Because the concentration differences of carbon dioxide and those computed from the amount of fossil fuel consumption correlated positively, the data captured by "IBUKI" is noted as one of the grounds for correlation between increases in fossil fuel consumption and carbon dioxide concentration. Greenhouse gas observation data from "IBUKI" is used in more than ten nations to forecast climate change, including computation of the carbon dioxide absorption and emission and evaluation of large-scale methane emissions.

2 Contribution to Resource and Energy Problems

○ The present situation of energy demand and supply

Primary energy self-sufficiency[1] in Japan is 6% (in 2013), suggesting almost all energy resources are imported. According to an estimation by the International Energy Agency, global energy demand in 2035 increases about 33% of demand in 2011.[2] A tight energy supply against rising demand is a global issue.

In Japan, energy-saving policies and products have been actively promoted in the industry following two oil crises in the 1970s, resulting in an increase of merely 1.3 times in the final energy consumption[3] overall

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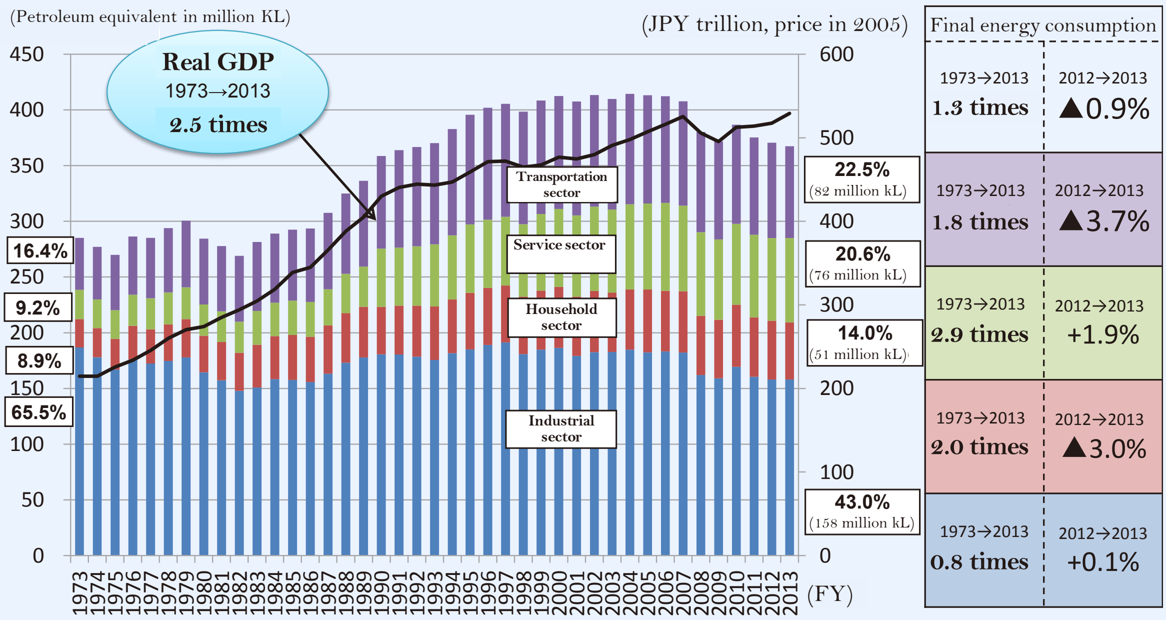
1 All energy required in Japan, including crude oil, coal, natural gas, various other energy supplied and losses in power generation and conversion to oil products.

2 "World Energy Outlook 2013"International Energy Agency

3 The amount of energy eventually used by consumers. Given the domestic supply of primary energy is 100, the final energy consumption is in the order of 69 (2012 Energy Statistics in Japan (Agency for Natural Resources and Energy (ANRE)))

during the period FY 1973 to 2015. The other side, the energy consumption in the transportation sector accounted for 16.4% in FY 1973 and 22.5% in FY 2013, an increase of 1.8 times (Figure 1-1-4).

■ Figure 1-1-4 / Change in Final Energy Consumption and Real GDP



(Note) The figures estimated from the input-output table (latest issue for results in 2005) and national accounting, etc. are used for part of the service and industrial sectors (non-manufacturers, food manufacturers, other industries, small- to medium-sized manufacturers) and short-term decreases in consumption in the service sector after the Great East Japan Earthquake are not completely reflected due to technical problems in statistics.

Source: Created by METI based on Energy Statistics in Japan, Annual Report on National Account and EDMC/Energy & Economic Statistics in Japan

The energy consumption in the service and household sectors increased 2.9 times and twice from FY1973 to FY2013, respectively. Carbon dioxide emissions in the transportation sector account for about 20% of all carbon dioxide emissions in Japan[1]. In addition alternative energy development in the transportation sector[2], which depends on fossil fuels such as gasoline and light oil, is important for diversifying energy sources in Japan which relies 99.7% on crude oil imports[3] to reductions in carbon dioxide emissions and global warming (mitigation),

○ R&D of next-generation automobiles and storage batteries

In the transportation sector, next-generation automobiles, including hybrid and electric vehicles, are expected to reduce carbon dioxide emissions. Hybrid vehicles are energized by either a gasoline engine or electric motor, while electric vehicles are driven only by electric motors and electricity is retained in a battery.

1 The total greenhouse gas emissions in FY 2013 in Japan were approx. 1.3 billion tons (carbon dioxide equivalent) (“2013 Greenhouse Gas Emissions” MOE)

2 “Energy Balance of OECD Countries 2014” International Energy Agency (IEA)

3 “FY2013 Annual Report on Energy” ANRE “Energy Balance of OECD Countries 2014” International Energy Agency (IEA)

Both hybrid and electric vehicles are equipped with a battery and motor, but the battery differs from that (lead storage battery) installed in conventional gasoline cars. The lead battery is the source of energy supplied to the electrical system of the car, but not large enough to drive the car. In contract, the battery used in electric vehicles is the core of the vehicle.

Storage batteries can be used repeatedly by recharging them. The lead storage battery, invented about 150 years ago, has been improved as the automobile industry has progressed and has long been used as the main storage battery on a wide scale. Recently, new lines of rechargeable batteries have been developed and commercialized. The main storage batteries currently on the market are: 1) lead-acid battery, 2) nickel-metal hydride battery, 3) lithium-ion battery and 4) NaS (sodium-sulfur) battery. Their applications vary, such as automobiles, consumer goods (mobile terminals, laptop PCs, etc.) and fixed systems depending on cost, capacity and other features. The main features and applications[1] of storage batteries 1) to 4) are described below:

1) Lead-acid battery: 150 years of history and result; low cost; used in automobiles (startup); emergency power supply for forklift trucks and hospitals.
2) Nickel-metal hydride battery: Long service life; rapid charge-discharge; used in consumer goods; hybrid vehicle applications (power supply).
3) Lithium-ion battery: Long service life; rapid charge-discharge; compact and high capacity; used in consumer goods (PCs); used in plug-in hybrid and electric vehicles (power supply).
4) NaS battery: Low cost; long service life; bulk storage; used with wind and large-scale photovoltaic power generation, etc.

Lead-acid battery

Lithium-ion battery

Nickel-metal hydride battery

NaS battery

Major storage batteries

Source: Lead-acid battery: (left) GS Yuasa International Ltd., (right) Hitachi Chemical Co., Ltd.
Nickel-metal hydride battery: (left) Panasonic Corp., (right) Toyota Motor Corp.
Lithium-ion battery: (left) Nissan Motor Corp., (right) TOSHIBA Crop.
NaS battery: (left and right) NGK INSULATORS, LTD.

Of these batteries, 2) nickel-metal hybrid battery and 3) lithium-ion battery are widely used as storage batteries for hybrid and electric vehicles. Storage batteries, which can store and carry electricity, have revolutionized our society.

1 "Future of the Rechargeable battery Industry" (May 2010) ANRE

One of the roles played by government to develop and disseminate storage batteries is to support R&D in national projects mainly implemented by NEDO.

