Chapter 1 State-of-the-art Initiatives toward Digitalized and Decarbonized Society

Under the vision of Society 5.0, we aim to create "a society that is sustainable and resilient against threats and unpredictable and uncertain situations, that ensures the safety and security of the people, and that enables each individual to realize well-being" by using a highly integrated system of cyberspace and physical space based on the value of a "human-centered society."

This chapter introduces state-of-the-art technologies that enable "fusion of cyberspace and physical space" for realization of Society 5.0 and efforts for their social implementation.

Section 1 Fundamental Technologies for Constructing Cyberspace

Society 5.0 uses ICT to accumulate a variety of data in a cyberspace. In this cyberspace, advanced analysis is conducted and the analysis results are reflected in physical space in order to change our society into a rich and high quality society for everyone. Fundamental technologies for constructing cyberspace include supercomputer and quantum technology to process massive amounts of data and conduct sophisticated analysis including simulations, and AI technology that assists automatic projection/judgment using the analysis results.

❶ Supercomputers

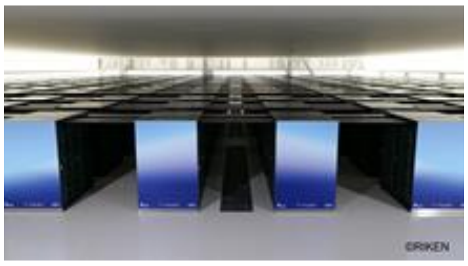
Supercomputers are computers with large-scale and high-speed computing power. In Society 5.0, these computers are absolutely essential for simulations to solve social challenges by using massive amounts of data called big data. Today, computer simulation has become the third method following traditional theory and experiment (See Part 2, Chapter 4, Section 2-2 i)

(1) Supercomputer K

Supercomputer K was operated at the Institute of Physical and Chemical Research (RIKEN) from September 2012 to August 2019. K had a wide variety of applications. For example, it succeeded in updating weather predictions every 10 minutes through simulations using measured data obtained from the Himawari-8 weather satellite. It is used also for research on dark matter, which may lead to elucidation of the origin of matter and the cosmos and development of a low rolling resistance tire with greatly improved anti-wear performance. In this way, K contributed to the creation of epoch-making achievements leading the world in various fields.

(2) Supercomputer Fugaku

In order to contribute to solving social and scientific problems facing Japan, a project to develop Fugaku to succeed K started in 2014. The supercomputer with the world's top computing power and versatility for various applications was developed through co-design of systems and applications and started operation in March 2021. Fugaku ranked No.1 in the world in four supercomputer rankings[1] two times in June and November 2020 when it was at the stage of system adjustment before starting operation. This is a world's-first achievement and it demonstrated its high performance and versatility to the world.

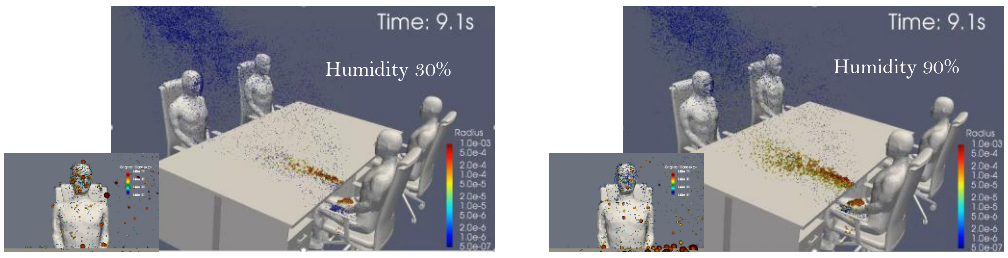


Supercomputer Fugaku
Provided by: RIKEN Center for Computational Science

Special Feature: Overcoming COVID-19
URL: https://www.r-ccs.riken.jp/en/fugaku/research/covid-19/

In addition, the ministry in cooperation with RIKEN decided to use a part of Fugaku that was under development for countermeasures against and study on COVID-19 in April 2020. Its simulations of the spread of droplets in indoor environments of public facilities and transportation facilities visualized droplets' spread by using easy-to-understand animations. Fugaku also scientifically verified the effects of facemasks, partitions and ventilation to reduce infection risk. This presentation of specific infection prevention measures in daily life attracted a great deal of attention and is used when the national and local governments, companies and other entities consider infection control measures.

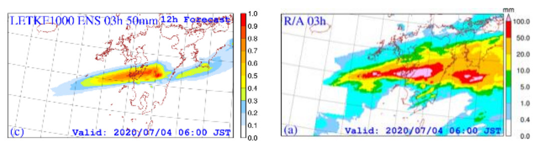
■ Figure 1-1-1: Simulation of the Spread of Droplets in Different Levels of Humidity in an Indoor Environment ■



Provided by RIKEN Center for Computational Science and Toyohashi University of Technology, Cooperation by: Kyoto Institute of Technology and Osaka University

The computing power of Fugaku is also used for R&D in meteorology. A numerical experiment of heavy rain that devastated Kyushu in July 2020 succeeded to predict heavy rain that may cause a disaster 12 hours ahead of the occurrence with a high probability. The result is expected to be used for disaster prevention and

■ Figure 1-1-2: Probability Prediction of Training during Heavy Rain in July 2020 ■



Left: Simulation result; Right: Observation by radar

Provided by Japan Meteorological Agency Meteorological Research Institute

[1] Ranking of processing power (TOP 500), ranking of application execution performance (HPCG), ranking of AI performance (HPL-AI) and ranking of big data processing performance (Graph500)

mitigation in the future.

Shared Computing Environment including Fugaku

The ministry is promoting construction of an innovative High Performance Computing Infrastructure (HPCI) that is a shared computing environment consisting of supercomputers of Japanese universities, research institutes and other entities connected by Science Information NETwork (SINET). The industry and other users across the country can use various supercomputers through the network, share computed data and jointly analyze data. With the cooperation of HPCI member universities and research institutes, the ministry has been promoting its use through special invitation for countermeasures and research on COVID-19. In this way, HPCI including Fugaku will function as state-of-the-art research infrastructure for the development of science and technologies in Japan, creation of innovations contributing to strengthening of Japan's industrial competitiveness and safety/security of people.

Column 1-1 What is SINET (Science Information NETwork)?

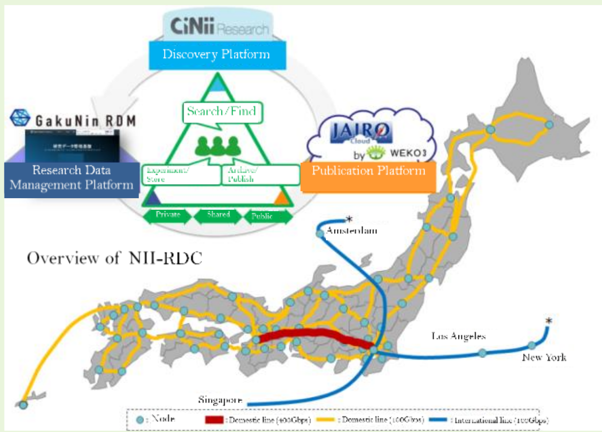
Physical activities have been significantly restricted around the world due to the COVID-19 pandemic and remote activities using information science and technologies have rapidly expanded. As a result, expectations are rising for activities using virtual space and digital information and we see new activity styles without temporal or geographical restrictions.

SINET is an ultra-high-speed information network designed and operated by the National Institute of Informatics (NII) as an academic information infrastructure that supports educational and research activities of universities, research institutes, etc. across Japan (see Part 2, Chapter 4, Section 2-2 (3) iii). In order to support community formation by a large number of people engaging in education/research and to facilitate distribution of a wide variety of academic information including a large volume of data, SINET has covered all 47 prefectures with 100-Gbps (partly 400-Gbps) lines for more than 950 universities/research institutes and has connected the United States, Europe and Asia with 100-Gbps international lines for global collaboration.

