Document 4

Materials for study received from related ministries for setting the Moonshot targets

Related ministries contributed suggestions for difficult social challenges and research ideas for their solutions that could yield a large, greatly significant payoff if realized and should be covered by the Moonshot Research and Development Program. The following 111 suggestions were collected from the Cabinet Office and eight ministries.

Challenge examples	Food	Health/ Medical	City	Energy	Environment / Resources	Industry/ Labor	Communication/ Technology	Space
No.	12	17	13	7	24	9	20	9

Suggestion examples

	Ambitious goals attracting people's interest (Moonshot targets)	**Difficult social challenges that could yield a great impact if realized and new value creation, suggested from an outlook of a future society**	**Keywords of areas/fields where research and development should be promoted**	**Examples of challenging research and development**
Food	Future offshore aquaculture leveraging the potential of the ocean	As we see food production on land coming close to its limitation in the midst of the growth of the world's population, effective utilization of oceanic production capabilities is a key measure for food supply. We will develop facilities for future offshore aquaculture to enable stable supply of food (source of protein) for the future while also aiming to increase natural marine resources including tunas and eels, promote industry of isolated islands, and manage Japan's EEZ appropriately.	Breeding and aquaculture Ocean engineering Renewable energy	• Aiming to realize nutritional support and water temperature adjustment which utilizes deep water by setting up off shore a floating bottomless enclosure that is hundreds of meters in diameter and 300 meters in depth. Making it possible to generate power from the temperature difference between deep water and surface water.
Health/Medical	Society where people live true to themselves with PHM (Personal Health Management)	To realize a society where future healthcare services based on each person's needs are provided, we will make it possible for everyone to have access to his/her own healthcare information based on scientific evidence by building a platform which collects, analyzes, and provides huge amounts of medical data stored in various locations in the country in an integrated way.	Personalized medical care Database systems Bioinformatics	• Building a large-scale human-data integration platform • Development of an environment for human big data utilization and transitional research for business • Providing future healthcare services based on scientific evidence
City	Virtual Earth [Simulation of the whole earth/Near future predictions]	To protect the people's lives and property from the threat of various natural disasters and raise their disaster prevention awareness, we will build advanced sensor networks on the ground, underground, and in the sea and space, and realize a society where policies are made based on real-time forecasting of near-future earthquakes and water cycle, highly accurate, comprehensive disaster information, and information concerning damage of cities and regions generated by such networks.	Remote sensing Model simulation Movements of the earth's crust and seabed	• Real-time observation of air/water cycle, earth's crust/plate, etc. by using optical fiber sensing and satellites • Advancing integrated simulation technology and analytical algorithms through a multilayer model • Real-time earthquake simulation technology based on observation data
Energy	Maximum utilization of solar energy by full spectrum technologies	We need to move out of the current social structure which is supported by carbon energy and create a sustainable society. We will create a foundation for an energy consumption system a human society should have in 2050 which fully utilizes the solar energy that is available more or less evenly across regions.	Renewable energy Energy conversion Optical/heat devices	• Developing materials and device structure for the use of infrared light by thermophotovoltaic power • Developing wavelength conversion materials and applying them to devices • Developing high-performance light-absorbing materials and multi-junction materials for widening the absorption wavelength range

Environment/ Resources	Japan as a resource-rich country Making a foray into extreme environment and frontiers	We will create resources from just about everything, e.g., by carrying seabed minerals to the ground, and collecting marine pollutants and industrial wastes. We will make effective use of resources gained in extreme environment such as ocean and space, for which we will also create exploration/development environment. We will make high grade resources out of natural resources through ultimate energy conversion and recycling technology.	Marine resources/energy Ocean engineering Decontamination/restoration technology	• Seabed collection station which will function as a base for transportation of resources gathered in deep sea • Efficiently collecting unused resources which could pollute environment • Producing highly useful resources from collected, unused resources
Industry/Labor	Society where everyone is connected, shares, and participates	In expanding our senses, physical abilities, and perception and substituting lost or decreased functions, we will make it possible to break through limits of human abilities together by everyone including able-bodied persons as well as seniors and the disabled making up for his/her weakness by relying on others' abilities.	Virtual reality Human engineering Robotics	• Quantification of senses, physical strengthening technology, "coevolution", expansion of human abilities by AI • Demystifying the mechanism of bodily transformation through continued activities • Physical strengthening/environment strengthening service technology according to the type of gene expression • Relationship between environment strengthening through VR/AR and self-efficacy or motivation for activity
Communication/ Technology	A leap in knowledge through utilization of quantum resources	Realization of quantum internet which connects quantum computers in a quantum link will enable synchronization with an atomic clock which advances GNSS (Global Navigation Satellite System), a distributed quantum interferometer which detects changes in gravity distribution, and large-scale quantum computation, and machine learning on a quantum computer is expected to produce an impact. As well, it will realize high-speed, large-capacity quantum cryptographic communication technology.	Quantum information Quantum electronics Machine learning	• Practical implementation of quantum interface between three or more different quantum physical systems • Long-distant communication of the quantum state by using optical fibers • Mutual connection between quantum computers
Space	Realization of a space colony	Faced with climate change and the surge in the world's population, it will be impossible to maintain the entire population on the earth alone. For this reason, we will expand the living area of the human species outside of the earth (e.g., Mars) by creating a space colony and support the fast increasing population.	Space utilization/exploration Aerospace systems Space photovoltaic power generation	• Space elevator which enables transportation of goods from the earth and space photovoltaic power generation • Construction technology and life-support systems required for space colony construction • Space debris removal technology to protect the safety in the orbit

<Future food>

Ambitious goals attracting people's interest (Moonshot targets)	Difficult social challenges that could yield a great impact if realized and new value creation, suggested from an outlook of a future society	Keywords of areas/fields where research and development should be promoted	Examples of challenging research and development
Realization of sustainable, compact bio-ecosystems by biomimetic IoT devices	By mimicking life's excellent sensing and information processing capabilities, we could realize miniscule drones made of parts which could act as both sensor and actuator, and low-priced, harmless biosensors, thereby making it possible to build autonomous, compact IoT ecosystems. By enabling autonomous food production and management according to demand, we could contribute to reduction of food wastes and food self-sufficiency while making up for labor shortage.	Biosensor Biomimetics IoT/Robotics	• Chemical information detection modelled after biological senses • Controlling a drone's position based on the spatial perception of birds and insects • Biomimetic information systems which come with characteristics such as energy conservation, a low environmental impact and robustness • Macro devices equipped with micro functions at a molecular and cellular level
Research into innovative solutions for nutrition/food issues through symbiosis and mutual aid between humans and microbes	We will establish microbiome research infrastructure suitable for the social needs based on comparison with human medical/health information in addition to consolidation and development of microbiome databases and solve future nutrition/food issues through realization of the following based on symbiosis and mutual aid between humans and microbes: 1) Improvement of a human's nutritional metabolism efficiency, 2) Improvement of the productivity of agricultural, livestock and marine products, and 3) Development of food, etc.	Environmental microbe Human/animal bacterial flora Bio-database	• Releasing the data maps of indigenous microbiome of soil, rivers, ocean, livestock, marine products, and humans • Improving human nutritional metabolism and achieving the average BMI of 22 in countries around the world • Increasing yield of agricultural and marine products by utilizing microbes
Solving food and environmental issues of the 21st century at the same time by realizing "Species Creation" which lets you design crops the way you want by Cybernetics Breeding	By developing a "Species Creation" system in which we have more freedom in designing and modifying crops thanks to advances in genome engineering technology and integration with AI and robotics, we will provide high-quality, high-performance food (Cool Japan) while creating innovative crops which are culturable at abandoned fields, fixate high CO2 (Cool Earth) and at the same time absorb useful resources. That way we will solve various issues of food and environment altogether.	Gene transfer/mutation creation Bioinformatics Omics analysis	• Selection system created from AI-based learning of breeders' skills by using omics data and ICT • AI which infers useful mutation, supported by a 3D structure forecasting system based on a database compiled on the difference of DNA sequences within and between species • Gene engineering technology which could let you transfer a variety of mutations you designed to many targeted genes
Creating new gene engineering technology originated in Japan which is superior to any overseas technology or patent	Basic patents for gene engineering technologies such as CRISPR/Cas9, etc. are owned by overseas entities, and domestic companies are unwilling to use those technologies because they could face high license fees or terms and conditions disadvantageous to them. They also seek higher performance than these technologies offer. By creating gene-editing enzymes which satisfy these needs in Japan, we will promote the use of gene editing in agriculture, industry, and medicine, and create new industries in Japan.	Gene transfer/mutation creation Enzyme chemistry	• Creating high-activity gene editing enzymes which do not infringe patents by analyzing and transforming the structure of existing gene editing enzymes • Demonstrating usefulness of new enzymes in each sector of agriculture, industry, and medicine and developing applied technologies
Controlling livestock viruses and plant viruses which could endanger our food infrastructure	As the risk of livestock/plant viruses entering Japan is growing due to the food globalization, it is hoped that a measure to control viruses will be developed before they wreak devastating damage. Control of livestock/plant viruses also holds promise for securing stable supply of food and preparing us against pandemic as it will reduce the possibility of livestock viruses mutating into infectious human viruses.	Protection against and control of infection Drug molecule design Proteome information processing	• Creating artificial protein and nucleic acid-like materials which control effects of viruses • Creating drugs which are effective against multiple viruses by focusing on common structure of viruses • Conducting detailed molecular analysis of virions and complexes of viruses and host factors
Realizing carbon dioxide absorption by super algae and circular aquaculture	As the current aquaculture relies on naturally-derived fish meal and fish oil for feeds, it is imperative to develop feeds for aquaculture that have less impact on the environment. By breeding and mass culturing of new super algae which absorb carbon dioxide and efficiently produce essential amino acids and essential fatty acids, we will realize circular aquaculture which uses such super algae as feeds.	Breeding and aquaculture Heredity/Breeding Ocean/Matter cycle	• Breeding super algae which grow in poor environment and produce essential amino acids/fatty acids efficiently • Breeding new fishery products for aquaculture that eat less and grow fast • Efficiently extracting active ingredients from residues resulting from fishery product processing