In "Development of High-performance Battery System for Next-generation Vehicles" by NEDO, battery components and peripherals were developed as well as developing a storage battery with approximately 1.5 times the performance[1] and 1/7 the cost of current storage batteries (at the beginning of the program in 2015). All commissioned companies successfully developed their own storage batteries that met the target values using unique cathode active materials and continued R&D for commercialization.

Hybrid and electric vehicles accounted for around 5% of all vehicles in Japan as of the end of FY 2014. For full-scale dissemination of electric vehicles, a network of charging stations nationwide and a secure driving environment are required. METI plans "Promotion project of the charging infrastructure for next-generation vehicles."

○ Further contribution of storage batteries

R&D of storage batteries is crucial to achieve a low-carbon society; not only as the energy source of next-generation electric vehicles, but also as a system to help stabilize output from solar, wind and other renewable energy sources and retain surplus electricity and as the core equipment for the smart community[2]. The development of an innovative storage battery far superior to lithium-ion batteries is desirable.

At present, MEXT is conducting a project called "Specially Promoted Research for Innovative Next Generation Batteries" covering the whole process from basic study to the strategy required for commercialization. In this project, marketing of a new type of storage battery (10 times the energy capacity and 1/10 the cost of lithium-ion batteries) in the 2030s, to achieve an electric vehicle with driving capability and cost equivalent to conventional gasoline powered vehicles, as an alternative to lithium-ion batteries, which have theoretical limits of capacity and resources. METI is conducting R&D to ensure commercialization in collaboration with METI.

■ Table 1-1-5 / Major projects for R&D of rechargeable batteries

Implemented by:	Period (FY)	Project name
METI / NEDO	1992 - 2001	Development of technology for dispersed storage of battery power
	2002 - 2006	Technological Development of High Power Lithium-ion Battery for FCVs and HEV
	2006 - 2010	Project of the development of an electric energy storage system for grid-connection with new energy resources
	2007 - 2011	Lithium ion and Excellent Advanced Battery Development (Li-EAD)
	2011 - 2015	Research and Development Initiative for Scientific Innovation of New Generation Batteries(RISING)
	2010 - 2012	R&D of Practical and integrated Energy storage systems for smart community
	2011 - 2015	Renewable energy system oriented rechargeable battery system technology R&D project

1 Battery system weight energy density: 70 Wh/kg, battery system cost: ¥200,000/kWh for a battery pack of around 3 kWh capacity

2 An environmentally conscious city, where electricity produced by renewable energy such as solar and wind power is stored in a large rechargeable battery or electric vehicles and supplied to households as required. This power can be supplied during outages caused by casualty.

	2012 - 2016	Advanced lithium-ion battery application technology development
	2012 - 2014	Storage Battery Material Evaluation Technology Development
	2013 - 2017	Advanced and Innovative Storage Battery Material Evaluation Technology Development
	2013 - 2015	Project for advanced technology addressing surplus power generated by renewable energy
MEXT / JST	2012 - 2022	Elements Strategy Initiative, Field of Catalyst and Rechargeable Batteries
	2013 -	Strategic Basic Research Program, Advanced Low Carbon Technology Research and Development "Next-generation Batteries (Specially Promoted Research for Innovative Next Generation Batteries)"
Cabinet Office	2009 - 2013	Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST): Innovative Basic Research Toward Creation of High-performance Battery

Column 1-6 R&D of Lithium-ion Batteries

The mass production of lithium-ion batteries for electronic devices such as computers and mobile phones allows us to use these electronic devices anywhere. Prompt and accurate information exchange, regardless of location, has also largely contributed to achieving an IT-based society. Mobile phones and other electronic devices, which are rechargeable with batteries and power generators, can be used in rural areas of developing countries, where electricity and books are mostly unavailable, to improve the literacy rate through reading books, prevent infectious diseases and deliver information on prevention of infectious diseases and on flooding, etc. From this perspective, lithium-ion batteries also help solve social issues.

The cathode materials of lithium-ion batteries currently available on the market include: 1) transition metal oxide (cobalt and nickel system oxides, etc.) and 2) olivine system (transition metals such as iron phosphate). Of the two systems, 1) transition metal oxide (cobalt, manganese and nickel systems.) was developed by (then) Prof. Goodenough of the Inorganic Chemistry Laboratory, Oxford University and Koichi Mizushima, Assistant of the Physics School, Faculty of Science at the University of Tokyo (now executive fellow, General manager of Yoshino Laboratory, of Toshiba Research Consulting Corp.) in Japan and others. The paper was presented in 1980. The anode materials include polyacetylene, a conductive plastic used as an anode by Akira Yoshino, then head researcher of the Research Institute, Asahi Dow Co., Ltd. (now fellow of Asahi Kasei Corp.) and others in 1981, but the problem was its instability. In 1985, Yoshino et al. developed a lithium-ion battery using carbon materials, since which time carbon-based lithium-ion batteries have become the mainstream. Japanese researchers have discovered important elements of lithium-ion batteries from the R&D phase to the commercial stage. A world-first commercial lithium-ion battery was put on the market by a Japanese manufacturer and Japanese-made lithium-ion batteries overwhelmed global markets with their high technological power and market share from the 1990s to the first half of the 2000s. With accelerated technological catch-up of manufacturers in emerging countries, their price competitiveness with low costs and increased appreciation of overseas application in markets, the market-leading spot occupied by Japanese lithium-ion batteries was overtaken by Korean counterparts at the beginning of the 2010s. Market formation, including technological power to produce innovative storage batteries, high added values in application and infrastructure services and systems is a key to maintaining Japanese competitiveness in new large storage battery markets targeting hybrid and electric vehicles, renewable energy systems and smart houses.

○ Appearance of fuel-cell vehicles

On December 15, 2014, Toyota Motor Corp., started marketing fuel-cell vehicles, which are driven by the chemical reaction (oxidation) of hydrogen, stored in the on-board fuel cell, with oxygen in the air. Energy is produced in the reverse process of "electrolysis of water"[1], which every child learns in science at junior high school. Fuel-cell vehicles are called the "ultimate eco-car" because the water produced by chemical reaction is only the substance discharged from moving vehicles.

Fuel-cell vehicle
Source: Toyota Motor Corp.

The above-mentioned electric vehicles also use no petroleum. Although having a battery which is rechargeable at home is advantageous, electric vehicles do have disadvantages in terms of limits on the storable amount of energy and short ranges compared to fuel-cell vehicles. In addition, recharging takes time. Fuel-cell vehicles using high-pressure hydrogen travel more than 500 km between charges and charging takes merely three minutes[2]. Fuel-cell vehicles can also supply electricity generated by hydrogen to other devices, with a potential supply about five times greater than electric vehicles[3]. The supplied electricity can be used as emergency power during disasters, or to mitigate any increase in on-peak power demand during times of tight supply.

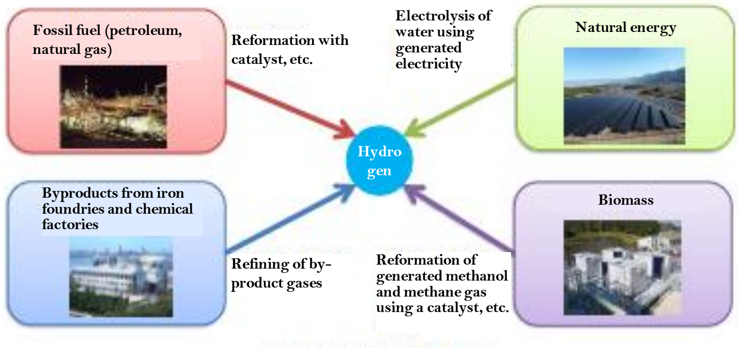
However, fuel-cell vehicles also face a big hurdle in dissemination, since the dissemination of fuel-cell vehicles and installation of hydrogen stations result in a chicken-and-egg dilemma. Hydrogen stations are crucial for disseminating fuel-cell vehicles, but the cost of constructing such a stations is very high, 400 - 500 million yen[4] while a conventional gas stations cost less than 100 million yen. To increase the number of hydrogen stations to a level equivalent to gas stations, around 35,000[5], dissemination of fuel-cell vehicles is essential. To overcome this dilemma, Toyota Motor Corp., announced the free use of its fuel-cell vehicle-related patents (about 5,680 patents solely owned by Toyota Motor Corp.) by 2020 less than a month after marketing its fuel-cell models, targeting efforts by other companies to develop fuel-cell vehicles and increasing the number of fuel-cell vehicles and hydrogen stations. The government launched to promote its efforts toward realizing a hydrogen-based society in the Strategic Energy Plan in April 2014. METI provides subsidies for constructing hydrogen stations from FY 2013 while deregulating for their installation.