This has enabled joint experiments with institutes in distant places in Japan and abroad (virtual laboratories), remote operation of laboratory instruments and data collection/sharing, which contribute to efficiency improvement and vitalization of R&D. HPCI connected by SINET sees active industrial use as well. A large number of enterprises are using the infrastructure in various fields of product development and infrastructure development, including simulations using supercomputers for life elongation and safety improvement of lithium-ion batteries.

NII also developed and started operation of the NII-RDC[1] which ensures to manage, share, open and discover research data. The service is expected to promote open science[2].

Overview of SINET
URL: https://www.sinet.ad.jp/en/top-en
Source: National Institute of Informatics



Overview of NII-RDC

Overview of SINET

Provided by National Institute of Informatics

1 The National Institute of Informatics-Research Data Cloud consists of three different platforms. GakuNin RDM is a service for allowing researchers to adequately manage and share research data with their research collaborators. JAIRO Cloud and CiNii Research easily open and discover their research output, including research data, respectively.

2 A new approach to promoting innovation through knowledge creation in science and technology. This will be realized by facilitating access to and use of publicly funded research results such as scientific papers and their underlying data by the scientific community, industry and the general public.

(3) Utilization of Fugaku and Beyond

Realization of Society 5.0 requires measuring of various factors of the real world and reproducing them in supercomputers. However, we cannot copy the real world in its entirety regardless of how many Fugaku-class supercomputers we might have. For this reason, Fugaku reproduces an environment that is as close to the real world as possible in cyberspace while simplifying parts of various phenomena of the real world, which are not considered essential. Using this cyberspace, Fugaku is conducting various simulations including things impossible to do in physical space. For example, it can reproduce a part of an urban area in cyberspace and predict damage from tremors caused by an earthquake and tsunami inundation and make evacuation simulations. The results can be used for study of effective disaster prevention/mitigation measures. Furthermore, use of AI technologies described below is expected to increase the speed and accuracy of simulations.

Toward realization of Society 5.0, it is necessary to develop supercomputers with even higher computing power. Existing supercomputers have been developed by improving computing power through advancement of the semiconductor processing technologies and efficiency improvement of power utilization, while at the same time enhancing their compatibility with AI technologies. However, because there is a limit in advancing semiconductor processing technology, development of new technologies is necessary for further enhancement of computing power. To this end, research is made on computers that make calculations in completely different ways using different technologies. One of them is the quantum computer that is introduced in "3 Quantum Technology" of this section.

Column 1-2 Realization of GIGA School Vision

Today, use of ICT is an everyday thing everywhere in society. For children who will live in Society 5.0, ICT terminals including smartphones, tablets and personal computers are must-have items alongside pencils and notebooks. PCs/tablets to all pupils have become standard for schools today.

However, ICT use in Japanese schools has fallen behind other countries in the world, while there is a disparity in school ICT environments among local governments. To address this situation, the ministry, under a "Realize GIGA[1] School Vision," has been working for rapid development of school ICT environments including PCs/tablets to all pupils at the compulsory education stage and a high-speed and large-capacity communication network in schools. In addition to the development of physical aspects, the ministry will undertake an education reform integrating the physical aspects with soft aspects/teaching systems, which include introduction of digital schoolbooks, teaching materials and other contents, and implementation/enhancement of teacher training in each region.

ICT is absolutely necessary as a fundamental tool that will support school education in the future. The integrated development of an environment where all pupils have PCs/tablets and a high-speed /large-capacity communication network will greatly change school education in Japan. At the same time, however, we should not forget that development of the ICT environment is a means and not the end. We need to surely cultivate quality and ability in children so that they can positively accept social changes, develop rich creativity, independently live as creators of a sustainable society in a future society that is difficult to predict and participate in formation of society.

Toward realization of Society 5.0 we will realize new school education through development of the ICT environment including PCs/tablets to all pupils and optimal combination of existing school education practice and ICT

"Realization of GIGA School Vision"
Purpose and Overview of Informatization of Schools

URL:https://www.youtube.com/watch?v=CtHWnraIajA
Source: MEXT

"PCs/Tablets to All Pupils in School"
Official promotion video

URL: https://www.youtube.com/watch?v=K0wxp_vyRKM
Source: MEXT

❷ Artificial Intelligence (AI) Technology

AI reproduces human intelligence artificially including learning, inference and judgement in computers. Toward the realization of Society 5.0, the application and utilization of AI technologies are aimed at conducting sophisticated analysis of diverse big data of real life and assisting human prediction and judgment in a wide range of areas including education and medical treatment. AI is also important for development of data driven-science (the method to seek the truth not by setting up and testing hypotheses but by analyzing vast amounts of data).

(1) Examples of R&D on AI Technologies

RIKEN Center for Advanced Intelligence Project ("RIKEN AIP Center") conducts research,

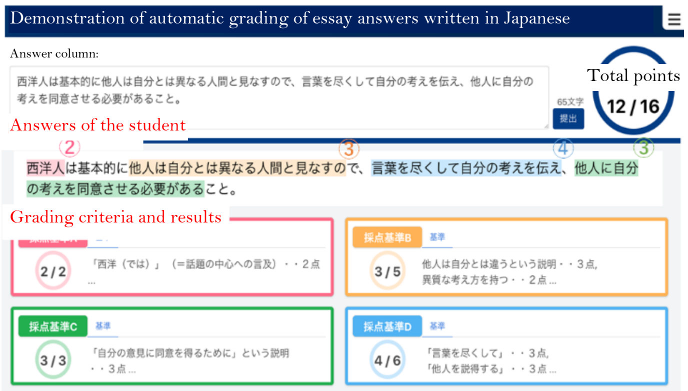
1 Global and Innovation Gateway for All

development and application of innovating basic AI technologies to contribute to advancement of scientific research and solution of challenges in the real world. By additionally working on ethical, legal and social challenges including privacy protection and development of legal systems, which are essential for spreading the technologies in society, RIKEN AIP Center promotes R&D on AI technologies that are necessary for human beings to flourish more than ever.

Research Example 1. AI Grading and Correcting of Essays/Descriptive Answers

One of the AI research targets is understanding of the meaning of human language activities including "talking and writing." This AI technology enables support for grading and correcting of essays and descriptive answers. Now, AI has reached the level to grade answers as accurately as human beings do when it is provided with several hundred examples of answer data graded by human beings.

■ Figure 1-1-3: Screen of Automatic Grading by AI ■

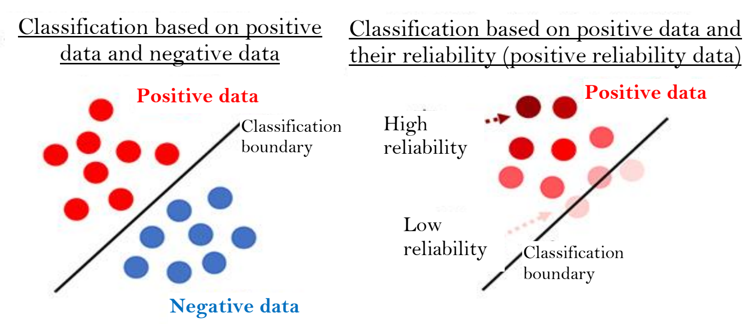


Provided by RIKEN AIP Center

Research Example 2. Development of an AI technology that enables data classification

The center successfully developed the AI technology that enables data classification for prediction and sign detection even if only limited data are available. For example, when a company tries to predict purchase of its products, the company can collect information on the past purchase of its merchandise (positive data) but cannot collect information on purchase of competitors' merchandise (negative data). For this reason, highly accurate purchase prediction has not been possible even by using AI. However, RIKEN AIP Center demonstrated that immeasurable negative data can be classified at high accuracy by using only positive data with information on their reliability.