Future offshore aquaculture leveraging the potential of the ocean	As we see food production on land coming close to its limitation in the midst of the growth of the world's population, effective utilization of oceanic production capabilities is a key measure for food supply. We will develop facilities for future offshore aquaculture to enable stable supply of food (source of protein) for the future while also aiming to increase natural marine resources including tunas and eels, promote industry of isolated islands, and manage Japan's EEZ appropriately.	Breeding and aquaculture Ocean engineering Renewable energy	• Aiming to realize nutritional support and water temperature adjustment which utilizes deep water by setting up off shore a floating bottomless enclosure that is hundreds of meters in diameter and 300 meters in depth. Making it possible to generate power from the temperature difference between deep water and surface water.
Realizing a super-sustainable society through design/control of bacterial population	We will create artificial soil which could control pathogenic bacteria, produce new biologically active substances, food, etc., make prevention of and restoration from pollution/degradation of water, soil, etc., and respond to climate change by designing/controlling bacterial population, plants, livestock, environment, etc. as a system, developing means to utilize metabolism and activity found there, and making the most of unknown functions.	Environmental microbe Metabolic control Plant microbe interaction/symbiosis	• Designing/controlling bacterial population utilizing big data and AI • Improving crop productivity dramatically with artificial soil utilizing designed bacterial population • Developing new drugs, environmental technologies, etc. utilizing designed bacterial population
Developing preservation technology based on the mechanism of living things which do not die even when they are dried up	We will promote CO2 reduction through reduced power consumption by establishing technology for long-term dry preservation at room temperature of cells, tissues, reproductive cells, and functional protein, based on the mechanism of creatures which do not die even when they are dried up. By using the technology for life preservation in a state where all metabolic processes are stopped, we will be able to safely transport living things in space environment.	Genetic resources Cells, tissues, seed preservation Conservation/efficient use of energy	• Long-term room-temperature preservation of enzymes, antibodies, medical reagents, agricultural products and food • Simple, stable, dry preservation of useful animal cells and gametes at room temperature and at low cost • Realizing energy-saving transportation of cells/gametes of living things between planets
Ideas of sea water farming/marine farms	While the largest bottleneck in agricultural production is water, groundwater that is fresh water is fast drying up. By developing crops that could grow with sea water or farming facilities which could use sea water, we will completely solve the issue of water resources in agriculture and produce food with sea water at plant factories or soilless greenhouses on Mega-Float-like floating structure on the sea.	Breeding of resistant variety Aquatic environment Protected horticulture/Plant factories	• Developing super salt-tolerant crops which could be grown with sea water • Developing mobile Mega-Floats • Developing integrated facilities for agriculture and fishery which combine plant factories and aquaculture facilities
Developing the "System for various changes of carbohydrates" to support stable supply of food	Food cannot be stored for 10 years. We will develop technology to create stably-preservable carbohydrates from plant-derived carbohydrates in anticipation of unpredictable long-term abnormal weather and growing uncertainty in the international situation. When food supply is enough, such carbohydrates are used as energy or industrial material, and they can revert back to food upon food shortage, or be used as ingredients for various types of nutrients.	Glycoscience Bioprocess Bioengineering	• Developing technologies for manufacturing and stabilizing carbohydrates from plants and microbes • Developing efficient manufacturing technologies of amino acids, fat, and vitamins from carbohydrates • Developing technologies for advanced conversion from saccharified substances to energy and valuables
Developing a system for highly accurate strategies for pest control and forecast using the next-generation computers	We will develop AI which has gone through reinforcement learning and deep learning of data concerning climate, the ecology of pests, chemical sensitivity, forecasting, crops, etc. AI will recognize crop varieties planted and pest samples trapped and present highly accurate cultivation conditions to mitigate damage based on a forecast using a pest outbreak simulation model.	Disease and pest control Model simulation Agricultural environment/Information engineering	• Accumulating various data and building a database concerning pest outbreaks • Developing a pest damage forecasting app to be installed on the next-generation computers • Developing sensors and traps used for recognizing types of pests and their population

<Future health/medical care (Life science) >

Ambitious goals attracting people's interest (Moonshot targets)	Difficult social challenges that could yield a great impact if realized and new value creation, suggested from an outlook of a future society	Keywords of areas/fields where research and development should be promoted	Examples of challenging research and development
Lifelong participation	We aim to create a society where seniors are actively involved as its important members by extending healthy life years through early detection of disorder and a control of aging and diseases with advanced technology and development of an environment in which advanced medical care is closely available anywhere in the country.	Cellular aging Examination/Diagnosis/ Treatment system Medical information system	• Controlling aging and diseases through single-cell-level quantitative pathological evaluation realized by having all human cells electronically cataloged and using quantum sensors • Non-surgery cancer treatment in which patients can return home the same day/Advanced medical care with "Anytime Health Sensing" available across the country • Very early detection of hidden disorder, e.g., dementia, depression, etc. before its onset with highly sensitive checkups and AI forecasting
Society where everyone is connected, shares, and participates	We will rapidly promote social participation by seniors and the disabled by replacing their lost or decreased functions with machines and IT. As well, by establishing a place for social activities in virtual space, we can create a society which offers diverse opportunities for involvement to everyone.	Sensors Artificial sense organs Substitution of biological functions	• Remote diagnosis by reproducing integrated understanding based on the five senses with a highly sensitive five-sense sensor • Support technology which equips learners with necessary skills • AI tutoring to help people become who they want to be
Realizing a safe and secure society of longevity with ultra-compact, powerful particle accelerators	The current particle accelerators, even the smallest ones, are dozens of meters long. By developing ultra-compact, powerful particle accelerators which could be placed anywhere, we could expect improvement of Japan's infrastructure and open the door for advanced treatment for more people. That way, we could realize a world-class society where people live safe, secure and long lives.	Particle accelerators Minimally invasive treatment system Application of quantum beams to medical care	• Developing medical small particle accelerators which can be installed in clinics • Developing highly accurate treatment which only kills cancer cells instantly • Visualizing super-microsurgery by developing small-sized high-definition X-ray equipment
Making anticancer drugs available to all patients	Peptide drugs have not spread widely because of their high price despite their advantages such as a wide range of efficacy, no side-effects, and quick action. By developing new technology, we will make them more affordable and offer them in the world.	Antibody therapy Selective synthesis Drug molecule design	• Logic drug design which has moved out of trials and errors by combining computational chemistry and rapid chemical synthesis
Society where people live true to themselves with PHM (Personal Health Management)	To realize a society where future healthcare services based on each person's needs are provided, we will make it possible for everyone to have access to his/her own healthcare information based on scientific evidence by building a platform which collects, analyzes, and provides huge amounts of medical data stored in various locations in the country in an integrated way.	Personalized medical care Database systems Bioinformatics	• Building a large-scale human-data integration platform • Development of an environment for human big data utilization and transitional research for business • Providing future healthcare services based on scientific evidence
Contributing to the international community and realizing a healthy society with longevity through a new strategy to control infectious diseases based on development of personalized medical research and development	By conducting factorial/mechanism analysis of a person's susceptibility to infection and a decline of immune strength caused by aging through AI-based omics/big data analysis and aging animal model experiments, we will develop new drugs and vaccines which work through a new mechanism and realize personalized medical care for infectious diseases and development of nutrition/food.	Personalized medical care Infection immunity Protection against and control of infection	• Developing treatments and preventive medicines based on the mechanism of "those who are not susceptible" by using genomic data • Drugs for a decline in immune function of seniors • Functional food which makes people less susceptible to infectious diseases
Extended Medicine: Realizing a society where there is no restriction in accessing advanced medical care through medical care's expansion into cyber space (including expansion of functions of doctors and patients as humans)	In cyber space where functions of medical care and humans are expanded, there will be no distance in time and space with medical care and everyone will have access to even advanced medical care. Big data of mobile edge computing terminals is shared with actual medical care/society and realizes a society of new-generation personalized medical care which optimizes limited medical resources.	Personalized medical care Mixed reality Medical information system	• Virtual hospital where patients reproduced in cyber space will be treated by doctors/AI • Developing the next-generation super computer (successor to "Kei") for medical use (quantum computing) • Biological edge sensing technology which enables real-time transmission of individual information of patients