The way in which hydrogen fuel is produced and supplied is another issue to address. Hydrogen is currently used for petroleum refineries, semiconductor manufacturing and processes in the metal industry, among others. This industrial hydrogen is produced mainly by steam reforming procedures, in which heat produced from fossil fuel is added to fossil resources such as methane and coal. This method causes carbon dioxide emissions in the production process. The electrolysis of water is also used to produce hydrogen, but

1 Oxidation-reduction reaction of water, in which water resolves into oxygen from an anode and hydrogen from a cathode by applying voltage
2 "Strategic Road Map for Hydrogen and Fuel Cells " (June 23, 2014), Council for a Strategy for Hydrogen and Fuel Cells, METI http://www.meti.go.jp/english/press/2014/0624_04.html、https://he-il.facebook.com/FPCJapan/posts/671399259615354
3 "Strategic Road Map for Hydrogen and Fuel Cells" (June 23, 2014), Council for a Strategy for Hydrogen and Fuel Cells, METI
4 "Strategic Road Map for Hydrogen and Fuel Cells" (June 23, 2014), Council for a Strategy for Hydrogen and Fuel Cells, METI
5 "Changes in Number of Filling Stations" (end of FY 2013) ANRE

on a smaller scale. Considerable energy (electric power) is required to resolve water into hydrogen and oxygen and when electrical power is generated from fossil fuel, carbon dioxide emissions are inevitable.

METI has been investigating the future prospect of hydrogen supply and demand while taking the costs of various hydrogen production and distribution methods and their effects on the environment into consideration. For instance, a large amount of hydrogen is contained in the byproduct gases emitted in the process of work at an iron foundry or chemical factory. These byproduct gases are mainly consumed by the factory as self-supplied fuel in Japan, but hydrogen extracted from surplus byproduct gases can be distributed elsewhere as required, or recaptured and refined to produce more hydrogen. According to a survey commissioned by NEDO[1], the hydrogen demand in 2030 is estimated at around 3 billion Nm^2/year[2] in Japan if hydrogen is used only for fuel-cell vehicles and home fuel cells (excluding self-supply demand in factories), while hydrogen that can be refined or produced from surplus byproduct gases or excessive hydrogen production capacity[3] at oil refineries is estimated at around 12 to 18 billion Nm^2/year, which may sufficiently meet energy demand.



Various hydrogen production methods

Source: "Strategic Roadmap for Hydrogen and Fuel-cells" METI

○ Toward a "hydrogen society"

R&D targeting a full-scale "hydrogen society", which not only uses hydrogen to develop fuel-cell vehicles and obtains surplus hydrogen from byproduct gases at factories, but also produces hydrogen without carbon dioxide emissions as the sole means of power generation. Hydrogen power generation technology is expected to be used to implement a clean power generation system without emitting carbon dioxide in a resource-poor country like Japan. As a practical example, hydrogen is produced overseas by electrolyzing water using electricity produced from renewable energy in spacious premises, or reforming from unused fossil fuel obtained on site using a technique to capture carbon dioxide[4] , while reducing the environmental load. The hydrogen produced in this manner is then liquefied, transported to Japan by tanker and used for power generation at hydrogen gas turbine plants. A large amount of hydrogen can be transported over a long distance and stored for an extended period by liquefying it at ultra-low temperatures or combining with organic matter, which can help overcome restrictions on location and time affecting electricity. Hydrogen gas turbine plants[5] and techniques to transport and store liquid hydrogen in bulk has been developed by companies in Japan. The energy carrier R&D in the "Strategic Innovation Promotion Program" by the Cabinet Office also supports research to promote these efforts. In the "Strategic Road Map for Hydrogen and Fuel Cells" created by METI in June 2014, an affordable, stable

1 "Feasibility Studies Research on the recent status for supply and demand of Hydrogen and Future Prospects" http://www.nedo.go.jp/library/seika/shosai_201311/20130000000462.html (Commissioned by NEDO to Mizuho Information & Research Institute, Inc.)
2 Nm^3 is a unit indicating the real volume of a gas, independent of pressure, temperature and humidity.
3 Hydrogen used for refining petroleum at the refinery is made by the hydrogen manufacturing system at the refinery.
4 Carbon Dioxide Capture and Storage (CCS) technology
5 "Hydrogen" or "hydrogen + other fuel" is burnt in the gas turbine to rotate the generator which produces electricity.

and totally carbon dioxide -free hydrogen supply system is intended to be established by around 2040.

3 Contribution to Infectious Disease Countermeasures

The battle between humans and infectious diseases has a long history. Smallpox was highly infectious and feared as a terminal disease since the pre-Christian Era. In the plague epidemic in Europe in medieval times, one in three is said to have died. The disease was feared as "Black Death" because the dead skin turned black. In 1918, Spanish flu raged worldwide as a novel influenza, affecting an estimated 600 million of the total global population of 1,800 million, 20 to 40 million of whom died.

After the 18th century, however, the development of vaccines and discovery of antibiotics largely improved the prevention and treatment of infectious diseases. The planned inoculation of the smallpox vaccine[1], developed in the 18th century, led to a declaration by the World Health Organization (WHO) that smallpox had been eradicated. As typically shown by these examples, infectious diseases no longer seemed a threat to humans with vaccines and antibiotics. However, so-called emerging infectious diseases[2] such as HIV (human immunodeficiency virus)/AIDS (acquired immunodeficiency syndrome), Ebola virus disease, SARS (severe acute respiratory syndrome), highly-pathogenic avian influenza and so-called re-emerging infectious diseases[3], including tuberculosis, malaria, dengue fever, rabies and drug-resistant bacteria still cause widespread fatalities.

In particular, the recent development of automobiles, airplanes and other means of transportation enables the extensive and prompt movement of large numbers of people and animals, which cause infections (natural hosts[4]), allowing the pathogens to spread much more quickly. In addition, raw lands untouched by humans have drastically changed by the development and the chance of humans to come into contact with unknown pathogens has increased and alongside it, the threat of infections. Effective prevention, treatment and diagnosis method are unavailable for many emerging diseases. R&D in this area is expected. The role of science and technology in contributing to establishing countermeasures for infectious diseases was highlighted with the SARS epidemic in 2002 and 2003, which affected many countries and regions.

○ SARS

On November 16, 2002, the first serious viral pneumonia patient was found in Guangdong province in the south of China and the disease spread worldwide from February 2003. 8,096 patients and 774 deaths were reported in 29 countries and regions before the WHO declared the termination on July 5, 2003.[5]

In March 2003, the WHO named this serious respiratory disease of uncertain origin "Severe Acute Respiratory Syndrome (SARS)," and established a WHO-SARS multicenter collaborative network comprising nine countries and 11 research institutions (later increased to 13 institutes) to identify the pathogen and establish diagnosis methods. Dr. Gro Harlem Brundtland, then WHO Director-General,

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1 Patients were searched and if found, smallpox vaccination (small pox shot) was given to the people around the patients according to "WHO Smallpox Eradication Program."

2 "Infections having increased in the last 20 years, or estimated to increase or newly approved in near future" according to the definition by WHO

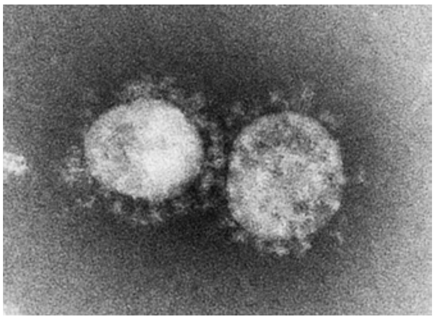
3 "Infections used to pose substantial threat and believed to be conquered once, but becoming a big problem again" according to the definition by WHO.