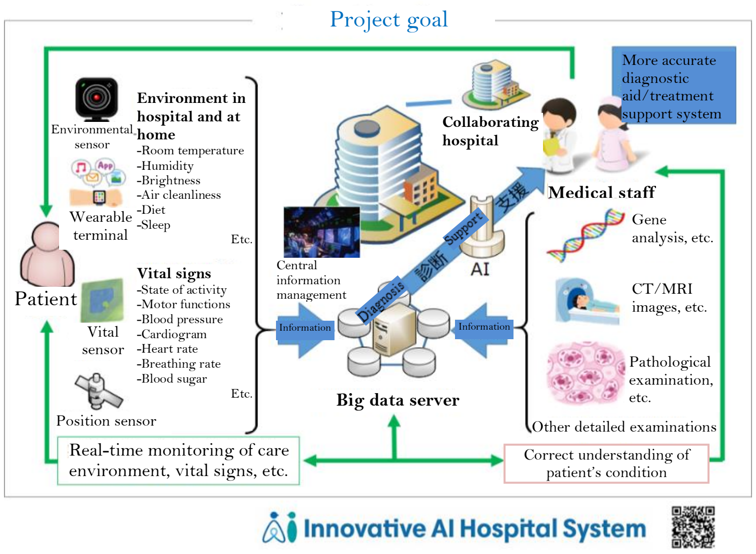
■ Figure 1-1-4: Classification Boundary Can Be Learned using Information on the Reliability of Positive Data ■



Provided by RIKEN AIP Center

(2) Medical Application of AI Technologies – AI Hospital -

■ Figure 1-1-5: AI Hospital System in Near Future ■



Source: Strategic Innovation Promotion Program (SIP)
R&D Plan for Advanced Diagnosis/treatment System in AI Hospital (March 25, 2021)

With a variety of progress in medical technologies, medical care has become highly complex and diverse, which imposes a burden on medical professionals and makes it difficult to take enough time to respond to individual patients. Under the Cross-ministerial Strategic Innovation Promotion Program (SIP) the government is promoting initiatives to provide state-of-the-art medical care to patients, while at the same time reducing the burden on medical professionals. An AI hospital system is to create medical settings where medical professionals can secure more time for response to patients to understand each other by making maximum use of AI.

Specifically, a project has started to collect a large amount of patient information including image, pathological diagnosis and gene information, build a large-scale and secure medical database and extract useful medical information through AI analysis. Aims of the project include accurate image/pathological diagnosis aid by AI and detection of signs of danger to patients. In order to reduce the burden on medical professionals, communication support tools including automated documentation of medical records using AI are being developed and verified. Another aim is to build a system to support development of medical AI tools and spread the developed tools in medical settings by developing a medical AI platform in cooperation with the Japan Medical Association and other entities.

Through these projects, the ministry aims to ensure the quality of medical care in a super aged society, control increase in medical costs, improve international competitiveness in medical care and reduce the burden on medical professionals.

(3) AI Technologies in Progress

Beyond the projects described above, a wide range of applications of AI technologies are expected in various fields of society. The 11th S&T Foresight Survey of MEXT National Institute of Science and Technology Policy (NISTEP) predicts agricultural robots for high-level judgment/work and AI systems that can learn sophisticated craftsmanship. As aging and depopulation are advancing, there is an expectation for functions that will support fulfillment of human potential and creativity.

It is also expected that progress in AI and simulation technologies will enable highly accurate prediction and judgment even with limited learning data of the real world. For example, it is a pressing issue to take measures against large-scale earthquakes/tsunamis and other disasters that are less frequent but would wreak tremendous damage. For phenomena with a small amount of available learning data, damage prediction analysis by AI in combination with simulation technology is expected to contribute to disaster prevention/mitigation.

In this way, AI technology is a key for a safe and secure society where people can flourish with AI's support for fulfillment of their potential.

❸ Quantum Technology

In recent years, quantum technology has come to be expected to generate innovations in a wide range of fields of society. Under the "Quantum Technology Innovation Strategy" formulated in January 2020, cross-sectional R&Ds have been promoted at eight bases[1].

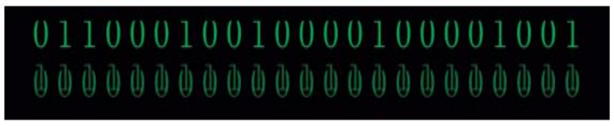
Quantum technology has various research areas. Here, we introduce initiatives regarding "quantum computers" which enable ultra-high speed computing under a fierce development race in many countries, and "quantum cryptographic communication" that will contribute to safe and secure data use.

(1) Quantum Computers which Enable Ultra-high Speed Computing

i Quantum and quantum computers

"Quantum" refers to a very small unit of matter/energy that has both particle and wave properties. Representative examples are atoms that form matter, and even smaller electrons, neutrons and protons that form an atom. The operation principle of a quantum computer is based on the unique phenomenon of quantum having both particle and wave properties.

■ Figure 1-1-6: Image of Bit Used for Computer ■



Above: number processing by existing computers
Below: number processing by quantum computer

Created by MEXT

Existing computers process binary numbers (0 or 1) and the unit for these two kinds of information is called a "bit" (see Figure 1-1-6). For example, 10 bits can express 1,024 (2 to the 10th power) numbers from 0000000000 to 1111111111. On the other hand, zero and one are superimposed in a quantum bit used by quantum computers. Whether it is 0 or 1 is determined based on measurement. This means that a quantum

[1] Quantum Security Center (NICT), Quantum Software Research Hub (Osaka University), Quantum Device Development Hub (AIST), Center for Use of Quantum Computer (University of Tokyo - enterprise collaboration), Center for Quantum Computing (RIKEN), Quantum Metrology and Sensing HQ. (Tokyo Institute of Technology), Quantum Material Center (National Institute for Materials Science) and Institute for Quantum Life Science (National Institutes for Quantum Science and Technology)

computer can process both 0 and 1 simultaneously before measurement and handle 1,024 states simultaneously with 10 quantum bits, which enables high-speed computing.

Quantum computer
Provided by RIKEN

The encounter between quantum mechanics and computers
Tohoku University's Science Café
152th lecture video Associate Professor OHZEKI
URL: https://youtu.be/rMAy2_lz-_o?t=19
Source: Tohoku University

ii Things we can do with quantum computers

Enormous and complicated computing by quantum computers makes what was impossible by existing computers possible.[1] Quantum computers with limited functions are already under experimental study in transportation/logistics, financial services, pharmaceutical/chemical and other fields. It is expected that use of quantum computers will dramatically advance alleviation of congestion, reduction of physical distribution costs, financial market prediction, new material development and drug discovery in the near future. It is believed that use of quantum computers will dramatically improve AI performance. For example, it is expected that analysis of big data accumulated in medical institutions and Social Networking Service (SNS) by high-performance AI will generate highly accurate diagnosis of disease conditions, high-speed marketing and other new services.

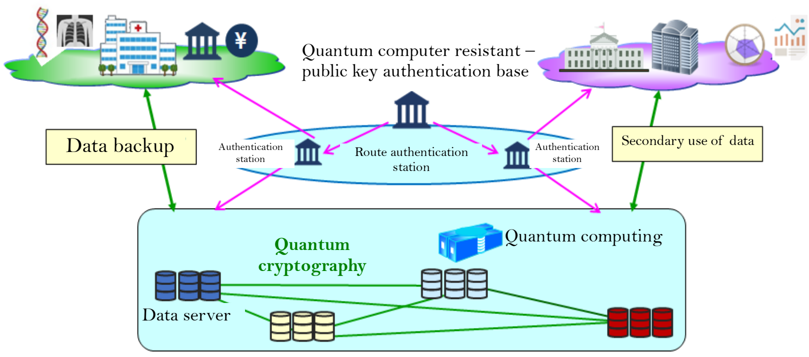
Quantum computing is a technology still in development and it is not yet known how it will influence our life. Mr. John Martinis, a quantum computing researcher at Google of the United States, compared the company's quantum computer "Sycamore[2]" to the world's first artificial satellite Sputnik 1. Sputnik 1 was not equipped with functions immediately useful for social life, but its historic success accelerated satellite study and gave rise to Global Positioning System (GPS), satellite communication and other technologies supporting society. In hopes that quantum computers will greatly change our society someday, researchers around the world are working hard to realize quantum computing.

