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Quantum Technology Innovation Strategy

(Final Report)

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Integrated Innovation Strategy Promotion Council

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I. Situation surrounding quantum technology (1)

Changes in domestic and international situations

• We are currently in the midst of a historic paradigm shift in economic and social structures worldwide.

The economy and society are undergoing a discontinuous transition from the traditional labor- and capital-intensive model to a knowledge-intensive model. Appropriately grasping this transition is the key to Japan's international competitiveness. Furthermore, Japan's geopolitical position and the international environment regarding its supremacy in high-tech technology are undergoing drastic changes, and expectations for cooperation with Japan are increasing, especially in the United States, Europe, and China.

• Japan is the first country in the world to advocate "Society 5.0" and a "data-driven society" as its vision for a future society, and in particular, artificial intelligence (AI) and data collaboration infrastructure are becoming increasingly competitive in terms of economic and industrial policy. It has become an important technological infrastructure that serves as a source of power. Quantum technology is a fundamental technology that will be the key to the further dramatic and discontinuous development of these important technological infrastructures. • From this perspective, international attention to quantum technology has rapidly increased in recent years, with countries such as the United States, Europe, and China positioning it as a source or innovative technology that will bring major changes to the future economy and society. We are currently accelerating our efforts.

• In a world where major changes can occur in all aspects, international competition to acquire cutting-edge technology and realize innovation is intensifying.In quantum technology, which is an important innovative and fundamental technology, it is important to understand the strengths of Japan and other countries. It is essential to carefully analyze and evaluate competitiveness and take strategic initiatives that make use of international collaboration/cooperation and international competition.

(2) Trends in other countries regarding quantum technology •

Many foreign countries, particularly the United States, Europe, and China, have clearly positioned quantum technology as a strategic fundamental technology and have significantly increased their research and development investment in recent years. At the same time, we are implementing strategic initiatives such as establishing research and development bases and developing human resources.

• In the United States, by formulating the ``National Strategic Outline for Quantum Information Science'' and enacting laws related to quantum information science, support for the formation of international research centers through the Department of Energy (DOE) and National Science Foundation (NSF), and the establishment of national The country strategically invests more than $200 million in research and development every year, including supporting the formation of industry-academia consortia for international standardization by the National Institute of Standards and Technology (NIST). • In addition, the EU has compiled the “Final Report on Quantum Technology Flagship” and has started projects worth 1 billion euros from 2018. In addition, countries such as the UK and Germany have positioned a wide range of quantum technologies as important technologies and are significantly expanding investment by promoting national R&D projects and establishing R&D bases. . • In China, quantum computers are positioned as an important science and technology project, and quantum information

Approximately 7 billion yuan is being invested in the development of the National Information Science Laboratory. • Outside of governments, large IT companies (Google, IBM, Intel, Alibaba, etc.) and venture companies (D-Wave, Rigetti, IonQ, etc.) are developing quantum technologies such as quantum computers, mainly in Europe, the United States, and China. We are actively investing in In October 2019, Google reported in the English scientific journal Nature that it achieved "quantum supremacy" for the first time using its independently developed quantum computer (a quantum computer can replace conventional computers such as supercomputers). Competition is intensifying, with companies announcing that they have demonstrated superior computing power.

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(3) Trends in Japan regarding quantum technology •

Japan has positioned “optical/quantum technology” as a priority technology area for the future in the “Fifth Science and Technology Basic Plan” (Cabinet decision in January 2016). In addition, in the "Integrated Innovation Strategy" (Cabinet decision in June 2018), as an innovative technology that will bring about changes in society, "maintain and improve the international competitiveness of the optical and quantum technology base in which Japan has strengths". We are considering and promoting initiatives based on these goals. • The Ministry of Education, Culture, Sports, Science and Technology has formulated the “New Promotion Policy for Quantum Science and Technology (Optical/Quantum Technology)” (August 2017), positioning quantum information processing, quantum measurement/sensing, and next-generation lasers as priority areas. Ta. Based on this, in FY2018, the government has begun providing focused support for quantum technology, including the launch of a new research and development program, the ``Quantum Leap Forward to Light Program (Q-LEAP).''

• On the other hand, so far no medium- to long-term strategy regarding quantum technology has been formulated for the entire country, and as a result, the relevant ministries (Cabinet Office, Ministry of Internal Affairs and Communications, Ministry of Education, Culture, Sports, Science and Technology, and Ministry of Economy, Trade and Industry) have their respective jurisdictions. The current situation is that the government as a whole has not always taken consistent efforts, such as conducting research and development initiatives individually.

