Chapter 3 Addressing Economic and Social Challenges

In order to achieve the goals set in the 5th Basic Plan: Sustainable Growth and Self-sustaining Regional Development, Ensure Safety and Security for Our Nation and its Citizens and a High-Quality, Prosperous Way of Life and Addressing Global Challenges and Contributing to Global Development we will work to solve challenges strategically by exploiting all scientific and technological innovations. Considering the reconstruction status from the Great East Japan Earthquake and other disasters, the national and local governments will work together on S&T innovations that will contribute to development of new technologies and new industries in the disaster-stricken areas.

Section 1 Sustainable Growth and Self-sustaining Regional Development

For the continued growth of Japan, it is necessary to ensure appropriate response to the increase of social costs confronting the country now and in the future. To this end, the government is advancing efforts on S&T innovations toward securing resources and realization of a sustainable society addressing super aging, etc.

In the area of environment and energy, based on the "Progressive Environment Innovation Strategy (decided by the Meeting to Promote Comprehensive Innovation Strategy on January 21, 2020)" the government is furthering the study aiming for the establishment of innovative technologies that enable reduction of past stock-based CO2 (beyond zero).

Furthermore, toward achievement of the "2050 Carbon Neutral" that was expressed in the Prime Minister's policy speech on October 2020, "Green Growth Strategy for 2050 Carbon Neutral" was formulated in December 2020 to promote social implementation of innovative technologies through various policy tools that include 2-trillion-yen fund, tax systems, regulations, standardization and international cooperation.

❶ Ensuring stable energy, resources, and food

(1) Ensuring stable energy and improving energy efficiency

A. Stabilizing and lowering the cost of clean energy supply

(A) Generation technologies pertaining to solar power generation system

The Ministry of Economy, Trade and Industry (METI) is conducting R&D on component technologies toward the commercial application of innovative technologies such as Perovskite solar cells[1] that are thin and lightweight to overcome restrictions on installation, the development of advanced peripherals, the

1 Solar cell created in Japan using materials with a crystal structure called Perovskite. Because it can be used in simple processes including coating and printing, significant reduction in production costs is expected.

maintenance technology toward improving the efficiency of the solar power generation system and developing low-cost recycling technology.

Under the "Advanced Low Carbon Technology Research and Development Program (ALCA)" and MIRAI program: "Realization of a Low Carbon Society, a Global Issue" area, the Japan Science and Technology Agency (JST) is promoting R&D on technologies pertaining to innovative sunlight utilization within a competitive environment. The targeted technologies are aimed at developments that have a high potential for greenhouse gas reduction and that are not merely extensions of conventional technologies.

(B) Generation technologies pertaining to floating offshore wind power plant

In order to expand the introduction of floating offshore wind power generation systems, METI is conducting a demonstration of a system with multiple turbines in the waters off Fukushima Prefecture for verification of safety, reliability and economy of the floating system, and a demonstration using new technologies off the coast of Kitakyushu city with the aim of establishing floating offshore wind power generation system technology and other projects.

The Ministry of the Environment (MOE) conducted a development and demonstration of Japan's first 2MW floating offshore wind power plant and established related technologies. Based on the technology development and demonstration, the commercial operation of offshore wind power started first in the country in 2016. Its secondary effects include new fishing places around the windmills. In FY2020 following the previous fiscal year, MOE implemented initiatives aimed at establishment of new methods for low-carbon and high-efficiency construction toward full-scale dissemination of floating offshore wind power generation. In addition, MOE implemented initiatives to promote decarbonization businesses by studying information contributing to early dissemination of floating offshore wind power generation, conducting various surveys necessary for individual regions to pursue local generation and local consumption of energy by using floating offshore wind power generation, and examining the feasibility and prospect of carbon dioxide reduction effects in the regions.

Toward cost reduction of floating offshore wind power plants, since FY2018 the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has been studying design and safety evaluation methods, etc. aimed at simplification of the floatation structure and installation methods while ensuring safety. Since FY2020, the ministry has been studying methods to improve the inspection efficiency.

(C) Technology development pertaining to geothermal and other renewable energy power generation

In order to solve problems of geothermal power generation, which include high risk and cost of resource exploration, operation efficiency and output stability at the power generation stage, METI has been developing technologies to improve exploration accuracy and drilling speed, streamline development and operation and stabilize output. The ministry is also conducting detailed prior examination of the next

generation geothermal power generation (supercritical geothermal system) with high generating capacity, which is a highly anticipated development.

In order to ensure advancement and social implementation of innovative technologies and promote necessary technology innovations toward prevention of global warming, the Ministry of the Environment (MOE) promoted not only the use of renewable energy and rational energy use, but also development, demonstration and dissemination of technologies leading to drastic reduction of energy consumption through use of innovative and highly CO2 emission reducing members /materials such as gallium nitride (GaN) and cellulose nanofiber (CNF), fuel cells, hydrogen energy, storage battery, CCUS[1], for example.

(D) Development of high efficiency thermal power generation systems and coal utilization technologies

METI has been implementing demonstration projects of the Integrated Coal Gasification Fuel Cell Combined Cycle (IGFC) and development of its element technologies (including large-capacity fuel cells), development and demonstration of high efficiency gas turbine technologies and development of further high–efficiency power generation using coal/Liquefied Natural Gas (LNG). The ministry is also developing technologies for efficient capture and utilization of CO_2 (Carbon dioxide Capture and Utilization (CCU)/Carbon Recycling) emitted from thermal power generation.

(E) Other technology development

METI has been developing an innovative oil refining technology toward greening of domestic refineries. The technology clarifies the composition of heavy oil at a molecular level and uses an oil refining technology that combines reaction simulation models, etc. to assess the components and reactivity of heavy oil in advance with the aim of reducing inefficient operation of refinery apparatuses through correct combination of operations of secondary devices, thereby contributing to the reduction of CO2 emissions.

(F) R&D related to nuclear power

i) Technologies to improve safety and nuclear security pertaining to nuclear power utilization

METI has been developing technologies and infrastructure under the Technological Development Program Contributing to Improvement of Nuclear Safety to enhance safety measures including sophistication of comprehensive risk assessment of nuclear power plants. This is based on what has been learned since the accident at the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (TEPCO). Japan has been working with the International Atomic Energy Agency (IAEA), the U.S. and other countries in a leadership role towards advancing international cooperation related to R&D on technologies for nuclear nonproliferation and nuclear security, as well as on those related to human resources development. Japan Atomic Energy Agency (JAEA) established the Integrated

[1] Carbon dioxide Capture, Utilization and Storage

Support Center for Nuclear Nonproliferation and Nuclear Security (ISCN). This center has provided training courses in nuclear nonproliferation and nuclear security. The ISCN and the IAEA have been jointly developing training materials and exchanging lecturers and information regarding human resources development based on the arrangement they made regarding the development of human resources for nuclear security. Efforts have also been made to develop technology for the following: 1) non-destructive assay of nuclear materials using the active neutron technique, and 2) nuclear forensics to identify the origin and history of nuclear and other radioactive materials out of regulatory control. The ISCN has also been contributing to strengthening detection capability for nuclear tests through the observation at Horonobe town and Mutsu city based on the noble gas joint measurement project with the CTBTO[1].

ii) Basic and fundamental R&D for nuclear science

In the Nuclear R&D, Infrastructure and human resource Working Group, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) comprehensively studied the following subjects: (1) development of new technologies that drastically improve safety, reliability and efficiency of use of nuclear energy, and (2) R&D and infrastructure/human resource development toward strengthening of human resources, technologies and industrial infrastructure beyond the boundaries of industry, academia and government. Based on the study result, with the aim of acquiring new knowledge to create nuclear innovations and find solutions regarding challenges, since FY2020 under the "Nuclear System R&D Project," in cooperation with the Ministry of Economy, Trade and Industry (METI), MEXT has been promoting strategic basic/fundamental research that will support the nation's nuclear technology by setting strategic themes to be tackled toward future social implementation.

JAEA is conducting basic and fundamental research in such fields as nuclear engineering, reactor engineering, fuel and material engineering, nuclear chemistry, environment and radiation science, partitioning and transmutation, computational science and advanced nuclear science. In addition, R&D on high-temperature gas-cooled reactors which have the possibility of a wide-range of industrial application including power generation and hydrogen production and inherent safety has been promoted in terms of the contribution to the enhancement of safety and to the diversification of nuclear use.

iii) Development of revolutionary nuclear technologies

Because nuclear energy is a practical option for carbon-free society, it is important to promote innovation of nuclear technologies that meets diverse demands of society in addition to safety improvement. Under the "program to support innovative nuclear technology development that responds to demand of society" In FY2019 METI started to support development of nuclear technologies with excellent safety, economy and mobility possessed by private companies and others.

1 Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization

iv) Securing and developing human resources in the nuclear field

There is the need to foster and secure a wide range of skilled human resources, in order to support the nuclear technology, ensure greater safety, and secure the safety of nuclear facilities and the smooth decommissioning of reactors in older nuclear power plants.

MEXT is supporting development of human resources in an effective, efficient and strategic manner, in collaboration with the relevant sectors of industry, academia and government, based on the Global Nuclear-HRD Initiative (GN-HRD). In FY2020 MEXT started significant revision of the initiative. Instead of individual support for projects of organizations, the ministry is supporting the efforts of multiple organizations including universities and research institutes to form a consortium as a center to establish a system for integrated human resource development. Under the Center of World Intelligence Project for Nuclear S&T and Human Resource Development ("the World Intelligence Project"), MEXT has been promoting human resource development based on the needs in the field of the decommissioning of Fukushima Daiichi Nuclear Power Station with the leadership of the Collaborative Laboratories for Advanced Decommissioning Science (CLADS) of the Japan Atomic Energy Agency (JAEA). When the meeting of relevant cabinet ministers on nuclear power held in December 2016 decided the government's policy to decommission the fast-reactor-breeder Monju, it was also decided to install a new research and test reactor on the site of Monju in the future. In FY2017 the government entrusted research on the reactor type to be installed. After studies at a deliberation council, etc., the government selected a research and test reactor for which the principal purpose is to use neutron beam, and started examination of its conceptual design and appropriate method of operation.

METI also has been supporting human resource development using funds provided by the Expenses for Commissioning Human Resource Development toward Improving Nuclear Safety, in order to educate field engineers involved in nuclear facility maintenance and in the nuclear safety industry. This undertaking is expected to contribute to the decommissioning of the TEPCO Fukushima Daiichi Nuclear Power Station and to the safety control of other existing nuclear power stations.

v) Research and Development of technologies, etc. for decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company, Inc.

Toward the decommissioning of the Fukushima Daiichi Nuclear Power Station, METI, MEXT and other relevant ministries and agencies have been taking measures in coordination and cooperation based on the Medium-to-Long-Term Roadmap for the Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company Holdings, Inc. (revised on December 27, 2019). In these measures, these ministries have been supporting R&D conducted by business operators on technologies that are technically difficult and that need the government to spearhead work on them. Such R&D includes

a technology for extracting fuel debris and a technology for examining the inside of reactor containment vessels.

Based on the Acceleration Plan of Reactor Decommissioning R&D for the TEPCO Fukushima Daiichi Nuclear Power Station (published in June 2014), MEXT has been promoting basic/fundamental R&D and human resource development in order to consolidate knowledge in Japan and overseas for safe, steady decommissioning. Specifically, CLADS is conducting basic/fundamental research including handling of fuel debris, treatment and disposal of radioactive wastes and clarification of accident development scenarios at the International Collaborative Research Building (Tomioka town, Futaba-gun, Fukushima). Furthermore, the World Intelligence Project that has been implemented since FY2015 was changed from a commissioned project of MEXT to a subsidy project conducted by JAEA in FY2018. Through integrating and linking excellent knowledge and experiences in various fields beyond the nuclear field around CLADS and across organizations of universities, research institutes and private companies, R&D and human resource development has been promoted in response to the medium- to long-term needs in actual decommissioning.

Development of facilities to establish the technical basis for decommissioning is also advancing. JAEA started full-scale operation of the Naraha Remote Technology Development Center (Naraha town, Futaba-gun, Fukushima), a facility for development and demonstration of remote operation equipment/devices (mock-up facility), in April 2016. In addition, with the aim of developing analysis methods, proper understanding and treatment/disposal of fuel debris and radioactive wastes, Okuma Analysis and Research Center (Okuma town, Futaba gun, Fukushima) started operation of some facilities in March 2018. Furthermore, the 1st building and the 2nd building are under development toward establishment of an analysis implementation system using the center.

vi) Nuclear fuel cycle technology

The Strategic Energy Plan (Cabinet Decision on July 2018) states "In order to resolve the issues related to reprocessing and disposal of spent fuels and mitigate the risks for and the burden on future generations, the government will make efforts towards a nuclear fuel cycle that contributes to the reduction of the volume and harmfulness of high-level radioactive waste and effective utilization of resources while adequately taking the past history into consideration and continuing to gain the understanding of relevant municipalities and the international community, and will promote reprocessing and plutonium use in LWRs[1]." Also "the government will promote R&D of fast reactors. through international cooperation with the United States and France."

Regarding the prototype fast-breeder reactor Monju, the meeting of relevant cabinet ministers on

1 Plutonium separated from spent fuel by reprocessing is mixed with uranium, processed into mixed-oxide fuel and used

nuclear power held in December 2016 decided not to resume its operation but move to decommissioning. Based on the decommissioning plan (approved by the Nuclear Regulation Authority in March 2018) JAEA has been working on decommissioning. First, unloading of the fuel assemblies from the reactor core to the fuel pool will be completed by the end of 2022 giving the highest priority to safety. Transport of the fuel assemblies from ex-vessel storage tank to the fuel pool started in August 2018 and transport from the reactor core to ex-vessel storage tank started in September 2019. Future decommissioning of Monju will be safely, steadily and systematically carried out while listening to opinions from the local area.

vii) Technology development toward radioactive waste disposal

The government is advancing basic/fundamental research of nuclear transmutation and group separation technologies using fast reactors or accelerators, which can contribute to the significant reduction of volume and hazardousness of high-level radioactive wastes.

For disposal of low-level radioactive wastes from research facilities and medical institutions, JAEA has been advancing necessary initiatives according to the "Plan on implementation of burial disposal" (approved in November 2009; changes to the plan were approved in November 2019)" that was formulated by JAEA based on the "Basic policy for implementation of burial disposal" (decision by the Ministers of MEXT and METI in December 2008) presented by MEXT and METI.

viii) Decommissioning of facilities owned by Japan Atomic Energy Agency (JAEA)

JAEA published the "Backend Roadmap" that is a long-term policy for decommissioning of the entire facilities of JAEA in December 2018. JAEA has an important role as a comprehensive nuclear R&D organization. In order to fulfill this role, it is important for JAEA to steadily proceed with decommissioning of the facilities that will no longer be used for research while at the same time ensuring public understanding and giving the highest priority to safety. MEXT will support JAEA's efforts and encourage safe and steady decommissioning of the nuclear facilities owned by JAEA.

ix) Efforts for understanding and co-existence with the public

MEXT has been supporting projects to deepen the understanding of the facilities among people nationwide and in regions where those facilities are located, towards the sustainable development of the region and education on nuclear power and other energy sources.

x) International nuclear energy cooperation

The Ministry of Foreign Affairs has been supporting the promotion of the peaceful use of nuclear science and technologies by IAEA and member countries' efforts to achieve Sustainable Development Goals (SDGs). Through technical cooperation based on the Regional Cooperative Agreement for Research,

Development and Training Related to *Nuclear Science* and Technology (RCA)" in the Asia-Pacific region, financial support to IAEA with contribution to the Peaceful Use Initiative (PUI) and strengthening of collaboration between IAEA and Japanese universities, research institutions and companies with expert knowledge and technologies, the ministry has been promoting capacity building of developing countries and supporting international deployment of Japan's excellent human resources and technologies. IAEA in cooperation with Japan designated an IAEA Response and Assistance Network Capacity Building Centre (IAEA-RANET-CBC) in Fukushima Prefecture in 2013 and implemented training for relevant people in Japan and abroad to strengthen their ability in preparation for and response to emergencies in August and November 2019. Its activities for international strengthening of nuclear security include an international symposium on transport security of nuclear materials held in cooperation with the Integrated Support Center for Nuclear Nonproliferation and Nuclear Security (ISCN), JAEA in Tokyo in November 2019.

MEXT has been leading the way in peaceful use of nuclear energy and nuclear non-proliferation by contributing to projects implemented by the IAEA and the Nuclear Energy Agency under the Organization for Economic Co-operation and Development (OECD/NEA[1]). Also, as part of MEXT's contributions to the Forum for Nuclear Cooperation in Asia (FNCA), which is led by the Cabinet Office, MEXT has been supporting FNCA member countries: Asian countries in particular, in their R&D and infrastructure development for the use of radiation and nuclear research reactors, for example.

METI also has advanced R&D for the establishment of verification technology for fast reactors by means of Japan-French cooperation, Japan-US cooperation and other international cooperation frameworks. Fast reactors are expected to contribute to reductions in toxicity and in the volume of radioactive waste.

Japan is also involved in wide-ranging cooperation in nuclear system R&D, etc. with the United States, France and other countries advanced in nuclear science through activities of the Generation IV International Forum (GIF).

xi) Efforts pertaining to the peaceful use of nuclear energy

Japan concluded IAEA in 1977 and signed the Additional Protocol in 1999. Pursuant to the agreement and the protocol, Japan has been complying with IAEA safeguards whereby IAEA verifies that nuclear materials are used only for peaceful purposes and are not diverted or misused for nuclear weapons assembly. Thus, pursuant to the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (Act No. 166 of 1957) (Nuclear Reactor Regulation Law), Japan has been implementing a system of accounting for and controlling nuclear material, providing reports to IAEA, and accepting IAEA inspections.

On May 28, 2020 the government reported the result of safeguard implementation activities in Japan

[1] OECD Nuclear Energy Agency

during 2019 to the Nuclear Regulation Authority. The result is provided to IAEA as information for its evaluation of our safeguards implementation activities. IAEA: in its safeguard's implementation report, concluded that all nuclear materials in Japan remained in peaceful activities in 2019 as well. Broader Conclusion has been reached since the implementation result in 2003.

(G) R&D of long-term energy technologies including fusion energy

Fusion energy is expected to be the prime future energy source that is important in a carbon neutral society, because its fuel resources abound, no greenhouse gases are emitted during power generation and small amounts of fuel can generate power on a large scale. It could completely solve energy and global environmental problems. With regard to the application of fusion energy, based on the "Roadmap for R&D on prototype reactor (first report)" formulated on July 24, 2018, three types of reactor have been the subject of advanced R&D and have produced world-class results in fusion: 1) the tokamak reactor (The National Institutes for Quantum and Radiological Science and Technology, High -Performance Fusion Experiment System: JT-60SA[1], 2) the helical reactor (National Institute for Fusion Science (NIFS), the Large Helical Device (LHD)) and 3) the laser fusion reactor (Institute of Laser Engineering, Osaka University, GEKKO-XII Laser and LFEX).

Japan has also been advancing the ITER Project[2], which demonstrates the scientific and technological feasibility of fusion energy through the construction and operation of an experimental reactor based on a seven-party international agreement, and Broader Approach (BA) activities that complement and support the ITER Project in partnership with EURATOM. Under the ITER project, construction of the experimental reactor ITER began in earnest in France to start operation in 2025. The commemorative ceremony was held in July 2020 when assembly of ITER started. R&D of the BA activities which include the move of JT-60SA to the adjustment phase toward experimental operation, are also progressing smoothly in FY2020.