[1] It is thought that development of general-purpose quantum computers that can be used for solving problems of the real world will require a certain period of time (20 to 30 Years) and that existing computers will be used complementarily with quantum computers.

[2] This quantum computer carried out an operation that would take 10,000 years for an existing supercomputer in 200 seconds (appeared in Nature in October 2019)

(2) Quantum Cryptographic Communication that Will Contribute to Safe and Secure Data Use

■ Figure 1-1-7: Quantum Secure Cloud ■



Source: Cabinet Office SIP Symposium 2020 Presentation Material (Technologies to realize Society 5.0 using light/quantum) November 17, 2020

Society 5.0 uses ICT to accumulate a variety of data in cyberspace, which requires safe and secure data use. Important technologies for this purpose are cryptography that completely prevents a third person from decrypting data and a technology for safe data storage. SIP is working on practical applications and demonstration experiments of functions for safe communication, storage and secondary use of important data into the future by using quantum cryptography and communication technologies (quantum secure cloud).

An important application example is in disaster medicine. When a medical institution in a devastated area loses electronic health records, its doctors need to obtain the electronic health records of their patients immediately and without being known by others from backups in various parts of the country. Electronic health records of 10,000 patients were stored distributed in an 800km area including Kochi and Tokyo, then the electronic health records were searched via satellite, found within 9 seconds (high-speed computation) and safely retrieved (cryptography). This is the world's first application of a quantum secure cloud in the medical field. For the future, SIP will further improve its performance for application in manufacturing, finance and other fields toward a society of safe and secure digitalization, data sharing and utilization.

Section 2 State-of-the-art Technologies Connecting Cyberspace and Physical Space

For realization of Society 5.0, we need technologies that connect cyberspace and physical space. In recent years, there has been progress in technologies to measure various physical space elements including electric current, temperature and brightness by using sensors and convert the information to machine-readable data. Progress has also been made in projects to analyze and judge the converted data with fundamental technologies including supercomputers and AI which are introduced in the previous section and reflect the results in physical space by using robotics. This section introduces: projects to make machines substitute for bodily functions by using various sensors for lifelong social involvement by every citizen; projects to improve the smoothness and safety of transportation while at the same time addressing labor shortage, and; advanced remote operation technology and robotics.

❶ Projects to Make Machines Substitute for or Support Physical Functions

Rapid development of population aging is increasing the importance of technologies to make machines substitute for or support bodily functions to help nursing care, nursing aid and life support. In this context, R&D is being conducted for substitution/support for human actions and communications by reading brain signals and transmitting them to machines. These technologies are aimed at a society that ensures the safety, and security of the people and that enables each and every one of them to realize well-being under the values of a "human-centered society."

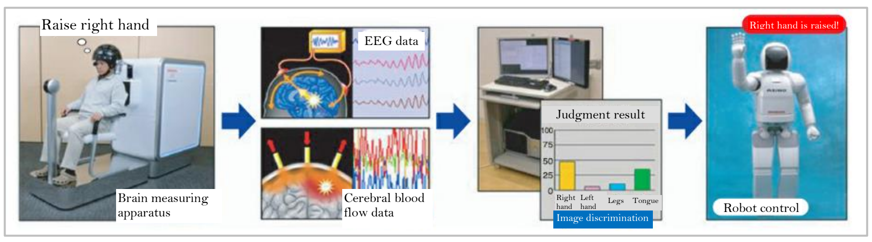
(1) BMI to Read Signals from Brain and Substitute for Bodily Functions

One of the state-of-the-art R&D elements attracting attention among technologies that help nursing care, nursing aid and life support is Brain Machine Interface (BMI). BMI is a technology that directly connects a brain to a machine by using brain information. For example, brain signals are read by sensors to directly move robot arms or artificial arms to support the motions of patients with neurological disorders in their arm or leg. Communication of people with disabilities of the mouth, etc. is helped by guessing the words the person wants to say based on the signals read by sensors and displaying the words on a screen. Wide application of BMI is expected including substitution of lost bodily functions.

Japan is leading the world in research into BMI that puts fewer burdens on patients by obtaining brain information indirectly from the head skin without damaging the body. For example, the Advanced Telecommunications Research Institute International (ATR) has developed an innovative therapy using BMI through its past research programs[1] and is working on its practical application for people with mental or developmental disorders.

Prior to the programs above, ingenious technologies had been developed, which include: discovery of the mechanism of motion commands from the brain, motor learning in the brain and visual processing, and use of the knowledge for robot control. A part of the technologies is used in the world's first full-fledged bipedal

■ Figure 1-1-8: Autonomous Control of ASIMO® ■



URL: https://youtu.be/WHg3YVIlBZc
Source: Honda Motor, ATR and Shimadzu Corp

Provided by Honda Motor, ATR and Shimadzu Corp

[1] Strategic Research Program for Brain Sciences of the Japan Agency for Medical Research and Development "BMI Technology Application of DecNef for development of diagnostic and care system for mental disorders and construction of clinical application bases" and Innovative R&D Promotion Program ImPACT "Visualization and Control of Brain Information"

walking robot, ASIMO, which was developed by Honda Motor. Combination of BMI and humanoid robots can accelerate substitution of operations difficult for humans and self-reliance support for the elderly. These technologies are expected to further develop for realization of the ideals of Society 5.0.

(2) Wearable Cyborg HAL Supports Motions in Accordance with the Intention of the Wearer

HAL,[1] developed by CYBERDYNE Inc., is a wearable cyborg that improves, assists and regenerates the ability to walk and other physical functions. HAL connects a human being and robot by sensors that read signals on the skin surface from the brain transmitted through the nerves. By wearing HAL, people with disabilities in physical functions can move according to the commands from the brain. At the same time, sensory signals are sent from peripheral nerves to the brain. These signals induce the brain to learn and regenerate physical functions. HAL is approved as a medical device and is covered by public health insurance in Japan. It is also used as a medical device in the United States, Europe, Asia, and the Middle East. In addition, the cyborg-type robot technology realized a new treatment method. It also led to the issuance of international standards for medical devices (International Standards for Safety of Requirement Medical Robots for Rehabilitation).

Wearable Cyborg HAL
Provided by CYBERDYNE Inc.

❷ Initiatives for Ensuring Smooth Mobility in an Aging and Population Reduction Society – Automated Driving

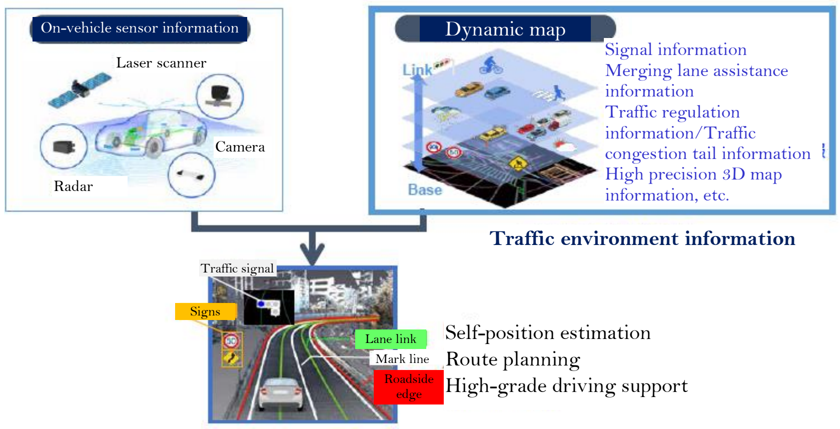
Automated driving contributes to: ensuring of means of transport for people with impaired motor function including the elderly and people with disabilities, and residents in under-populated areas; response to driver shortages in logistics and mobile service industries, and: solution of social challenges including traffic accidents and congestion. For realization of a society where every citizen can move safely and securely, we need, beyond driving aids for drivers who are responsible for driving, practical application of advanced automated driving where automated driving systems recognize and judge the conditions by using sensors that detect the environment surrounding the vehicle and drive based on their judgment.