4 Animals coexisting with pathogens in natural world. Pathogens don't act to threat the life of natural host inside the body of natural host. Many of emerging infections are said to be originated from animals or natural hosts.

5 "Infection diseases whose incidence in humans has increased during the last two decades or which threatens to increase in the near future " (as of December 31, 2003), WHO

said "This syndrome, SARS, is now a worldwide health threat. The world needs to work together to find its cause, cure the sick, and stop its spread." The National Institute of Infectious Diseases in Japan participated in this network and was designated as the reference laboratory in West Pacific region. After exhaustive efforts of member institutes, which closely shared information about research results through the network, a new coronavirus was found to be the pathogen of SARS in a remarkably short time, about a month.

SARS coronavirus micrograph and SARS characteristics



Source: NIID

SARS is a novel infection with unknown SARS coronavirus as the pathogen, and develops normally 2 to 10 days after infection. Symptoms are fever over 38°, cough, short breath and other respiratory symptoms and breathing difficulty. Fatality is close to 10%. The virus infects others who swallow viruses scattering by sneezing of a patient, or touching phlegm or body fluid of a patient, but can be terminated with normal antisepsis (e.g. ethanol).

In Japan, the Council for Science and Technology Policy (CSTP) designated research into SARS diagnosis and inspection as an emergency R&D issues subject to the Special Coordination Funds for Promoting Science and Technology on May 12, 2003 and R&D of diagnosis method and vaccine were conducted. The early symptoms of SARS were difficult to distinguish from flu and vaccines and cure were not established either. Correct and early diagnosis and patient isolation were important to prevent the epidemic. The RT-PCR method was available at the time. This method involves detecting viruses by increasing the virus gene contained in fluids sampled from the nose or throat of patients. It took more than half a day to obtain the results and the detection sensitivity was poor. In some cases, patients with negative results were, in fact, infected by the disease. Masato Tashiro, director of Department of Virology III of the National Institute of Infectious Diseases (now emeritus researcher) and others developed a reliable and simplified diagnosis kit that could detect the SARS coronavirus efficiently within an hour, in collaboration with Prof. Koichi Morita (now dean) of virology, Institute of Tropical Medicine, Nagasaki University and Eiken Chemical Co., Ltd. This diagnosis kit was distributed to the quarantine station located at airports and municipal health institutes, etc. nationwide to prevent SARS invasion into Japan at the point of entry and the spread of infection where the for viruses invaded the country. The kit was supplied to Southeast Asian nations to control the SARS. On December 18, 2003, MHLW approved the manufacture of the kit and made it generally available. The cost of examination by use of the kit has been covered by health insurance.

After the WHO declared its termination of outbreaks, a further 14 SARS patents were reported worldwide[1]. Under these circumstances, the repeat of a SARS epidemic is still possible. RIKEN announced the discovery of a compound that could inhibit the growth of the SARS coronavirus in September 2004 as part of "Protein 3000 Project" of MEXT (FY 2002 to FY 2007). RIKEN simulated the binding of proteins and compounds based on the 3D protein structure of this virus required for replication and a database containing about 1 million compound structures and selected more than 100 compounds as candidate antiviral drugs. Later, the Tokyo Medical and Dental University and National Institute of Infectious Diseases estimated the virus replication suppression activity of compounds selected by RIKEN using monkey cells infected with the SARS coronavirus and identified a compound having significant virus

1 "Global Alert and Response: Severe acute respiratory syndrome(SARS)" (as of May 18, 2004), WHO

breeding inhibitory activity. The practical application of SARS drugs is now underway.

This study approach was successful in highlighting candidate compounds for new drugs in a short time using computers and also contributed to R&D of the SARS coronavirus. It is also expected to be useful for R&D of other emerging infectious diseases requiring prompt action.

Fortunately, no SARS patient was found in Japan, but SARS epidemic clearly showed the importance of R&D in identifying the pathogen and diagnosis, treatment and prevention procedures in a crisis response for the global epidemic of unknown viruses.

Column 1-7 Contribution to preservation and restoration of world heritage

Japan has ceaselessly contributed to the international community through science and technology as one of the global front-runners, including maintenance and restoration of the world's cultural heritage. The Historic Sanctuary of Machu Picchu and Nazca Lines in Peru are cited as examples of activities using the KAKENHI.

Prof. Tadateru Nishiura of the Institute for Cultural Studies of Ancient Iraq, Kokushikan University and others conducted research to appropriately maintaining the monument while utilizing the Machu Picchu site as a forum for education and tourist resources in cooperation with the Ministry of Culture in Peru. Specifically, they strove to accurately understand the deterioration of the site such as damage to stone materials and deformation of the stone-lined walls of the "Sun Temple," as the core of the monument, using 3D measurement and stereo photo surveys[1] and provided a maintenance/restoration manual containing optimum materials and techniques through various field surveys and experiments. Academic discussions and meetings with the Peruvian government, UNESCO and other related parties are necessary to establish a maintenance and restoration project based on the outcome of this research.

Since 2004, Prof. Masato Sakai and Prof. Emeritus Isao Akoshima of the Faculty of Literature and Social Science, Yamagata University and others have created a distribution map of Nazca Lines in the entire Nazca Plateau ranging approximately 20 x 15 km by analyzing high-resolution images taken by a commercial satellite of the U.S and on-the-spot investigation. In this process, they discovered more than 20 new animal and other images and more than 100 figures and at present, recorded details by on-site 3D measurements. They also analyzed traces of flooding using the advanced Japanese land observation satellite "DAICHI." The outcomes can be used to protect the Nazca Lines from flood and artificial manipulation and prevent land development without knowing the existence of images and figures. Yamagata University founded a research institute in Peru in 2012 and concluded an agreement for the study and protection of the cultural heritages with the Ministry of Culture in Peru in 2015.

As mentioned above, Japan's science and technology have helped maintain and restore global cultural heritage. Cultural heritage is a valuable asset to all humans and cooperation in protecting it using knowledge, technologies and experience accumulated in Japan helps diversified global cultures develop, as well as improving the international status of Japan.

Section 3 The Contribution of Science and Technology to Economic Growth

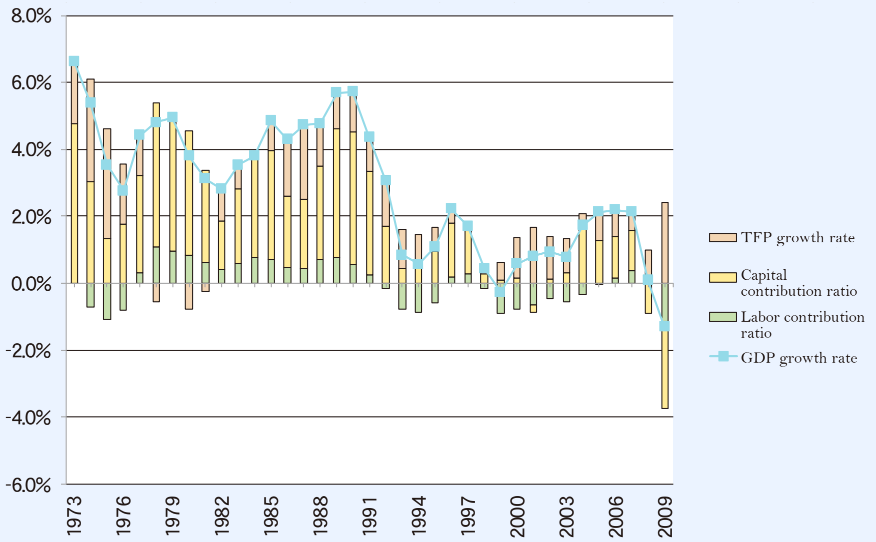
Science and technology impact on the society and economy when valuable R&D's outcomes are commercialized. Generally, it takes a long time to receive the economic benefits from the outcomes. Nevertheless, Science and technology development increases not only short-term market demand but also long-term firm's productivity of the national economy. It also creates other various social benefits

1 The technology to record an object in three dimensions by taking multiple photos

including the safety, security of people, cultural values, etc. In this section, we focus on the effects of science and technology on economic growth, particularly the growth of the national economy[1].