(4) The need for the nation to tackle quantum technology

• In recent years, foreign countries such as the United States, Europe, and China have positioned quantum technology as a fundamental technology that will bring about changes in the future economy and society, and is also extremely important from a security perspective, and in recent years, they have been In addition to formulating strategies, the government and industry are working together to significantly expand investment.

• On the other hand, although Japan has strengths, superiority, and competitiveness in basic theory, knowledge, and fundamental technology due to the accumulation of basic research on quantum technology over many years, it is difficult to put the technology into practical use and industrialize it (system It must be said that Japan is in an extremely serious situation, with some fields and areas lagging behind other countries in its efforts to achieve this goal.

• Although the government positioned optical and quantum technologies as important technologies for the first time in the 5th Science and Technology Basic Plan (FY 2016) and the “Integrated Innovation Strategy” (FY 2018), currently the relevant government Ministries and companies are at the stage where they have started their own R&D efforts, and efforts are not necessarily consistent and sufficient. If things continue as they are, Japan will fall far behind other countries in the development of quantum technology, and we need to be acutely aware that we are in a situation where the foundations of the country's future growth and development and the safety and security of its people could be threatened. . • For this reason, as a nation, we have clearly set the vision of society that we should aim for, with an eye on future changes in industrial and business structures, and we are working not only on short-term technological development but also on industrial innovation. With this in mind, we will formulate this ``Quantum Technology Innovation Strategy'' as a new national strategy based on a medium- to long-term perspective of 10 to 20 years.

• Going forward, based on this strategy, we will combine the collective efforts of Japan's industry, academia, and government to strongly promote and develop a wide range of efforts from research and development to social implementation to lead quantum technology innovation. I will do it.

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II. Basic policy

• Quantum technology is an innovative technology (core technology) that will be the key to the dramatic and discontinuous development of Japan's economy and society (Quantum Leap). It is essential to ensure that this is linked to the resolution of the various issues facing our country and to sustainable growth and development in the future.

For this reason, this strategy defines these ideas and concepts as “quantum technology innovation.” We will clearly position ourselves as a nation and develop comprehensive and strategic efforts as a nation.

• In doing so, instead of viewing "quantum technology" as a narrowly defined concept, it should include a wide range of technologies related to quantum technology and technologies that are essential as peripheral technologies from the perspective of "quantum technology innovation." It is necessary. Furthermore, it is extremely important to combine these "quantum technologies" and existing (classical) technologies in a complementary and synergistic manner and promote them in an integrated and comprehensive manner.

• In addition, under the “Integrated Innovation Strategy” formulated by the Integrated Innovation Strategy Promotion Council, it is designated as “the most advanced fundamental technology that will affect all scientific and technological innovations” toward the realization of “Society 5.0”. It is important that we steadily acquire and strengthen fundamental technologies that will be essential for our country in the future through the three strategic technologies of AI, biotechnology, and quantum technology, and drive future industry and innovation.

• From this perspective, the “AI Strategy,” “Bio Strategy,” and “Quantum Technology Innovation Strategy,” which will be discussed and formulated at the conference, are positioned as three important technology strategies for the country. The government will strongly promote and develop consistent efforts across the government as a whole, covering the major areas of the government and closely integrating and coordinating each other.

• Furthermore, in promoting the "Quantum Technology Innovation Strategy," we will clarify the areas of quantum technology that the country should strengthen, given budget and resource constraints, and ensure Japan's strengths and competitiveness as well as international Strategic efforts that combine strong collaboration and cooperation are essential. At the same time, with regard to quantum technology, given that the time span for industrialization and commercialization differs greatly for each individual technology, we have foreseen a medium- to long-term period of approximately 10 to 20 years and a period of approximately 5 to 10 years. It is important to promote planned and strategic initiatives that take a bird's-eye view of the entire situation from both short and medium-term perspectives and keep in mind the spread of related and peripheral technologies and their social implementation.

• This strategy has the following three basic policies.

<Three basic policies> ÿ

Strategic development of “quantum technology innovation” ÿ Integrated

and comprehensive promotion of quantum technology and existing (classical) technology,

etc. ÿ Strengthening of integration and collaboration between quantum technology innovation strategy, AI strategy, and biostrategy

<Scope of quantum technology innovation> • Based on

the science of quantum and the technology that applies it (quantum technology), encompassing a wide range of related technologies (including technologies that are essential as peripheral technologies), and integrating those results. It refers to innovation that leads to industrialization, commercialization, etc.