To this purpose, in addition to development of vehicles, we need a system that summarizes information on traffic conditions necessary for safe and secure automated driving and distributes the information to vehicles. SIP is working on development of a technology to create digital maps (dynamic maps) in cyberspace by combining changing data including other vehicles driving in the surrounding area, the state of congestion, signals and traffic regulations with high precision 3D map information and distribute the dynamic map to self-driving cars.

[1] Hybrid Assistive Limb, Wearable Cyborg HAL, ROBOT SUIT, HAL and Hybrid Assistive Limb are registered as trademarks of CYBERDYNE Inc. in Japan

Dynamic maps provide more diverse information with higher accuracy compared with the information provided by ordinary car navigation systems. This enables grasping of one's own vehicle position and the surrounding traffic environment in detail at the lane level, while read-ahead information enables planning of safe travel routes. Dynamic Map is used in the self-driving car released by Honda Motor in March 2021. This is the car that is equipped with Level 3 technology for the first time in the world.

■ Figure 1-1-9: Mechanism of Automated Driving ■



Source: Cabinet Office SIP Symposium 2020 Presentation Material
(Automated driving (system and service expansion)) (November 17, 2020)

3 Robot Operations in Dangerous Environments – Asteroid Explorer HAYABUSA2 -

Asteroid Explorer HAYABUSA2 was launched from Tanegashima Space Center in December 2014 and arrived at the Ryugu Asteroid in June 2018, about three years and seven months after the launch. Its exploration for about 17 months after the arrival used a sophisticated remote control technology from a distance of about 300 million kilometers, and sophisticated robotics for smooth operation in a communication environment of up to 40 minutes round trip (see Part 2, Chapter 3, Section 4-2 (5)). As described later, this exploration accomplished multiple feats for the first time in the world.

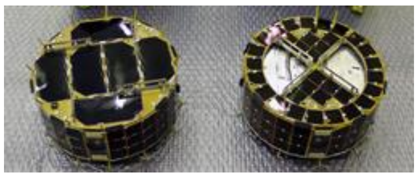
Ryugu, explored by HAYABUSA2, is considered to contain large amounts of organic matter and hydrous minerals and to be in a state close to the early solar system. It is expected that analysis of the matter brought back from Ryugu will help understanding of the origin of the solar system and life.

(1) Robotics that Enables Autonomous Behavior

Sophisticated robotics was applied in Micro Nano Experimental Robot Vehicle Minerva-II 1, for example. Minerva-II 1, which is a small explorer robot with a hexadecagonal pillar structure about 18cm in diameter, carried out temperature observation, photographing and other operations. The exploration including transmission of the obtained data to a probe was carried out completely autonomously using advanced robotics. Mobile exploration by small explorer robots on asteroid surface and deployment of multiple robots are both world's-first achievements.

Asteroid Explorer
HAYABUSA2
Provided by Mr. IKESHITA Akihiro

Asteroid Ryugu
Provided by Japan Aerospace Exploration Agency (JAXA)



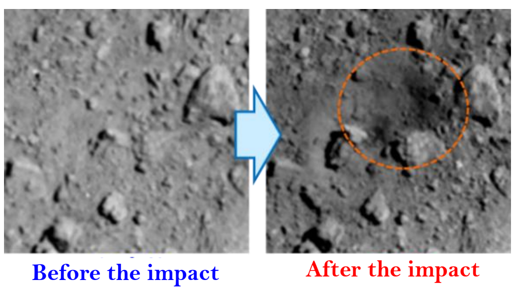
Mini explorer robot
Minerva-II 1
Provided by JAXA

Path of HAYABUSA2 to Return to the Earth
URL:https://www.youtube.com/watch?v=NoikAU9VuCw
Source: JAXA

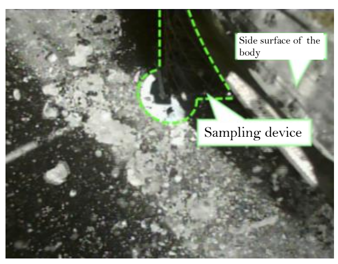
(2) Remote Control Technology for Remotely Performing Sophisticated Operations

Sophisticated remote control technology was used when asteroid explorer HAYABUSA2 made its first touchdown on the Ryugu asteroid to collect surface samples. HAYABUSA2 gradually descended toward Ryugu from above, and at an altitude of some tens of meters, fully switched to autonomous landing mode and made a further descent using a target marker (a light-reflecting spherical object with a diameter of about 10 cm), which was dropped in advance, as a guide. As a result, HAYABUSA2 achieved a high landing accuracy of about 1 m from the target landing point, and also succeeded in collecting surface samples by using a cylindrical device.

In the second touchdown performed to collect subsurface samples, HAYABUSA2 succeeded in landing at an even higher accuracy (60 cm from the target landing point) than in the first touchdown. Subsurface material, which is likely to be less altered by solar wind and cosmic rays compared to surface material, is regarded as important for examining whether organic matter from the early days of the solar system exists on the asteroid. This time, HAYABUSA2 fired an impactor onto the surface of Ryugu in advance to create an artificial crater, and collected samples from a place where debris, scattered upon the creation of the crater, piled up. The splendid achievements of the creation of an artificial crater on an asteroid surface and the two successful touchdowns on the same asteroid are both world firsts.



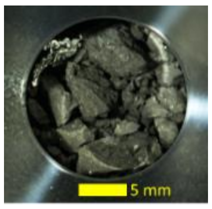
Artificial crater (a pit and scattered rocks, etc. were confirmed)
Provided by JAXA, etc.



2nd touchdown (rock pieces, etc. scattered after firing of the impactor)
Provided by JAXA, etc.

Capsule Recovery and Future Plans

HAYABUSA2, which departed Ryugu in November 2019, separated a capsule enclosing the sampled matter near the earth and made the capsule reenter the atmosphere on December 5, 2020. The capsule was collected in a desert of southern Australia on December 6, 2019. In the capsule brought back to Japan, about 5.4g (about 50 times the target value 0.1) including many grains close to 1cm. For the future, detailed analysis by research groups in Japan and abroad is scheduled promising significant scientific results.



Sampled matter
Provided by JAXA, etc.

HAYABUSA2, which traveled about 5.2 billion km in six years, was found to be in a sound condition and still holding about one half of the engine fuel, which is a result of the technical progress after the first HAYABUSA and the smooth and efficient operation. Currently, the probe is on the way to explore 1998KY26, which is a small asteroid rotating on its axis at a high speed, and it is expected to arrive at the asteroid after about 11 years in 2033. The project aims to develop long-term navigation technologies for probes and elucidate the origin of small asteroids with the possibility of hitting the earth.

As described above, the HAYABUSA2 operation succeeded in controlling a probe that is 300 million km away and in its high-accuracy landing. This remote operation and autonomous control technology may be applied to robotics including remote operation and control in dangerous environments (cold regions, deserts, etc.) where human beings cannot enter, and automated driving. Technologies for high-accuracy probe control and operation are expected to be used in future explorations including Martian Moons Exploration (MMX[1]) as well.

Section 3 Efforts to Ensure Safety and Security Including Carbon Neutrality Sought by Society 5.0

Society 5.0 aims to create a "society that is sustainable and resilient against threats and unpredictable and uncertain situations, to ensure the safety and security of the people." We are exposed to the threat of unknown infections, large-scale earthquake/tsunami, weather and other disasters. Heavy rains including typhoons and cloudbursts which cause flooding and sediment disasters are on the increase. This is said to be an effect of climate change, or global warming, due to the increase in greenhouse gas emissions from human activities.

There are projects to advance climate change prediction by using supercomputers. Based on the latest scientific knowledge ("Climate Change in Japan 2020") the average temperature of Japan will rise and extremely hot days will increase in many areas by the end of the 21st century. This section introduces efforts to protect the safe and secure living that is sought by Society 5.0. Measures against infections,

[1] Martian Moons eXploration is a project to recover samples from Martian moon Phobos in order to uncover the origin of the Martian moons and the process of evolution of Mars and near Mars space. Development is underway toward launch in 2024.