The concept of growth accounting, in which the economic growth rate can be divided by the contribution ratio of different factors, is very useful to understand the relation between science and technology activities and national economic growth. Economic growth rates can be broken down to the contribution of labor input, capital input (capital investment) and (Solow's) residual which is also called Total Factor Productivity (TFP) (Figure 1-1-6).

■ **Figure 1-1-6 / Decomposition of the Japanese economic growth**



Note: The operation rate and total actual working hours are taken into account in the capital and labor, respectively.
The input share of labor is assumed to be 0.6.
The growth rate in the above data is given by the moving average for three years.

Source: Created by MEXT and the Science, Technology and Innovation Policy Research Center , National Graduate Institute for Policy Studies based on "Investigation and Research on the Introduction of Science, Technology and Innovation Policy into Macro Economy Policy System " NISTEP DISCUSSION PAPER No. 226 ("Science of Science, Technology and Innovation Policy" mission-oriented investigation and research in the Science, Technology and Innovation Policy) (October 2013), National Institute of Science and Technology Policy.

In Japan, aging society with declining birth rate has a negative effect on labor input and capital input has gradually declined after the mid-1990s. Therefore TFP becomes more important for the national economic growth. Japan's TFP growth rate declined from the 1970s to the late 1990s, and slightly recovered thereafter.

TFP is the index not only for the fruits of R&D activities but also for whole productivity improvements which is based on a person's originality and ingenuity, accumulation of managerial know-how, etc. So it is difficult to measure the direct effect of R&D on TFP growth rate as in other things being equal, with using

[1] Many economists, including Masahiko Aoki, Kenneth Arrow (Nobel Economics laureate in 1972) and Edward Prescott (Nobel Economics laureate in 2004) cite the importance of TFP (total factor productivity) in economic growth and supporting knowledge accumulation.

only macroeconomic data such as R&D expenditure and TFP growth rate.

Recently, some approaches to study detailed relationships between variables using micro data of large-scale statistical survey are available. For instance, the Economic and Social Research Institute (ESRI) of the Cabinet Office analyzed the contribution of knowledge spillovers[1] for firm's performance and revealed that it is quite large that cannot be ignored[2]. This analysis uses firm-level microeconomic data in Japan from 1995 to 2005. ESRI's analysis also revealed that public R&D funding for private sector does not crowd out[3] private firm's R&D investment on average, and moreover, specific field such as the environment and information and communication technology, public R&D funding accelerate private's R&D activities.

The National Institute of Science and Technology Policy (NISTEP) analyzed the effect of R&D on economic growth and TFP, it is the most important factor of economic growth in Japan, and concluded that the government R&D investment pushes up TFP growth rate by the synergetic effect with R&D activities of private sector[4]. .

The NISTEP (mission-oriented investigation and research in "Science of Science, Technology and Innovation Policy") conducted quantitative analysis on the effect of R&D of companies, universities and public research institutes on the productivity of factories of manufacturing industry using "Census of Manufacturers"(METI) and "Survey of Research and Development" (MIC) from 1987 to 2007. In addition, this study focuses on the R&D's spillover effect of public research institutions (including universities) on the productivity of private factories as well. Figure 1-1-7 shows contribution ratio of TFP growth rate divided into four factors, contribution of corporate R&D, contribution of inter-company R&D spillover, contribution of public R&D spillover and contribution of other factors, every five years in 20 years. This result indicates that public R&D investment boosted firm's TFP growth through the last 20 years regardless of economic conditions, which means public sector contributed to increase economic growth rate of Japan. It seemed that government R&D investment supported the economy during the economic stagnation, which suggests its effectiveness for economic growth.

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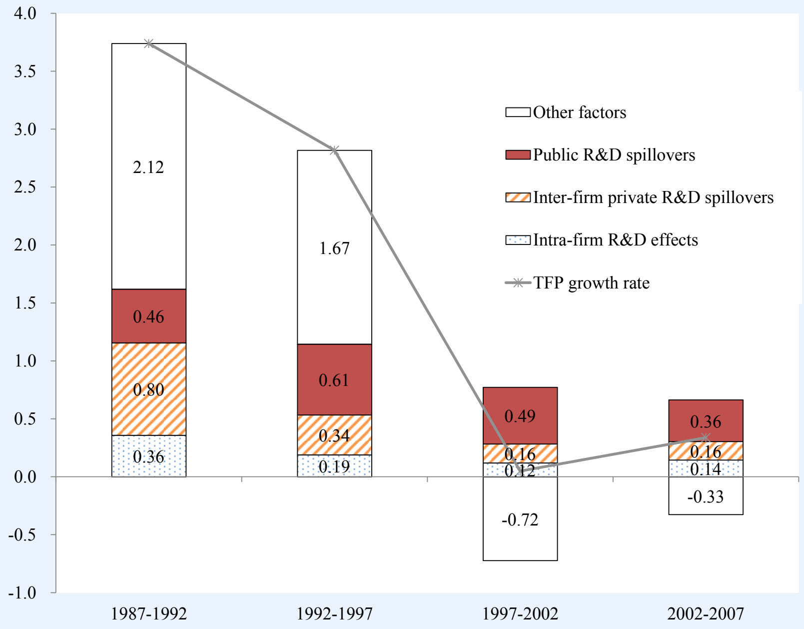
1 Effects of knowledge on the productivity of other economic entities through various routes.

2 "The Effect of Knowledge Spillover on Japanese Firm's Productivity" ESRI Discussion Paper Series No. 221, September 2009, Economic and Social Research Institute, Cabinet Office

3 The effect of a public R&D fund to decrease corporate R&D investment.

4 "Economic Analysis of Innovation Outcomes" (Investigation and Research concerning the Follow-up Study on 3rd Science and Technology Basic Plan NISTEP REPORT No. 119, March 2009, National Institute of Science and Technology Policy
The analysis of the effect of "R&D integration level," "the ratio between No. of researches and No. of employees" and "R&D integration level funded by public institutes" on the TFP growth rate using individual data from the Survey of Research and Development and Basic Survey of Japanese Business Structure and Activities confirmed the positive contribution of "R&D integration level" or "ratio between No. of researches and No. of employees" to TFP growth rate. Because the R&D cost is significantly low, the direct effect of "R&D integration level funded by public institutes" on TFP growth rate could not be found, but the analysis using cross terms led to a possibility of synergetic effect of "R&D integration level funded by public institutes" with "application research." The more the corporate attaches importance on information from universities and higher education facilities for innovation, the higher the TFP growth rate. This result suggests that the effect of TFP rise is greater if companies have contact with universities and public institutes.

■ Figure 1-1-7 / Breakdown of TFT rise rate factors for manufacturers (annual % point)



Note: The study revealed that:

1) Factory productivity is affected by both in-house R&D and R&D of other companies in proximity in technology and location.
2) The factory productivity is also affected by R&D of universities and public research institutions when the company is in the technologically related industrial area.
3) The effect of R&D of universities and public research institutions on factory productivity is greater when the company proactively promote in-house R&D.
4) Inter-company business and capital relationship improve R&D spillovers between the related companies.

Source: "Plant Location and Private and Public R&D Spillovers: Productivity Effects through Technological, Geographic and Relational Proximity" NISTEP DISCUSSION PAPER No. 93 (mission-oriented investigation and research in "Science of Science, Technology and Innovation Policy") (May 2013), National Institute of Science and Technology Policy

Also, there is ongoing detailed analysis of clarify the relationships between R&D activities, innovation and economic growth using individual data in statistic surveys. The Statistics Bureau of MIC conducted "Surveys of Research and Development" in compliance with OECD "Frascati Manual," and recently the National Institute of Science and Technology Policy conducted "Japanese National Innovation Survey"[1] based on the OECD "Oslo Manual." Studies based on these surveys are also underway.