METI has been developing a panel that integrates electric power production and supply, which is necessary for space photovoltaic power generation, while at the same time conducting technology development for its weight reduction and efficiency improvement of the power transmitting unit in order to contribute to efficiency improvement of wireless power transmission using microwaves.

Construction of ITER (International Thermonuclear Experimental Reactor) in November 2020
(Cadarache in Saint-Paul-Lès-Durance, France)
Source: ITER Organization

1 In August 2008, operation of the JT-60 break-even test facility was suspended. The facility was subsequently dismantled for repairs and its reassembly was completed in March 2020. Now it is in the process of adjustment toward the start of operation.

2 International joint project to demonstrate scientific and technological feasibility of fusion energy through the construction and operation of an experimental fusion reactor based on a seven-party international agreement (Japan, EURATOM, the U.S.A., Russia, China, South Korea and India)

Japan Aerospace Exploration Agency (JAXA) has been conducting R&D of elemental technologies toward practical use of space-based solar power.

<Reference>

Website on fusion energy study: Fusion Energy -Connect to the Future

https://www.mext.go.jp/a_menu/shinkou/fusion/

The way to fusion energy - ITER

https://www.youtube.com/watch?v=QEohCE1famE (Source: iter japan – QST)

B. Stable energy use using energy storage technologies including hydrogen/storage batteries

METI is conducting the technological development and demonstration of batteries and fuel cells. Specifically, the ministry is promoting efforts for implementation of technological development for optimal control and management methods when introducing large batteries for power systems, which will become necessary with the expansion of renewable energy introduction. Technological development was conducted also for the performance enhancement and cost reduction of lithium-ion and post lithium-ion batteries for next-generation vehicles,[1] such as plug-in hybrids or fully electric cars. R&D on fuel cells for domestic use and other fixed uses, and on vehicle fuel cells, has focused on lowering costs while increasing durability and efficiency. Toward further spread of fuel-cell vehicles, the ministry had installed about 137 hydrogen stations, mainly in four major cities, as of FY2020.

MOE has been implementing "Construction of autonomous distributed energy system using hydrogen" since FY2018. With a view to a future society that will use a huge amount of renewable energy, the project aims to establish methods to introduce and use an autonomous hydrogen energy supply system by constructing a system that can supply renewable energy as power and heat without depending on a power system but instead by using storage batteries and hydrogen based on regional conditions.

MEXT is promoting R&D related to the next-generation storage battery with greatly higher performance compared with conventional ones in a technology area of special focus of the "Strategic Basic Research Programs - Advanced Low Carbon Technology Research and Development (ALCA)" of JST. In addition, the ministry started R&D in industry-academia collaboration at the advanced storage battery R&D centers of the "Open Innovation Platform for Industry-Academia Co-creation Program." The "JST MIRAI program – Large-scale project" is promoting R&D of a high-efficiency, low-cost, compact and long-life innovative hydrogen liquefaction technology that will contribute to expansion of hydrogen utilization including hydrogen power generation, storage of surplus power and transportation means.

C. Improvement of energy utilization efficiency and consumption reduction using new technologies

1 Innovative storage battery with higher energy density compared to all-solid batteries and lithium-ion batteries

The Cabinet Office through SIP has been working on the "Energy system of IoE society" since FY2018 toward realization of an IoE society where various energy sources are connected to a network enabling supply and demand management of energy. The project promotes R&D toward social implementation of the universal power module and wireless power transmission systems, which will enable optimum control of diverse input power sources including renewable energy by using gallium semiconductor devices.

METI has been conducting a demonstration of a virtual power plant that remotely integrates and controls consumer-side energy resources spread across the power grid including energy facilities such as renewable energy power facilities and storage batteries, and demand response, to make them function as one power plant and use them for adjustment of supply and demand.

MOE has been implementing projects to establish an advanced model for implementation of CO2 emissions reduction measures with the overall highest cost performance in the various regions by introducing independent/distributed energy systems that will use renewable energy, and independent cables, etc. in public and other facilities, and by optimizing energy supply and demand to increase the ratio of renewable energy in the regions.

Under the "JST MIRAI Program – Large-scale Project" JST promoted R&D on an innovative thermoelectric conversion technology that enables use of heat sources in the environment (e.g., waste heat, body heat) as independent power source for sensors.

RIKEN (The Institute of Physical and Chemical Research) has been conducting R&D on technologies for devices that realize radical lower power consumption and great improvement of energy conversion efficiency, with creating new materials science that enables innovation in electricity consumption under completely novel concepts.

JAXA has been conducting R&D on reduction of the fuel consumption and environmental load of airplanes. JAXA is accelerating R&D in this area in collaboration with the industry, etc. because it is directly related to international competitiveness. For instance, the R&D tackles technologies for reducing NOx from engines and improving their efficiency, and technologies for electrification of aircraft propulsion, while taking into account the potential R&D trends of next-generation airplanes and beyond. JAXA is also developing, maintaining and improving large-scale experimental facilities that include a jet engine for technology demonstration, the operation of which started in FY2020.

The New Energy and Industrial Technology Development Organization (NEDO) has been implementing the Strategic Innovative Energy-Efficient Technology Program through open public invitations for proposals. The program focuses on key technologies listed in the Strategy for Energy Efficiency Technologies 2016 (revised in July 2019), for effective promotion of R&D and the spread of energy-efficient technologies.

The Building Research Agency has been conducting R&D for environmentally-sound and efficient use of resources/ energy in housing, construction and urban planning fields.

D. Application of innovative materials, devices, etc. to a broad range of areas

Toward practical use of power devices that use the next-generation semiconductors including gallium nitride (GaN) which will enable significant reduction of power consumption by 2030, under "R&D on next-generation semiconductors contributing to realization of an energy-efficient society", MEXT promoted R&D on the next-generation semiconductors integrally from materials processing to device and system applications, also using theories and simulations. In addition, the ministry started the "MEXT Program for Creation of Innovative Core Technology for Power Electronics" toward practical application of super-energy-saving and high-performance power electronics equipment by developing optimum power devices, circuit systems and passive elements/interconnection materials to make the most of excellent material properties of the next-generation semiconductors including GaN, and a total system design of power electronics equipment in combination of the above.

Under the "Strategic Basic Research Programs – Advanced Low Carbon Technology Research and Development Program (ALCA)"and JST MIRAI program: "Realization of a Low Carbon Society, a Global Issue" area, JST is promoting R&D on innovative materials development/application and chemical processes.

The National Institute for Materials Science (NIMS) has been promoting R&D for stable energy supply and efficient energy use. The R&D includes: high-efficiency batteries or solar cells for construction of network systems that promote use of diverse energy sources; energy conversion/storage materials for effective use of energy; R&D toward the breakthrough of high-output semiconductors for energy efficiency, high-luminance light materials, etc.; high-efficiency/performance transportation equipment materials and energy infrastructure materials contributing to a low environmental burden society.

METI has been developing technologies for: producing plastic materials and other major chemical products from carbon dioxide and water by using solar energy (artificial photosynthesis project); highly efficient production of organosilicon materials without using metallic silicon; replacement of the batch synthesis method of functional chemicals with the flow synthesis method, and accurate and speedy evaluation of performance and characteristics of lithium-ion cell materials. The ministry is also developing basic information necessary for development and safety assessment of compounding/processing technologies for cellulose nanofiber production according to the purpose of use, which promises cost reduction in the production process, optimization of the manufacturing process and a mass production effect.

Column 2-1 Next-generation semiconductor GaN: from blue LED to power electronics

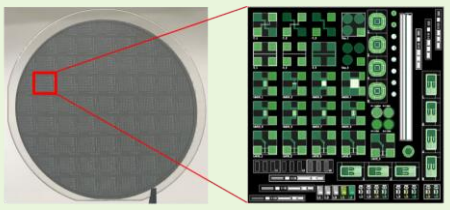
Gallium nitride is a semiconductor used as material of the blue light emitting diode (LED.) Three Japanese researchers involved in its invention received the 2014 Nobel Prize for Physics. The birth of the blue LED completed the three primary colors of light: red, green and blue, which led to the white LED, which possessed superior color rendering. Full-color electric bulletin boards along roads and in stations were made possible by the invention of the blue LED. The high-brightness, low power consumption and long-life LED has replaced almost all light bulbs for traffic signals and home lighting equipment, which made a big contribution to the energy-efficient society. In addition, the blue-violet laser known as Blu-ray has been developed from the blue LED technology and enabled high-density optical recording five times denser than DVD. As a result, colorful pictures and powerful sound can be casually enjoyed at home. In this way, GaN is used also in the cultural field.

GaN, which has brought about revolutions in the field of optical technique one after another as described above, is now attracting attention as a semiconductor for electric power control that will contribute to significant reduction of GHG emissions. Power electronics devices that control electric power (AC-DC conversion and voltage adjustment) are incorporated in almost all electric appliances, but there is a problem of big power loss from component silicon semiconductors, etc. during power conversion. Replacement of the current silicon with GaN will enable significant reduction of power loss and miniaturization and light-weighting, which promises energy efficiency in various electric equipment. Expansion of the use of renewable energy and electrification/energy efficiency on the demand side are absolutely necessary for achievement of 2050 carbon neutrality. It is expected that the momentum will further increase to spread the use of power electronics equipment necessary for distributed power systems using renewable energy and for electric vehicles not emitting GHGs. Here GaN has a big role to play and raises expectations.

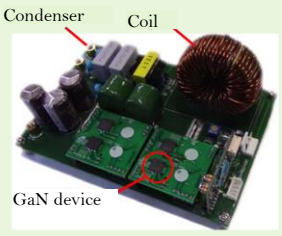
However, in order to mount GaN in power electronics equipment, it is necessary to solve the issues of crystal quality and production cost of GaN. Practical application is difficult without a low-cost and stable supply of high-quality crystals with considerably fewer defects compared with GaN used for blue LED. In order to bring out excellent physical property of GaN and realize highly reliable devices, MEXT has promoted basic research necessary for technologies to produce GaN crystal substrates with few defects to create sophisticated devices. Results including growing of large-diameter crystals with few defects and development of a technology to electrically activate ion-implanted GaN substrate show the possibility of using GaN power devices for large electric power, which is difficult under the existing methods. Power electronics is a composite technology combining power devices, passive elements (coils, condensers, etc.) and circuit systems that mount and control them. The excellent characteristics of GaN power devices alone cannot realize super-energy-efficiency and highly efficient innovative power electronics equipment.

In FY2020 MEXT started a project to promote R&D of basic/fundamental technology of innovative power electronics in integration of three fields: circuit system, power device and passive elements. Japan's material research including power semiconductor and passive elements is already at the world's top level. Developing system design technology of the whole field of power electronics

taking advantage of the strength in these fields is the key to realization of an energy-efficient society. It is expected that the next-generation power semiconductors including GaN will support power electronics equipment and contribute to significant performance improvement of electronic vehicles, robots, power conditioners and other equipment.



Power semiconductor device created on 2-inch GaN crystal wafer
Provided by Nagoya University



Circuit system mounting GaN power semiconductor device
Provided by Nagoya University

Blue light-emitting diode
Provided by Meijo University

(2) Securing a stable supply of resources and recycling

A. R&D of seabed resource exploration/production

Based on the result of the SIP 1st period "Next-Generation Technology for Ocean Resources Exploration," since FY2018 the Cabinet Office has been running the SIP 2nd period project "Development of Innovative Technologies for Exploration of Deep-Sea Resources." The program aims to develop technologies ahead of other countries to efficiently explore and produce rare earth mud and other mineral resources from deeper than 2,000m deep-sea floors. In FY2020 the project succeeded in sea trial of technologies necessary for long-term deep-sea exploration and is steadily making progress toward social implementation.

Since FY2018 MLIT has been supporting technology development for integrated control equipment of an electric system for the Floating Production Storage and Offloading System (FPSO) and autonomous underwater vehicles (AUVs) for submarine pipeline maintenance, and promoting advance into the ocean development market by the maritime industry.

In order to contribute to the promotion of industrial use of the ocean by Japan, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) is promoting understanding of biological and physical cycles in the ocean and the origin of useful resources and providing obtained scientific knowledge, data, technologies and samples to the related industries.

The National Institute of Maritime, Port and Aviation Technology (MPAT) is conducting R&D pertaining to submarine construction, transportation/ communication between ocean base and sea floor, etc. MPAT is also conducting research on the development and improvement of techniques for safety evaluation of offshore structures and for reducing environmental impacts. These techniques are the basis of key technologies for the exploitation of ocean resources and energy.

B. R&D on technologies for resource saving and substitute materials of rare earths and rare metals

To overcome the constraints imposed by the scarcity of certain elements, such as the rare earths and rare metals that are necessary for next-generation cars and wind power generation and also to save energy, MEXT and METI have been conducting mutual R&D on materials.

To overcome Japan's resource constraints and improve its industrial competitiveness, MEXT is promoting the "Element Strategy Initiative: To Form Core Research Centers" in order to find completely new materials that eliminate the need for scarce elements such as rare earth and rare metals by theoretically elucidating and applying the functions of elements.

METI has developed materials that are more magnetic than conventional ones and that greatly reduce use of rare metals in the Technological Development of New Structural Materials Contributing to Drastic Weight Reduction of Transportation Equipment. Furthermore, in order to promote effective use of Japan's urban mines and realize stable supply of resources as well as resource and energy efficiency under the program to increase the sophistication of the resource circulation system, the ministry is working on the development of technologies for automatic sorting of waste products and components and high-efficiency refining. In order to improve the resilience of the rare earth supply chain that has high risk of supply disruption, through the Technological Development and Demonstration Contributing to Improvement of Supply Chain Resilience, the ministry is pursuing the development of high-performance magnets that minimize the use of or do not use rare earth and technologies using low-quality rare earth that is difficult to use due to many impurities.

C. Development and demonstration of biomass utilization technologies

Toward commercialization of bio-jet fuel by around 2030, METI is conducting demonstrations related to: biomass gasification/liquefaction technology (converts wood, etc. to H2 and CO gasses and produces fuel from the gasses by using catalysts); pilot-level tests for an integrated production process including microalgae culture techniques and other component technologies, and ATJ technology (production of fuel from bio ethanol by using catalysts).

Under the Strategic Basic Research Programs – Advanced Low Carbon Technology Research and Development Program (ALCA) and JST MIRAI program: "Realization of a Low Carbon Society, a Global Issue" area, JST is promoting R&D on innovative biotechnology to produce chemicals from biomass, which can replace petroleum products.

RIKEN has been conducting leading studies on the cyclic use of carbon, which has been consumed in petrochemical products, through interdisciplinary studies on plant and microbial sciences, chemical biology and synthetic organic chemistry. Another RIKEN endeavor is R&D on the establishment of innovative bioprocesses towards the discovery of new materials derived from biomass.

The Public Works Research Institute is conducting research on effective utilization of resource and

energy with a focus on sewage facilities.

(3) Securing a stable food supply

In addition to medium- to long-term R&D, Ministry of Agriculture, Forestry and Fisheries (MAFF) is promoting technology development with a view to field implementation with clear goals in order to overcome challenges in the agriculture field by using science. For example, aiming at stable food supply, productivity improvement of agriculture and other purposes, MAFF is conducting research to develop super-high-yielding crop varieties, crops suitable for harsh environments, and breeds of cow with high lifetime productivity. To help achieve Japan's food self-sufficiency target, MAFF is also working to develop food and feed crops that have novel features in terms of quality and processability and techniques for differentiation and quality improvement of livestock products by using domestic feed.

Furthermore, MAFF is implementing the Smart Agriculture Demonstration Project in 148 districts across the country. The project covers development of smart agriculture technologies including: advanced production management using ICT; an automated driving system of farm machines using satellite positioning information and image data; and, robots for levee weeding or harvesting of vegetables and fruits; as well as demonstration of the economic effects of their introduction to the production field.

In order to accelerate social implementation of smart agriculture in light of the challenges experienced in the fields, the ministry compiled the direction of measures in the Smart Agriculture Promotion Package (formulated in October 2020 and revised in February 2021).

Based on this package, the ministry pursued steady implementation of the demonstration and dissemination of the results, fostering of agriculture support services including farm work contracting and agricultural machinery sharing, and verification of the safety and rulemaking for robotics that requires solution of safety issues before installation in the field. MAFF in cooperation with relevant ministries and agencies also tackled study on standardization of agricultural information for promotion of ICT utilization in agriculture and development of open API for data coordination of agricultural machinery, etc. In February 2021 the results were formulated as the "Guidelines for API Development in the Agricultural Field" for farm machinery manufacturers, ICT venders and other business operators. In addition, the operation of "Agricultural Data Collaboration Platform (WAGRI)" was started in April 2019 to realize data-driven agriculture. Participating enterprises are providing new services for farmers. The ministry is advancing R&D on the Smart Food Chain to optimize food chains by expanding WAGRI and connecting agricultural production, distribution, processing, consumption and export through data.

With the accelerated focus on SDGs and environmental issues in Japan and abroad, it is imperative for the nation to lead the world by building a sustainable food supply system. To this end, in March 2021 an interim report on "Strategy for Sustainable Food Systems, MeaDRI" was compiled to achieve both sustainability and productivity improvement of the food, agriculture, forestry and fishery industries

through innovations. Study is now underway toward the formulation of the strategy in May.

With the aim of sustainable harvesting of marine biological resources, MEXT has been conducting R&D to clarify the physiology of marine organisms for innovative production under "sophistication of technologies to secure living marine resources" among the programs to develop technologies that promote use of marine resources.

The Public Works Research Institute is implementing research on improvement and maintenance of agricultural production base in snowy cold regions to contribute to enhancement of the food supply, and fisheries base in cold sea to contribute to enhancement of the food supply.

Column 2-2 Will Insects Save the World?

The world population is expected to increase by about 2 billion to 9.7 billion by 2050. While the resources, land and water of the Earth are limited, global warming will progress and we have to address many global challenges including the stable supply of protein, elimination of malnutrition by producing nutrient-rich foods and control of air pollution caused by food production and land use.

In order to solve the problems related to food production and consumption, Moonshot Goal 5 sets an ambitious goal "Creation of industry that enables sustainable global food supply by exploiting unused biological resources by 2050." Toward this goal, R&D of 10 projects started with the aim of constructing "Food Production Systems Achieving Both Food Supply Expansion and Global Environment Conservation" and "Food Consumption Systems Realizing Zero Food-loss and Waste (References 1 and 2)."

Application image
Provided by Gryllus Inc

One of the projects aims for domestication of crickets that are thought to have high efficiency in protein production and small environmental burden in the process of breeding. Now, most people may feel uncomfortable eating insects, but how will they feel if the food is excellent in shape, taste and functions? This is one example. We hope that the researchers involved in the 10 projects will generate results that change the world through trial and error and in friendly rivalry through discussions and cooperation with entrepreneurs and young people who will forge the future. Beyond R&D we hope they will contribute to solutions of food issues of the world by disseminating and sharing the R&D results in society to gain the understanding of many people.

Cabinet Office website

MAFF website

<Reference URL>

1 Cabinet Office Website
https://www8.cao.go.jp/cstp/moonshot/index.html

2 MAFF Website
https://www.affrc.maff.go.jp/docs/moonshot/moonshot.html

Column 2-3 Reducing Agrochemical Use and Labor by Pinpoint Spraying using Drone

A breakthrough technology using drones and AI to spray agrochemicals in the needed places and amounts has been made practicable.

Today, while concerns about use of agrochemicals are growing among consumers, farmers are also making efforts to reduce use of agrochemicals and the labor of spraying them for the purposes of production cost and labor reduction and in an effort to achieve environment-friendly agriculture.

The pinpoint chemical spraying using drones attracts attention as a technology that serves the interests of both producers and consumers.