COVID-19 infection in particular, are introduced in Chapter 4.

❶ Realize a Decarbonized Society toward Sustainable Global Environment

The 2015 Paris Agreement decided that both developed and developing countries would address climate change. Even under the COVID-19 pandemic in 2020, climate change was recognized just like COVID-19 as a pressing issue to be solved by human beings for realization of a sustainable society. In October 2020, Japan declared to realize a carbon-neutral, decarbonized society (make GHG emissions including CO_2 and methane equal to the sum of greenhouse gas absorption and removals) by 2050. Innovative technologies are essential for realization of decarbonization together with economic growth. In this context, a "Green Growth Strategy Through Achieving Carbon Neutrality in 2050" ("Green Growth Strategy") was formulated for steady social implementation of innovative technologies toward a decarbonized society.

In April 2021, Prime Minister Suga said "Japan aims to reduce its greenhouse gas emissions by 46 percent in fiscal year 2030 from its fiscal year 2013 levels, setting an ambitious target which is aligned with the long-term goal of achieving net-zero by 2050. Furthermore, Japan will continue strenuous efforts in its challenge to meet the lofty goal of cutting its emission by 50 percent."

(1) Government's Efforts toward 2050 Carbon Neutral Decarbonized Society

i Green Growth Strategy

The Green Growth Strategy takes global warming countermeasures as a growth opportunity and presents a vision of energy supply and demand for realization of a 2050 carbon neutral and decarbonized society as an industrial policy to create a "virtuous cycle of economy and environment." At the same time, the strategy presents policies to bolster private enterprises' initiatives, which include budget (Green Innovation Fund), tax system (promotion of decarbonization investments by enterprises, etc.), regulatory reform and standardization (relaxing unreasonable regulations that do not assume new technologies) and international cooperation, for example. For 14 key industrial fields that promise growth, which include offshore wind power generation, hydrogen, automobile and storage battery and resource circulation-related industries, the strategy formulated action plans with ambitious goals, and measures and routes to realize them. Based on the Green Growth Strategy, the government will take every possible policy measure to provide strong support for positive challenges of enterprises toward decarbonization.

ii Green Innovation Fund

Achieving the 2050 Carbon Neutral and decarbonized society requires attempting more ambitious innovation than ever. For that reason, the government will provide thorough support from technology development through demonstration to social implementation in the priority industrial fields that are essential for a decarbonized society and form the basis of industrial competitiveness[1].

Specifically, for the priority fields: (1) greening of electric power and electrification, (2) realization of a hydrogen society and (3) carbon dioxide fixation and reuse, the government will set aggressive 2030 targets (e.g., performance, introduction rate, price, CO_2 reduction ratio) and create a new fund (Green Innovation Fund) of two trillion yen at the New Energy and Industrial Technology Development Organization (NEDO) to continuously provide support for enthusiastic R&D by enterprises that pronounce commitment to the targets for the next ten years. Through this fund, the government aims to induce R&D and capital investment by private companies and draw in ESG (environmental, social and governance) funds[2] from the world, which are estimated to be 3,000 trillion yen, and thereby generate a virtuous cycle of economy and environment.

iii Strategy for Sustainable Food Systems, MeaDRI

Agriculture, forestry and fisheries are vulnerable to the impacts of climate change. There are already white immature grains[3] of paddy rice, insufficient coloring of apples and other degradations caused by high temperature. Intensified damage due to increase in precipitation is also causing damages in agriculture, forestry and fisheries.

On the other hand, because the emissions from agriculture/forestry account for one fourth of 49.0 billion tons (CO_2 conversion) of the world's GHG emissions, the role of the industry is important in reducing and absorbing GHG as well.

For this reason, the "Strategy for Sustainable Food Systems, MeaDRI"[4] sets zero CO_2 emission from agriculture, forestry and fisheries, reduction in the use of chemical pesticides/fertilizer and other targets as the vision by 2050. Specific initiatives for decarbonization include: R&D for electrification /hydrogenation of agriculture/forestry machinery and fishing boats; use of biochar that has both carbon storage and soil improvement effects; R&D for absorbing and fixing carbon dioxide including fast growing trees and elite trees (see Column 2-11) and; promotion of energy systems based on local production for local consumption.

Strategy for Sustainable Food Systems, MeaDRI
URL:
https://www.maff.go.jp/e/policies/env/env_policy/meadri.html
Source: Ministry of Agriculture, Forestry and Fisheries

---

[1] Reference: https://www.meti.go.jp/press/2020/03/20210312003/20210312003.html

[2] ESG investment considers not only usual financial information but also environmental, social and governance elements. The concept of assessing sustainability of business administration has spread particularly among institutional investors such as pension funds managing large assets in a super long term. The concept alongside the UN SDGs is attracting attention as long-term risk management with climate change in mind and as a benchmark for evaluation of new revenue generating opportunities for enterprises.

[3] High temperature and lack of sunshine lower the rate of photosynthesis and make ripening end before albumin is filled with starch. As a result, the albumin have gaps that reflect light and make the grain appear white. This phenomenon, which lowers the grade of the rice, is increasing under high temperatures in recent years.

[4] Strategy formulated by MAFF in May 2021 to realize through innovations both productivity improvement and sustainability of the food, agriculture, forestry and fishery industries.

(2) R&D toward Clean and Economic Environmental Energy System

i Initiatives for high-accuracy prediction of climate change and utilization of the results

For the central and local governments to draw up and implement measures to address climate change, high-accuracy projection information is absolutely essential as the basis. For this purpose, a project was conducted to upgrade prediction of climate change through development of climate models by using Earth Simulator and other supercomputers[1]. Using this and other results, MEXT and the Japan Meteorological Agency (JMA) compiled scientific knowledge including the latest climate change projection and released "Climate Change in Japan 2020." It shows that the average temperature in Japan will rise, the number of extremely hot days and sultry nights will increase and typhoons will intensify near Japan at the end of the 21st century.

Furthermore, the Data Integration and Analysis System (DIAS) has been developed as an information infrastructure to accumulate big data including observation and prediction information on the global environment for integrated analysis. The DIAS provides information contributing to climate change solutions and other important issues. Its past achievements include building a system to predict flooding caused by typhoons (see Part 2 Chapter 3 Section 3-1 (3)).

ii Earth observation in international cooperation

To understand the status of global warming, countries and related organizations around the world have conducted various earth observations, such as space based and in-situ observations, and have found the scientific basis necessary for tackling climate change issues. The Global Earth Observation System of Systems (GEOSS) was built with the aim of conducting comprehensive and continuous whole Earth observation by integrating space based and in-situ observations and information systems via international cooperation. As an international framework to promote the GEOSS, the Group on Earth Observations (GEO) was established. As of February 2021, 246 countries and international organizations are participating in the GEO.

In addition, through the Future Earth which is a global initiative, the government is promoting international joint research in cooperation with stakeholders in Japan and abroad.

iii R&D toward a decarbonized society

Stable energy supply and use contributing to carbon neutrality is one of the top priority issues for Japan to tackle toward a decarbonized society that enables sustainable development. Because "fusion of cyberspace and physical space" by using supercomputers will consume a large amount of electricity, we need technologies for efficient use of electric power. R&D to generate energy while suppressing GHG emissions

[1] Integrated Research Program for Advancing Climate Models (TOUGOU)

and efficiently store and use generated energy will lead to a 2050 carbon neutral and decarbonized society.

Toward Practical Application of Fusion Energy (The ITER Project, etc.)

Fusion is the source of energy generated by the Sun and other stars in space. R&D on fusion energy is conducted with the aim of reproducing the process on Earth and using the generated energy for power generation and other purposes. For this reason, the R&D is called efforts to realize "Sun on Earth." Because fusion energy generation uses hydrogen as fuel, "its resource is abundant in sea water" and "its generation does not emit carbon dioxide." It is thought that a large amount of energy equivalent to 8 tons of petroleum can be obtained from 1g of hydrogen fuel. For this reason, fusion energy is expected to fundamentally solve energy and environmental problems.