Revolutionary medical treatment strategy aiming for circulation control presented in Society 5.0	The numbers of patients in line for transplantation by organ are 740 for hearts, 350 for lungs, 340 for livers, and 12,150 for kidneys. Total replacement of organs/tissues is impossible for engineering science alone, so we will collaborate with bio and information fields and aim for a hybrid of living tissues and advanced materials and development of transplantable organs that are autonomous (no need of driving power outside of the body) and operable externally.	Studies of artificial organs	• Ultra-compact antithrombogenic external heart-lung machines • Decellularized organs • Implantable artificial hearts that are operable/adjustable externally
Future Medical Development 2040: Realizing an energetic society from Health Smart Home	The following will be realized in future medical care in 2040: 1) “Biological activity monitoring using virtual space and minimally invasive treatment” based on microtechnology/nanotechnology, 2) “Precise personal management and self-care-type medical treatment” which enables health checkup at Health Smart Home, outside of the hospital management, and remote medical care, and 3) “Health/medical ecosystem where people can have fun” which acts as a substitute or supplement to drugs	Medical information system Remote diagnosis/treatment system Promotion of health	• Developing sensors/technology which could monitor physical condition while in bathroom or sleeping • Developing health promotion methods with game factors based on biological omics information • Developing immune function enhancing methods according to the person’s constitution to prevent infectious diseases/cancer
Dealing with health hazard in a destructive situation and action schemes using space technology, AI, and remote medical care technology	• AI robot that can be housed in a suitcase-like container & remote medical care system using a 3D hologram. Medical service system in a destructive situation using medical IoT and a mobile satellite communication kit. • We will develop an AI-based hazardous environment alert system based on analysis of the earth’s surface environment data obtained from satellites. As well, we will explore ways to improve environment by using specific energy waves.	Remote diagnosis/treatment Medical robots Remote sensing	• Mobile satellite communication • AI robot remote diagnosis • Satellite measuring the earth’s information
Lifelong participation Creating a society where people enjoy good health throughout their lifetime	Facing the acceleration of population decline, dwindling birthrate and an aging population, we will maintain and improve technological capabilities, a Japan’s strength, by consolidating and making AI-based analysis of data of how one has lived over the course of his/her life. At the same time, we will create a society where people can stay healthy and work for long without concerns over geriatric diseases by enhancing preventive medicine and providing appropriate medical services.	Preventive medicine Promotion of health	• Developing dementia prevention/care and assisted living programs according to the condition of each elderly person • Developing innovative medicines and robots to overcome geriatric diseases.
Welfare innovation Realizing inclusion/diversity	We will realize a society where diverse values of individuals are accepted and “awareness” arises naturally by 2040. By maintaining/expanding physical and mental functions and empowering individuals and communities, we will also strive to build new social relationship which is similar to “collaborative relationship” extending over a community in which everybody is accepted and recognized by others and able to be socially engaged easily.	Human mechanical systems Brain-machine interface Living assistance technologies	• Technologies for maintaining/expanding mental and physical functions by nerve connection and sensory/motor function support • XR community assist system for collaborative relationship which encourages awareness • Livelihood support/physical assistance robots to help people keep living at home as long as they wish
Smartification of infrastructure New social system which transcends time and space	We expect to see excessive demand for medical and nursing care in cities and labor shortage in the provinces in 2040. We will strive to solve such challenges by new infrastructure for medical and nursing care which transcends constraints of time and space, and practically implement a social system in which people can connect with society when they need, and pursue their best way of living while their individual preferences, such as where they want to live, are respected.	Remote diagnosis/treatment system Biological modeling/Physiome Biomechanics	• Fewer cases of sudden deterioration of condition by symptom forecasting/Technology for optimum smart access to resources of medical/nursing care • Highest-level training even in rural areas (XR + innovative biological modelling technology) • Developing equipment with which anybody can help others even in an emergency/Emergency drones
Health-investment-type society New era of data distribution	As disease structure changes and it is increasingly important to deal with lifestyle-related diseases, in particular, we will create an environment to support individuals in the aspects of both technology and humans, not to speak of health management, in which individuals have options to realize their own lifestyles and can invest in their health based on the understanding of their options.	Medical information system Biological information/measurement Life information	• Avatar (digital twin) which encourages behavioral transformation/Visualization of mind and action data • System to guarantee rights of ownership/utilization and integrity of data • Demystifying disability preventive mechanism of exercise and formulating strategies for promotion of health and disease treatment

Manufacturing pandemic vaccines by utilizing Silkworm Insect Factory	We are facing growing risk of infectious pandemics as a result of change in global environment and the globalization of distribution. We will not only evaluate this danger economically but treat it as a national security issue, and establish a Silkworm Insect Factory system which makes safe, home-manufactured vaccines at normal times and can quickly supply vast amounts of vaccines in an emergency.	Use of insect functions/Production of useful materials from insects Entomopathogenic microbes/viruses Infection prevention/control	• System to manufacture vaccines in 20 days after acquiring genetic information of viruses • System capable of manufacturing vaccines for 300,000 people in 30 days at any time • System to manufacture vaccines that are entirely made in Japan including their intellectual property rights
Designing methods for health and longevity/rejuvenation through all-Japan combined cohort studies of genetic information/intestinal flora	Through the activation of Mesenchymal Stem Cells (MSC), we will reduce the number of people who need long-term care to as close to zero as possible by preventing frailty (decline of motor/cognitive functions by aging). To this end, we will collect data of one million people concerning frailty through large-scale combined cohort studies, etc. and develop methods to prevent frailty through MSC activation.	Preventive medicine Human/animal bacterial flora Bioinformatics	• Genome/microbiome cohort study which clarifies the relationship between frailty, biomarkers, and intestinal flora • Designing methods (medical care, food, etc.) to prevent/treat frailty by increasing MSC activation
Making Japan one of the best countries in terms of people's health and longevity	Extended healthy life years will bring inflated social security costs down to reasonable levels, increase GDP by the increase of healthy and socially-active people, and lead to creation of new markets in a range of industries including health, food, medicine, examination, equipment, cosmetics, aesthetics, etc.	Human/animal bacterial flora Bioinformatics Regenerative medicine	• Demystifying causal relationship between health maintenance/disease and microbiome through genome/microbiome cohort studies • Building a future society system which realizes health and longevity by developing and promoting high-quality, highly-reproducible production technology concerning regenerative medicine and gene therapy