This technology first takes images of the entire field through automated drone flights and analyzes the condition of plant leaves by using AI to identify the place where plants are damaged by pests. Next, a drone carrying chemicals automatically arrives at the place according to the analysis result and controls the pests by pinpoint chemical spraying of the place. Because this technology could reduce agrochemical use to one tenth of the conventional amount and takes only one tenth of the operation time of the conventional spraying using power sprayers, it is expected to make a significant contribution to further reduction in the amount of agrochemical use and labor of farmers.

Detection of pest damaged parts by AI (above)
Pinpoint chemical spraying by drone (below)
Provided by OPTiM Corp.

<Reference URL>
MAFF Website
https://www.maff.go.jp/j/kanbo/smart/drone.html

❷ Achieving a sustainable society to handle hyper-aging, depopulation, etc.

(1) Establishment of a society in which people enjoy long and healthy lives with world-leading medical technology

In order to contribute to the realization of a society where citizens stay healthy and live longer, medical R&D that contributes to the provision of world-leading medical care and to the generation of industrial activities for the realization of such a society will be promoted in a planned and comprehensive manner. To this end, efforts are being made under the leadership of the Headquarters for Healthcare Policy, also based on the new Healthcare Policy (Cabinet Decision on March 27, 2020) and the Plan for Promotion of Medical Research and Development (decided by the Headquarters for Healthcare Policy on March 27, 2020.) that entered the second period in FY2020.

Medical R&D budgets that had been used separately by individual ministries have been unified in the Japan Agency for Medical Research and Development (AMED) to organize six integrated projects shown in B (1) to (6) and AMED leads consistent R&D from the basics to practical application.

Based on the Act on Anonymized Medical Data That Are Meant to Contribute to Research and Development in the Medical Field (Act No.28 of 2017), the first enterprise was certified in December 2019 followed by the certification of the second enterprise in June 2020. The government is developing the environment by requesting medical institutions and local governments, etc. for cooperation regarding the provision of medical information to the certified enterprises in order to help their operations take off.

A. Efforts including R&D to address COVID-19

For R&D, etc. to address the COVID-19 pandemic, in addition to the FY2020 supplementary budget and the reserve fund, including the budget that has been implemented since FY2019 to support treatment, diagnosis, vaccine development and other R&D, the government allocated about 193 billion yen in seven stages.

Universities and other institutions have advanced R&D on treatment since the confirmation of COVID-19 in Japan and produced research results including confirmation of the effect of nafamostat to inhibit viral infection. In order to promote studies on the effect and safety of existing medicines and development of medicines with new action mechanisms, through AMED the government supported basic research and clinical research, which include: antiviral drugs (favipiravir, ivermectin); anti-inflammatory drugs (adrenomedullin) and; plasma product (high immunoglobulin).

Regarding diagnostics, through AMED the government supported fundamental research including rapid diagnosis kits for the gene amplification test, antigen rapid diagnosis kits and test reagents, which were put into practical use. The result of the performance evaluation of the antibody test kit was reflected in the MHLW guideline for COVID-19 treatment. Furthermore, under a program to develop viral infection control technologies, the government supported R&D leading to the solution of infection problems, development and demonstration of equipment/systems to meet the field needs to control COVID-19. In addition to the support through AMED, the Program for Building Regional Innovation Ecosystems of MEXT supported R&D of equipment that packages the entire process after sampling toward social implementation of the "COVID-19 rapid detection system using the SmartAmp Method" in the Kanagawa area.

For vaccine development, through AMED the government supports basic research, non-clinical and clinical studies by domestic enterprises, universities and other organizations in order to meet the demand for acceleration of vaccine development and enhancement of the supply system in Japan.

As the COVID-19 epidemic exposed again the need for a global response system, through AMED the government is supporting the enhancement of the research foundation and basic research of infectious

diseases in Japan and abroad ("project to create research foundation on emerging/reemerging infectious diseases" under MEXT), while developing the foundation for advancement of clinical research/trials led by Japan in Asia ("Project to network clinical research/trials in Asia" MHLW).

B. Six integrated projects

① Project for Advanced Drug Discovery and Development

In order to promote practical application of medicines that meet the needs in medical practice, R&D has been promoted considering the characteristics and nature of the modality of each process covering all stages from exploration for drug targets to clinical research.

Examples in FY2020 are: drug discovery research in industry-academia-government cooperation using clinical specimens with high-quality clinical information; development of production technology with a view to industrialization of biomedicine including continuous production of antibody drugs and basic technology for their practical application, and; enhancement of the foundation for drug discovery support through technology development toward acceleration of the development of cryo-electron microscopy, including its automation and remote control.

② Project for Medical Device and Healthcare

R&D has been promoted on medical equipment and health care contributing to advancement of diagnosis/treatment, prevention of disease and improvement of QOL[1] through integrated utilization of AI, IoT, measurement, robotics and other technologies. Under this project, support is provided in cooperation by METI, MEXT, MHLW and MIC with the leadership of AMED.

Initiatives in FY2020 include: enhancement of the development of innovative medical equipment that uses AI, robotics and other technologies based on the future medical and welfare needs and; promotion of the development of medical equipment for early diagnosis/prevention according to the characteristics of the disease and minimally invasive treatments.

③ Project for Regenerative/Cellular Medicine and Gene Therapies

Toward practical application of regenerative/cell medicine, the following: basic research on cell culture/differentiation induction; non-clinical and clinical research by disease/tissue and development of basic technologies for production; elucidation of the clinical state of intractable diseases and drug discovery by using iPS cells specific to the disease and construction of necessary foundation, and R&D on gene transfer and editing technologies. In addition, R&D integrating these research fields has been promoted.

In FY2020, under The Program for Regenerative Medicine Networks of MEXT, the government

[1] quality of life

promoted basic research toward practical application of regenerative/cell medicine using iPS cells, somatic stem cells, etc. and integrated research with gene therapy, and drug discovery research based on the understanding of the pathological mechanism by using iPS cells, etc. The R&D was promoted integrally from the basics toward practical application in coordination with the clinical research/trials under the research project of MHLW for practical use of regenerative medicine and the development of production technology under the basic technology development project of METI for industrialization of regenerative medicine and gene therapy.

④ Project for Genome and Health Related Data

The government pursues personalized prevention and medical treatment by promoting the development and use of genome data infrastructure and R&D for prevention of disease onset/progression, diagnosis and treatment overviewing life stages.

In FY2020, under the MHIW project to develop an integrated database of clinical genome information, additional data were registered to Medical Genomics Japan Variant Database (MGeND) that accumulates and integrates clinical, genome and other information, which was followed by its disclosure. Furthermore, based on the Action Plan on Whole-genome Analysis, the ministry's research project for practical use of innovative cancer treatment promoted the construction of basic information and systems that contribute to elucidation of new genetic predispositions that explain the diversification of the clinical features of hereditary tumors. In addition, the Tohoku Medical Megabank Project of MEXT is further enhancing the genome data infrastructure by starting whole genome analysis of 100,000 general residents in public-private cooperation.

⑤ Project for Basic Medical Research

Toward application of R&D results in the medical field, basic R&D has been promoted for elucidation of life phenomena mechanisms including brain functions, immunity and aging, and the mechanisms of various diseases.

In FY2020, the government strengthened the infection research base in Japan and abroad and promoted basic research based on the impact of COVID-19. Regarding cancer, development of effective treatments and research for discovery/development of promising seeds were promoted. In the field of brain function research, research was advanced to elucidate the operating principle of the human brain by elucidating the whole aspect of the neural circuits performing high-order functions of non-human primates at the neuron level and by mapping brain structure and functions.

⑥ Project for Seeds Development and Research Base

The government builds a research system beyond the framework of academic organizations and

disciplines to conduct basic research including creation/development of breakthrough seeds toward creation of new modalities and implement international joint research. The government also develops systems and mechanisms for seeds discovery/transfer and high-quality clinical research/trials at support centers for research bridging and clinical research core hospitals, while at the same time promoting construction of reverse translational research and empirical research bases.

In FY2020, under the Advanced Research and Development Programs for Medical Innovation of MEXT the government continued promotion of advanced basic research, while at the same time reinforcing support for seeds research at support centers for research bridging and developing a system to implement and support safe and high-quality clinical trials/research at clinical research core hospitals in cooperation with MHIW in order to build research bases.

C. R&D related to individual areas of disease

R&D related to individual areas of disease has been promoted under the six integrated projects described above. Because the R&D requires response to diverse diseases and flexible responses including infection control, R&D under the integrated projects will be promoted in a way that allows flexible management according to the disease.

Major initiatives related to individual disease areas, "infectious diseases" in particular, include support for treatment, diagnostics and vaccine development of COVID-19 to address the epidemic. Regarding cancer and intractable diseases, tentative analysis was promoted based on the Action Plan on Whole-genome Analysis (first edition). The aim is to promote better medical care for patients with cancer, intractable disease and other diseases through medical development, promotion of personalized medicine and other efforts. In the area of geriatrics and dementia, the dementia R&D project supported a large-scale cohort study on dementia to elucidate dementia pathology based on the Basic Principle for Dementia Policy.

D. Moonshot R&D

In order to achieve the goals such as realizing a society for enjoying one's life with relief and release from health concerns until 100 years old, relevant ministries will work together on the Moonshot R&D project in Healthcare Policy in order to tackle social challenges that are difficult to realize but expected to have a big impact if realized, while ensuring link with the goals set by the Council for Science, Technology and Innovation (CSTI).

In FY2020, such projects which contribute to the realization of a society where citizens stay healthy and live longer, research on artificial hibernation, mitochondrial medicine, elimination of tissue inflammation-inducing cells, microinflammations and tissue embryonization were adopted through public invitation. Research will start after formulation of concrete research plans.

E. Inhouse R&D

For inhouse medical R&D conducted by inhouse research institutions of relevant ministries, the secretariat of the Headquarters for Healthcare Policy, relevant ministries, the inhouse research organizations and AMED constructs a system for constant information sharing and promotes overall strategic and systematic R&D in appropriate coordination and role sharing with the R&D support provided by AMED based on the characteristics of the individual institutions.

In FY2020, inhouse research institutions implemented a liaison and adjustment meeting to share information and conducted cooperative research through the Drug Discovery Support Network that builds a strong collaboration system to support commercialization research aimed at creation of innovative new drugs based on the results of universities and public research institutions.

Specific examples include fundamental technology development and strategic promotion of life science R&D at RIKEN toward health and longevity through biological understanding of homo sapiens. The National Institutes of Biomedical Innovation, Health and Nutrition (NIBIOHN) and other organizations aggressively pursued R&D responding to new needs and areas where effective R&D is desired in order to create new innovations toward the world's top level R&D and medicine. Furthermore, the National Institute of Advanced Industrial Science and Technology (AIST) tackled development of technology contributing to cell isolation in order to support screening of drug candidate compounds at the Drug Discovery Support Network.

(2) Building infrastructure for sustainable cities and regions

A. Compact and functional town development

In response to people's diversifying living needs, the National Institute for Land and Infrastructure Management (NILIM) is conducting: development of suburban residential area planning evaluation techniques based on the living support functions; research on wide-area linkage of city functions in regional cities in order to promote inter-zone linkage, and; development of planning evaluation techniques for solution of major city problems in order to promote Smart City and other research.

B. Research on transportation systems

The Integrated Innovation Strategy 2020 determined the direction to promote automated driving as a project of the SIP Second Period that is R&D program with increased focus on social implementation of results. In the SIP Automated Driving (expansion of system and services), CAO is working on the construction of dynamic traffic environment information including signals and the merging of support toward advanced automated driving on open roads and the implementation of Tokyo coastal area demonstration with participation of 29 organizations from diverse fields including domestic and foreign car manufacturers, car parts manufactures and universities. The ministry is also developing simulation

technologies necessary for safety assessment in cyberspace in order to spread automated driving.

As an effort toward an automated driving society, MIC is studying technical requirements including frequency sharing that are necessary for introduction of V2X communication. In order to enable observation of surrounding traffic conditions toward realization of safe and secure automated driving, the ministry is conducting R&D on technologies to collect dynamic information from various information sources, integrate the information as real-time traffic conditions and distribute necessary information to automated driving vehicles.

Toward practical application of automated driving, the National Police Agency is implementing R&D on signaling information provision using road side infrastructure, cloud, etc.

The National Research Institute of Police Science is conducting studies on traffic characteristics on high-standard expressways, and psychological characteristics of elderly drivers, as well as research on emerging traffic related issues including automated driving and the causes of accidents.

METI is implementing a technology development project toward new delivery services using automated delivery robots.

MLIT has been promoting technology development that helps further improvement of safety of railway traffic, including development of a system to enable detection of deformation of railway facilities and early detection of abnormal parts by using 3D point group data obtained by laser.

MPAT has been conducting R&D of technologies pertaining to vessels and use of the oceans by using the technologies as well as electronic navigation. In the field pertaining to vessels, the institute has been implementing research that contributes to significant reduction of accidents at sea and socially reasonable safety regulations for the purpose of ensuring the safety of marine transportation. Research is also being conducted to increase the efficiency of maritime transportation and develop transportation systems.

In the field of electronic navigation, the institute has been conducting R&D on advancement of the air traffic system in order to expand air traffic capacity, improve the convenience of air traffic and aircraft flight efficiency and reduce the environmental impact of aircraft, while improving the safety of air traffic.

The National Agency for Automobile and Land Transport Technology is responsible for the following: preventing accidents involving vulnerable road users; research on technologies for ensuring the safety of land transportation including the promotion of the development and practical application of next-generation heavy vehicles; testing and research of technologies for environmental conservation; conformity inspection regarding technological standards of automobiles; and the verification of technological requirements for automobile recalls.

C. Construction of a comprehensive life care foundation system in the communities

For the purpose of clinical applications and life support, MEXT and MHLW are working to develop technologies that can decode information in the brain in non-invasive or minimally invasive ways, to treat,

recover and complement physical functions.

In support of disabled people's independence and participation in society, MHLW has been implementing the Project for Development and Promotion of Equipment to Support Independence of Persons with Disabilities. They seek to develop convenient support apparatuses that can be used easily by disabled people, as per their needs

METI is promoting a project to provide support to private business operators who are engaged in R&D on welfare apparatuses. To facilitate the practical application of robot care devices, which is one of the priority areas for development, METI has been implementing the Project to Promote the Development and Standardization of Robotic Devices for Nursing Care and other Welfare Equipment to support development of robotic devices that contribute to the independence of elderly people by private businesses.

Toward construction of a universal society where everyone including the elderly and people with disabilities can engage in activities freely without stress through development of high-precision positioning indoor environments, MLIT in industry-academia-government collaboration promoted development of an environment for creation and spread of navigation services at major transport terminals.

With the aim of establishing methods for visualization of barrier-free effect of houses/architecture, the National Institute for Land and Infrastructure Management (NILIM) is conducting research to grasp the ease of activities in a living environment (ease of living, ease of movement and ease of assistance) quantitatively using a barrier-free environment assessment program with indices of the physical activity level of residents (including the physically unimpaired, the elderly, wheelchair users and caregivers), which will improve health maintenance management of the residents in accordance with their life stage.

(3) Extending service life for efficient and effective infrastructure

Under PRISM (Public/Private R&D Investment Strategic Expansion Program) "innovative construction and infrastructure maintenance and innovative disaster prevention/mitigation technologies field" the Cabinet Office promotes "change through innovation" by allocating additional budget to and accelerating promotion of i-Construction and other measures of relevant ministries and agencies. In order to realize steady and efficient infrastructure maintenance while accelerating open innovation brought about by effective use of data, the ministry in cooperation with MLIT is promoting construction of an infrastructure data platform that coordinates data of the national and local governments and the private sector.

MLIT and METI have promoted the development and introduction of robots to maintain social infrastructure and implement anti-disaster measures more effectively and efficiently.

MLIT is promoting i-Construction where ICT is used in all construction production processes from investigation/survey to design, installation, inspection, maintenance and renewal. The aim is 20% improvement of productivity in construction sites by FY2025. For maintenance and renewal, the ministry

will pursue efficiency improvement and sophistication of inspections by actively using new technologies, and pursue labor saving and cost reduction by introducing new materials. Taking COVID-19 countermeasures as turning point, the ministry will accelerate expansion of use of BIM/CIM[1] in public works to enable digital processing of a series of processes from design/construction to maintenance as well as stock utilization, while at the same time promoting digitalization of advanced skills. The aim is a drastic improvement of productivity and shift to noncontact/remote operations through digital transformation (DX) in the infrastructure and physical distribution fields.

In order to promote i-Construction and accelerate DX in the infrastructure field, the Geospatial Information Authority of Japan (GSI) is developing "National Geodetic Datum," which is a common rule for positional information used in individual processes of: investigation, survey, design, construction, inspection, maintenance and renewal. GSI is implementing technology development on novel survey techniques contributing to improvement of the accuracy, efficiency and reliability of 3D surveys.

For promotion of i-Construction, National Institute for Land and Infrastructure Management (NILIM) is conducting the following research: development of 3D models for data distribution, development of procedures/standard proposals for work progress control/inspection using ICT for various types of works, "research on improvement of construction productivity with full utilization of ICT" to develop methods for central management of information useful for maintenance/management on a 3D model. In cooperation with other MLIT departments and agencies, NILIM has been developing: technologies for more efficient maintenance of sewerage facilities; utilization of existing buildings in order to ensure continued safe use of existing housing and social capital stock through more efficient and advanced inspection, repair and renewal, and; techniques and technologies for utilization of existing buildings and building lots.

Public Works Research Institute has been working on the development of: methods contributing to an effective (efficient, advanced) maintenance cycle of existing structures (bridges, pavements and management facilities); methods for renewal/construction of structures, which enables maintenance and long service life in accordance with the management level for bridges, civil engineering structures and tunnels, and; cross-cutting (roads, rivers, harbors, fishing ports and agriculture) technologies and systematization for maintenance and renewal of infrastructure susceptible to frost damage, complex deterioration and other damages.

MPAT has been working on: enhancement of functions of capital area airports by conducting research on the improvement of safety and maintenance efficiency of airport infrastructure including runways; the inspection and monitoring of coastal zone infrastructure supporting the economic/social activities of the country, and; the maintenance efficiency and reduction in lifecycle cost.

1 Building Information Modeling/Construction Information Modeling
By introducing 3D model in the stage of survey and design the method facilitates information sharing across the project through linkage and development of the 3D models in each stage of subsequent construction, maintenance and renewal to ensure efficiency improvement and upgrading of a series of construction production and management systems.

NIMS has comprehensively conducted R&D in the material field, in which Japan excels, for technologies to inspect, diagnose, repair and upgrade infrastructure and evaluate reliability of materials as well as for development of new structural materials with the aim of extending the service life and enhancing the earthquake resistance of the social infrastructure.

❸ Improving competitiveness in manufacturing and value creation

(1) New manufacturing systems

A. Construction of a platform for supply chain system

Construction of a new platform to integrate engineering system chains and production process chains will promote data utilization, improve productivity and create new added values.

In an effort to develop the platform, METI is supporting creation of advanced cases and developing compatible formats for sharing data of various machines and equipment. For small and medium manufacturers facing challenges in data utilization, METI has started to develop consultation centers to train and dispatch specialists who propose improvement plans and technologies tailored to each challenge. In response to the global pandemic of COVID-19, the ministry will support development of domestic production centers of products, components, materials, etc. for which the production centers are highly concentrated and conduct technology development that will contribute to resilience of the supply chain; the development will include replacement or reduction of use of components/materials that heavily rely on foreign countries and speedy and flexible recombination of the supply chain through data coordination, for example.