In order to induce a fusion reaction, it is necessary to heat the fuel to over 100 million degrees Celsius to generate a high-temperature plasma state[1]. It is thought that when the plasma state is maintained for more than 1,000 seconds, the state will become stable for continuous power generation in theory. The ITER (International Thermonuclear Experimental Reactor) project[2] is a large-scale international project to validate whether the massive amount of energy generated through fusion reaction can be extracted as heat and used continuously as a new energy source. Japan is also a member of the ITER project and is conducting R&D into major equipment of an experimental fusion reactor.

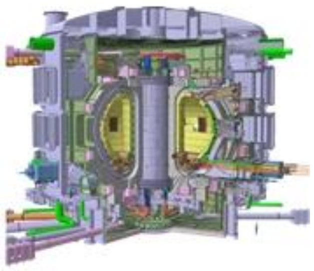
For practical use of fusion energy, economic efficiency (small size, high output and low unit price for generation) is absolutely necessary. Under the Broader Approach (BA) activities[3] to build the technical base necessary for a fusion DEMO (Demonstration) reactor, R&D has been conducted to maintain the plasma state with a pressure higher than the ITER target for a long duration by using the fusion experiment device, JT-60SA, and a fusion DEMO reactor is being designed at the International Fusion Energy Research Centre. When this is realized, small fusion reactors will be able to generate high output energy. Research on other approaches[4] to induce fusion are also advancing. The aim of fusion R&Ds with multifaceted approaches is to have practical application of fusion energy in sight by the middle of the 21st century to contribute to realization of a decarbonized society. (See Part 2, Chapter 3, Section 1-1 (1) i (vii) and Part 2, Chapter 4, Section 2-1 (4) i (i).)

[1] State where electrons are separated from the atom in gas due to high temperature and where electrons and ions can freely move

[2] A large-scale international project with participation of Japan, Europe, the United States, Russia, China, South Korea and India. The facility is under construction in France.

[3] The project is implemented jointly by Japan and Europe in Rokkasho village (Aomori) and Naka city (Ibaraki) to complement and support the ITER project, and R&D is conducted toward a fusion DEMO reactor with the aim of early practical application of fusion energy

[4] Other than the tokamaku method adopted for ITER and JT-60SA, a representative example of magnetic field confinement is the helical method, while a representative example of inertial confinement is the laser method



Schematic View of ITER
Provided by ©ITER Organization

JT-60SA being adjusted start operation
(Naka City, Ibaraki)
Provided by National Institutes for Quantum Science and Technology

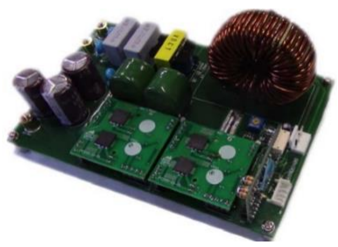
Toward Realization of Fusion Energy
URL: https://www.mext.go.jp/a_menu/shinkou/fusion/
Source: Website of MEXT

Initiatives to Enable Large-capacity Storage – Next-generation Storage Battery

Next-generation lithium-sulfur battery under charge/discharge performance evaluation

The aim of technologies of energy storage is efficient storage of generated electric power. Today, utilization of renewable energy sources including solar light, wind and geothermal heat is promoted in order to reduce CO_2 emissions. For efficient use of renewable energy that is greatly influenced by natural conditions, it is effective to store electric power that is generated exceeding demand in storage batteries. It is imperative to develop excellent next-generation technologies of energy storage[1]. The Japan Science and Technology Agency (JST) is promoting R&D on next-generation electricity storage consistently from the basics to practical application.

Efforts to Reduce Power Loss – Power Electronics



Power electronics circuit
Provided by Nagoya University

Power electronics is a technology necessary for conversion between AC and DC as well as of voltage. For example, solar cells and storage batteries output DC electricity, but home electronics and EV run on AC electricity. In such cases, it is necessary to convert DC to AC by using power electronics. In this process, efficient conversion with less power loss saves energy.

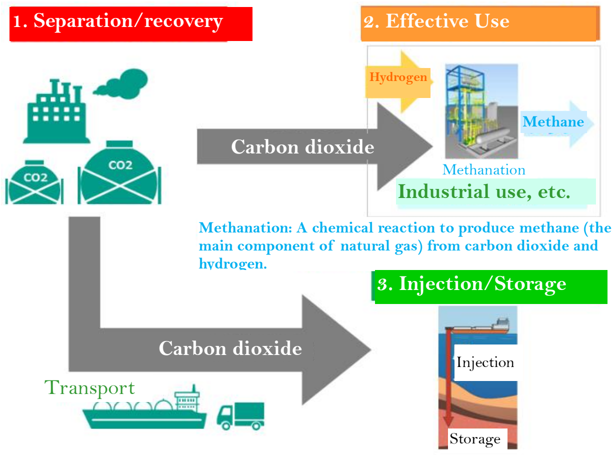
Innovation of power electronics is supported by power semiconductors. One of them is gallium nitride (GaN) which was used for the invention of the blue light-emitting diode that received the Nobel Prize in Physics in 2014. Expectations are rising for practical application of next-generation power semiconductors including GaN and power electronics that can maximize their characteristics. Japan started projects to promote creation of ultra-energy efficiency and high-performance power electronics equipment that will support a 2050 carbon neutral and decarbonized society[2].

[1] Electricity storage technology to realize high capacity that greatly exceeds the capacity of existing batteries. An example is the lithium ion battery which received the Nobel Prize in Chemistry in 2019.
[2] Reference: https://www.mext.go.jp/b_menu/boshu/detail/mext_00103.html

Improvement of Energy Use Efficiency

Reduction of energy loss in power generation, transmission and distribution, operation of power generation facilities to match power demand and manufacturing with low environmental burden are important for efficient use of energy resources to reduce impact on the environment.

■Figure 1-1-10: Separation/Recovery, Effective Use and Storage of Carbon Dioxide ■



RIKEN conducts innovative R&D for highly efficient generation, conversion/storage and use of energy and resource circulation. Examples are: research on organic solar cells with significantly improved conversion efficiency and; research to convert carbon dioxide in the atmosphere into useful substances including fuel and materials through actions of plants and microorganisms.

The National Institute of Advanced Industrial Science and Technology (AIST) and the New Energy and Industrial Technology Development Organization (NEDO) are conducting R&D on a technology to separate and capture carbon dioxide emitted from industrial activities and store it deep in the ground (Carbon dioxide Capture and Storage: CCS) and a technology to use the CO_2 effectively (Carbon dioxide Capture, Utilization and Storage: CCUS).

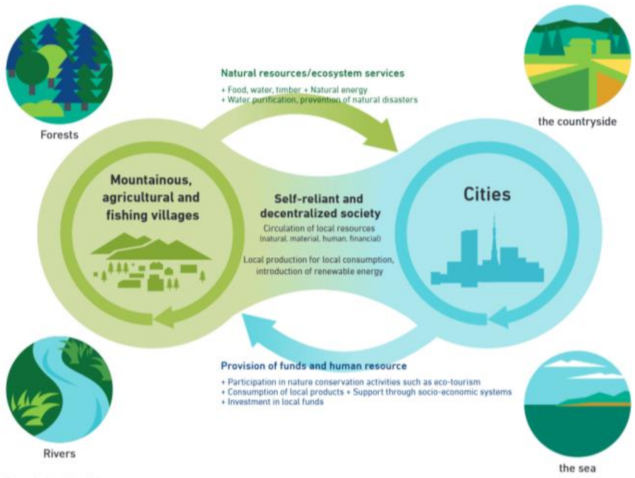
Toward early social implementation of CCUS, AIST and NEDO are demonstrating technologies for separation, capture, transport and storage of carbon dioxide emitted from commercial-scale thermal power plants, as well as demonstrating technologies to produce methane and ethanol from carbon dioxide in flue gas of waste treatment plants and in the atmosphere[1].