<Future city>

Ambitious goals attracting people's interest (Moonshot targets)	Difficult social challenges that could yield a great impact if realized and new value creation, suggested from an outlook of a future society	Keywords of areas/fields where research and development should be promoted	Examples of challenging research and development
Building permanent infrastructure Realizing social infrastructure which will not fall for a long time	We will build sturdy infrastructure which will not fall for a long time by greatly improving durability of construction materials and buildings and using materials that are reparable after deterioration. As well, we aim for infrastructure that can be used for ever by making materials/parts super durable to slash maintenance and repair costs.	Construction management Quantum beam measurement method Big data analysis/utilization	• Diagnosis technology which predicts minute objects, internal state, and future which cannot be perceive by our senses • Super durable infrastructure which will not fall for a long time • Infrastructure made of materials/parts that can be restored after damage
Protecting people from natural threats	To protect people's lives from various natural disasters, we need to establish some technologies in advance, e.g., technology for predicting the occurrence of natural disasters, technology for canceling disaster risks, etc. Accordingly, we will strive to find early indications of large-scale natural disasters and prepare conditions for prompt evacuation and survival while trying to completely insulate us from earthquakes.	Natural disaster forecast/analysis/counter measure Optical engineering/Photon quantum science Space utilization/exploration	• Power generation technology based on natural disaster energy such as typhoon/Technology for complete insulation from earthquakes • Real-time assessment of every phenomenon on the ocean, etc. using optical sensors • 24-hours satellite monitoring system (ultra-high-resolution, geosynchronous optical satellite)
Great infrastructural revolution	We will build sturdy infrastructure which will not fall for a long time by greatly improving durability of construction materials and buildings and using materials that are reparable after deterioration. As well, we aim for infrastructure that will not be dilapidated by avoiding the use of materials that easily deteriorate, and thereby preventing road cave-ins, collapse of tunnels and bridges, and power failure and fire from damage to transmission cables.	Materials for social infrastructural structure Composite materials/New materials Design/production of circulative/recyclable materials	• Building infrastructure which lasts 1,000 years by combining ancient Roman technology and modern science • Transport aircraft which can travel to space any number of times (materials that heal on their own instantly in extreme conditions) • Tunnels that recover on their own from fire damage
Realizing a safe and secure society of longevity with ultra-compact, powerful particle accelerators	The current particle accelerators, even the smallest ones, are dozens of meters long. By developing ultra-compact, powerful particle accelerators which could be placed anywhere, we could expect improvement of Japan's infrastructure and open the door for advanced treatment for more people. That way, we could realize a world-class society where people live safe, secure and long lives.	Particle accelerators Quantum beam measuring method Application of quantum beams to industry	• Instant inspection of bridges/tunnels by driving a vehicle equipped with nondestructive inspection equipment • Prolonging useful life of asphalt pavements by electron beam irradiation • Developing nondestructive detectors of dangerous goods to realize a safe and secure society
Infrastructural revolution	There are concerns over rapidly deteriorating social infrastructures in Japan which were developed intensively during the country's high economic growth period. Around 67% of roads and bridges and 50% of tunnels will be 50 years old or older in 2033, and are expected to require around five trillion yen for maintenance and operation. It is imperative to take efficient measures against deterioration and for extending service life.	Quantum beam measuring method Maintenance engineering Laser	• Ultrahigh-speed nondestructive inspection of infrastructural deterioration by ultra-compact laser equipment
Society free from accidents/traffic congestion, making roads safer for children and seniors	By development of advanced computerization and networking realized by the coordination between automobiles and roads, we will make automatic collision avoidance and automated driving a reality, slashing traffic accidents and congestion. We will realize efficient, stress-free traffic based on remote control and automatic control without sole dependence on automotive sensors.	Mobile networks Advanced traffic systems Intelligent robots	• Fully automated driving based on a reading of human feelings and conditions through dialogue • Smart mobility system which automatically assigns vehicles when and where needed • Architectural foundation technology to realize optimum MaaS/Negotiation between AIs for connection between means of transportation • System enabling optimum traffic control
Infrastructure with super long service life	Many infrastructures in Japan were developed during the period of the country's economic growth and their deterioration is expected to accelerate going forward. It is hoped that infrastructures which excel in cost, service life, energy consumption, productivity, and CO2 emissions will replace such existing infrastructures that reach the end of their useful life all together. We will realize this by utilizing steel-structured infrastructures more effectively.	Materials for social infrastructural structure Joining/Bonding/Welding Reliability	• Developing innovative, high-performance steel material that excels in corrosion resistance and strength • Developing innovative joining technology that excels in corrosion resistance and strength • IoT-based monitoring technology

Infrastructural revolution [Fully automatic construction sites/Unmanned sites]	To respond to the decline in the number of skilled workers in development/maintenance and operation of infrastructure, we will realize "unmanned construction" which automatically completes all construction processes without requiring workers assigned to the site.	Recognition of action environment BIM/CIM Composite materials/New materials	• Collaborative construction technology using multiple construction machines, 3D printers, etc. based on 3D drawing information • Automation, especially that related to technology for concrete-like new materials compatible with 3D printers • Robots/drones which have innovative sensors, actuators, and mobility
Infrastructural revolution [Super long-term durability and building of permanent structure]	To build infrastructures that will be used and grow in value over centuries, we will strive to maximize current and future values of infrastructures of the whole country by developing construction materials that have super long-term durability and innovative technology which enables easy yet accurate inspection.	Technologies for structural design/nondestructive inspection Composite materials/New materials Reliability engineering/Quality assurance	• Structural design technology suitable for highly durable materials • Advances in design technology to prevent the entry of deterioration elements (water, saline matters, etc.) • Self-healing/repairing materials using microbes, etc.
Realizing traffic environment with Society 5.0 in view	In anticipation of an era in which all vehicles are self-driving cars or connected cars and various mobile units are connected to each other through communication devices, we will realize safe/secure and smooth traffic environment free from traffic accidents, violations, and congestion by developing communication technology which offers traffic control information.	Mobile networks Advanced road traffic systems Network security	• Communication technology which enables high-speed, large-capacity, multi-connectivity communication with low latency • Using traffic flow as communication infrastructure based on communication among mobile units • Information security technology concerning distribution of traffic control information
CO2 absorption by photosynthesis which does not rely on the sunlight and expansion of the living area of the human species into space	By controlling the environment of the whole earth the way we want, we will prevent the ice age as well as unexpected abnormal weather while maintaining stable food supply and biodiversity through stabilization of air and water circulation. We will secure permanent living area of the human species by expanding our comfortable living area through designing environments of planets other than the earth, such as Mars.	Plastid functions/Photosynthesis Global environment/Impact of global warming Energy generation/conversion	• Chloroplasts which absorb quantum energy highly efficiently through bio-nano hybrid materials • Photosynthesis which does not rely on the sunlight through quantum-biological energy conversion • Absorbing gigatons of CO2 by cultivating super-accumulating crops which do not rely on the sunlight
Virtual Earth [Simulation of the whole earth/Near future predictions]	To protect the people's lives and property from the threat of various natural disasters and raise their disaster prevention awareness, we will build advanced sensor networks on the ground, underground, and in the sea and space, and realize a society where policies are made based on real-time forecasting of near-future earthquakes and water cycle, highly accurate, comprehensive disaster information, and information concerning damage of cities and regions generated by such networks.	Remote sensing Model simulation Movements of the earth's crust and seabed	• Real-time observation of air/water cycle, earth's crust/plate, etc. by using optical fiber sensing and satellites • Advancing integrated simulation technology and analytical algorithms through a multilayer model • Real-time earthquake simulation technology based on observation data
Society where nobody falls victim to natural disasters	As massive earthquakes are forecast, and global warming is causing greater damage from the frequent occurrence of flood and sediment disasters, it is imperative to come up with disaster-prevention measures that protect people's lives. Accordingly, we will strive to create a society where nobody falls victim to natural disasters by developing technology to mitigate natural force, unique disaster-prevention facilities in the world, and technology to automatically assess the local situation even at night or in any natural conditions and ensure the safety of local residents.	Earthquake disaster prevention Natural disaster forecast/analysis/counter measure Remote sensing	• Complete insulation from earthquakes by floating or raising the ground level of the whole block where important facilities are based • Automated operation of disaster prevention facilities based on real-time monitoring information • Inspection by satellites, drones, etc./Advancing surveying technology/Evacuation order/Developing disaster-prevention shelters and suits/Advancing rescue operations