In order to maintain and strengthen the international competitiveness of our maritime industry, MLIT supported technology development for productivity improvement through more efficient and advanced processes of ship development/design, shipbuilding and operation by utilizing information communication technologies including IoT and big data, and organized the challenges and measures for supply chain optimization in the shipbuilding industry. According to the roadmap developed in June 2018 for practical application of maritime autonomous surface ships, the ministry is implementing demonstration projects and will develop an environment necessary for practical application of maritime autonomous surface ships by taking advantage of the knowledge obtained through the projects.

The National Institute of Information and Communications Technology (NICT) is conducting pioneering R&D on brain activity measuring technology to enable exploration of latent needs based on brain information.

B. Development of innovative production technologies

In order to ensure high quality laminate shaping and improve efficiency of its component development, METI is working on elucidation of metal melt and solidification phenomena during shaping and

development of advanced measurement and equipment control technologies, for example.

(2) Integrated materials development system

A. Construction of highly reliable materials database

For strengthening of the international competitiveness of our materials industry, the government is building a materials development system by integrating numerical simulation, theories, experiments, analyses and data science. The government is promoting consolidation and database compilation of reliable materials data held in industry, government and academia for the system construction.

B. Establishment of materials development technologies utilizing databases

NIMS, a central organization of materials research, is working on the implementation of new material designs for groundbreaking magnets, batteries, electric heat control, etc. by constructing a material database and advancing fusion with data science.

Section 2 Ensure Safety and Security for Our Nation and its Citizens and a High-quality, Prosperous Way of Life

In order to ensure safety and security for our nation and its citizens and a high-quality, prosperous way of life, it is necessary to work toward disaster prevention, mitigation, and national resilience, as well as to ensure comfortable living environments and occupational health for citizens. In addition, it is essential to appropriately deal with changes in the national safety and security situations and the occurrence of crime, terrorism, and cyberattacks. To address these issues, the Meeting to Promote Comprehensive Innovation Strategy compiled the "Direction of Science, Technology and Innovation toward Realization of Safety and Security" in January 2020.

❶ Addressing natural disaster

(1) Improvement of prevention capabilities

Under Tokyo Metropolitan Resilience Project, MEXT has been building an ultra-high density seismic observation system in public-private collaboration by integrating seismic observation data held by government agencies, local governments, private companies, and others. The ministry is also collecting sensor information concerning the collapse margin of structures including non-structural components (piping, ceiling, etc.) by using the 3D Full-Scale Earthquake Testing Facility to collect large amounts of diverse data that will contribute to integrated public-private disaster response, business continuity, disaster prevention actions by individuals, etc. for maintenance of urban functions. The data will be shared and analyzed by industrial, public and academic sectors, which will lead to creation of new value.

MLIT has been developing and operating the Nationwide Ocean Wave Information Network for

Ports and Harbors (NOWPHAS) in mutual cooperation with MPAT and other research institutions. Data on waves and tidal levels observed across Japan are collected through this network, and details are published on MLIT's website in real time[1].

Public Works Research Institute is working on technology development to reduce damage of flood disasters that have become extreme in recent years and damage of tsunami and sea level rise, prevent and mitigate sediment disasters caused by sudden natural phenomena, and reduce damage of snow/ice disasters caused by extreme weather.

The Building Research Agency is conducting technology development to ensure the structural safety of buildings, thus contributing to prevention of damage/collapse due to natural disasters and ensuring continued use of buildings.

Towards early recovery and reconstruction after a major earthquake, MPAT is conducting research on forecasting earthquake- and tsunami-induced deformation and performance degradation for structures in coastal areas and the areas behind them, for the improvement of safety and reliability for facilities in coastal areas.

(2) Improvement of predictive capability

Under the Headquarters for Earthquake Research Promotion (Director: the Minister of MEXT; Hereinafter: HERP), administrative agencies and universities are working in close cooperation on seismological investigations and research.

Considering that the long-term evaluations so far by HERP which estimates the probability and magnitude of future earthquakes could not cover massive earthquakes with a rupture area beyond the expected regions such as the 2011 off the Pacific coast of Tohoku Earthquake, and also in light of the 2016 Kumamoto Earthquake that occurred on the active faults, HERP has been reviewing and revising its long-term evaluations, including publication strategy. In light of the tremendous damage caused by the tsunami of the 2011 off the Pacific coast of Tohoku Earthquake, HERP is also conducting evaluation of tsunamis generated by various earthquakes.

MEXT launched the "Research Project for Disaster Prevention on the great Earthquakes along the Nankai Trough" which includes research and development on scientific assessment of seismic activities when "Anomalous Phenomena" along the Nankai Trough are observed, and on appropriate disaster management for the areas where damage is anticipated. In the Integrated Research Project on Seismic and Tsunami Hazards Around the Sea of Japan, controlled-source structure survey and investigations of tsunami deposits were conducted to advance research on an earthquake source fault model and a tsunami source model that would be applicable to the Sea of Japan and its coast.

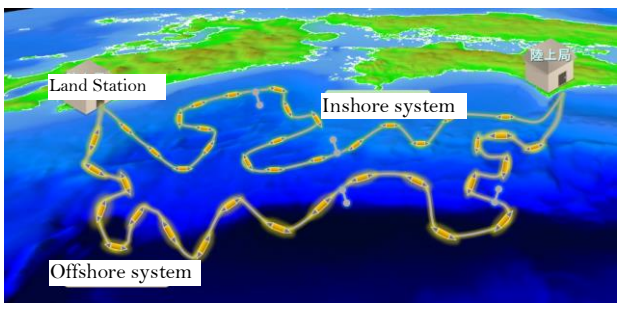
After the Great Hanshin-Awaji Earthquake, comprehensive earthquake observation networks were built

1 http://www.mlit.go.jp/kowan/nowphas/

in land areas. Although several sea-area observation networks have been built, there are far fewer observation points in these networks than in land-based observation networks. Accordingly, National Research Institute for Earth Science and Disaster Resilience (NIED) is operating the Dense Oceanfloor Network system for Earthquakes and Tsunamis (DONET) that is a dense submarine network equipped with seismometers and hydraulic gauges for real-time seismic observation in the seismic source region of the anticipated Nankai Earthquake. Furthermore, off the Pacific Coast of Tohoku where large aftershocks and tsunamis are likely to occur, the Seafloor observation network for earthquakes and tsunamis along the Japan Trench (S-net) has been operated to directly detect earthquake and tsunami to contribute to accurate and prompt communication of disaster information. In addition, the construction of the Nankai Trough Seafloor Observation Network for Earthquakes and Tsunamis (N-net) was advanced in the sea area extending from off the coast of Kochi Prefecture to Hyuganada, where the observation network is not yet installed in the anticipated seismic source region of the Nankai Trough Earthquake (Figure 2-3-1).

In the field of volcanology, the Integrated Program for Next Generation Volcano Research and Human Resource Development was launched in FY2016 in response to the eruption of Mt. Ontakesan in 2014. The program promoted integrated research of "observation, prediction and measures" in coordination and jointly with other fields in order to contribute to reduction of volcano disasters in addition to existing observation research. The project also fostered volcano researchers who have comprehensive knowledge and advanced technique.

■ Figure 2-3-1/ Nankai Trough Seafloor Observation Network for Earthquakes and Tsunamis ■



Source: MEXT

The National Institute for Land and Infrastructure Management conducts "response to increasingly severe disasters" which include development of methods for prior estimation of sediment disaster caused by a large-scale earthquake.

National Research Institute for Earth Science and Disaster Resilience (NIED) is observing various tremors ranging from feeble tremors imperceptible to the human body to strong tremors causing big damage by using about 1,900 high-performance and high-precision seismometers covering the entire land area of Japan evenly and densely. It operates about 200 seismometers and tsunami meters in sea area and started full-scale operation of Monitoring of Waves on Land and Seafloor (MOWLAS) in November 2017. MOWLAS is an earthquake, tsunami and volcano observation network covering all land and sea areas of Japan, including the Fundamental Volcano Observation Network (V-net) for 16 volcanoes in Japan. NIED is advancing research and implementation of real-time prediction of earthquakes and tsunamis as well as observation and prediction of volcanic activities by using MOWLAS and has provided observation data to

the Japan Meteorological Agency. NIED also promoted use of the observation data by research institutes, local governments and the private sector including railway companies.

In addition, NIED is also conducting research on sediment, storm and flood damage prediction based on multisensing and research contributing to reduction of damage caused by natural disasters including evolving snow/ice disasters and coastal disasters. The efforts include: road condition evaluation using AI; creation of new information including whole-area high-resolution snow information using radar, a snow cover change model, etc.; expansion of the provision area of the snow-weight distribution information; construction of an information website on snowdrifts in Niseko; social application of snow/ice disaster prevention information including provision of snowfall/snow-melting information to local governments by introduction of IoT to the existing snow-melting devices, and; participation in an innovation creation project in cooperation with private enterprises. For promotion of R&D on lightening risk prediction based on comparative analysis with MP radar[1] data, etc., NIED is conducting continuous observation of lightening using a lightening discharge path 3D observation system in the Tokyo metropolitan area.

Japan Meteorological Agency (JMA) in cooperation with MEXT is collecting, processing and analyzing data of the fundamental observation/research network for earthquake, using the results for disaster prevention information, and providing them to the Earthquake Research Committee Headquarters for Earthquake Research Promotion and others. JMA also developed the Automatic Hypocenter Determination Method (PF method[2]) and introduced the method in April 2016. For earthquake early warning, JMA developed IPF method[3] and PLUM method[4] in preparation for future multi-segment earthquakes and massive earthquakes for which the risk has been widely recognized after the off the Pacific Coast of Tohoku Earthquake. IPF and PLUM methods have been introduced in December 2016 and March 2018 respectively. JMA is also advancing technology development for their further sophistication in cooperation with NIED. Against tsunami, JMA introduced a method for high-accuracy prediction of tsunami height based on the observed offshore tsunami waveform (tFISH[5]) in March 2019.

The Meteorological Research Institute (MRI) researches the following topics: the development of real-time scale estimation of tsunami/earthquake to mitigate damage by tsunamis, and tsunami forecasting based on offshore tsunami monitoring data; research of technologies for monitoring and analyzing crustal movements that help improve the accuracy of grasping of changes in fixation between plates along the Nankai Trough, and development of a monitoring method to advance volcanic activity assessment and prediction.

To collect geological information useful for disaster prevention/mitigation, the National Institute of

1 Multi-parameter radar that can simultaneously transmit / receive two types of radio waves (horizontally and vertically polarized waves)
2 Phase combination Forward search
3 Integrated Particle Filter method for accurate estimation of seismic centers even when multiple earthquakes occurred simultaneously has been developed in cooperation with the Disaster Prevention Research Institute, Kyoto University.
4 Propagation of Local Undamped Motion method. Method for appropriate estimation of seismic intensity of large-scale earthquakes with a very wide area of strong vibration
5 tsunami Forecasting based on Inversion for initial sea-Surface Height

Advanced Industrial Science and Technology (AIST) investigates geological surveys of active faults, tsunami deposits, and active volcanoes, and publishes the results of these surveys. In order to evaluate the distribution and the paleoseismology of active faults, AIST conducted geological surveys of seven in land fault zones (Shibetsu, the western margin of the Shizukuishi Basin, the eastern margin of the Yokote Basin, Nobi, Yamada, Median Tectonic Line and Kikukawa). AIST added information of the tsunami flooding area on the coast of Fukushima Prefecture to the Tsunami Deposits Database. For short-term predictions of Nankai megathrust earthquakes, AIST continued to operate the observation well network groundwater levels (water pressures), groundwater temperatures, crustal strains and seismic waves. Integration of AIST strain gauge data at 12 observation sites into the constant observation system of the Japan Meteorological Agency (JMA) since June 2020 enabled JMA to quickly assess and release information related to the Nankai Trough Earthquake.

AIST conducted field investigations and observed/analyzed volcanic products around the volcanos where eruption activities were observed (Kuchinoerabujima, Nishinoshima and Sakurajima volcanos). These were expected to be petrological and mineralogical studies leading to understanding ongoing eruption and predicting transition of volcanic activities.

Japan Agency for Marine-Earth Science and Technology (JAMSTEC) in cooperation with universities and other relevant organizations is implementing survey and observation related to seafloor earthquakes and volcanoes by using research vessels and various types of observation equipment in the expected Nankai trough source region, and the oceans surrounding Japan and the West Pacific Ocean. By advancing methods to analyze data from these observations, JAMSTEC predicts transition of seismic and volcanic activities through large-scale and high precision numerical simulation.

GSI is responsible for observation, analysis, and R&D on crustal deformation and plate motions through GNSS[1] CORS[2] network, Very Long Baseline Interferometry (VLBI[3]), and Interferometric Synthetic Aperture Radar (InSAR[4]). Detailed monitoring of crustal deformation in and around volcanoes has been implemented through integrated analysis of GNSS volcanic observation data, which have been collected by several institutes, such as JMA, NIED, the Hot Springs Research Institute of Kanagawa Prefecture, and the Earthquake Research Institute of the University of Tokyo.

The Japan Coast Guard (JCG) has been operating the GNSS-A seafloor geodetic observation and bathymetric surveys. The data and results are regularly published.

1 Global Navigation Satellite System

2 There were 1,300 electronic reference stations across the country as of the end of March 2021.

3 An advanced technique that utilizes radio waves from deep space as far as billions of light years away for precisely measuring the distance between two radio telescopes situated thousands of kilometers away from each other within a tolerance of a few millimeters.

4 Synthetic Aperture Radar: a technique for using an artificial satellite for obtaining information about the evolution and state of earth's surface.

(3) Improvement of response capabilities

In the First Period of the SIP Program, "Enhancement of Societal Resiliency against Natural Disasters (FY2014-2018)", the Cabinet Office developed the "Shared Information Platform for Disaster Management (SIP4D)," which is a system to gather disaster information on digital maps and enable information sharing among relevant organizations. At the time of the Heavy Rain in July 2020 and other disasters, the Information Support Team (ISUT: an initiative of the disaster prevention department of the Cabinet Office) provided information support by using SIP4D for disaster response by local governments. In the second period of SIP "Strengthening of National Resilience (disaster prevention/mitigation)" that started in FY2018, the Cabinet Office is promoting R&D and social implementation in order to construct an information system that makes the best of the latest science and technologies including satellites, IoT and big data to support decision making by the central and municipal governments in the event of a natural disaster. The office is also promoting R&D into Disaster Chatbot, a system of automatic talk with AI on SNS at the time of disaster, through demonstration experiments with local governments and other participants.

Quasi-zenith satellite system Michibiki started service on November 1, 2018. The service consists of disaster crisis management reporting to provide disaster prevention weather information through Michibiki and collection of safety information of evacuees in shelters, etc.

MIC has been conducting R&D on ICT for improving the disaster-resistance of information and communications facilities, and for collecting data on damage at times of disaster. In addition, MIC has vigorously applied its research results, such as a communication system that can be carried in disaster-stricken areas for emergency restoration of communications (a movable and deployable ICT resource unit) in communities in Japan and worldwide.

NIED conducts research on the development of systems to share and utilize information of various natural disasters and has been conducting necessary demonstrations and providing information for public disaster response based on its role as a designated public institution. At the time of the heavy rain disaster that caused grave damage centered in Kumamoto prefecture in July 2020, NIED integrally summarized information collected in SIP4D and information collected in the disaster area and provided the results together with past information and analysis results related to the disasters to the disaster response organizations through NIED-CRS (crisis response site open to the public) and ISUT-SITE (open only to the disaster response organizations). The websites displaying maps supported the activities to help isolated villages along the Kuma River.

The Ministry of Defense (MOD) is conducting research on high-mobility powered suits that enables quick and agile action and travel on uneven ground while reducing weight load on personnel. In order to quickly secure an alternative means for damaged bridges after a large-scale disaster to support rescue of victims and rapid deployment of restoration teams, MOD has been conducting research for establishment

of an emergency bridge foundation technology using light-weight and high-intensity composite materials.

FDMA's National Research Institute of Fire and Disaster (NRIFD) has advanced R&D on a fire-fighting robot system for deployment in the event of disasters at energy or industrial infrastructure sites. These robots feature sophisticated autonomy based on geospatial information technology and ICT, as well as cooperation and coordination among the robots. Thus, they will be able to collect information and discharge fire-fighting water at disaster sites that are accessible only to robots. The institute completed a firefighting robot system for field deployment in FY2018, deployed the system at the Fire-defense Headquarters and studied optimization of its functions toward development of specification of a production model. In addition, the NRIFD conducted R&D of the following technologies: (1) high-accuracy prediction of earthquake damage to oil tank (identification of characteristics of short-period ground motion that is likely to cause damage to the oil tank body, influence of long-period ground motion on individual tanks due to differences in underground structure, etc.); (2) Powerful foam extinguishing technology tailored to the scale of fire, oil type, etc. of oil tank; (3) More suitable assessment of fire risk of highly reactive chemical substances (e.g. water reactive substance, substance prone to ignition caused by heat accumulation) stored or handled in petrochemical complexes) and safety management while firefighting. In addition, NRIFD started R&D related to quantitative diagnosis standards, etc. on the soundness of steel plate with internal coating.

Furthermore, the NRIFD conducted research on optimization of ambulance operation, R&D on search and rescue technologies using image information taken from the air obtained by UAV[1], etc. in segment disaster sites and a method to remove debris piled up all over the place in order to improve firefighting capabilities at the time of disaster. In preparation for large-scale spread of fire in built-up area, which is feared after a Nankai Trough earthquake or earthquake that hits the Tokyo area directly, the NRIFD conducted R&D to advance simulations of urban fire spread, elucidation of the phenomena of fire whirlwinds and flying sparks that expand damage, utilization of the results for evacuation guidance for residents and firefighting activities. In addition, the NRIFD conducted R&D on improvement of capability to investigate the cause of a fire in order to take effective fire prevention measures, and also launched R&D on effective evacuation from a building.

NICT has been increasing the sophistication of an airborne Polarimetric and Interferometric Synthetic Aperture Radar system (Pi-SAR) that can observe the ground surface in disaster-stricken areas as needed, regardless of weather conditions. NICT is also developing the following technologies: geographically-distributed network technologies that will allow local networking even when the public communication infrastructure is devastated due to a disaster, etc., and real-time information analysis technology to analyze SNS postings and extract disaster-related information. Together with the municipalities, NICT is

[1] Unmanned Aerial Vehicle

conducting demonstration experiments of these technologies during disaster drills, etc.

NILIM is conducting the following activities: (1) research on collapse recognition and real-time flood prediction for responsive information communication to help evacuation and flood fighting; (2) development of rapid testing of the soundness of key buildings (e.g., government offices) of local governments which were damaged by an earthquake, and; (3) research on design objectives of independent energy systems for continued daily living after a disaster. In the port sector, NILIM is conducting research on an immediate damage estimation method for port facilities in large-scale earthquakes.

Public Works Research Institute is developing technologies to support risk management of water disasters in Japan and abroad, and technologies for minimizing damage of a major earthquake to structures and their early restoration.

JAXA has been contributing to various disasters monitoring and grasping of the state of disaster using the second Advanced Land Observing Satellite DAICHI (ALOS-2[1]) and other satellites (See Chapter 3 Section 4).

In response to the global outbreak of COVID-19, METI will advance introduction of EdTech to schools and development of online contents that promote home schooling. The ministry will also enhance support for non-face-to-face/remote business activities. The support includes promotion of use of cross-border e-commerce, construction of digital business talk platforms and promotion of smart security.