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III. A vision of society created by quantum technology innovation

• As the paradigm shift toward a knowledge-intensive society progresses rapidly, we are working to realize the next-generation social vision of Japan's social vision of "Society 5.0" and "data-driven society" through "quantum technology innovation." It is important to clearly establish the image of the future society to be achieved.

• This strategy proposes the following three social images as the future state that Japan should aspire to. In addition, in order to achieve this, in the following chapters, we will analyze and evaluate Japan's strengths and competitiveness from both medium- and long-term and short- to medium-term aspects, and will discuss key technological areas and specific promotion measures. shall be specified.

<Three visions of society that we should aim for> ÿ

Achieving a productivity revolution As

the population is expected to rapidly age and the working population decreases in the near future, we will need to stay ahead of technological innovations. Through the "quantum revolution" following IT (digital) and AI, we will strengthen Japan's industrial competitiveness and thereby dramatically improve productivity.

``Quantum computer technology" and ``quantum simulation technology" that perform ultra-high-speed, massively parallel information processing to solve problems that require unrealistic amounts of time with current supercomputers can be used in a wide range of fields, including information communications, manufacturing, finance, transportation, pharmaceuticals, and chemistry. Creating new value in industrial and social fields. In addition, we are developing materials by using quantum measurement and sensing technology, which has accuracy and sensitivity that surpasses existing technologies, and quantum physical properties and materials technology, which utilizes quantum properties that occur in the microscopic world. , realizing innovations in semiconductor, device manufacturing, power storage, energy saving, energy creation, etc.

ÿ Realization of a healthy and long-lived society

As Japan becomes a super-aging society ahead of other countries, we will realize a world-class society with health and longevity through innovative medical care and health management using quantum technology. Quantum measurement and sensing technologies

such as quantum sensors and imaging, which have ultra-high sensitivity and high resolution compared to conventional technologies, enable treatment and drug discovery based on essential understanding of life phenomena, as well as highly accurate early diagnosis and monitoring. This has led to dramatic developments in life science and medicine, and has led to innovations in related medicine, pharmaceuticals, and medical device industries.

ÿ Ensuring the safety and security of the country and its people

As the amount of highly confidential digital information, including personal information, increases rapidly, communication and encryption technology that applies quantum effects will help realize a highly secure society and ensure the safety and security of the country and its people.

Due to the rapid development of quantum computer technology in recent years, there is a possibility that public key cryptography can be broken, but while we are moving forward with the transition to quantum-resistant computer cryptography, we are trying to maintain the only principle of security. With its "quantum communication and cryptography technology," we are building and upgrading a security environment with confidentiality and integrity, and also contributing to strengthening industrial competitiveness. Furthermore, with highly sensitive and highly accurate quantum measurement/sensing technology that surpasses existing technologies, we will establish Japan's unique technological base that is not dependent on other countries, and utilize quantum computer technology in a wide range of fields. and contribute to ensuring the safety and security of the country and its people.

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ÿ. Five strategies for realizing quantum technology innovation 1. Technology

development strategy

• Considering that the individual technologies included in quantum technology have different time frames for social implementation, we will analyze domestic and international R&D trends and national strengths and competitiveness from both medium- and long-term and short- to medium-term aspects. After evaluation, it is necessary to identify the technical areas that should be prioritized. • In doing so, in addition to the quantum technologies themselves, we will combine these with existing (classical) technologies in a complementary manner, and take a bird's-eye view of the entire technology system, including related and peripheral technologies, and develop technologies that suit the characteristics of the technologies. It is extremely important to strategically develop efforts to prioritize research and development and realize step-by-step practical application.

(1) Key technology areas • In order to achieve the future social image set out in III through quantum technology innovation, the following four "key technology areas" will be set as the technology areas that will form the basis of quantum technology. • For each major technology area, analyze and evaluate domestic and international R&D trends, Japan's strengths and competitiveness, and contributions to Japan's future industry and innovation, and then develop medium- to long-term and short- to medium-term plans for each. Establish comprehensive and individual policies with a clear outlook. Based on this, the country should place particular emphasis on technological issues that should be promoted immediately (priority technical issues) and research issues that should be steadily promoted from a medium- to long-term perspective (fundamental technology issues). , set. • Furthermore, international competition is intensifying in the four major technological areas listed here, and technology is progressing extremely rapidly. For this reason, it is essential to accurately grasp the latest trends and flexibly review priority technical issues, etc. based on this information.