<Future energy>

Ambitious goals attracting people's interest (Moonshot targets)	Difficult social challenges that could yield a great impact if realized and new value creation, suggested from an outlook of a future society	Keywords of areas/fields where research and development should be promoted	Examples of challenging research and development
Growing out of carbon energy society	Create high-value energy supply/storage system and save energy by revolutionizing the technologies for fully exploiting underutilized sources and gaining unrestricted control of energy through storage/conversion, laying out the foundation for a carbon-free energy system worthy of human society in 2050.	Carbon-free society Renewable energy Energy transportation/storage /conversion	• Transport/store/convert energy sources other than electricity • Innovative electro-hybrid aircraft • Electricity-free laser directly driven by solar power
Power generation with plant roots	Exploit plants' strategy for obtaining nutrition to meet the expected rise in on-site electricity demand from increased use of robots and drone AI	Heredity/breeding Energy-saving/energy-efficiency	• Develop plants with strong roots • Develop electrodes for root power generation • Develop multi-purpose closed container using root electricity
Full spectrum technology for maximizing solar energy usage	We must grow out of the current social structure supported by carbon energy and create a sustainable society. Set the foundation for a carbon-free energy system worthy of human society in 2050 by fully exploiting the solar energy distributed throughout the world evenly.	Renewable energy Energy conversion Photo/thermal device	• Develop thermophotovoltaic materials/structures for infra-red device • Develop wave length conversion materials and applied device • Develop high-performance light-absorbing/hybrid materials for absorbing a wider range of wavelength
Total thermal control for society wasting no energy	Create high-value energy supply/storage system and save energy by revolutionizing the technologies for fully exploiting underutilized thermal energy and achieving its unrestricted control, laying out the foundation for a carbon-free energy system worthy of human society in 2050.	Phonon control Energy-saving/energy efficiency Energy conversion/control	• Zero thermal loss by capturing phonon, control heat flow direction with thermal rectification, electronic (thermoelectric) cooling method superior to coolant system • Develop porous material to reduce/facilitate solid-gas heat transfer • Develop technologies for reducing/facilitating heat transfer through radiation
Active control and circulation of global CO2	Develop the technology/application for producing low-carbon liquid fuel from hydrogen obtained by electrolysis using renewable electricity and CO2 captured by DAC, realizing a carbon-reduced carbon recycling system. Average global temperature rise can be capped to 0.6 degrees Celsius from 1990 level by controlling the CO2 level in 2100 on par with 2000.	Low-carbon society Extensive/efficient use of CO2 Renewable energy Separation/distillation/purification	• Renewable power generation technology • Technologies for producing H2 and liquid fuel from H2 and CO2 • DAC and other technologies for separating/retrieving CO2 • Technology for powering internal combustion engines and standardization of fuel properties
Growing out of carbon energy society	Clear the goal for 2050 with revolutionary technologies for fully exploiting underutilized sources and gaining unrestricted control of energy through storage/conversion, creating the foundation for a new system of energy usage for human society.	Energy transportation/storage Laser Inertial confinement fusion	• Transmit electricity from space to the ground using laser with small atmospheric attenuation • Fusion ignition with super high-power laser and the most powerful magnetic field on earth
"Revolutionary battery" with one of the largest capacities and fastest charging/ discharging speeds	Battery with large capacity and very short charging time that can be used for the rising number of EV, mobile devices, wireless appliances will let consumers use those battery-installed products without waiting for them to be charged.	Renewable energy Energy transportation/storage Fuel cell, battery material	Large-capacity graphene supercapacitor

<Future environment/resource>

Ambitious goals attracting people's interest (Moonshot targets)	Difficult social challenges that could yield a great impact if realized and new value creation, suggested from an outlook of a future society	Keywords of areas/fields where research and development should be promoted	Examples of challenging research and development
Society where daily lives are unaffected by disasters and citizens do not have to evacuate	Build a society without natural disasters, or where daily lives are not affected as basic infrastructure is maintained. Even when there is an impact, then the affect people should be able to resume their ordinary lives quickly by not having to evacuate.	Natural disaster prediction/analysis/response Basic infrastructure resiliency Recovery/reconstruction engineering	• Establish fault-proof power transmission/communication systems • Disaster-proof cities where people in the pass of major typhoons can take refuge • Eliminate lightning strike damage by controlling weather • Housings that can be rebuilt quickly on the spot
Rebuilding Japan as a natural resource powerhouse Reaching out to extreme environment/frontiers	Move ocean bed mineral resource to the ground, retrieve marine pollutants and industrial wastes, turning everything into useful resource. Leverage resources obtainable from ocean, space, and other extreme environments, while creating suitable exploratory/development frameworks. Refine planetary resource by ultimate energy conversion/recycle technologies.	Marine resource/energy Maritime engineering Decontamination/recovery technologies	• Seafloor retrieval station for gathering and transporting deep-sea resource • Efficient retrieval of unused resources that are also potential contaminants • Produce high-value material from underutilized resource retrieved
Cool Earth	Establish technologies for leveraging CO2 in the atmosphere and for controlling sunlight safely through accurate risk assessment, in order to control the global temperature rise as required and free the human society from wide-ranging global climate change concerns such as torrential rain and other extreme weathers as well as increased epidemics risk.	Low-carbon society Climate change Global warming	• Lower fossil fuel consumption to zero by advanced catalyst chemistry and other methods for exploiting CO2 • Dramatically reduce CO2 level by developing super-plants that grow in extreme environments • Control global temperature by spraying aerosol with low environmental load, assisted with monitoring satellites
Innovation for building a recycling society	Developing countries are faced with issues with water scarcity, disposal of radioactive materials, marine plastic litters, and geopolitical risks involving the uneven distribution of rare metals and bioresources. Initiate innovations for addressing them to build a recycling society where everyone can live safely, without leaving a negative legacy for future generations.	Water resource, water cycle Material recycling system Leveraging biological features	• Sea water desalination/cleaning technology with improved membrane filtration • New technologies for using radioactive materials as energy sources • Retrieving rare metals from urban mines, biological resource recycling technologies
Super-plants and wood-based biodegradable materials for a society with zero CO2 emission	Two-thirds of Japan is covered with forests, which can be a source of wood, energy, and industrial materials with super-high strength, can withstand super-high temperatures, do not release gas, can be recycled, and are biodegradable. At the same time, develop forests with quick-growing trees that absorb a large amount of CO2 to establish an efficient cycle of production/collection/forest-rebuilding.	Wood-based biomass Interaction/symbiosis between plants and microorganisms Biodegradable material	• Develop technologies for producing materials from wood-based biomass superior to products already available • Grow tree species best suited to material production and catching the largest amount of CO2, develop soil microbes that stimulate tree growth
Cut Japan's biomass disposal cost to zero. Make local biomass businesses profitable.	Japan is rich in a wide range of biomass resources, but the nation must spend money to dispose them as it is difficult to make money with the material. Design/build a "local biomass chemistry system," by which biomass available from rural and urban communities are measured accurately by type/timing/amount and turned efficiently into useful materials and energy throughout the year.	Biomass utilization Renewable energy Local empowerment/sustainability	• Develop/deploy a demand/supply matching system for biomass using AI • Optimization/scaling of conversion process for biomass with different qualities/volumes • Develop low-cost and maintenance-free biomass processing equipment
Structure-based metagenomic drug design for total nitrogen recycle control	Soil microbes are inefficient in their use of fossil fuel-based fertilizer that has negative impact to economy and environment. To improve their efficiency, develop a new technology for structure-based metagenomic drug design combining metagenomic analysis and structural biochemistry, create a molecularly targeted drug for controlling nitrogen dynamics, and help establish a low-carbon society	Soil environment Structural biochemistry Global climate change	• Structure-based metagenomic drug design for total nitrogen recycle control

Using insects and microbes as “natural cleaners” to degrade/recycle waste	Mixed/infectious waste, which was difficult to be recycled and had to be burned or buried, can be digested/degraded/neutralized by using insects, microbes, and other soil creatures in safe, low-energy, and zero-emission “natural cleaner” facilities. The resulting product can be used as fertilizer and chemical materials.	Microbe features Leveraging insects, producing useful material Insect physiology and biochemistry	• Build a system for turning waste into energy and high-value materials • Improve waste processing efficiency by modifying biological functions through genome editing • Bio-recycling system for space and other extreme environments
Turning air into resource	Separate and retrieve ubiquitous gaseous resources (e.g. nitrogen, oxygen, CO2, and argon) from the atmosphere using DAC and other technologies, then turning them into chemicals, fuel, protein, and other useful materials in a highly efficient manner using renewable energy. This will bring the ultimate recycling society where resources that have been underutilized are completely exploited by innovative technologies.	Separation/refinement/distillation Energy saving/efficiency Energy conversion	• Develop materials/methods for efficiently targeting/separating/concentrating dilute gaseous resources (e.g. nitrogen, oxygen, CO2, and argon) • Develop technologies for reducing CO2 efficiently using the retrieved gas and renewable energy, together with a process for producing valuable products • Innovate high-efficiency energy conversion technology
Green revolution	Develop super-plants/super-microalgae that grow much faster than existing floras to catch a large amount of CO2, a green-house effect gas, to boost the level of CO2 stored in forests. The human race can be effectively freed from global climate change concerns by efficiently reducing the level of CO2 in the atmosphere.	Wood-based biomass Low-carbon society Genetic insertion/modification	• Creating woody plants by giving them high density and mechanical strength, inducing secondary growth to change the sink capability and modify lignin structures • Improve photosynthetic capability and resilience against environmental stress • Boost productivity through plant-microbe interaction, improve environmental stress resilience, cultivation technology for high-performance plants
Total carbon recycling	Recycle CO2 as a carbon resource by turning the gas into a useful material without concentration or pressurization. Plastic waste that cannot be easily recycled can be burned to retrieve heat energy, with the double purpose of converting the CO2 generated. A total carbon recycling technology leveraging material/chemical/thermal recycling technologies will lead to the ultimate circular economy with zero carbon emission, bringing a world where resources are evenly distributed.	Technology for using resource/energy efficiently Catalyst property analysis Reaction mechanism	• Develop chemical manufacturing technology using CO2 resource
Biological manufacturing revolution Realize a society not dependent on oil-based fuel or plastics	A society with well-developed biotechnology using organisms to produce sufficient fuel and plastics - Cut fossil-based CO2 emissions, a global climate change factor, to almost zero. - Overcome the risk of oil supply termination, Japan emerging as a new resource-rich country. - Additional benefit: a new market for high-performance products only possible with biological manufacturing may be created.	Bio-informatics Exploit biological features Genetic insertion/modification	• Establish biological database • Industrial application of next generation sequencer/Super high-speed long-chain DNA synthesis technology/genome editing technology • Develop technologies for identifying/creating microorganisms with desired functions
Develop plastics that degrade at the end of product life cycle	Almost 13 million tons of plastic waste flow out into the sea every year. At this rate, the volume of marine plastic waste will surpass that of fish by 2050. This must be changed by stopping the plastic waste flowing into the sea and polluting the environment.	Marine environment Biodegradable material High-performance polymer	• Establish methods for developing materials by backtracking from marine biodegradation mechanism • Give a switching function to start biodegradation depending on environmental parameters • Develop biodegradable plastics using encapsulated degradation enzyme and other methods
Recycling material to save the planet “Solving global CO2 problems”	Achieving net-zero CO2 emissions with a system for recycling resources can solve global climate issues. At the same time, new industries may emerge, leveraging new energy sources and methods for saving them based on recycled carbon/nitrogen, together with exploiting biological properties.	Low-carbon society Renewable energy Material recycling system	Clear challenging targets for net-zero CO2 with technologies for sustainable energy (e.g. renewable energy and smart community)/circular economy (e.g. CCUS)/bio-economy