(4) Response to the Great East Japan Earthquake and reconstruction/rebirth

A. Industrial recovery from, and reconstruction after, the Great East Japan Earthquake in the afflicted regions

For the restoration of the offshore marine ecosystem, which was damaged by tsunamis on the Pacific coast of Tohoku, MEXT has established the Tohoku Marine Science Center in collaboration with municipalities and national ministries. The center has been conducting surveys and other research on the offshore marine ecosystem. The results have been used to draft a local fishery plan and to select the locations of fish farms.

Toward realization of the Fukushima Innovation Coast Framework, MAFF has been supporting development and demonstration of state-of-the-art agriculture and forestry robots in the Hamadori area of Fukushima Prefecture damaged by the nuclear disaster. The aim of the project is to reconstruct these industries by implementing advanced agriculture, forestry and fisheries using high technologies first in Japan.

Aiming at revitalizing agriculture, forestry and fishery, which are the main industries in the areas affected by the disaster, at accelerating the restoration and reconstruction of farming and fishery villages,

1 Advanced Land Observing Satellite-2

and at fostering new types of agriculture, forestry and fishery that have high growth potential, MAFF has been conducting on-site empirical research by applying state-of-the-art technologies and promoting the dissemination of the research results. In doing so, MAFF has established empirical research sites for agriculture in Iwate and Fukushima prefectures and empirical research sites for fishery in Miyagi and Fukushima prefectures, while setting up social implementation centers in Iwate, Miyagi and Fukushima prefectures. Specifically, distinctive empirical studies (crop rotation in rice paddies, greenhouse horticulture, fishing-boat fisheries and fish culture, release and processing, etc.) are conducted in cooperation with farmers and fishermen in the affected area and according to the conditions of the respective prefectures.

Furthermore, in order to lead the reconstruction and revitalization of Fukushima Hamadori and other areas over the long term at the initiative of the government by further developing the Fukushima Innovation Coast Framework, the Reconstruction Agency in cooperation with the relevant government offices will establish an international education and research center as the central facilities for R&D and human resource development. As the hub of creative reconstruction, the center will gather domestic and foreign knowledge to the Fukushima Hamadori and other areas that suffered serious damage from the nuclear disaster, and conduct the R&D and human resource development which are essential for the creative reconstruction of Fukushima including the creation of new industries. The center will also disseminate and share experience and achievements with the world as it is a responsibility of the country that has experienced a nuclear disaster, and by using the knowledge obtained in the process, the center aims to strengthen the industrial competitiveness of Japan and create innovations contributing to solution of common challenges for Japan and the world. The basic concept will be formulated within FY2021 toward establishment of the center.

B. Efforts on compensation for nuclear damage

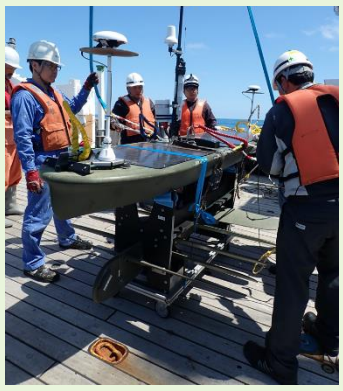
The purpose of the Act on Compensation for Nuclear Damage (Act No. 147 of 1961) is to protect persons suffering from nuclear damage and to contribute to the sound development of the nuclear industry by establishing the basic system regarding compensation in case of nuclear damage caused by reactor operation etc. The act concentrates liability for nuclear damage on the nuclear operators and places unlimited liability without fault on them. In order to ensure prompt payment of compensation by the nuclear operators, the act provides an obligation of provision of financial security by nuclear operators and the aid from the government when nuclear damage exceeds the financial security amount, as well as establishment of the Dispute Reconciliation Committee for Nuclear Damage Compensation to ensure smooth and appropriate payment of damages.

Since the accident at the TEPCO Fukushima Daiichi and Daini Nuclear Power Stations (hereinafter: the accident), a number of residents have been forced to live in evacuation shelters or to give up business activities such as manufacturing and sales. 10 years after the accident, it is essential that these victims

continue to receive compensation promptly, equitably and appropriately, so that they may return to safe and secure living as quickly as possible. To this end, various measures have been taken for victims of the accident based on the Act on Compensation for Nuclear Damage.

MEXT instituted the Dispute Reconciliation Committee for Nuclear Damage Compensation. The committee has been formulating guidelines to indicate the damaged items that can be classified with certain criteria and the extent of compensation, with the input of local opinions, and it has been reviewing these guidelines as needed. Furthermore, the Nuclear Damage Compensation Dispute Resolution Center has been conducting reconciliation of alternative dispute resolutions while improving its operations and increasing in personnel. In addition, in cooperation with relevant organizations, the center is making efforts so that the affected people who are yet to claim for damages concerning the nuclear accident can claim damages early. The government approved the revised New Comprehensive Special Business Plan in May 2017 (several changes were approved later,) which made mention of providing prompt and appropriate compensation for nuclear damage by TEPCO and for its streamlined management. The government has been providing assistance to TEPCO through the Nuclear Damage Compensation and Decommissioning Facilitation Corporation for providing compensation smoothly.

Column 2-4 Efficient Seafloor Crustal Movement Observation by Using the Unmanned Surface Vehicle "Wave Glider" – expected to greatly improve the reliability of risk assessment of huge earthquakes

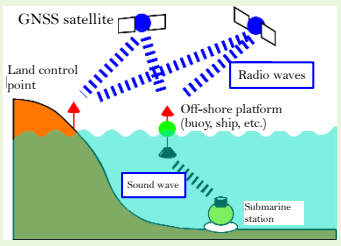


Wave Glider just before throwing in
Provided by JAMSTEC

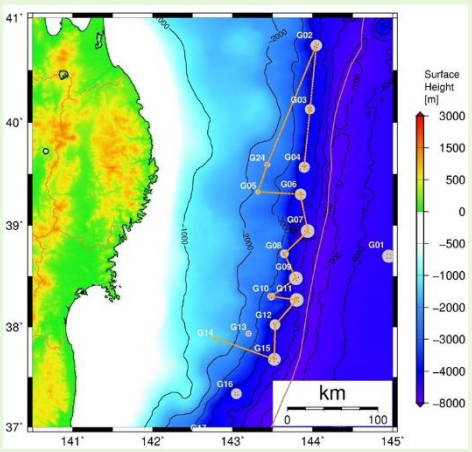
Japan locates at the boundaries of multiple plates that cover the earth. Huge earthquakes including the off the Pacific coast of Tohoku earthquake in 2011 repeatedly hit Japan and caused enormous damages due to huge tsunamis.

These huge subduction-zone earthquakes are phenomena that release the strain caused by the inter-plate locking between the oceanic and continental plates. Therefore, the state of the inter-plate locking is a very important information to predict the size and occurrence time of earthquakes. However, because the plate boundary surfaces are located beneath the seafloor, it is necessary to obtain seafloor observation data of crustal movement in order to know the locking state. Observation stations using the method that combines observation at sea surface and acoustic-ranging between the sea surface and bottom have been set up around Japan. The observations have provided a lot of important knowledge for elucidation of the occurrence process of subduction-zone earthquakes. For example, it is found that the crustal movement in the sea area along the Japan Trench reached several tens of meters at the time of the Pacific coast of Tohoku earthquake. However, the observation requires a ship as a sea surface platform, which involves enormous cost.

To address this issue, a research team of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and Tohoku University developed a new observation system using the unmanned surface vehicle "Wave Glider." Through observation using the system for about 40 days from June to July 2020, the team succeeded in obtaining data with the accuracy equal to the observation using ship. The cost of the operation for about 40 days is one tenth or lower than the cost of ship observation. In the future, development of a system for implementation of more efficient seafloor crustal movement observation is expected by appropriately using unmanned equipment or manned vessels according to the environment. It is expected that the unmanned ocean observation equipment will be used for submarine topography survey, meteorological and oceanographic observations, and climate change research.



Schematic diagram of the method that combines observation at the sea surface and sea surface-bottom acoustic-ranging
Provided by JAMSTEC



Track Chart of Wave Glider
Provided by JAMSTEC

❷ Ensuring food safety, living environments, and occupational health

(1) Ensuring food safety and security

MEXT publishes the Japanese Standard Tables of Food Composition, which lists the composition of the Japanese diet. As pooling of high-quality data had been required to address the needs of the modern Japanese diet, MEXT completely revised the table into "the Standard Tables of Food Composition in Japan 2020 (eighth revised edition)" in December 2020. The new table lists a greater variety of foods, for example.

In order to ensure the stable supply of safe agricultural, livestock, and marine products and food, MAFF conducts regulatory research and development, e.g., control measures for prevention/reduction of chemical/microbiological hazards in foods during production, processing and distribution; testing methods and more effective control measures against major livestock diseases to reduce the risk of spread of the diseases and economic loss in the livestock industry; pest control measures to reduce damage to agricultural production.

(2) Ensuring safety and security of the living environment

A. Efforts for measures against radioactive substances

The organizations concerned are working together on development of technology and research and study towards establishing measures to deal with radioactive substances, for the purpose of remediating the environment contaminated by radioactive materials released in the accident at the TEPCO Fukushima Daiichi Nuclear Power Station.

Not only does MAFF develop technologies aimed at the effective and efficient countermeasures on radioactive materials in forests and farmlands, but it also has demonstrated the technologies so far developed. Their results have been published swiftly. MAFF is also developing technologies to deal with various post-decontamination challenges, such as technologies for restoration/improvement of soil fertility of agricultural land after the decontamination and proper potassium application to control absorption while ensuring safety of agricultural products.

MOE has compiled a strategy for developing technologies regarding the volume reduction and recycling of radioactive substances towards the final disposal of soil and waste outside Fukushima Prefecture derived from decontamination within the prefecture. The ministry has also been carrying out a project to verify the effects and safety of technologies that can be utilized for volume reduction and other purposes.

JAEA moved into the research building of the Fukushima Environment Creation Center. In coordination and cooperation with Fukushima Prefecture, the National Institute for Environmental Studies (NIES) and others, JAEA is conducting R&D into technology for measuring radiation doses, research on the behavior of radioactive substances in the environment and R&D on technologies for the volume reduction and recycling of radioactive substances. The aim is to restore environments that were contaminated by

radioactive substances released in the accident at the TEPCO Fukushima Daiichi Nuclear Power Station.

B. Efforts to clarify environmental risks to children

In FY2010, MOE started a large-scale, long-term birth cohort study, the Japan Environment and Children's Study (JECS), by enrolling 100,000 pairs of parents/ children across the country in the study. In this study, blood of parents and children and other biological samples of the subjects were taken, preserved and analyzed. Follow-up studies will be conducted using questionnaires, until the children reach 13 years of age to clarify the influences of environmental chemical agents on children's health.

For implementation of the study, National Institute for Environmental Studies (Programme Office) conducts research planning and chemical analysis of biological specimens, the National Center for Child Health and Development (Medical Support Center) provides medical support, and regional centers of 15 districts have been conducting follow-up studies. MOE will handle external evaluation of this study, public relations/dialog and international cooperation, while re-examining the environmental policies based on the results of this study.

Japan Environment and Children's Study (JECS)
http://www.env.go.jp/chemi/ceh/en/index.html

❸ Ensuring Cybersecurity

For the purpose of comprehensively and effectively advancing measures for Cybersecurity pursuant to the Basic Act on Cybersecurity (Act No. 104, 2014), the Cybersecurity Strategy was decided by the Cabinet on July 27, 2018 after deliberations by the Cybersecurity strategy headquarters led by the government. The government has been promoting R&D on technologies related to cybersecurity based on the strategy.

Since FY2018 the Cabinet Office has been working on SIP "Cyber Physical Security for IoT Society." Toward realization of a secure Society 5.0, the program is promoting development and demonstration of Cyber Physical Security Infrastructure that can be used for protection of an entire large supply chain including IoT system services and SMEs, and its social implementation in diverse social infrastructure and services as well as industrial fields with a wide supply chain, which include manufacturing, distribution and building management.

Through NICT and other entities, MIC has been promoting R&D in the field of cyberattack observation and cybersecurity. MIC aims to use its technical knowledge obtained through the R&D to train security human resources who have practical ability to handle increasingly sophisticated and complex cyberattacks.

To this purpose, MIC has been implementing practical cyber defense exercise (CYDER[1]) for government agencies, local governments, and others, and SecHack365 to train young security personnel at the National Cyber Training Center organized in NICT.

Aiming at cybersecurity of the entire supply chain in Society 5.0 that will be realized through IoT and AI, METI formulated the Cyber Physical Security Framework (CPSF) that is compiling an overview of the measures required from industry in April 2019 and is developing guidelines for each industry field based on CPSF. The Cyber Physical Security Research Center that was established by AIST in November 2018 analyzes increasingly sophisticated and complex threats with the fusion of cyberspace and physical space and promotes and implements R&D on technologies to tighten security against threats. The Industrial Cyber Security Center of Excellence established at the Information-technology Promotion Agency in April 2017 has been promoting activities such as development of human resources who will play central roles for cybersecurity of control systems at critical infrastructure operators in addition to information systems.

❹ Addressing national security issues

The National Security Strategy (National Security Council/Cabinet decision on December 17, 2013) states: "The advanced technology of Japan constitutes the foundation of its economic strength and defense forces and is also a valuable resource that the international community strongly seeks from Japan. Therefore, Japan should encourage the further promotion of technologies, including dual use technologies, thereby strengthening Japan's technological capabilities."

The 5th Science and Technology Basic Plan suggests that "the fruit of science and technology have the potential to make impacts in multiple areas" and "In view of the increasingly challenging environment surrounding national security, in order to ensure the safety and security of the nation and its citizens, it is important to make use of Japan's many outstanding technological strengths." Based on the National Security Strategy and the 5th Basic Plan, it is necessary to promote R&D on technologies necessary to address national security issues in cooperation with relevant ministries and through industry-academia-government collaboration.

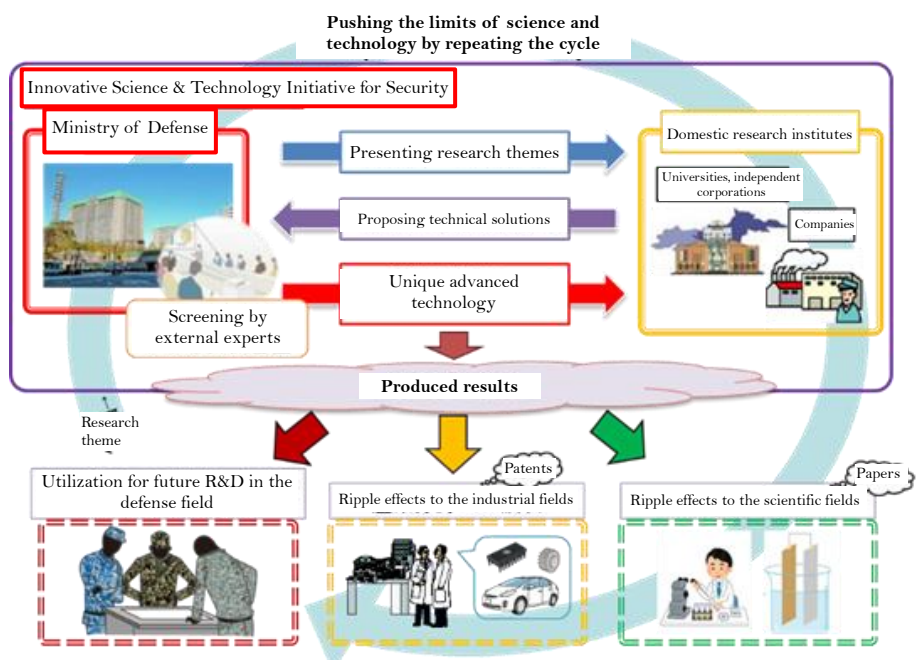
The Public Security Intelligence Agency collects and analyzes information pertaining to the actual state of technology leaks including through corporate acquisition and information theft in cyberspace for the purpose of preventing technology leaks in accordance with the Integrated Innovation Strategy 2020. etc. The information is provided to relevant organizations as needed.

Hoping for future contribution to R&D in the field of defense, MOD launched Innovative Science & Technology Initiative for Security to publicly invite and commission basic research on advanced civil

[1] CYber Defense Exercise with Recurrence

technologies (Figure 2-3-2) in FY2015.

■ Figure 2-3-2/ Innovative Science & Technology Initiative for Security ■



Source: Acquisition, Technology & Logistics Agency (ATLA)

Since FY2017 MOD has been working for practical application of ICT and other civilian technologies that progress rapidly with a short innovation cycle in a short period of time of 3 to 5 years in close collaboration of engineers and operators.

The National Research Institute of Police Science has been developing a damage prediction simulator anticipating radiation attack in an urban area. The institute improved its virtual radiation measurement system that uses pseudo radiation sources and smartphones. The improved system is used for first response training simulating nuclear security cases, radiation education in the medical field and other purposes.

The institute also evaluates the power and sensitivity of homemade bombs made of commercially available materials and used for international terrorist attacks, conducts their demonstration tests and implements research that will contribute to measures for sales entities who sell chemical substances that can become materials of explosives.

Column 2-5 Research on Blast Pressure Mitigation

Improvised explosive devices (IEDs / Homemade explosive devices) are often used in international terrorists' attacks. In most cases, it is difficult to move / carry them for disposal. National Research Institute of Police Science had a research project and developed a mitigation agent to reduce the damage in case of an explosion, under cooperation with manufacturers and other research institutes. It was shown that the mitigation agent could greatly reduce the blast pressure and flame of the explosion of surrounding IEDs (see the photo). This study is underway concerning practical use of this mitigation agent to protect human lives and property from IEDs.

Difference in explosion with and without the power reduction agent
(left: without the agent; right: with the agent (almost no flame)
Provided by the Explosion Investigation Section, Second Department of Forensic Science, National Research Institute of Police Science

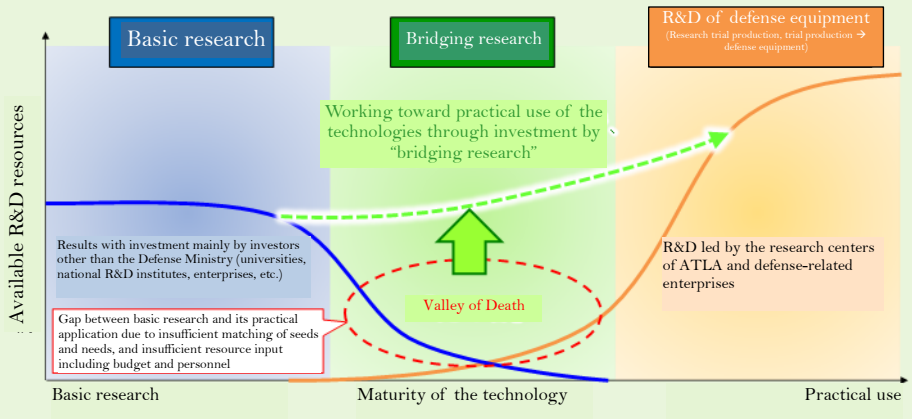
Column 2-6 "Bridging" Results of Basic Research to R&D of Defense Equipment

In recent years the progress of R&D is remarkable in the civilian sector. In the past, advanced technologies developed in the defense sector were deployed to the civilian sector, but now many defense technologies come from the civilian sector. Countries around the world are making efforts to obtain advanced technologies from the civilian sector in order to get ahead of others in security technologies.