The NISTEP uses the results of the "2nd Japanese National Innovation Survey" in 2009, and analyzes relations of government policies such as public funds and subsidies, R&D, innovation and productivity of emerging companies and mature enterprises. As shown in Figure 1-1-8, the analysis revealed that:

1) The R&D expenditure per employee of firms receiving public funds (tax deductions, subsidies) is greater than that of firms not receiving public funds.
2) When firms invest in R&D actively, probability to introduce innovation increase

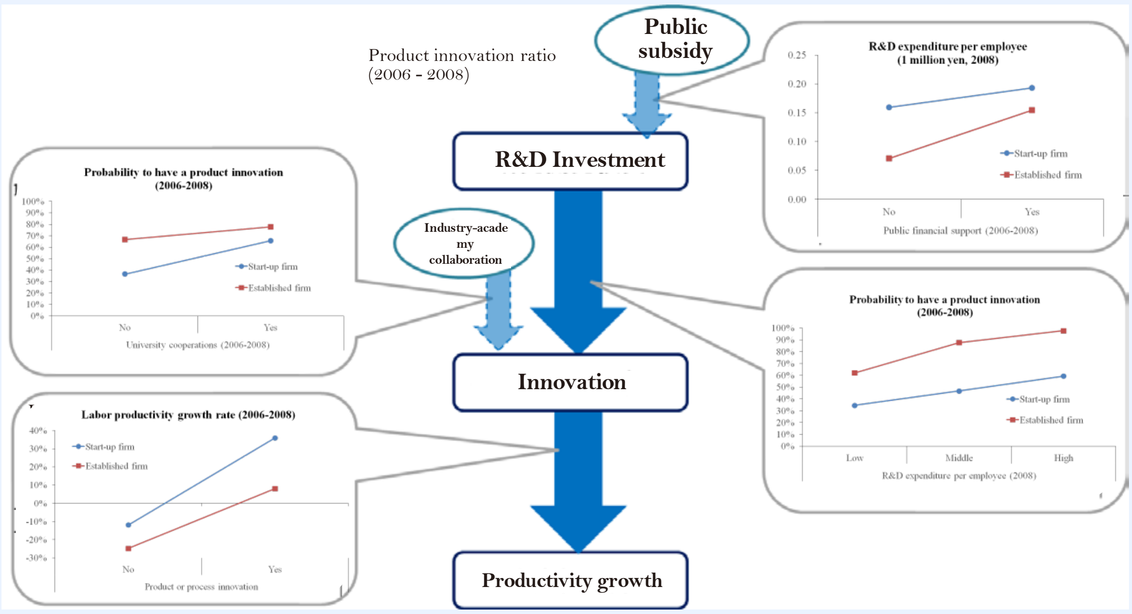
1 The national survey of innovation defines innovation activities as "the efforts such as design, R&D and market research required for development processes targeting innovative products or services, or improvement of work," product innovation as "introducing new or radically improved products or services for the company," and process innovation as "introducing new or radically improved production processes or delivery methods for the company."

3) When the firms collaborate with universities (particularly emerging companies), probability to introduce innovation increases.

4) Innovative firms have the benefits of higher labor productivity growth rate.

The effect of public funds by the government on corporate R&D is statistically significant and promotes innovation contributing to economic growth.

■ Figure 1-1-8 / An example analysis on the effect of public funds and industry-academy collaboration on productivity improvement



Note: The company not exceeding two years from foundation is defined as start-up firm and a company having a history of two or more years is defined as established firm.

Source: "R&D, Innovation and Business Performance of Japanese Start-ups: A Comparison with Established Firms" NISTEP DISCUSSION PAPER No.104 (December 2015), National Institute of Science and Technology Policy

OECD published an international comparison of the effect sizes of R&D on innovation and productivity[1]. The analytical results showed that public funding for innovation activities promoted investment in innovation (R&D, ICT investment, education and training of employees, etc.) by the firms, and product innovation is strongly related to labor productivity.

These analytical results suggest the importance of governmental support for innovation as public funds. It encourages further innovation, and increases labor productivity.

Section 4 Major Scientific and Technological Events

The progress of science and technology has brought a convenient and affluent lifestyle. To give a familiar example, we used to buy train tickets at stations, but the ticket changed to a traffic IC card and we no longer buy a ticket each time we get on the train. The traffic IC card is usable not only for traveling but

1 "Innovation in Firms: A Microeconomic Perspective pp. 118-120" (2009), OECD

also shopping.

We used to look for a public telephone to call someone when we were out, or had trouble meeting someone outside. Now, we make or answer calls by mobile phone or smartphone. We can even access the Internet via a smartphone, which eliminates the need to carry around a heavy laptop computer.

On March 21, 2015, the Cabinet Office, Government of Japan announced a "Public Opinion Survey on the Social Awareness." According to the survey on the current situations of Japan, "Science and Technology" was ranked highest, accounting for 30.1% in response to the question of which areas may keep on the right track, suggesting that the public thinks positively about science and technology. For instance, for science and technology in the medical field, regenerative medicine developed rapidly after world-first human iPS cells had been created in November 2007 in Japan. In September 2014, retinal pigment epithelium made of iPS cells was transplanted to a patient suffering from age-related macular degeneration, which is an age-related disease of retinal pigment epithelium in the retina and incurable after developing. The successful transplant was a world-first and such progress of science and technology gives patients a great deal of hope.

Science and technology also sometimes touch our hearts. In September 1992, many people would be moved by images of the first Japanese astronaut performing experiments in the space shuttle, or in June 2010, the asteroid explorer "HAYABUSA" returned to Earth seven years after its launch and traveling 6 billion kilometers, despite many troubles.

The Great East Japan Earthquake in March 2011 followed by the accident at TEPCO Fukushima Daiichi Nuclear Power Station caused devastating damage. Four years on, many problems remain to be addressed.

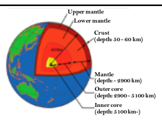
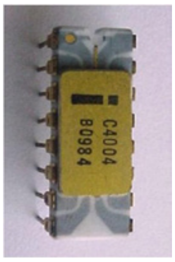
The total of evacuees from the areas under evacuation orders reached about 79,000 as of January 2015, meaning many people are still unable to return to their hometowns. 11 municipalities are included in areas directly decontaminated by government, but area-wide decontamination based on the decontamination plan had only been completed in 4 municipalities as of January 2015. Decommissioning of TEPCO Fukushima Daiichi Nuclear Power Station is assumed to take a long time and related organizations, departments and agencies tackle the R&D for decommissioning through mutual cooperation.

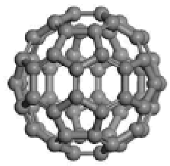
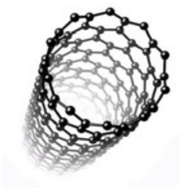
Recovery and reconstruction have made steady progress compared with the state immediately after the Earthquake, and efforts need to be continued in various aspects in future..

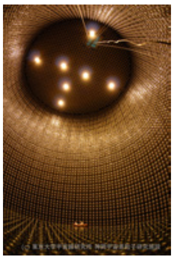
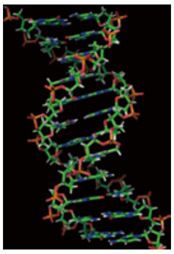
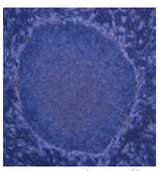
As mentioned in the "What the Science and Technology Policies should be in the Future in View of the Great East Japan Earthquake (suggestion)" made at the Council for Science and Technology (CST) held on January 17, 2013, several problems were highlighted in this earthquake. For instance, the administration and experts failed to provide accurate and timely information based on scientific and technological limitations and uncertainty, and did not engage in dialog with citizens concerning risks. They should seriously take people's concerns about nuclear power generation and disbelief in administration and experts, which arose during the disaster and which persist. The government, determined to remedy past mistakes, is currently striving to reconstruct and revive afflicted regions, including reconstruction from the nuclear power disaster, through the powerful promotion of science, technology and innovation while simultaneously encouraging understanding of, reliability in and support for science and technology, by increasing opportunities for sharing of scientific information and dialog on science, technology and society.