Realize full recycle utilization and super-recycling	The supply of natural resource is limited. The quality of mineral ores is expected to keep degrading. Removing impurities add a huge cost to the process of resource recycling. These problems can be overcome by technologies leveraging low-grade materials.	Resource separation/security/ assurance Recycle/circulation/reuse/ conversion Reliability	• Technology for utilizing low-grade materials • Technology for leveraging materials suited to recycling
Retrieve resource from sea water	Japan imports most of natural resources, with some having limited sources, a risk for resource utilization. Exploiting rare metals, magnesium, and other mineral resources in sea water can reduce this risk.	Reaction/separation/ distillation Resource separation/security/ assurance Extraction	• Technology for retrieving magnesium and other resources from sea water and utilizing them
Resource “full-recycling” society	Address global climate change, water scarcity in developing countries, marine plastic waste, geopolitical risks from unequal distribution of resources, and other problems by innovative technologies, so future generations will not be burdened by negative legacies and live safely in a resource recycling society with net-zero CO2 emission.	Water resource/recycling Zero emission Decontamination/ purification technology	• Eco-friendly artificial precipitation technology • Small and low-cost off-the-grid water infrastructure technology not requiring waterworks • Zero-emission vessel using e-fuel (produced from hydrogen and CO2) and new sailing ship designs
Sustainable materials for infrastructure	Steel, cement, and petrochemicals, vital for infrastructure, lead to massive GHG emissions during their manufacturing process. Realizing zero emission by innovating this process or by developing gas-absorbing products will immensely contribute to clearing Paris Agreement goals.	Low-carbon society Zero emission Eco-material/ energy-saving process	CO2-abosorbing cement
GHG-capping agriculture	Rice field, farming plots, and livestock release N2O and other GHGs, difficult to control because small emission sources are widely distributed throughout the world. Capping these gases will immensely contribute to clearing Paris Agreement goals.	Eco-friendly agriculture Livestock feed Fertilizer	Cattle feed with balanced amino acids
Extensively leveraging marine resource	Japan, a maritime nation, must not waste the rich potential of the sea surrounding it. Develop technologies for massive and wide usage of deep-sea water for various purposes, e.g. power generation by using the temperature gap between surface and deep waters, and also for air conditioning, agriculture, fish farming, and drinking water. New sources of renewable energy will emerge through this initiative, and by global extension and market creation to island and littoral nations, global climate change and challenges for developing nations may be resolved.	Renewable energy Marine resource/energy Maritime engineering	• Establish technologies for developing/maintaining long water pipes for mass intake deep-sea water • Establish technologies for large floating body system to be used in severe sea conditions • Establish high-efficiency binary power generation technology operating with small temperature difference
Achieve planetary health	Real-time identification of GHG/air pollutant sources and monitoring them can deter GHG/air pollutant emissions, as well as help accurate evaluation of their volume/reduction achievements. Develop innovative technologies for reducing/absorbing/fixating emissions to go beyond stabilizing GHG/air pollutant levels and achieve “planetary health.”	- Remote sensing - Atmospheric environment monitoring - Cross-border pollution assessment	• Develop atmosphere observation sensor installed on stationary satellite • Develop quasi-real-time atmospheric concentration calculation/transmission device installed on satellite • Build a system for detecting/notifying large emission sources automatically
Society with zero marine plastic waste	Build a sustainable plastic-recycling society by combining several approaches, i.e. producing plastics from biomaterials instead of fossil fuel, thorough recycling, monitoring waste sources, and technologies for retrieving/processing marine plastic waste, also develop markets in developing countries by solving their problems.	Biodegradable material Recycling Technologies for removing pollutants and restoring environment	• Low-cost/high-performance bio plastic • Plastics that quickly biodegrade in correct way • Giving recycled material qualities equal to fresh sources • Technologies for separating/retrieving marine plastic waste
Clean air innovation	In order to realize an environment wherein people can breathe air as fresh as in forest even in building-filled Tokyo, establish technologies for reducing air pollutant coming from sources in Japan to zero, while pollutants drifting from outside the country will be processed/neutralized before reaching the border. At the same time, airborne pollens can be processed while still in the air to produce clean atmosphere.	ICT device/intelligent machine systems Decontamination/recovery technology Model simulation	• Automatic facility control using simulation based on satellite information and AI • Neutralize PM 2.5 and other air pollutants while they are airborne • Detect asbestos in construction material with its constituent percentage as low as 0.1 percent, neutralize it without damaging the structure

Build massive planet monitoring platform using civilian aircraft	The network of civilian aircraft, traditionally used for transportation, will be repurposed as a giant platform for monitoring the earth from high altitude instead of satellites, creating new values in addressing global climate change challenges and helping disaster mitigation with more accurate weather forecast. Semi-real-time gathering/processing/broadcasting of data will radically change popular attitude to climate change and help drive movement for clearing the Paris Agreement goal of keeping the temperature rise within 2.0 degrees Celsius.	- Atmospheric science - Aeronautical on engineering - Government-academia-business partnership (open innovation)	• A totally new observation science using data more frequently refreshed and accurate than satellite information • Revolution in meteorology and evolution of climatology based on big data from above • Real-time visualization of CO2-level distribution for changing CO2 awareness/response

<Future industry and labor>

Ambitious goals attracting people's interest (Moonshot targets)	Difficult social challenges that could yield a great impact if realized and new value creation, suggested from an outlook of a future society	Keywords of areas/fields where research and development should be promoted	Examples of challenging research and development
Hyper-evolution of manufacturing "Passing down technological prowess to future generations"	Develop technologies for creating robots that can judge/analyze the best processing solution for manufacturing tailor-made products based on the given materials and working environment. Realize intelligent manufacturing by giving human sensitiveness to high-throughput, successfully transferring accumulated skills to next generations and boosting productivity at the same time.	Robotics Multifunctional material Super-precision processing	• Sensors that can digitize sensitivities of skilled workers, AI/robot that can replicate their judgement and behavior • Sensitive soft manipulator with delicate touch on par with human hands • Build material assessment/diagnosis database with AI/MI
Learn how to understand this complex world and predict/design future society	Chances of new discoveries are decreasing because of human cognitive limitation. Automatic data-based identification of issues and future prediction can establish a scientific approach for making policy decisions, individual behaviors, and social interventions.	Knowledge discovery and data mining Bio-database Model simulation	• Automate knowledge acquisition by AI robots, extend it to all intelligent tasks • Catalogue all cells, understand/predict interaction between human race and environment • Establish a predictive system methodology that can bidirectionally couple the systems of human society and nature
Solve biohazard challenges and create a new bio-industry	Fundamentally solve the problem of risks inherent to biological products that are "useful but dangerous" (biohazard), e.g. genetically modified plants/animals, bacteria, or invasive foreign species whose safety has yet to be established, leverage those animals/plants to pioneer a completely new bio-industry.	Infection Recombination Creation/assessment of useful GMO	• Create synthetic auxotrophs, an ideal biocontainment method
Organize "transforming humanoid" teams to support the rich land, city, and industry	The lack of experts for maintaining/managing forests, rebuilding infrastructure, and industries is an urgent issue to be solved in order to sustain/develop Japan's rich land, city, and industry. Form a government-academia-business partnership to create/commercialize teams of "transforming humanoid" that anyone can control and perform superhuman feats by fusing with or morphing into other devices, solving the expert scarcity issue by extending human capabilities exponentially.	Robotics Evolution/development/learning Human-machine system	• Transformation technology for achieving superhuman capabilities by fusing/morphing devices • Human augmentation assistance technology for learning control techniques and extending human capabilities exponentially
Manufacturing process revolution	Manufacturing industry uses huge amount of energy. Introduction of hyper-efficient manufacturing process through innovative technology has become an urgent issue.	Industrial application of quantum beam Laser High energy density science	• Giant 3D laser printer that can output cargo aircraft and vehicle quickly • Develop new structures for diamonds and metal-carbon composites using laser compression
Clearing air mobility revolution challenges	Start an "air mobility revolution challenge" project to achieve 1) "pilotless air transportation" to introduce a new mode of mobility, "flying car," to the society with the purpose of solving mobility issues during disasters, in mountain regions and remote islands, and inside urban areas, and 2) "EV air transportation" to cut down CO2 emissions in the sky to zero to address the issue of increasing aviation demand.	Aerospace system Zero emission Autonomous system	• AI decision-making technology for pilotless vehicles • Leverage technologies for designing all-wing aircraft and hydrogen fuel to develop a prototype for an experimental vehicle with super-high fuel efficiency
Society all members can connect/share /participate	Help the human race overcome its limits with external assistance for solving physical challenges faced by everyone, with or without age/disability handicaps, e.g. supporting damaged/lost senses, body functions, or sensory abilities.	Virtual reality Human engineering Robotics	• Quantify human senses, physical augmentation technology, and "co-evolving" AI for extending human capabilities • Understand the mechanism of physical transformation caused by continuous activity • Physical/environment augmentation service technology for different types of genetic manifestation • Relationship between environment augmentation with VR/AR and self-efficacy/motivation