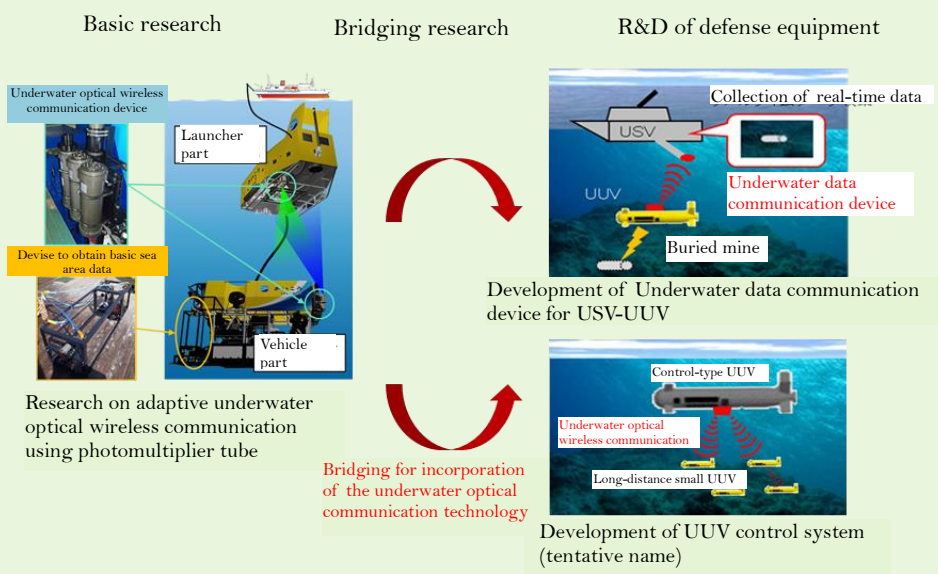
In this context, in FY2020 the Acquisition, Technology & Logistics Agency started "bridging research" to identify at an early stage promising advanced technologies among the results of basic research obtained through the Security Technology Research Promotion Program, and mature and apply them to R&D of defense equipment speedily and flexibly.

"Bridging Research" will "analyze" and determine the growth potential of innovative burgeoning technologies, "consider" the extent of their growth potential and "examine" whether they can be used for technologies subject to concentrated investment, while at the same time actually developing the technologies.

Through these efforts the program aims to create defense equipment that can become a game changer in the future.



Examples of Bridging Research: multiplexing of underwater optical wireless communication
Demonstrated communication between multiple small and light devices considered for use as defense equipment by using the result of "the research on adaptive underwater optical wireless communication using photomultiplier tube" conducted by JAMSTEC under the Security Technology Research Promotion Program



Section 3 Addressing Global Challenges and Contributing to Global Development

Response to climate change is a pressing issue for the world as well as Japan. Based on the Paris Agreement that became effective in November 2016 and the Climate Change Adaptation Act (Act No. 50 of June 13, 2018), the country needs to enhance efforts to mitigate climate change by greatly reducing greenhouse gas emissions while making efforts for adaptation.

❶ Addressing global climate change

(1) Development of technologies for observation of the earth environment and continued observation

A. The promotion of Earth observations

To understand current global warming trends, many countries and organizations worldwide have been observing the Earth from the outer space by satellite, as well as by ground-based and maritime observation systems. To enhance the effectiveness of global efforts for tackling climate change problems, Earth observation data should be integrated and analyzed through international collaborations, to accumulate useful scientific knowledge as a basis for policymaking in each country. It is also important to develop the Global Earth Observation System of Systems (GEOSS), which consists of multiple systems that facilitate access by many countries and institutions to observation and other scientific data. The Group on Earth Observations (GEO) was established as an international framework to promote the development of the GEOSS. It had 247 countries and institutions as members as of March 2021. Japan has been playing a leading role on the GEO Executive Committee.

B. Satellite-based observation

To promote satellite observations of the earth, JAXA has been operating the Global Change Observation Mission - Climate "SHIKISAI" (GCOM-C), the Global Change Observation Mission - Water "SHIZUKU" (GCOM-W) and the Advanced Land Observing Satellite-2 "DAICHI-2" (ALOS-2) and so on, and has been conducting R&D for the Advanced Land Observing Satellite-3 (ALOS-3), Advanced Land Observing Satellite-4 (ALOS-4) and for other satellites (See Chapter 3, Section 4).

In order to help clarify climate change and its effects, MOE, with related ministries and agencies as well as relevant organizations at home and abroad, has developed and is operating global CO_2 and methane observation technologies using the Greenhouse Gases Observing Satellite "IBUKI" (GOSAT) and "IBUKI-2" (GOSAT-2). In addition, the ministry is conducting continuous monitoring by using airplanes and ships, and monitors on the ground. With the aim of further promotion of climate change countermeasures, GOSAT has been used for clarification of the global concentration distributions of CO_2 and methane, as well as estimation of absorptions and emissions by month and region. The project revealed a trend of rising concentration of CO_2 and methane through seasonal changes since 2009 when the observation started. The

project also suggested a possibility of identifying the sources and amounts of greenhouse gasses emissions from human activities. "GOSAT-2" improved the accuracy of observation of CO_2 and methane that have been observed by GOSAT and added CO to its observation targets. Carbon dioxide is emitted not only from human activities such as industrial activities and fuel consumption but also from forests and activities of other living things. On the other hand, carbon monoxide is emitted from human activities but not from forests and activities of other living things. Its aim is to estimate CO_2 emissions of "human origin" through observation and analysis of CO_2 emissions in combination with carbon monoxide emissions. The successor GOSAT-2 was launched in October 2018. In addition to succeeding the mission of GOSAT, that is, to observe global greenhouse gas concentration, it aims to contribute to transparency increase of emissions reporting based on the Paris Agreement through new functions to identify sources of emissions of human origin and improve accuracy of emissions estimation. Furthermore, in order to continue the mission of water cycle and GHG observation and further enhance its observation capability, since FY2019 the ministry has been promoting development of the Global Observing Satellite for Greenhouse Gasses and Water Cycle (GOSAT-GW) that mounts the successor sensor of GCOM-W (Advanced Microwave Scanning Radiometer 3: AMSR3) and the successor sensor of GOSAT-2 (Total Anthropogenic and Natural emissions mapping SpectrOmeter-3: TANSO-3).

C. Ground and oceanographic observations

The marine environment is rapidly changing in recent years: sea temperature is rising, ocean acidification is progressing worldwide and oceans are polluted by plastic wastes, for example. We need to understand the changes in the marine environment for the preservation of oceans and marine resources and their sustainable use, and elucidation of global environmental changes. To this end, JAMSTEC has been constructing an integrated ocean observation network by combining drifting floats, moored buoys, observation by vessels and other means.

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and Japan Meteorological Agency (JMA) in cooperation with MEXT and other relevant organizations are participating in an ocean observing system (the Argo program[1]) for a detailed understanding of changes in the ocean interior around the world to improve the accuracy of climate change prediction. The Argo program aims at the real-time monitoring and evaluation of oceans around the world based on Argo floats deployed in these oceans.

MEXT is promoting research and observation in various fields related to the Antarctic and the Arctic, where it is possible to accurately measure global environmental changes. Under the Antarctic Research Programs, research and observation in the Antarctica have been conducted based on the 9th Six-Year plan for Antarctic Research Program (FY2016- FY2021).

[1] Based on the understanding that environmental issues significantly and seriously affect the humanosphere, the Environment Research and Technology Development Fund, a policy-oriented competitive research fund, was created.

The Arctic is known as the place where warming is most rapidly progressing due to various mechanisms. On the other hand, the melting of ice in summer presents the possibility of various uses for Japan and other countries. Both for correspondence to global climate change and contribution to sustainable use of the Arctic, it is essential to enhance scientific knowledge that is their basis.

To this purpose, MEXT launched the Arctic Challenge for Sustainability Project II (ArCSII) as the successor to the Arctic Challenge for Sustainability Project (ArCS) in FY2020. In order to realize sustainable society, including Japan, the project evaluates the impact of rapid environmental changes in the Arctic on human society toward social implementation of the research results, while implementing international joint research and other initiatives to provide domestic and foreign stakeholders with scientific knowledge forming the foundation of legal policies for international rule making regarding the Arctic.

Under the ArCSII, MEXT conducted observation of the Pacific sector of the Arctic Ocean by using the oceanographic research vessel Mirai as part of the Synoptic Arctic Survey (SAS) that is an international observation project which can cover the entire Arctic Ocean by several icebreakers and research vessels.

In FY2020, the ministry made the basic design of Arctic research vessels into an international research platform capable of observing the sea ice areas for which data has not been sufficient.

JMA has also been observing greenhouse gasses in the atmosphere at three sites in Japan and at the Showa Station in Antarctica. In addition, JMA is observing greenhouse gasses in seawater and in the atmosphere near seawater by using an ocean weather observation ship and in the atmosphere at high elevations in the northwest Pacific Ocean by using an aircraft. These data and other observed global warming-related data and their analyses are made available to the public. JMA has also been observing the ozone layer and ultraviolet rays in the atmosphere at three sites in Japan and at the Showa Station in Antarctica.

Column 2-7 Enhance Observation of the Rapidly Warming Arctic Region – Decision on the Construction of an Arctic Research Vessel

The Arctic is the region where warming is progressing the most on Earth. The sea ice area of the Arctic Ocean in summer became the smallest in recorded history in 2012 and the second smallest in 2020. The area rapidly decreased to about two-thirds the size when compared with 35 years ago. Moreover, record-breaking high temperature has been observed in many places. For example, the temperature hit 38°C in Russian Siberia in June 2020, which is the highest recorded temperature in the Arctic region. These unprecedented climate changes can have serious impacts not only on the vulnerable ecosystem of the arctic region but also on the global weather/climate, which would influence the global environmental, economic and social sustainability beyond the North Pole.

JAMSTEC has been using the oceanographic research vessel Mirai for multi-item and highly accurate observation (sea ice reduction, sea water warming and desalination, reduced nutrients, acidification, etc.) of the radically changing Arctic Ocean. Furthermore, the agency has contributed to

various climate and weather discoveries, which include: meteorological observation of the arctic region which can improve typhoon route prediction, and; arctic warming and continent cooling caused by sea ice reduction influence the climate of Japan.

Observation with Mirai is shedding light on the need for observation data of the Arctic Ocean to understand the impact of the global weather/climate change in Japan and the world. However, the observation data network of the Arctic Ocean is still extremely insufficient compared with the middle-latitude sea area and the Antarctic Ocean. In addition, although ships have been the major means for the Arctic Ocean observation, Mirai is not an ice breaker and therefore Japan's observation with the vessel has been limited to some sea areas in summer.

To address this issue, from FY2017 to FY2020 JAMSTEC conducted various studies toward the construction of an arctic region research vessel with ice breaking capability. The arctic region research vessel that was found necessary based on the studies is an unprecedented ice-breaking research vessel that mounts equipment capable of observation equal to Mirai and new equipment including a scientific fish finder and combines necessary and sufficient ice-breaking and ice-resistant performance with observation performance also covering ordinary sea areas. The budget for the construction of the arctic region research vessel was included in the FY2021 budget. The construction of the vessel will be started soon and completed in around 5 years.

Image of the arctic region research vessel to be constructed
Source: JAMSTEC

The vessel will enable multi-item and highly accurate observation research also in the seasons when it was impossible for Mirai; namely in spring when sea ice begins to melt and in autumn when ice begins to form in the Arctic Ocean. It is also expected to become an international research platform to lead observation projects in cooperation with foreign countries. It is hoped that understanding of the environmental changes in the Arctic Ocean and teleconnection with other regions through the observation research will contribute to the advancement of prediction of climate change as well as prediction of typhoons, heavy rains, heavy snow, etc. that have been causing large-scale disasters in recent years.

<Reference>
Oceanographic research vessel Mirai navigating in the Arctic Ocean (Website of ArCSII)
https://www.nipr.ac.jp/arcs2/mirai2020/#video-aurora20201016

(2) Advancement of climate change projection/prediction technologies using super computers, etc.

In the Integrated Research Program for Advancing Climate Models (TOUGOU), MEXT has been promoting R&D towards the creation of basic information that will be necessary to address climate change. For this purpose, supercomputers including the Earth Simulator are used to advance climate change projection technologies through development of climate models, etc. Using the results, the Ministry released "Climate Change in Japan 2020" (MEXT and JMA) [1] compiling scientific knowledge including the latest climate

[1] See Column 2-9 What Climate Will Japan Face at the End of the 21st Century? – Climate Change in Japan 2020 -

change predictions in December 2020. MEXT has made international contributions through the climate models that were developed in its projects: they are the most frequently used climate models in the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) that compiles scientific knowledge on climate change.

MRI under JMA has developed the MRI Earth System Model for global warming prediction. It can simulate the effects of aerosols on clouds, changes in the ozone layer and the carbon cycle. Using this model, the institute is making near-future climate change predictions (i.e., about 10-year lead time) and long-term predictions based on IPCC emissions scenarios. The institute has also developed a sophisticated cloud-resolving regional climate model that has sufficient resolution to simulate Japan's unique local climatic phenomena for regional climate warming prediction.

JAMSTEC has been making full use of its supercomputer systems to develop the most advanced predictive models and simulation techniques. These are used to elucidate the possible impacts of global environmental changes on Japan and to help solve climate change problems from the viewpoint of marine science.

(3) Development of information platform integrating observation and projection/prediction data

Under the Program to Promote Development of Global Environmental Data Platform, MEXT has developed the Data Integration and Analysis System (DIAS). The DIAS is an information platform that accumulates, integrates and analyzes big data of the global environment (observation information, projection/prediction information, etc.) to contribute to solving climate change and other global issues. The DIAS has supported R&D in Japan and abroad and produced results including a system that predicts floods caused by a typhoon, etc. MEXT is working to establish a management structure to ensure its long-term stable use by a large number of users including researchers and enterprises in Japan and abroad, and is also promoting development of common fundamental technologies contributing to solution of social challenges in various fields including, energy, weather, disaster prevention and agriculture.

For the creation, under the World Data System (WDS), of a scientific data platform that will be the largest size in the world and that is being promoted by the International Science Council (ISC[1]), NICT has been selected to host this endeavor's International Program Office (IPO). NICT is building a network with the Science Council of Japan (SCJ) and related domestic and international research institutions. By gathering scientific papers and their reference data on Earth observation, NICT is developing a global-scale science data platform that allows the stored data to be analyzed and is conducting R&D for reference relation analysis among reference data of different papers.

By analyzing the data from the Superconducting Submillimeter-wave Limb-Emission Sounder

1 This global academic organization aims to strengthen international activities in the applied science and other science fields for the benefit of society. ISC was established by integration of the International Council for Science (ICSU) established in 1931 and the International Social Science Council (ISSC) in 2018 and covers all scientific fields.

(SMILES [1]) that NICT developed in cooperation with JAXA, NICT issues warning on global environmental changes based on the new knowledge and has been releasing observation data for free use since FY2020. NICT is also promoting unique mathematical algorism analysis of the global environment observation data from the Greenhouse Gases Observing Satellite (GOSAT), etc. The institute is also distributing monitoring/forecast and alarms regarding solar activities and the electromagnetic environment around the earth, which influences how radio waves are transmitted, while conducting integrated collection, management, analysis and release of space environment observation data. In addition, NICT is advancing the development of space environment measurement/prediction technologies to further advance these observation technologies and prediction technologies using logical models and AI.

JMA is collecting observation data on the above items from ships, Argo Floats and satellites and by using other means, and has been analyzing such data. These results have been published in a report called The State of the Ocean Climate, which provides information on current conditions and the prospects for changes in oceanic fluctuations related to global warming.

(4) Efforts for reduction in carbon dioxide and other emissions

With the concept of Carbon Recycling technology, METI considers CO2 as a resource, and promotes separating, capturing, and recycling this material. CO2 will be recycled into concrete through mineralization, into chemicals through artificial photosynthesis, and into fuels through methanation[2] to reduce CO2 emissions into the atmosphere. METI formulated the Roadmap for Carbon Recycling Technologies in June 2019 in order to promote technology development of Carbon Recycling, and in accordance with the roadmap is advancing technology development including bio jet fuel, CO2 absorption type concrete and bio production process for biomass-derived chemical products.

Aiming at the practical use of CO2 Capture, Utilization and Storage (CCUS[3]), METI is advancing R&D for the demonstration of an integrated system designed to separate, capture and transport CO2 from large CO2 emission sources and store it underground at depths of more than 1,000 m, and also developing technologies to drastically reduce costs and improve safety. In steel manufacturing, the ministry is developing (1) hydrogen reduction steel making process technology (COURSE50) and (2) ferro coke technology toward significant reduction of CO2 emissions from steel making processes and energy efficient. Efforts for (1) include: technology development for iron ore reduction using hydrogen and for separation and capture of carbon dioxide by using unused exhaust heat in the steelmaking process. Efforts for (2) include: technology development to lower the temperature and improve the efficiency of iron ore reduction

[1] Superconducting Submillimeter-Wave Limb-Emission Sounder: SMILES performs observations of the atmospheric limb by using an offset Cassegrain antenna. The high-sensitivity, low-noise superconducting receivers of SMILES receives submillimeter waves emitted by atmospheric trace species in order to measure the concentrations of ozone and other molecules. The frequency range from 300 GHz to 3,000. GHz is the submillimeter-wave range. GHz is the submillimeter-wave range. SMILES uses sub-millimeter waves ranging from 624 GHz through 650 GHz.

[2] Technology to synthesize methane that is the principal component of natural gas from carbon dioxide and hydrogen.

[3] Carbon dioxide Capture, Utilization and Storage

by using coke produced through utilization of low-quality material (ferro coke).

MOE has been compiling (1) costs of separating and recovering most of the CO_2 from exhaust gas from coal fired power plants, (2) design and construction of Japan's first full-scale CO_2 separation/recovery equipment toward assessment of degradation in power generation efficiency and environmental impact, and (3) methods for smooth introduction of carbon capture and storage (CCS) suitable for Japan. METI and MOE have jointly conducted geological investigations, including elastic wave explorations, to determine areas suitable for CCS in Japan. Since FY2018 the ministries have been implementing demonstration of CO_2 Capture and Utilization (CCU), artificial photosynthesis and methanation initiative as well as examination and evaluation of the CO_2 reduction effects over their lifecycle.

Toward achieving the GHG reduction goal set by the International Maritime Organization (IMO) to reduce the total GHG emissions from international shipping at least 50% by 2050 and eventually phasing out them as early as possible in this century, in November 2020 Japan led to the agreement on strengthening the international regulation to improve energy efficiency of newly built ships (up to 50% reduction) and to reduce CO2 emissions from existing ships to promote replacement of old inefficient ships with new greener ships. In addition, MLIT in cooperation with MOE conducted the model demonstration of LNG-fueled ships to maximize reduction of CO2 emissions in actual operation.

MPAT has been in charge of research on fundamental technologies to significantly reduce GHG emissions from ships, which contribute to achieving regulatory control aiming at zero emissions with social rationality, resulting in mitigating environmental impact.

MPAT is promoting onsite surveys and experiments in coastal areas for quantitatively measuring the atmosphere/seawater gas exchange rate and the carbon flow between the seawater and benthic ecosystems. The aim is to establish a method for measuring blue carbon, which has potential for both domestic and international applications.

NILIM is conducting studies on: sewerage disposal technology to reduce greenhouse gas emissions and collect energy and resources; and effects of greening to improve urban environment.

Column 2-8 Acceleration of R&D into Electric Aircraft toward a Carbon Neutral Society

Demand for aircraft temporally decreased under the influence of the COVID-19 pandemic, but is expected to increase again in the long term. Toward realization of a carbon neutral society, the aircraft industry needs to further reduce its carbon dioxide emissions. It is said that the key to this goal is R&D into electric aircraft that use electric power in addition to low-carbon fuels.