As can be seen in life sciences, consideration of ethical, legal and social issues arising from the progress of science and technology must be addressed. We must adjust more for relations of science, society and lifestyle as cyberspace develops and various innovative technologies are widely used. It is therefore important for all stakeholders, including citizens, policy makers and researchers, to participate in discussions on social systems and cooperate in taking measures necessary for solving various issues which may accompany the progress of science and technology.

Tracking recent developments in science and technology (from 1965 onward)

Year	Invention and discovery of science and technology	Social events relating to science and technology		Natural disaster and Law/policy on science and technology
		World	Japan	
1965 	• Observation of cosmic background radiation (U.S.)			
1966 Plate tectonics theory (Photo shows the Earth's internal structure)			• Start of commercial nuclear power generation • Development of interstitial free plate (IF steel)	
1967	• Establishment of the plate tectonics theory (U.K.: Mackenzie, et at) • Discovery of photocatalyst (Honda-Fujishima Effect) (Japan)	• First heart transplant operation (South Africa, Dr. Barnard)		• Enactment of Basic Law for Environmental Pollution Control
1969		• Moon landing of Apollo 11 (U.S.)		
1970 	• Invention of 1K-bit DRAM (U.S.)	• Effectuation of Treaty on the Non-Proliferation of Nuclear Weapons	• Japan World Exposition (Osaka) • Launch of satellite "OSUMI"	
1971	• Invention of 4-bit microprocessor (U.S.)		• Start of commercial production of carbon fiber	• Inauguration of the Environment Agency
1973 4-bit microprocessor	• Establishment of technology for genetic modification (U.S.: Cohen, Boyer) • Discovery of statin (Japan: Akira Endo et al.)			
1974	• Suggestion of possibility of ozone layer depletion by CFC (U.S.)			• Launch of the Sunshine Program
1975		• First personal computer in the market (U.S.)		
1976		• Genetic Modification Guideline discussed at Asilomar Conference (U.S.)		
1977  Discovery of statin (Photo: Drugs for hypercholesteremia)		• The last smallpox report (Somalia)	• Sales of personal computers • Launch of stationary weather satellite "HIMAWARI"	

				• Development of VLSI (IC)	
1978			• Birth of first test-tube baby(U.K.)		
1979		• Invention of digital signal processor (U.S.)	• Accident at the Three Mile Island Nuclear Power Plant (U.S.)	• Walkman goes on sale	
1981		• First clone of mammal (U.S, Switzerland)	• First flight of a space shuttle (U.S.)		
1982				• CD players go on sale	
1983		• Discovery of AIDS virus (France: Montagnier, U.S.: Gallo)			
1984		• Discovery of fullerene (U.K.: Kroto et al.)		• Start of satellite broadcasting	
1985	Fullerene (Photo: Model figure)	• Successful information transmission via optical fiber (U.S.)	• Sales of Windows (U.S.)	• The International Exposition (Tsukuba)	
		• Discovery of ozone holes (U.S.)			
1986		• Discovery of high-temperature superconducting phenomenon (Switzerland: Muller, Germany: Bednorz)	• Accident in Chernobyl nuclear plant (Soviet)		• Enactment of the Law for Facilitating Governmental Research Exchange
			• Accident of space shuttle Challenger (U.S.)		
			• Start of space station “Mir” operation (Soviet)		
1987			• Montreal Protocol on Substances that Deplete the Ozone Layer	• Start of mobile phone services	
1988			• Establishment of IPCC		
	Carbon nanotube (Photo: Model figure)		• Start of commercial Internet (U.S.)		
1989		• p-type GaN blue LED (Japan: Isamu Akasaki, Hiroshi Amano)			
1990		• Invention of WWW (U.K.)	• Start of Human Genome Project (U.S.)		• Eruption of Mt. Unzen
1991		• Discovery of carbon nanotube (Japan: Sumio Iijima)			
1992			• United Nations Conference on Environment and Development (Brazil)	• First Japanese astronaut on board the space shuttle (Mamoru Mori)	
1993		• Production of human somatic cell nuclear transfer embryo (U.S.)		• Start of commercial Internet services	• Enactment of the Basic Environment Law
1994	H-II rocket	• Confirmation of top quark (U.S.: Fermi National Accelerator Laboratory)		• Launch of the H-II rocket	

1995		• Proving of mathematical conundrum Fermat's last theorem (U.K.) • Development of the nano microscope (Japan)	• Worldwide hit of Windows95	• Sodium-leak accident in fast breeder "MONJU"	• Enactment of Science and Technology Basic Law • The Great Hanshin Earthquake
1996		• Birth of clone sheep Dolly (U.K.)	• BSE problem (U.K.) • Adoption of CTBT	• Development of blue semiconductor laser	
1997			• Adoption of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (Japan)	• Sales of hybrid vehicle	• Enactment of the Organ Transplantation Law
1998	Confirmation of mass of neutrino (Photo: Super-Kamiokande)	• Confirmation of mass of neutrino (Japan: Super-Kamiokande)	• Start of constructing the International Space Station (Japan, U.S., Europe, Canada, Russia) • Foundation of Google (U.S.)		
1999			• World Conference on Science, Budapest Declaration (Hungary)	• Experimental observation of SUBARU Telescope (Hawaii) • First organ transplant from brain-dead person • JCO critical accident in Tokaimura	
2001	 Human genome decoding (Photo: Model figure)		• Withdrawal of U.S. from the Kyoto Protocol • Sales of iPod (U.S.)	• First BSE patient in Japan • Start of general use of ETC • Start of IC card boarding ticket service	• Restructuring and Reorganization of government ministries and agencies • Setup of the Council for Science and Technology Policy • Transformation of national research institutions into incorporated administrative agencies
2002		• Success of rice genome decoding (Switzerland, U.S.)	• World Summit on Sustainable Development (South Africa)		• Enactment of Basic Law on Intellectual Property
2003		• Completion of human genome decoding (Japan, U.S., Europe)	• SARS pandemic	• Bird flu epidemic • Start of digital terrestrial broadcasting	
2004	 Human iPS cell		• Foundation of Facebook (U.S.) • Presentation of Palmisano Report on the promotion of innovation (U.S.)		• Transformation into the national university corporation • Sumatra Earthquake/Indian Ocean Tsunami

2005			• Effectuation of the Kyoto Protocol • Determination of planned construction site of ITER at Cadarache (France)	• The 2005 World Exposition, (Aichi) • Internet penetration rate exceeding 70%	
2006			• Shale gas revolution (U.S.)		
2007		• Report of human iPS cell production (Japan: Shinya Yamanaka)		• Start of EEW service	• Enactment of Basic Act on Ocean Policy
2008					• Enactment of the Basic Space Law
2009	 HAYABUSA	• Confirmation of warming in the entire Antarctic Continent (U.S.: Washington University) • Confirmation of rapid decline of Arctic sea ice (U.S.)		• Novel influenza epidemic • Sales of electric vehicles driven by lithium-ion battery	• Enactment of Act on Enhancement of Research and Development Capacity and Efficient Promotion
2010				• Return of HAYABUSA	
2011				• Accident in Fukushima Daiichi NPS	• Great East Japan Earthquake
2012		• Discovery of Higgs boson (EU.: European Organization for Nuclear Research (CERN))		• Sales of electronic book terminal	• Launch of the renewable energy feed-in tariffs
2013	 Methane hydrate	• Methane hydrate gas production test using decompression procedures in the marine area as world first (Japan)		• First Japanese captain of the International Space Station (Koichi Wakata)	• Tokyo awarded the 2020 Summer Olympics & Paralympics.
2014			• First clinical trial of retina implant with iPS cells (Japan) • Ebola epidemic	• Smartphone penetration exceeding 50% • STAP cell research falsification issue • Sales of fuel-cell vehicles	• Enactment of Cyber Security Basic Law • Eruption of Mt. Ontake
2015					• Inauguration of the National Research & Development Agency