Goal: Create a "technology roadmap" for each priority technology issue and conduct research based on this

Promote and develop strategic initiatives such as development support

<Main technology areas>

Quantum computers/quantum simulation Quantum measurement/

sensing Quantum communication/

ciphering Quantum

materials (quantum physical properties/materials)

<Overall policy>

Each major technology area and each individual technology area within it is determined based on the degree of technological development and progress, the status of industrial involvement and participation, and the progress made through practical application and commercialization. Since the time spans for social implementation differ, we will consider and promote efforts to prioritize research and development and realize practical application, depending on the characteristics of each technology.

Quantum computers and quantum simulations require strategic efforts with a medium- to long-term outlook in hardware development, while some software, quantum measurement/sensing, quantum communication/encryption technologies need to be complemented with existing (classical) technologies.•As it is expected that practical application will be possible in the short to medium term through collaboration, strategic efforts will be made to prioritize and commercialize each technology area based on the following individual policies.

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At the same time, spin-up technology is being developed for both quantum technology and related existing (classical) technology. Promote efforts to bring related and peripheral technologies into practical use through applications, etc.

<Specific measures> The

national government, in collaboration and cooperation with related ministries, will take a comprehensive view of the technology system, including related and peripheral technologies, targeting priority technological issues, and will take measures for the next 20 years or so. In the meantime, a "technology roadmap" showing specific initiatives that should be promoted by the public and private sectors will be created and formulated in conjunction with this strategy.

Based on this roadmap, the government will implement projects and R&D funding directly under national control (e.g., Cabinet Office's Strategic Innovation Program (SIP), Ministry of Education, Culture, Sports, Science and Technology's Q-LEAP, Japan Science and Technology Agency (JST)). ``Future Society Creation Project'', Ministry of Economy, Trade and Industry/New Energy and Industrial Technology Development Organization (NEDO) ``AI chip/next generation computing technology development project that enables high efficiency and high speed processing''), etc. Promote research and development support, etc.

Based on this roadmap and based on the above-mentioned support, the government will attract investment from the private sector depending on the progress of research and development, and promote research and development through industry-academia collaboration and public-private collaboration, as well as commercialization and business by companies. Promote and develop a wide range of initiatives aimed at achieving this goal.

The government conducts basic and fundamental research through R&D funding (e.g. Grants-in-Aid for Scientific Research, JST Strategic Creative Research Promotion Project) from a medium- to long-term perspective, targeting fundamental technology issues. Promote support, etc.

i) Quantum computers/quantum simulations • Quantum computers make it possible to calculate some problems that require unrealistic time scales even with current supercomputers (classical computers) in a short time and with ultra-low power consumption. It is an innovative technology that can bring about dramatic innovation in all fields of industry and society. As development competition between governments and companies is intensifying, especially in Europe, the United States and China, and R&D investment is expanding significantly, it is essential for Japan to take strategic initiatives.

• Among the basic technologies for realizing gated quantum computers, superconducting qubits are a technology that originated in Japan and are one of the leading candidates. Japan has high technological capabilities comparable to those in the world when it comes to the production and control of high-quality superconducting quantum bits, and there are prominent researchers who are highly regarded internationally.

Meanwhile, in other countries, for example, IBM is promoting the commercialization and service of quantum computers using superconducting qubits, and Google is also promoting the Reiwa era Rapid technological progress has been seen over the past few years, with a paper published in October 2017 claiming that ``quantum supremacy'' has been achieved. Furthermore, the competitive environment is becoming more intense with the entry of venture companies such as Rigetti and Chinese companies (such as Alibaba). However, issues such as controllability and scaling (large-scale integration) have been pointed out regarding superconducting qubits.

• Research and development competition for silicon qubits is intensifying internationally, with attention being focused on increasing the number of qubits by applying existing semiconductor integration technology. In Japan, RIKEN has successfully developed the world's highest fidelity silicon quantum bit. Compared to superconducting qubits, the scale and progress of research and development are lagging behind, and scaling (large-scale integration) is also an issue.