For design development of electric aircraft, aerodynamic analysis, structural analysis and system design technologies that have been cultivated by the Japan Aerospace Exploration Agency (JAXA) and the aircraft industry remain important technologies. However, major components including high-output motors and large-capacity batteries, areas where the aircraft industry does not have sufficient knowledge will also become important. For this reason, JAXA in cooperation with domestic enterprises and relevant ministries launched the Electrification ChaLlenge for AIRcraft (ECLAIR) Consortium in July 2018. This is Japan's platform to develop electric aircraft systems by combining industry-academia-government strengths including the electrical industry. In this consortium, industry, academia and government participants jointly developed and shared the "Future Vision of Aircraft Electrification" and are promoting technology development based on the vision. The Future Vision set fuel (energy) consumption reduction goals according to the date of new passenger plane introduction as shown in Figure 1.

As part of its joint research, ÉCLAIR Consortium is studying the airframe concept with focus on the fuel consumption reduction goal for the 2030s (Figure 2). By adopting a hybrid propulsion system that generates propulsion with both jet engines under the main wings and the electric fan at the tail part of the body, changes in the airframe are minimized to reduce technical risks involved in the development. The electric fan is driven by the electricity generated by the jet engines and is accelerated by drawing in slowly flowing air at the tail of the fuselage. In this way, propulsion is generated with higher efficiency compared with conventional jet engines. While exploring the best position of the electric fan through numeric fluid simulations, JAXA is preparing for a demonstration experiment to examine the safety and fuel reduction effect of the hybrid propulsion system. JAXA plans to promptly transfer the results of the demonstration to the industry in order to support the entry into the future electric aircraft development.

Electrification of aircraft is a new technology to reduce energy consumption by considering the entire aircraft to be one system and will generate synergy with the introduction of bio fuel and hydrogen fuel. Acceleration of the R&D is expected to develop a new specialty of Japan's industry.

Commencement time	Airframe size	Fuel consumption reduction rate
2030s	**Narrow body and smaller**	**10%**
2040s	All sizes (narrow and wide)	30%
2050s	All sizes (Including innovative airframe forms)	50%

Figure 1 Fuel Consumption Reduction Targets by Age of Airframe introduction
Provided by JAXA

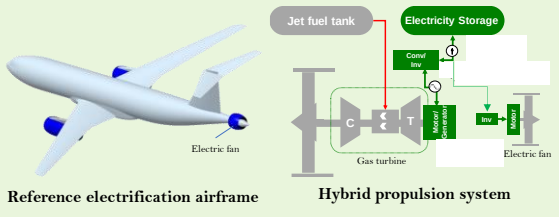


Figure 2 Concept of Reference Electrification Airframe with Electric Fan Mounted at the Fuselage Tail
Provided by JAXA

(5) Development of technologies to address climate change and their spread to economic and social activities

The Integrated Innovation Strategy 2020 (Cabinet Decision on July 17, 2020) took up environmental energy as one of the application fields that should be strategically tackled. Toward establishment and social implementation of innovative technologies, the government will surely execute the environment innovation strategy and is working for realization of Carbon Neutrality by 2050.

In order to support planning and promotion of climate change adaptation measures under the Integrated Research Program for Advancing Climate Models (TOUGOU), MEXT has been creating climate change projection information based on the various needs. The information is provided to local governments through the "Regional Adaptation Consortium" built for cooperation with MOE and other relevant ministries and agencies in addition to the DIAS. MEXT is also promoting Future Earth, which is a global initiative on global environment research including climate change in collaboration with stakeholders in Japan and abroad. In addition, MEXT accelerated regional decarbonization and worked for network construction with universities, etc. in order to deploy the regional model to the world.

Since FY2020 MAFF has been working on the development of carbon sink technology using materials including biochar, blue carbon and wood biomass as global warming adaptation technologies in agriculture, forestry and fisheries. The ministry is also tackling technologies: to adapt to climate change in forestry and fisheries fields; to address damage by wildlife; to control pests and invasive alien species, and to reduce GHG emissions in animal husbandry. The ministry is also promoting development of GHG emissions reduction technologies for agriculture through global cooperation.

As one of the studies using the Environment Research and Technology Development Fund, MOE has been implementing the "Comprehensive Research on Projection of Climate Change Impacts and Evaluation of Adaptation (S-18)" aimed at creation of the latest scientific information on projection of climate change and adaptation evaluation to support Japan's adaptation to climate change. The ministry is comprehensively promoting the strategic studies and other research on observation/monitoring, projection and assessment of climate change and its impacts as well as countermeasures using the Environment Research and Technology Development Fund.

Based on the Climate Change Adaptation Act and the Climate Change Adaptation Plan approved by the Cabinet in November 2018, the government has been further enhancing adaptation measures. Based on the act and the plan, the Center for Climate Change Adaptation at the NIES has been providing the latest information on adaptation in cooperation with relevant ministries and agencies as well as research institutions through the Climate Change Adaptation Information Platform (A-PLAT) and supporting studies on the impact of and adaptation to climate change and adaptation efforts by local governments and other bodies in scientific aspects. To allow stakeholders in various regions to cooperate in promoting adaptation measures, the Regional Council on Climate Change Adaptation based on the Climate Change

Adaptation Act was set up in seven regional blocks across the country.

MRI is addressing the development of real-time observation and monitoring technology for the detection of unusual meteorological phenomena, such as intense localized downpours, by means of dual polarization radar, phased array radar and global positioning system (GPS). MRI is also advancing the development of a numerical prediction model with high enough resolution to display intense localized downpours, in order to improve the accuracy of weather information and thereby to help reduce damage from local meteorological phenomena.

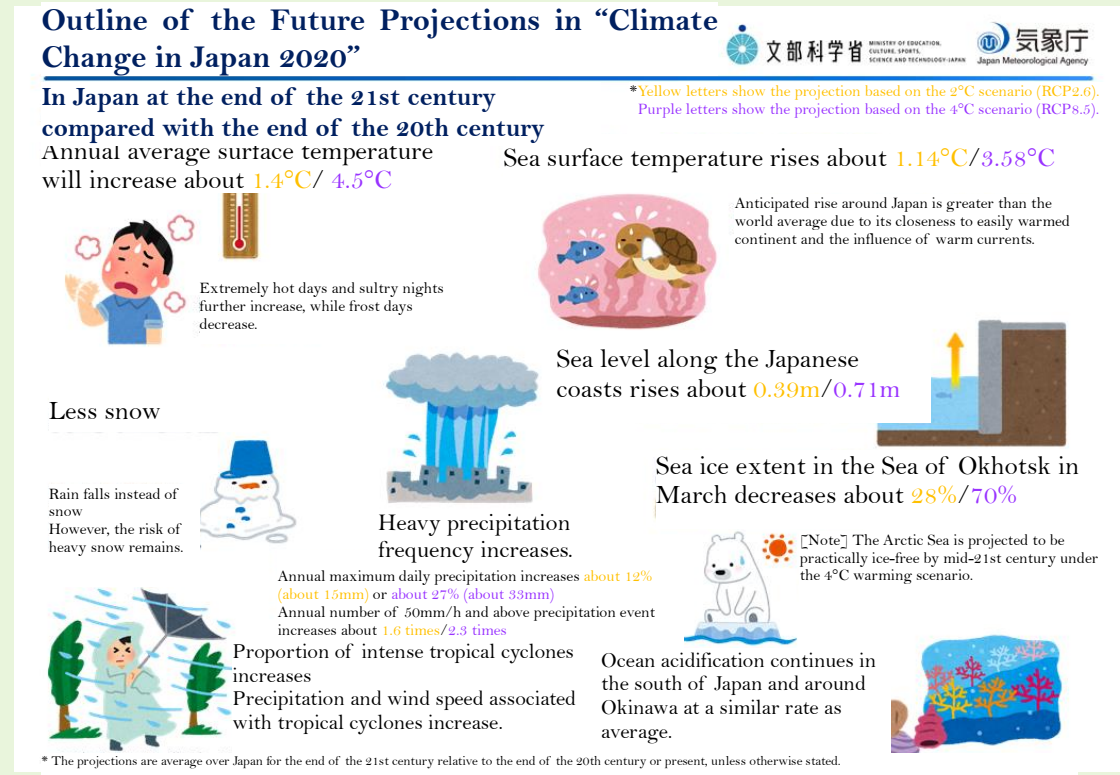
Column 2-9 What Climate Will Japan Face at the End of the 21st Century? – Climate Change in Japan 2020 -

In recent years, various changes in the climate system including surface temperature rise and more frequent heavy rains have occurred and are projected to become more severe. Since 2020, this situation, due to the spread of COVID-19, cities were locked down and curfew was issued in many countries. As a result, our everyday life drastically changed and socio-economic activities were greatly restrained. However, even under these conditions, CO2 concentration in the atmosphere and the average temperature of the world are continuing to rise. We must address climate change now.

In this context, MEXT and JMA comprehensively compiled the latest scientific knowledge including the results of climate change studies at MEXT and climate change observation/projection by JMA and released "Climate Change in Japan 2020" as fundamental information (evidence) for consideration of related mitigation/adaptation and impact assessment by the national and local governments, commercial enterprises and the public.

The report summarizes the past changes in the atmospheric GHG concentration that causes climate change and the past and projected changes in climate variables (surface temperature, precipitation, sea level, sea water temperature, etc.) of in and around Japan. The projections are made for the end of the 21st century based on the 2°C warming scenario (with achievement of the Paris Agreement's 2°C target) and the 4°C warming scenario (with no additional mitigation measures beyond the current situation).

Reference (in Japanese): https://www.mext.go.jp/b_menu/houdou/mext_00405.html



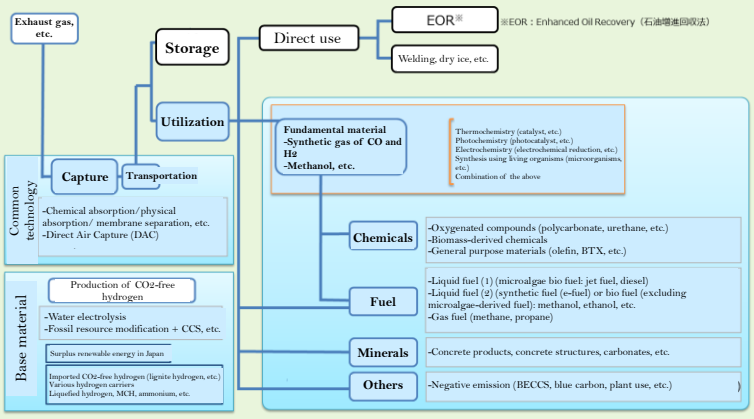
Outline of the Future Projections in "Climate Change in Japan 2020–Assessment. Report on Observed and Projected Climate Change in the Atmosphere, on Land and in Oceans–"

Source: Outline of "Climate Change in Japan 2020" MEXT and JMA, P13

Column 2-10 Carbon Recycling

To address climate change, it is important to promote efforts to create a virtuous cycle of economy and environment.

In CCU that captures and effectively uses carbon dioxide in the atmosphere and from various emission sources, carbon recycling separates and captures CO2 as a "resource," reuses it as concrete through mineralization, as chemical products through artificial photosynthesis, and as fuel through methanation to reduce CO2 in the atmosphere or suppress new CO2 emissions. CO2 is expected to be used for (1) chemicals, (2) fuels, (3) mineral, and (4) other applications.



Carbon Recycling Technology Roadmap (Excerpt)
Source: METI and the Agency of Natural Resources and Energy

Carbon recycling is a key technology of a carbon neutral society and Japan is competitive in this field. Concrete and polycarbonate using CO2 as raw material have already been successfully made practicable and plastic containers manufactured using CO2 are used as cosmetics bottles.

However, many of the carbon recycling technologies have the challenge of high cost. In particular, CO2-free hydrogen is still expensive, and technologies using hydrogen requires innovation. For this reason, the short-term target is set for production of concrete from CO2, CO2 bio fuel using algae and other technologies that do not need hydrogen, and use for high value added products including functional chemicals, health foods and medicine, while replacement of existing general-purpose articles with new materials including carbon recycle methane and synthetic fuel is expected in the long term. Currently industry, academia and government participants are together actively promoting innovations toward practical application of these technologies.

Carbon Recycling Empirical Research Center (Image)
Source: website of the 2nd Industry-academia-government International Conference on Carbon Recycling 2020
https://carbon-recycling2020.go.jp/movie/r-info-1.pdf

Column 2-11 Development of elite tree and expectations on them

Forest Tree breeding started nationwide in 1954, and about 9,000 individual trees excellent in growth and other properties were selected as "the plus-trees" from forests across the country in order to secure excellent seedlings in response to the increased wood demand after the Second World War. Nowadays, most forestry seedlings are brought up from seeds and scions produced from the plus-tree clones. Seedlings propagated from the plus-tree clones were planted in test sites, their growth and wood quality were surveyed for several decades, and highly rated clones were used for crossbreeding. Among over 200,000 individuals that were thus obtained, trees that were expected to have more excellent performance were selected as the second generation plus-trees, which we call "elite trees." Being excellent in growth characteristics including early growth, the elite trees are expected to increase revenue opportunities through reducing silviculture cost and shortening time to harvest, and thereby contribute to the improvement of the forestry profitability.

Elite Tree "Japanese cedar Kyu2-203" four years after planting (left) and the first generation pick (right)
Provided by the Forest Tree Breeding Center, Forest Research and Management Organization

Pollen-free Japanese seder created through genome editing
Provided by the Forest Tree Breeding Center, Forest Research and Management Organization

Increase of pollinosis caused by pollens of Japanese cedar and other plants has become a major social and economic issue in Japan. Through the past research, clones with very few pollens were found and developed as less-pollen Japanese cedar and cypress varieties. In addition, pollen-free Japanese cedars that do no produce pollen at all (male sterile) were found in many places and development of pollen-free varieties with excellent growth and wood quality are now underway through breeding activities such as crossbreeding with elite tree clones. However, the traditional forest tree breeding procedures required many years to select individuals with excellent properties in multiple traits. To overcome this issue, development of a breeding method utilizing genome information, which is also widely used in crop breeding, has been promoted, particularly in Japanese cedar, and necessary infrastructure has been developed over the last ten years. One of the outcomes of these efforts is the development of a DNA marker which enabled us to detect individuals with pollen-free genes with a high precision. Thanks to the DNA marker, the screening of individuals with pollen-free genes, which used to take several years, can now be done within several days. Researchers also succeeded in breeding pollen-free Japanese cedar by applying genome editing that can induce changes in targeted genes. Furthermore, technology development is underway to predict properties of individual trees by analyzing genes related to economically important traits such as growth, wood quality, and environmental stress tolerance.

Pollen-free elite trees with many excellent properties including even better growth and wood quality and tolerance against environmental stresses may be developed in a shorter period of time in the future. Deployment of elite trees is expected to contribute to the development of forestry and the forest product industry through the stable supply of high-quality lumber and enhance use of domestic lumber, while contributing to the realization of a carbon neutral society through increase in carbon storage in forests and wood products.

❷ Responding to biodiversity loss

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has been producing assessment reports with the aim of strengthening the coordination of science and policies regarding biodiversity and ecosystem services. In February 2019, a technical support unit for the invasive alien species assessment was set up under IGES. In order to ensure effective reflection of Japan's knowledge in the assessment reports in the process of creation, domestic liaison conferences were held in October 2020 and March 2021 gathering experts involved in IPBES in Japan and relevant ministries and agencies. Furthermore, MOE held a symposium titled "Biodiversity and Lifestyle – What We Can Do toward the New Normal" based on the IPBES Global Assessment Report in March 2021. In addition, MOE continued to implement the "Predictive Estimation of Natural Capital and Ecosystem Services through Integration of Social and Ecological Systems" by using the Environment Research and Technology Development Fund. The research aims to strengthen the international link between science and policies through provision of knowledge for assessment by IPBES, and compiled the research results of the last five years.

Japan has a part in and supports activities of the Global Biodiversity Information Facility (GBIF) that aims to collect data on biodiversity so that the data can be made available worldwide. Japan also provided GBIF with biodiversity data in cooperation with National Science Museum and National Institute of Genetics which are both GBIF nodes (data providing centers). Data accumulated by GBIF are expected to serve as fundamental for evaluation at IPBES.

In order to support development of new cultivars by private companies and other breeders using genetic resources of plants from foreign countries, MAFF has been promoting bilateral joint research with mainly other Asian countries and conducting surveys focusing on collection and evaluation of genetic resources. While in its gene bank project concerning genetic resources is for agricultural purpose, NARO collects, preserves, assesses and provides genetic resources of rice and other crops.

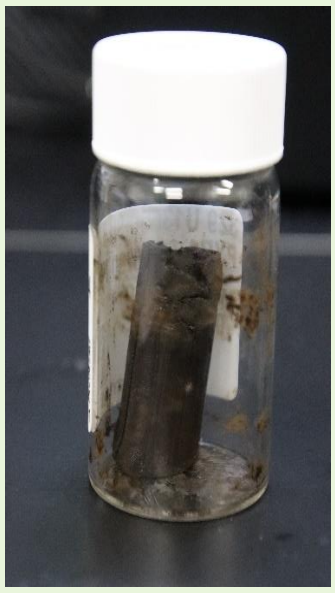
The National Institute of Technology and Evaluation (NITE) has collected, preserved and distributed biological resources and has also organized information on these resources in terms of their genes and genetic lineages so as to make the information accessible to the public, including researchers and industry. NITE has also joined the network composed of 28 organizations from 15 countries and regions, which aims for the preservation and the sustainable use of microbial resources and has actively supported Asian countries in their efforts to use biological resources by constructing cooperative relationships with them according to the Convention on Biological Diversity (CBD). Furthermore, NITE has constructed and launched the Data and Biological Resource Platform (DBRP) as a comprehensive database of information related to microorganisms, providing one-stop access to bioresources and related information.

The adverse effects of global warming, ocean environmental degradation and overexploitation of marine species have become increasingly obvious. The conservation of marine biodiversity is also significant challenges for humans. In "Advancement of Technologies for Securing Living Marine Resources" under

the Ocean Resource Use Promotion Technology Development Program, MEXT is implementing R&D for the purpose of comprehensively elucidating marine ecosystems. Research has been conducted for restoration of the marine ecosystem off the Pacific coast of Tohoku region damaged by tsunami.

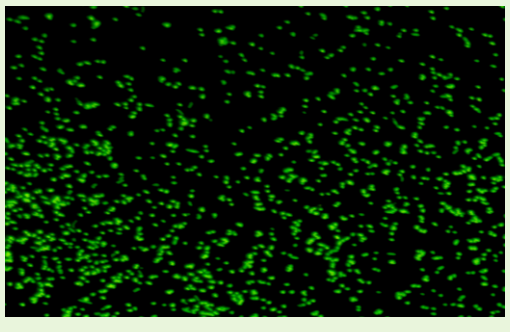
Column 2-12 Successful Revival of Microbes from Ancient Subseafloor Sediment Formed 100 Million Years Ago —the World of Ultra-low Nutrition Lives Uncovered by Scientific Offshore Drilling—

"Under the dark and deep sea floor is devoid of life." This was the common understanding of the subseafloor environment about 70 years ago. However, this image has been continuously recast by an international ocean drilling programs (see Chapter 4, Section 2-1 (4)) led by Japan, the United States and Europe since 1986. Today, it is known that there are an enormous number of microbial life that corresponds to several percent of the entire life and are as diverse as the life on Earth's surface (the paper's DOI:10.1073/pnas.1919139117). Because the strata under the seafloor consist of very fine particles, even small creatures like microorganisms cannot move freely. Furthermore, substances that can be their nutrients decrease with the increase of the distance from land and depth beneath the seafloor. Thus, the strata under the seafloor are an extremely severe and nutrient limited environment for life. How deep and old can microorganisms survive in the subseafloor strata? Are they traces of past life, or are they still living? In order to answer these questions, a research team led by Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and the University of Rhode Island collected samples from under the seafloor of the South Pacific Ocean, the oldest strata was formed 101.5 million years ago (Middle Cretaceous when dinosaurs were flourishing on land) and cultivated them with substances to feed microorganisms.