Material revolution	The world has profoundly changed with the birth of new materials, improvement of their performance, and discovery of new phenomena (e.g. computer and LED lighting). Accelerate metal material development, build big data for metals, and leverage AI for their development to introduce super-light, super high temperature-resistant, super anti-corrosive, super long-life, and extremely recyclable materials, bringing disruptive socioeconomic innovations.	Powder processing/metallurgy First-principle calculation/material design simulation Diffusion/phase transformation/phase diagram	• Accelerated research with simultaneous mass sample creation/assessment technology • MI/AI technology for super-light/super high temperature-resistant/super long-life properties • Technology for researching the mechanism of high-performance material
Avatar control with brain-machine interface	By giving human pilots sensory feedback from humanoid robots they are controlling through bidirectional brain-machine interface technology, physical senses can be extended to operate a third arm and give 360-degrees vision, enabling safe operation without risking lives even in disaster sites and space or other extreme environments.	Brain-machine interface Behavioral environment recognition Wearable device	• Data input and sensory feedback through brain-machine interface • 360-degrees recognition, extending human senses to additional organs/limbs • Full-body powered suit

<Future telecommunication and technology>

Ambitious goals attracting people's interest (Moonshot targets)	Difficult social challenges that could yield a great impact if realized and new value creation, suggested from an outlook of a future society	Keywords of areas/fields where research and development should be promoted	Examples of challenging research and development
Society freed of crime and terrorism	With acts of terrorism against facilities on the rise, targeting general public not directly linked to terrorist organizations, measures to prevent those attacks must be introduced quickly. If criminal and terrorist activities can be neutralized before they are carried out, the plotters will not become perpetrators and their targets will not become victims. In a society where harming someone become impossible, there will no crime nor terrorist violence.	Image processing/ recognition Network security Autonomous system	• Crimes and terrorist activities are predicted/contained/neutralized, vehicles/aircraft are remotely inactivated • Security soft than can enhance its performance autonomously • Underwater drones to prevent seaborne terrorists/pirates, monitor unidentified vessels
Realize post-internet system	The internet is reaching its limit in addressing the oncoming demands from our society. Japan can lead a movement for building a new network architecture surpassing the internet and create an innovative network that is as transparent and ubiquitous as air, becoming a most fundamental part of infrastructure. The initiative can help develop "seed" technologies that will spearhead the new era.	Network architecture Network security Autonomous system	• Distributed/parallel-processing hardware based on generic components and distributed OS • Network architecture enabling autonomous operation/self-healing/ self-regression • Network configuration/operation technologies for fully autonomous operation and self-healing/self-regression • Automatic Service-driven optimization for contents delivery platform technology
Build artificial brain that can recognize, judge, predict, and decide like a human being	Realize AI system by analyzing the decision-making process of human brains and emulating it, creating an AI that can recognize, judge, predict, and decide like a human being. This AI can recommend solutions to social issues and assist human beings in any situation, maximizing the wellbeing of human society.	Analyze/leverage brain big data Nonintrusive brain activity survey/analysis Brain-model information processing	• Build a large-scale whole-brain activity database, establish decoding model • Develop brain-model AI that can make decisions based on a variety of value judgments • Develop brain-model AI that can operate on sparse data and use outstandingly less energy
Leveraging quantum resource to transcend human intelligence	Building a new internet of quantum computers connected by quantum mechanics technology can enhance the Global Navigation Satellite System (GNSS) by synchronizing atomic clocks, detect gravitational distribution shift by diffusion quantum interferometer, and enable massive quantum computation, giving quantum machine learning a meaningful impact. Also establish high-speed large-capacity quantum encrypted communication technology.	Quantum information Quantum electronics Machine learning	• Build a quantum interface between three or more different physical quantum systems • Long-distance quantum state transmission by optical fiber • Interconnection between quantum computers
Build a research network based on a massive cross-organizati on security operation center (SOC)	Security operation centers (SOC) run by large organizations in Japan can leverage real-time privacy protection technology to share information as well as gather intelligence, perform integrated analysis, info-sharing, and respond to incidents at a massive scale across organizations and build a large cybersecurity research network in Japan.	Network security Privacy protection Machine learning	Mass-scale intelligence/auto-analysis technology for defense against cyberattacks, info-sharing/automated response technology used across organization, real-time privacy protection technology
Realize society free of traffic accident/ congestion ensuring free and safe mobility to children and seniors	The advance in intelligent and networked vehicle/road technologies will lead to automatic collision prevention and autonomous driving, dramatically reducing traffic accidents/congestions. An efficient and stress-free transportation is realized by remote/autonomous control not dependent on vehicle-embedded sensors.	Autonomous system Advanced traffic system	• Automatically detect/notify/correct driver errors • Diagnose urban traffic system to automatically optimize traffic mode
Neutralize cyber-terror attacks	Block/neutralize cyberattacks against all information systems to prevent those attacks reaching physical space, making the cyberspace safe for all members of society.	Network security Privacy protection Machine learning	• Automatic detection of deceptive information generated by AI • Automatic judgement on whether a machine-learning service is designed to incite or with malice • Build explainable and fair AI without bias or prejudice