(3) Efforts Toward Regional Decarbonization

State-of-the-art R&D is not enough for realization of a decarbonized society; it is also essential for regional communities to change their economic society including values. It is important to promote regional planning and initiatives based on scientific knowledge in cooperation among universities and communities. For this reason, projects are being promoted to create fundamental knowledge that will support realization of a decarbonized society in regional communities by taking advantage of cross-cutting knowledge from the humanities and social sciences to the natural sciences, while at the same time spreading the results and building forums for cooperation among universities and communities.

[1] Reference: https://www.env.go.jp/earth/brochureJ/ccus_brochure_0212_1_J.pdf

■ Figure 1-1-11: Conceptual illustration of Circular and Ecological Economy (Local SDGs)■



Provided by the Ministry of the Environment

Toward industry creation, reform of economic society and lifestyles and solution of social challenges, there are specific projects for redesigning economic society through transition to "decarbonized society," "circular economy" and "decentralized society." Through this process, the government aims to create "Circular and Ecological Economy (Local SDGs[1])" to maximize the vitality of both local districts and cities. Specifically, in order to realize 2050 Carbon Neutral Decarbonized Society in collaboration among the national and local governments, the "Council for National and Local Decarbonization" was set up for discussion by relevant ministries, local governments and other entities on concrete measures from viewpoints of people and lives. Initiatives for decarbonization in lifestyle include the following:

○ Using GHG observing satellites to grasp the state of increase in carbon dioxide and methane concentrations on Earth

○ Introducing EV sharing to promote construction of decarbonized local transport models tailored to new lifestyles

○ Technology development and demonstration for thoroughgoing reduction in energy consumption through efficiency improvement of various devices incorporated in a variety of electrical apparatuses (lighting equipment, servers, microwave ovens, etc.) by using GaN.

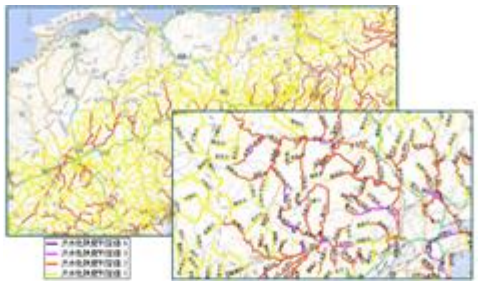
❷ Efforts for Disaster Prevention/Mitigation to Enhance Resilience against Large-scale Disasters

Ten years have passed since the Great East Japan Earthquake that caused an unprecedented catastrophe. Being aware of the important lessons learned from the Earthquake, we need to enhance resilience against predicted large-scale disasters by utilization of the convergence of knowledge through information communication technologies that have progressed in the past 10 years.

For this purpose, disaster information should promptly be shared among relevant stakeholders, therefore an environment to support such activities needs to be developed.

[1] Regional Circulation Symbiotic Spheres is a vision to realize SDGs that promote local economic circulation and integrally solve environmental, economic and social challenges, while ensuring sustainable use of local resources and environmental conservation in order to solve various local social challenges. For example, city dwellers satisfy their daily life needs and support sustainable regional development in rural districts by paying for gifts of nature through products provided by rural districts and eco-tourism. This is an approach to maximize the vitality of both rural districts and cities.

National Research Institute for Earth Science and Disaster Resilience (NIED) developed a network[1] for information sharing among national governments, local governments and relevant organizations. For the development of unified situation awareness in the time of disaster, NIED has visualized the information publicly available and also provided disaster response entities on their respective websites[2]. These initiatives have enabled instantaneous disaster information sharing for disaster response, i.e., road closure, emergency water supply spots, etc. (see Part 2, Chapter 3, Section 2-1 (3).) At the time of the torrential disasters in July 2020, the information sharing system contributed to helping isolated villages along the Kumagawa River and supporting other relief operations by promptly transmitting information collected from the disaster sites to disaster response entities.



On the left: Use at the time of an earthquake in the northern part of Osaka prefecture
On the right: Example of displaying flood warning hazard distribution of small and medium rivers
Provided by NIED

Outline of the Shared Information Platform for Disaster Management (SIP4D)
URL: https://www.sip4d.jp/
Source: NIED

Improvement of Earthquake Prediction Technologies

Issues were revealed at the time of the Great East Japan Earthquake; there was insufficient earthquake observation data in sea areas and that targets of the long-term evaluation did not cover huge earthquakes centered in sea areas. Overcoming these issues, the government has developed and operated seafloor observation networks for earthquakes and tsunamis. Above all, an observation network is under construction in the sea area surrounding Nankai Trough where the probability of M8-9 class earthquakes occurring within the next 30 years is assessed at 70 to 80 percent (as of January 1, 2021). The aim is to detect earthquakes and tsunamis in real-time and directly through the sea area observation network, which can disseminate faster than that used through observation instruments on the ground and provide information at an early stage. Existing earthquake/tsunami observation networks on the ground and in sea areas are also used for tsunami warning and earthquake early warning.

While advancing earthquake survey and research using vast amounts of observation data obtained from the earthquake/tsunami observation networks, a new research project using information science[3] including AI started in FY2021 with the aim of clarifying earthquake mechanisms and improving earthquake prediction

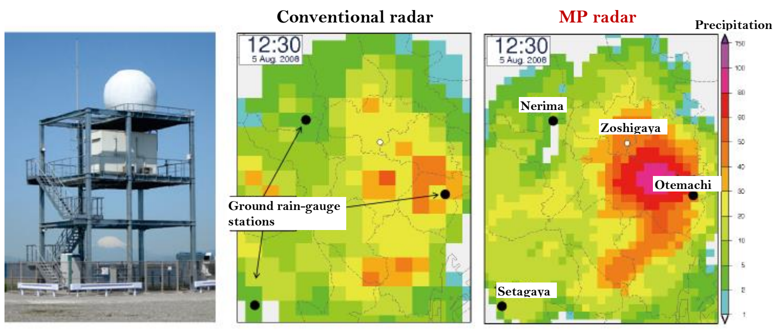
[1] Shared Information Platform for Disaster Management (SIP4D)
[2] Website to post information available to the public: NIED Crisis Response Site (NIED-CRS) (renamed to bosaiXview in March 2021)
Website to post information not available to the public: ISUT-SITE for disaster response bodies
[3] Earthquake research project using information science

technologies.

Improvement of Technologies to Forecast Water-Related Disasters

More reliable forecast of water-related disasters is needed for disaster response. For example, if we can forecast so-called "Guerrilla Rainstorms" local rainstorms caused by cumulonimbus clouds, it will greatly help quick evacuation and disaster responses. NIED has developed an "X-band MP (multi parameter) radar" that can observe the intensity of rainfall more accurately compared to conventional weather radars by transmitting and receiving two types of radio waves oscillating vertically and horizontally. This observation technology was transferred to the Extended Radar Information Network (XRAIN[1]), deployed throughout Japan and enabled monitoring of Guerrilla rainstorms. As shown by these examples, NIED is pursuing studies to deliver more accurate information for disaster responses before and after the occurrence of water-related disasters by using a variety of state-of-the-art sensing equipment, making forecasts through simulations using supercomputers, and monitoring the conditions after the disaster.

■ Figure 1-1-12: Development of Technologies for Observation/Prediction of Guerrilla Rainstorms ■



Provided by NIED

Disaster Research based on Convergence of Knowledge

Research on disaster prevention/mitigation involves multi-disciplinary fields including the humanities and social sciences, historical science, disaster medicine, sociology, economics, education, engineering for a resilient society and research to elucidate disaster mechanisms; therefore, comprehensive R&D integrating the knowledge of all these fields is required.

For example, historical materials and old documents passed down in communities are valuable materials recording past disasters and can help physical research including estimation of the intervals between and scales of past earthquakes. Learning also from the Great East Japan Earthquake, the International Research Institute of Disaster Science at Tohoku University conducts disaster research integrating arts and science based on archiving, research and analysis of historical materials. Its results include clarification of aspects of past earthquakes and tsunamis through development of an earthquake damage distribution map based on old documents handed down in the communities.

[1] eXtended RAdar Information Network: a real-time rainfall observation system using X-band MP radars