Year	Japanese Nobel Laureates (natural science)
1949	• Hideki Yukawa, Nobel laureate in physics (Prediction of the existence of mesons)
1965	• Shin-Ichiro Tomonaga, Nobel laureate in physics (Fundamental work in quantum electrodynamics)
1973	• Leo Esaki, Nobel laureate in physics (Experimental discoveries regarding tunneling phenomena in semiconductors)
1981	• Kenichi Fukui, Nobel laureate in chemistry (Presentation of frontier orbit theory)
1987	• Susumu Tonegawa, Nobel Prize in Physiology or Medicine (Discovery of the genetic principle for generation of antibody diversity)
2000	• Hideki Shirakawa, Nobel laureate in chemistry (Discovery and development of conductive polymers)
2001	• Ryōji Noyori, Nobel laureate in chemistry (Work on chirally catalyzed hydrogenation reactions)
2002	• Masatoshi Koshiba, Nobel laureate in physics (Pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos)
	• Koichi Tanaka, Nobel laureate in chemistry (Development of methods for identification and structure analyses of biological macromolecules)
2008	• Makoto Kobayashi, Toshihide Maskawa, Nobel laureate in physics (Presentation of Kobayashi and Maskawa theory)
	• Osamu Shimomura, Nobel laureate in chemistry (Discovery and development of the green fluorescent protein (GFP))
	• Yoichiro Nambu [Note], Nobel laureate in physics (Discovery of the mechanism of spontaneous broken symmetry in subatomic physics)
2010	• Akira Suzuki, Ei-ichi Negishi, Nobel laureate in chemistry (Palladium-catalyzed cross couplings in organic synthesis)
2012	• Shinya Yamanaka, Nobel Prize in Physiology or Medicine (Discovery that mature cells can be reprogrammed to become pluripotent)
2014	• Isamu Akasaki, Hiroshi Amano, Shuji Nakamura [Note], Nobel laureate in physics (Invention of efficient blue light-emitting diodes)

Note: U.S. nationality as of March 2015

Column 1-8 Encouragement by seniors to students in science and technology

Seniors engaged in scientific or technological work and actively promoting science and technology in Japan discussed how they were interested in science, or the scientific or technological events that impressed them, as well as what they would like to convey to students who follow suit:

- Tomohiro Tachi, Assistant of the Graduate School of Arts and Sciences, the University of Tokyo

I currently study computational origami. To cite an actual example, I developed software to design a developed figure "Origamizer" to build free 3D forms in 2007 as a world first. This software automatically creates a developed figure to fold a 3D form with a sheet of paper based on data entered using a unique algorithm (Figure 1). I also study "moving origami." A moving structure can be designed with thick and solid materials by replacing the folding line of origami with a hinge (joint) of two flat panels (Figure 2). The study of origami is basic study to consider forms, but hardly known in other fields. I would like to create practical forms useful in architecture and furniture using origami theory. In fact, a researcher successfully created an artificial blood vessel for medical applications using the characteristics of origami that can be folded and expanded with ease.

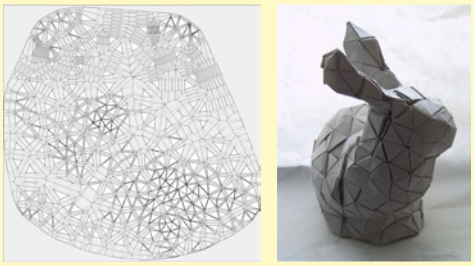


Figure 1 Examples of design using the Origamizer

Figure 2 An example of "moving origami"

My specialty, computational origami, is the result of combining various fields, including mathematics, computational science, design and structural dynamics. I learned architecture in university and this academic field comprises various academic disciplines, including structural dynamics, environmental control, planning, cognitive science, history, design, material science and law. It is a field of learning to find a solution to an issue by combining several academic fields with dexterity and I sense the similarity with computational origami.

The most impressive event in science and technology is the rapid progress in computer graphics technology. My specialty, computational origami, is closely related to computer graphics. For example, images used in computer games and videos, such as skin surfaces, are very clear and real as if taken in real films. I am also interested in virtual reality, which reproduces not only the visionary sense but also force and touch and I feel it is increasingly close to reality. I am particularly fascinated by the mechanism of virtual reality, or specifically from a philosophical perspective, by the method of presenting images and sound equivalent to the real experience.

Looking back on my childhood, I remember frequently reading magazines which plainly explained science and playing with electronic addendum while in elementary school. A robot arm was one such addendum. At the time, I also liked to play with origami and learned Miura folding[1] that allowed the folded paper to expand at once by pulling the diagonal line to the right and left and let it be folded again with ease.

1 Miura folding is a method of folding invented by Dr. Koryo Miura (the present Emeritus Professor of the University of Tokyo) at the Department of Aerospace Laboratory, University of Tokyo (the present Space Science Laboratory, JAXA) in 1970 in his study of work breakdown mechanisms. The portable map is a familiar application.

During my high school years, I remember the physics teacher who explained mechanisms behind everyday things such as the flying mechanism of airplanes and space heating systems. Space heating is connected to the warmer environment about which I learned during undergraduate days. Many teachers in high school taught us about learning, rather than just studying for exams and I learned from them how to interconnect knowledge. This mindset is still useful.

I would like to tell students, in line with my high school motto, you should be a person who can study and think for yourself. When dealing with a design subject, I felt the importance of examining the subject from various angles. I would like you to have such flexibility.

・Mina Iwama, GE Healthcare Japan

I am currently engaged in research into medical MRI transmission antennas. My motivation increases when I find where and how the technology in which I used to be engaged is used and how MRI containing the antenna I designed can help in diagnosing patients.

I was interested in science when my father, who designed video recorders, often discussed his job. I also liked to go to the science museum and see experiments like flame reactions. When I saw a remote-controlled surgical operation on TV as a child, I was impressed at how advanced medical treatment was available, not only in developed nations. These experiences prompted me to select the science course.

Recently I read an article about body communication using imperceptible electric fields generated on the surface of the body. Communication will be made when we touch something. This can be applied in various ways and I am interested in its future prospects.

I recommend students to retain many options. Learning many things makes your future bright. You can select what you are most interested in from what you learned and you should then work with what you selected, seriously and honestly. When you take care of your feeling of being interested in something, these elements will interconnect someday to form a new idea.

・Yuri Nakane, Taisei Corporation

I am engaged in soil purification, including the dissolution of hazardous substances in the soil using microorganisms and decontamination of contaminated soil by cleaning it in a diagonal drum similar to a washing machine. The job of a construction company is usually considered building, but this company also has many technologies to restore the environment such as soil purification and the volume of environmental work is increasing. I was assigned as site foreman of subway construction before the present work. After the subway started services, I was deeply moved when looking at the floors and walls that I had made.

Taisei started site management using an IT machine called the “field pat” in 2011. Before implementing this machine, paper design charts and drawings were used on site and whenever a change was made, these charts and drawings were modified by hand on the desk in the office. In contrast, the field pat allows us to correct drawings immediately when a change is made and share the latest information with all parties concerned. The efficiency is increased by sharing the current details of the construction site, irrespective of time and location. That is what brings our filed the usefulness of science and technology to us.

I experienced the Great Hanshin-Awaji Earthquake when I was a third grade elementary student. I still remember the appalling situations. Heap of rubble were immediately removed by heavy construction equipment and new roads were opened, allowing water tank trucks to come in the city. I felt grateful for that. Based on this experience, I was interested in the work that helps people, particularly civil engineering that was of substantial aid in the recovery from the disaster. In my junior high school days, the Akashi Kaikyo Bridge was opened. When I crossed the bridge by car with my family, I was overwhelmed by the magnificence of the bridge. One of the reasons I chose the construction industry is that I was moved by the ability of men to create such a magnificent structure. I was wondering the tick tick movement of the clock in my childhood and broke down several clocks to examine the internal structure. I chose the science course because I liked to do these things.

I would like the students to select what you like without hesitation. Especially the women interested in the science course should choose the science with confidence.