Realize quantum ICT society superior to the current information processing society	Leverage quantum technology to realize high-capacity network overcoming the limit of optical communication as well as computers for advanced AI impossible now, leading to a society freed from security threats by advanced computers, and without computational delay caused by information explosion.	Quantum information Quantum electronics Quantum device	• Massive high-capacity quantum network overcoming the limit of optical communication • Massive accurate quantum computer • Quantum memory for storing quantum states
Develop autonomous intelligence that can work together with human beings to make Nobel Prize-winning discoveries, supporting the human race and its society	Develop an intelligent system that can autonomously discover knowledge/principles overlooked by the human race. Advance health and comfort, sustain civilization, and extend human living sphere. Formulate hypotheses and validate them automatically using a vast amount of data that cannot be processed or comprehended by human effort, realizing a collaborative creation between the human race and machine to enhance productivity of intelligent tasks.	AI-driven science Robotics Human-agent interaction	• AI robotics for automatically hypotheses formulation/validation based on data • Systems to help human beings understand the validity of knowledge beyond human comprehension • Intelligent systems to assist dialogues/communication between human race and systems, helping them coexist
Future earth simulation for "showing the earth's (society's) future using all scenarios based on predictive science"	Build a virtual earth simulator combining predictions from all areas to show the near future. Climate change, demography, and economic activities will be comprehensively predicted and presented as scenarios, supporting policy and business decisions to enable global- or society-level controls and harmonizing the whole with parts.	Big data analysis/usage Model simulation	• Predictive system methodology that can bidirectionally couple the systems of human society and nature • Test/establish predictions in focus areas • Support UN policy decisions and SDGs commercialization decisions
Efficient society where everyone can use AI and no one has to waste their energy	Realize a society where everyone can use AI safely and easily, without being at the mercy of AI with nebulous decision-making rules or huge IT corporations, to further streamline/automate activities in all areas, taking advantage of technological benefits offered by AI to enrich personal lives.	Machine learning Brain-machine interface Network protocol	• Safety-certified driverless vehicles • AI that can have its decisions explained • Establish service protocols giving data providers due dividends according to their data used
The Second Internet: a national intranet of a different level, accessible to all citizens, with built-in features making cyberattacks impossible	No infrastructure based on the internet can be free from cyberthreats. Take an exactly opposite approach to build a domestic intranet, or "the Second Internet," using virtualization technology, with enhanced control features such as shutting down particular traffics quickly, tracking all traffic metadata, basically banning end-to-end communication, and mandatory registration.	Network architecture Virtualization technology Authentication	• Super-massive VPN system • Large-scale authentication system with capacity for distinguishing 100 million users simultaneously at any given moment • New client software technology for accessing the Second Internet
10 Gb-class national network without any external power source	Communication network is a vital part of infrastructure whose servicers are dependent on power supply, without which will cease to work. Build a new communication network using only devices that are small, use less power, and run on advanced software, to realize a stable 10 Gb-class network that can operate without relying on external power source (e.g. running semi-permanently just by solar or geothermal energy).	Virtualization technology Network/LAN Saving energy and improving efficiency	• Power-saving core relay system • Reduction of relay nodes and access circuit terminators • Software for simplifying core networks • Access circuit terminator and overlay method for the new system
Running programs inside another program, a dream come true	Build a system for running child software (function) safely inside its parent software's (caller) memory and control the child's I/O real-time. A virtual OS started inside a software will run and manage other software within its virtual environment.	Virtualization technology Operating system Programming language processing system	• Develop semi-virtual CPU (safe and high-speed) • Develop a system for running multiple virtual software simultaneously under control • Develop virtual memory for CoW, shared memory, and mmap
Creation of integrated platform for cyberthreat intelligence	Build a cyber security platform by effectively integrating cyberthreat intelligence, realizing the "vitalization of cybersecurity business by leveraging integrated threat intelligence," "optimization by standardizing the process of screening threat intelligence," and "advanced cybersecurity approach by individual and companies by offering screened threat intelligence."	Network security Machine learning Network configuration/ operation /management/ evaluation technologies	• Develop threat intelligence data platform for integrating threat intelligence • Establish a method for automatically screening threat intelligence • Develop gateway protection appliances using threat intelligence
Cyberpsychology technology for "correcting" malware	As malware employing advanced statistics, machine learning, and AI become more complex, the current analytical methods will begin to struggle to cope with them comprehensively. By applying psychological approaches for reforming young people, such as counseling and retraining, advanced malware can have their behaviors understood and brought under control.	Malware response Network security Intelligence information processing	• Create a cyber-fraud model to identify the target of malware • Develop a practical cyber-fraud method based on game theory and psychology • Automatically estimate attackers' strategies from malware targets

IT service infrastructure with no need for software maintenance	IT systems demand a large resource for maintenance. Software do not have physical life limit as hardware do. An IT service infrastructure with no need for software maintenance can free up the software maintenance resource for more creative tasks.	Software security Software engineering Service configuration platform technology	• Automatic system generation for using current systems on the latest infrastructure • Automatic bi-directional conversion between software and design documents • Software immunity through automatic health-check
"Philosopher's stone" information security system embedded as system hardware	IoT devices must coexist with the ever-changing internet but gradually go out-of-date. Automate cyberattack response by embedding a hardware chip, or a "philosopher's stone" that can automatically detect/rectify vulnerabilities so IoT devices can stay up-to-date until their hardware expires.	Network security Machine learning Malware response	Research for automatic detection of attacks against vulnerabilities and automatic configuration of defense methods
High-capacity communication technology to let everyone download their favorite movies in an instant	By distributing the entire radio/optical wave bands in the best way for users, based on their usage and without being restricted by allocation rules, individuals can have access to super-high capacity communication service. This also leads to a robust communication system that can skip the bands having problems.	Radio wave band	Cognitive communication High-power/wide-band communication Dynamically optimized radio wave allocation
Realize society wherein human race and robots can coexist safely and securely	In a society where robots and the human race can live together, robots having problems or involved in crimes must be removed or shut down. The technology required still does not exist and needs to be developed.	Robotics Risk management	• Eliminate drones that are illegal or threat to the public safety

<Future space business>

Ambitious goals attracting people's interest (Moonshot targets)	Difficult social challenges that could yield a great impact if realized and new value creation, suggested from an outlook of a future society	Keywords of areas/fields where research and development should be promoted	Examples of challenging research and development
Enable a sustainable usage of space by the human race, ensure the development of living conditions as well as economy and society on earth.	As human activity in space increases, the number and volume of discarded satellites and its parts turned into space debris are rising. By reducing the space debris and enabling a sustainable use of space by the human race, the development of living conditions as well as economy and society on earth can be ensured.	Space usage/exploration Aerospace system Aerospace environment	• Autonomous approach/capture/removal technology for space debris of indeterminate shape • Fuel supply/maintenance technology for satellites in orbit
Total reform of space usage "Realizing a society where everyone can access space easily"	Aim for a "reform to allow to be done in space what can be most efficiently done there," while "building extra-small low-cost satellites that can do everything there is to be done in space, and facilitating the integration of and collaboration by those satellites" within limited budgets, to achieve a world wherein space has become part of ordinary social infrastructure.	Space usage/exploration Remote sensing Big data analysis/utilization	• High-capacity communication/network technology • Development of high-performance information processing technology and super-small sensors for small satellites • Realization of big data analytics fusing ground and satellite data, information processing and analytical technology using AI • A new terahertz radio wave technology
Mars endurance race	The human race, with its population about to reach ten billion, is about to embark on a journey to Mars. Japan can lead the course by hosting a race to land on Mars first from stationary orbit. A stationary satellite of existing type will be launched from a government or commercial satellite and release multiple competing landers from stationary orbit. Targets other than landing, e.g. obtaining water spectrum data, will also be set.	Space usage/exploration Aerospace system	Piggyback satellites will be set in Mars' stationary orbit by the government. Landers must survive the touchdown, be lighter than 100 kilograms (piggyback payload limit), retrieve relevant data for future colonization, and meet other conditions.
Extend fields of activity in space "Turn space into a flagship for solving all issues on the ground, while enjoying positive impact to science, technology, and education"	Invest heavily in space to solve major natural disasters, global climate change, aging/declining population, and many other issues on the ground. Take example from Apollo program to raise Japan's science intensity for generating revolutionary ideas and values.	Space usage/exploration Reduce/reuse/recycle in space Autonomous space system	• Complete retrieval of space debris, replacement/repair/fuel supply technology in space • Building a crewless space experimental factory/research station and autonomous/distributed planet exploration system • Ultra-long distance inter-stellar/inter-planetary navigation system, semi-permanent power generation and extra-efficient power saving technologies
Revolutionize daily living from space (realize safe and secure living)	Counter the increasing natural disasters by monitoring the ground situation from space around the clock to provide timely evacuation instructions and secure communication/power source in times of disasters, safeguarding precious lives and a platform for safe and secure living.	Space usage/exploration Aerospace system Space-based solar power (SBSP)	• Satellite system for real-time ground surveillance (optical communication link and data processing technologies) • SBSP and crewed sub-orbital transportation system usable in disasters • Space debris removal technology for orbital safety
Realize space colony	Faced with global climate change and exploding global population, it has become impossible to sustain the human race only on Earth. Extend human territory into outer space (e.g. Mars), by building a space colony to support the surging population.	Space usage/exploration Aerospace system SBSP	• Space elevators for sending supplies from the ground, SBSP • Construction technology and life-support system for building space colony • Space debris removal technology for orbital safety
Extending areas of activity in space	Space industry market in 2017 was worth 400 billion USD and expected to grow. In order to survive a fierce space development race, Japan must create a revolutionary space industry.	Space usage/exploration Laser High energy density science	• A new rocket propulsion technology using ground-based high-power laser • Space debris removal by ground-based laser • Large atmospheric space telescope using laser-generated plasma mirror

Orbital solar power station	Renewable energy has the advantage of not emitting CO2 but provided only 6.9 percent of total electricity in 2018 because of footprint and cost constraints. Deploying PV panels in space and transmitting power to ground locations as required will solve the footprint and cost problems.	Renewable energy Energy transportation/ storage Space usage/ exploration	• Research into space-based large antenna technology • Research into high-efficiency power transmission using microwave
Space debris catcher satellite	With the amount of space debris on the rise, our daily lives may be set back 60 years if they hit operational satellites, disrupting communication and GNSS services. A system for catching and retrieving space debris will help the global society by establishing space safety.	Space usage/exploration Aerospace environment Laser	• Automated threat detection by AI • Large-diameter optical systems • Space debris image recognition • Laser propulsion