Sample from a 100 million old stratum below sea floor
Provided by JAMSTEC

If the microorganisms are alive, they will take (eat) the substances (food). After cultivation for the period from 21 days to one year and a half, 99.1% of the organisms in the samples from the oldest stratum started to eat the food and multiply. Based on the number of microorganisms and the organic and inorganic matter (microbial nutrients) distribution that has been discovered through scientific ocean drilling around the globe, it is known that living organisms under the seafloor are under an extremely low-nutrient condition that is too severe to survive. The result of the project shows that a large part of the microorganisms "on the verge of life and death" have survived



Microorganisms multiplied from the 100-million-year old stratum under the sea floor
Provided by JAMSTEC

while being captured in the 100-million old strata. Future in-depth analysis of the multiplied microorganisms and the original microorganisms in the samples is expected to unveil the microorganisms' ability for ultra-long-term survival and their evolution (the paper's DOI: 10.1038/s41467-020-17330-1)

Explanation by the researchers
(JAMSTEC YouTube Channel)

Section 4 Pioneering Strategically Important Frontiers

In addition to enhancing industrial competitiveness and addressing economic and social challenges a range of science and technology to support the appropriate development, utilization, and management of the oceans and space serves as a firm foundation for Japan's subsistence. At the same time, since such science and technology have additional value, such as enabling Japan to earn admiration and respect in the international community and promoting the scientific education of citizens, it is necessary to continually enhance this asset based on a long-term perspective.

❶ The promotion of oceanographic R&D

As an “oceanic state” that is surrounded by the sea on all sides, Japan needs to produce STI results befitting this condition. For this purpose, it is important to steadily work on R&D of technologies for ocean surveys and observation—including areas of sea ice, deep seas, and below the seabed—and technologies for contributing to sustainable development and utilization of the seas, which includes biological resources, transportation, tourism, and environmental conservation, as well as technologies to help ensure the safety of the seas, and the scientific knowledge and fundamental technologies necessary to support all these efforts.

Deep-sea scientific drilling vessel
Chikyu
Source: JAMSTEC

Manned research submersible
SHINKAI 6500
Source: JAMSTEC

The Cabinet Office is promoting efforts to solve technology development challenges related to oceans in close cooperation with the Headquarters for Ocean Policy and ensuring consistency with the Third Basic Plan on Ocean Policy (Cabinet Decision on May 15, 2018).

In light of the formulation of the 3rd Basic Plan on Ocean Policy, in January 2019 MEXT revised the R&D plan pertaining to ocean science and technology (formulated at the CST's Subdivision on Ocean Development in 2016) and has been promoting R&D in the marine S&T fields contributing to innovations toward creation of future industries.

Using vessels, probes, observation equipment and other means, JAMSTEC has been conducting survey and research in ocean including the deep sea bottom and ice-infested waters that are difficult to access, as well as simulation using the obtained data and archiving and dissemination of the data. Using these technologies JAMSTEC is promoting basic research to elucidate the actual state of the areas that need further elucidation.

(1) Ocean survey and observation technologies

For the purpose of understanding the subseafloor microbiosphere, the mechanisms of ocean-trench earthquakes and tsunamis, and the genesis as well as the possible existence of marine resources, JAMSTEC has been advancing the development of technologies for drilling by using the deep-sea scientific drilling vessel Chikyu and technologies for real-time observation by using DONET. These technologies are also utilized for surveys, research and the development of other technologies. The ministry has also been conducting research and surveys that focus on the seas around the Japanese archipelago and the entire Pacific Ocean. Specifically, crustal structures are explored by using research vessels, the manned research submersible SHINKAI 6500 and unmanned submersibles, towards deepening our understanding of phenomena related to the deep ocean floor, such as tsunamis and huge earthquakes that can cause devastating damage.

(2) Technologies contributing to sustainable ocean development, use, etc.

MEXT has been implementing R&D of observation/measurement technologies for efficient and highly accurate understanding of marine ecosystem, marine environment and other marine information using a wide range of advanced technologies and knowledge held by universities, etc. under the "Technology Development for Understanding of Marine Information" within the framework of the program for developing technologies for promoting the use of marine resources.

In order to contribute to the promotion of industrial use of the ocean by Japan, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) is promoting understanding of biological and physical cycle in the ocean and origin of useful resources and providing obtained scientific knowledge, technologies and samples to the related industries (See Chapter 3 Section 1, 1(2)).

(3) Technologies contributing to the securing of safety and security on the Oceans and preservation of ocean environment

The adverse effects of global warming, ocean environmental degradation and overexploitation of marine species have become increasingly obvious. The conservation of marine biodiversity and the sustainable use of marine biological resources are significant challenges for humans. In the "Advancement of Technologies for Securing Living Marine Resources" under the Ocean Resource Use Promotion Technology Development Program, MEXT is implementing R&D for the purpose of realizing innovative production based on an understanding of the physiology of marine species and for the purpose of comprehensively elucidating marine ecosystems (See Chapter 3 Section 3-2).

MPAT is conducting research on the development and improvement of techniques for safety evaluation of offshore structures and for reducing environmental impacts. These techniques are the basis of key technologies for the exploitation of ocean resources and energy.

JCG has been gathering information of ship movements for the purpose of ensuring safe marine transportation and improving operational efficiency. JCG is developing a system to predict vessel traffic flow and feedback the information to the vessels based on the analysis of these big data.

❷ Promotion of R&D in space science

Today, space systems including positioning, communication and observation are supporting the security and economic/social activities of the nation and are also increasing their importance as infrastructure for realization of Society 5.0. In this context, space activities embark on an age of public-private co-creation and there are efforts to vitalize industries through space use in a wide range of fields. As the progress of space exploration expanded human activities beyond terrestrial orbit to the moon and deeper space, the success of Hayabusa 2 in conducting sample collection from an asteroid demonstrated the high level of the nation's S&T and raised the expectations of the public. Space is further increasing its importance as a S&T frontier and driving force of economic growth. It can be a big driving force in innovation creation in Japan.

With this understanding, the government renewed the Basic Plan on Space Policy (Cabinet Decision on June 30, 2020) and is promoting the nation's space development and use comprehensively, systematically and powerfully as a national strategy.

(1) Space transportation systems

Space transportation systems that have a role to launch satellites are a key pillar for the development and utilization of space. Technologies for sending satellites to their designated altitudes whenever needed are vital for the autonomy of Japan's space activities. The development of a new flagship rocket started in FY2014 and various combustion tests have been conducted to expand Japan's autonomous space activities and ensure its international competitiveness. The first new test rocket is scheduled for launch in FY2021. With the aim of increasing international competitiveness by achieving both further launch cost reduction and high reliability of key rockets as well as improvement of the satellite operability, Japan has been promoting the development of the Epsilon S rocket.

Launch of H-IIA F43
Source: JAXA

Using H-IIA and H-IIB, our key rockets, Japan successfully launched the Cargo Transfer Vehicle "KOUNOTORI-9" in May 2020 and the data relay satellite 1 and the optical data relay satellite in November 2020. The KH-IIB rocket ended its operation with the launch of "KOUNOTORI-9". The rocket greately contributed to the improvement of the reliability of Japan's technology by susuccessful launching

all nine KOUNOTORI.

(2) Global positioning satellite systems

The Cabinet Office started a high-precision positioning service based on a 4-satellite constellation of Quasi-Zenith Satellites MICHIBIKI on November 2018. Toward the 7-satellite constellation to be established in FY2023 and its function and performance improvement, the office is promoting the development of MICHIBIKI-5, 6 and 7. Toward further utilization of MICHIBIKI, relevant ministries and agencies are working together on various demonstration experiments including automated driving of automobiles and farm machines, physical distribution and disaster prevention.

(3) Satellite communication and broadcasting systems

In order to realize internationally competitive next generation geostationary communication satellites, MIC and MEXT have been jointly developing the Engineering Test Satellite 9 since FY2016. This satellite will be developed for the purpose of demonstrating technologies of electric propulsion, high-power generation, and flexible payload toward launch in FY2023.

(4) Earth observing system

Through GOSAT launched in FY 2008 and GOSAT-2 launched in FY2018, MOE has demonstrated that global CO_2 and methane concentrations have been rising year by year. In order to aggressively expand this mission and grasp the effects of the measures toward the decarbonized society, the ministry is promoting the development of its successor, GOSAT-GW for the launch scheduled in FY2023.

With the aim of elucidating the mechanism of global water cycle and climate change, JAXA has been operating SHIZUKU (GCOM-W) launched in May 2012 and SHIKISAI (GCOM-C) launched in December 2017. Data from SHIZUKU together with the data from the Global Precipitation Measurement (GPM) core satellite launched in February 2014 under the international cooperation project with NASA[1] are used by JMA to improve the accuracy of precipitation estimates and for various other purposes, including weather forecasting and fishing ground detection. SHIKISAI is used also to grasp the situation of overseas large-scale forest fires. In order to continue the mission to observe the water cycle and GHG and further strengthen observation capability, JAXA is developing the Global Observing SATellite for Greenhouse Gases and Water Cycle (GOSAT-GW) that will mount successor sensors of SHIZUKU and IBUKI-2.

In addition, DAICHI-2 (ALOS-2) launched in May 2014 is contributing to disaster prevention and management, and solutions to global issues such as global warming through monitoring of various disasters, grasping of damage situations and the observation of forests and ice of Polar Regions, etc.

1 National Aeronautics and Space Administration

Currently JAXA is developing advanced optical satellite-3 (ALOS-3) and advanced radar satellite-4 (ALOS-4) capable of wide-area and high-resolution imaging. JAXA launched optical data relay satellites in November 2020 and is working for demonstration of optical communication between these satellites, which will enable instantaneous relaying of satellite data of affected areas to the ground when a natural disaster strikes. This is expected to help speedy disaster countermeasures in the future.

Optical data relay satellite
Source: JAXA

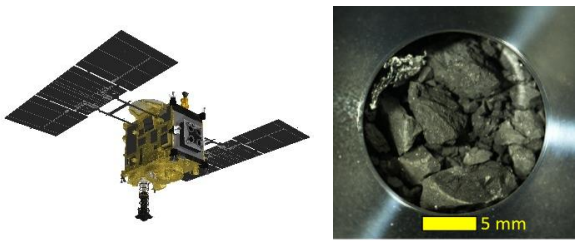
Furthermore, JMA observes tropical cyclones and sea surface temperature, etc. by using Himawari-8 and Himawari-9, to contribute to prevention of natural disasters and monitoring of climate change, not only in Japan but also in the entire Asia Pacific region.

Technologies whose use for earth observation from satellites will contribute to disaster management/mitigation include sensing systems using the terahertz band that can sense the vertical distribution of water vapor and its oxygen concentration more accurately. MIC is working on R&D on fundamental technology toward realization of these sensing systems and has developed a light-weight micro satellite sensor.

Toward stable operation of Japan's satellites, MEXT and JAXA have established and have been operating the SSA[1] system since FY2002 to observe space debris, etc. from the ground. The entire government including the Ministry of Defense will construct a new SSA system toward FY2023.

(5) Space science and exploration

Regarding R&D in space science, JAXA has been playing a pivotal role. JAXA has achieved globally unrivaled results in X-ray and infrared astronomical observation, such as by developing and operating the world's first satellite for simultaneous X-ray photography and X-ray spectrography and by using the Hayabusa probe to collect samples from the asteroid Itokawa. Venus Prove AKATSUKI put into Venus orbit in December 2015 produced results leading to the elucidation of the mechanism of "super rotation" in the Venus atmosphere. HAYABUSA2, launched in December 2014, achieved an array of the world's first brilliant feats after arriving at the Ryugu asteroid, including formation of an artificial crater on the surface of the asteroid and twice-repeated touch downs to the same asteroid. HAYABUSA2 returned to the vicinity of the Earth in December 2020 and



Asteroid Explorer Hayabusa 2 (left) and collected sample (right)
Source: JAXA

[1] Space Situational Awareness

separated the mounted capsule toward the earth. Later the capsule was collected in a desert in Australia. Samples from Ryugu were confirmed in the capsule and will be analyzed in detail. The explorer is heading toward exploration of another asteroid (scheduled to arrive in 2031).

In addition, the Mercury Magnetospheric Orbiter MIO of the BepiColombo international collaborative mission to Mercury (launched in October 2018) in cooperation with the European Space Agency (ESA) is now navigating toward Mercury. JAXA is also developing the small moon landing demonstrator (SLIM[1]) in an attempt to conduct Japan's first lunar landing, the satellite XRISM[2] (both SLIM and XRISM are scheduled for launch in FY2022) and the Martian Moons eXploration (MMX) program for sample return from Mars (scheduled for launch in FY2024). In this way JAXA has been active in establishing a leading position in the world as well as in promoting R&D on space science that helps broaden the frontiers of space for humankind

(6) Human space activities

The International Space Station (ISS) Program[3] is an international project collaboratively implemented by fifteen countries: Japan, the U.S.A., Europe, Canada and Russia. In this project, Japan assumes the role of developing and operating the Japanese Experiment Module "KIBO" and the uncrewed cargo transfer spacecraft "KOUNOTORI" (HTV[4]). KOUNOTORI has been used to resupply KIBO and the ISS. Japanese astronauts have carried out longstay missions aboard the ISS. The Japanese team has various achievements, such as establishing crewed and uncrewed space technologies, establishing an international presence for Japan, promoting the space industry, contributing to society through social benefits accruing from the use of space (e.g., generating high-quality protein crystals leading to drug discovery, acquiring medical knowledge, creating materials useful for next-generation semiconductors and deploying small satellites), and educating young people. All KOUNOTORI from the 1st (2009) to the 9th (2020) successfully completed their missions. With the functions unique to KOUNOTORI, including one of the world's best supply capacities (up to 6 tons) and capacity to mount multiple units of large test equipment, the spacecraft supported the use and operation of ISS. Taking advantage of the experience through KOUNOTORI, Japan is developing its successor, a new space station resupply vehicle (HTV-X) targeting better carrying capacity with reduced development and operation costs.

In November 2020, astronaut NOGUCHI Soichi boarded a private spacecraft of the United States as the first non U.S. Citizen to do so and began his long-stay mission on ISS for about six months.

[1] Smart Lander for Investigating Moon
[2] X-Ray Imaging and Spectroscopy Mission
[3] The International Space Station is a cooperative program based on the ISS Intergovernmental Agreement between Europe, the U.S.A., Russia, Canada, and Japan for the joint development, operation and utilization of a permanently inhabited Space Station in low Earth orbit (about 400 km above the Earth's surface).
[4] H-II Transfer Vehicle

Column 2-13 Activities of Japanese Astronauts toward International Space Exploration

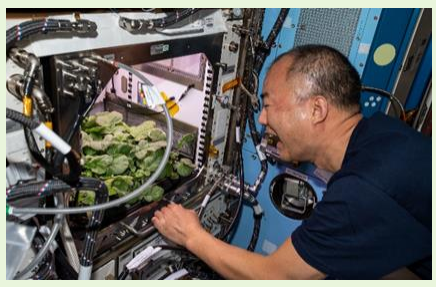
At 9:27 a.m. (Japanese time) on November 16, 2020, the first Crew Dragon, a private spacecraft of the United States carrying three U.S. astronauts and Astronaut NOGUCHI Soichi was launched from Kennedy Space Center. The spacecraft succeeded in docking with the international space station (ISS) on the next day and the four astronauts started their long stay for about six months. Astronaut Noguchi is the first non-American boarding a private spacecraft of the United States. This is the third space flight for Astronaut Noguchi after a hiatus of about 10 years. He is the first Japanese to board three kinds of spacecraft (U.S. Space Shuttle, Russian Soyuz and the U.S. Crew Dragon).

Around the spring of 2021, boarding of Astronaut HOSHIDE Akihiko on Crew Dragon 2 is scheduled and his long stay mission on ISS will begin. Astronaut Hoshide will serve as ISS Commander (Captain) as the second Japanese to take this job. Long-stay mission in ISS is scheduled also for Astronaut WAKATA Koichi around 2022 and Astronaut FURUKAWA Satoshi around 2023.

As a result of Japan's expressed intention in October 2019 to participate in the International Space Exploration "Artemis Program" proposed by the United States, MEXT and the National Aeronautics and Space Administration (NASA) signed a joint declaration on moon exploration cooperation in July 2020 to confirm activity opportunities for Japanese astronauts in Gateway, a manned space station orbiting the moon, and on the moon. In October of the same year, eight countries including Japan signed the Artemis Accords that show the common recognition of the participating countries regarding principles of a broad array of private space explorations including the Artemis Program. Momentum is further rising for international space exploration. The scope of manned space activities is expanding from low earth orbit including ISS to deeper space including the Moon and Mars. International space exploration is expected to evolve in a major way in the future. Based on the situation, in October 2020 MEXT announced that JAXA would start to recruit new Japanese astronauts in autumn of 2021 toward the latter half of the 2020s where their activities on the Moon are assumed. In order to maintain a certain number of Japanese astronauts, recruitment will be made roughly once every five years.

Reference: Highlights of the first half of the ISS long stay mission of Astronaut Noguchi
https://www.youtube.com/watch?v=phgoaK3m3Kk

Inside of spacecraft Crew Dragon
Provided by JAXA, NASA and SpaceX



Astronaut Noguchi conducting plant experiments in ISS
Provided by JAXA and NASA

(7) International space exploration

The International Space Exploration "Artemis Program" is a program led by the United States to construct Gateway, a manned space station orbiting the Moon, conduct technology demonstration toward manned exploration on Mars in the future and continued manned activities on the Moon with participation of private enterprises. Japan decided to participate in the Artemis Program in 2019. Europe and Canada also expressed their intention to participate. Based on the decision above, MEXT and NASA signed a joint declaration on moon exploration cooperation in July 2020. Later in December, the Japanese government and NASA signed a memorandum of understanding concerning the cooperation for Gateway. The memorandum provides a legal framework to enable the cooperation confirmed in the joint declaration, which include Japan providing equipment to Gateway, and NASA providing Japanese astronauts multiple opportunities to board Gateway.

(8) Efforts for enhancing the use of space

Concerning the use of space, MEXT established a system for increasing the utilization of expertise possessed by government, industry and academia. Under this system, entrustment expense fees for the promotion of aerospace science and technology is used for the purpose of expanding the base of space users by discovering potential users of satellites and developing new utilization methods. Using this system MEXT continues R&D on space utilization technologies with a view to their practical use in human resource development, disaster prevention, the environment and other aerospace fields.

METI is developing the Hyperspectral Imager Suite (HISUI) that enhances remote detection capacity for oil resources. After installing HISUI on the Japanese experiment module "Kibo" of the International Space Station in December 2019, the initial checkout of equipment and development of a ground data processing system were conducted in FY2020. The ministry also supports development of low-price and high-performance space parts/components using civilian technologies, provides opportunities for their demonstration on orbit and is developing autonomous flight safety system toward drastic cost reduction of rockets for small satellite. In addition, in order to increase the use of space data that has been becoming big data, the ministry provides the government's satellite data for open and free use and is also developing a user-friendly satellite data platform (Tellus).