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• Regardless of the underlying technology, it is expected that it will take 20 to 30 years to put a fault-tolerant gate-type general-purpose quantum computer into practical use. The ``quantum supremacy'' paper published by Google has been hailed as an important milestone, but there are many challenges to overcome in order to put a general-purpose quantum computer into practical use. Therefore, in order to develop actual quantum computers (hardware), it is necessary to promote research and development from a medium- to long-term perspective based on Japan's strengths and competitive technologies. Additionally, in parallel with this, it is important to promote the spread and development of research and industry in various fields, such as the realization of quantum computers without error correction (NISQ) and the development of related and peripheral technologies. .

• In recent years, competition in the development of software for quantum computers (quantum software (architecture, algorithms, compilers, applications, etc.)) has accelerated, with both gate-type and annealing-type software centered on venture companies as well as universities and research institutes. are doing. Development of software for gated quantum computers is progressing rapidly in the United States and other countries. Japan does not have a large number of researchers, but there are young researchers who are internationally successful in both gate-type and annealing-type research. In the future, in parallel with the development of quantum computers (hardware), this is an area where rapid progress and acceleration of research and development and social implementation is expected.

• Quantum simulation is expected to contribute to the elucidation of the functions of materials and the search for new materials through the simulation of many-body electron systems, and research and development competition is expanding with Europe, the United States, and China. There are researchers in Japan who are highly regarded internationally. In addition to prospects for technological development toward practical use in simulators and annealing-type quantum computers that utilize these, there are also technological areas that are expected to spread and expand into related industries, such as the development of optical technology and refrigerators. Its importance is increasing.

• Efforts toward practical application of annealing-type quantum computers are ahead of gate-type quantum computers as quantum computers that specialize in combinatorial optimization problems. Based on an annealing method theoretically proposed by Japanese researchers, Canada's D-Wave has developed and released the world's first commercial device using superconducting qubit technology. Although other countries have taken the lead in the development of actual machines, Japan still has world-class researchers in terms of theory. In 2018, the National Institute of Advanced Industrial Science and Technology (AIST) succeeded in manufacturing Japan's first superconducting quantum annealing machine (50 qubits). Furthermore, RIKEN and NEC Corporation (NEC) are also conducting research and development toward the development of a

• Ion trap is a technology that confines ions in space using electromagnetic fields such as lasers, and is attracting attention as a promising physical system for realizing quantum computers. In the United States, companies have already commercialized NISQ devices. On the other hand, with regard to cooled ions, there are issues such as the long gate time of qubits and the decrease in fidelity related to gate operation, as well as individual control of qubits and miniaturization of optical elements for scaling up. There is.

• Optical quantum computers use technology to express quantum bits using photons produced by lasers, and significant progress has been made in recent years in research and development. Since it can operate at room temperature and in the atmosphere, there is no need for refrigerators or vacuum equipment, and there are prospects for networking through optical communications, high-speed gate operation, and miniaturization, making it a promising technology. It is considered a technology. On the other hand, issues have been pointed out, such as the difficulty of gate operation and the improvement of gate accuracy.

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<Priority technology

issues> Gate-type quantum computers (superconducting qubits)

Quantum software (gate-type/annealing-type quantum computers) Quantum simulation (cold atoms)

Annealing-type quantum computers (superconducting

qubits)

<Basic fundamental technology issues>

silicon qubit ion trap

Optical quantum computer etc.

<Individual policy>

It is expected that it will take 20 to 30 years to put a gate-type general-purpose quantum computer into practical use, and it is also expected to require a large amount of money to develop an actual machine. However, the development and possession of actual hardware and the establishment of basic technology for this are extremely important not only for maintaining and strengthening the country's R&D capabilities, but also from the perspective of industrial policy, and will encourage Japanese companies to enter the market. At the same time, we are promoting national research and development efforts.

At this time, we will promote a wide range of research and development from the perspective of ensuring diversity, taking into account the fact that the preferred technology to realize this computer has not yet been determined, and will focus on superconducting quantum bits, in particular, where Japan has strength and competitiveness. Promote strategic initiatives on two fronts.

In addition, as a step-by-step approach toward the development of an actual device, we are developing NISQ, quantum bit fabrication technology (structural analysis technology, microfabrication technology, three-dimensional mounting technology), dilution refrigeration technology, microwave control technology, low-temperature electronics technology, and hardware. Research and development of related and peripheral technologies such as architecture will be promoted in parallel, and efforts will be made to put these technologies to practical use in the short to medium term.

In parallel with hardware development, we are promoting research and development of quantum software (both gate-type and annealing-type quantum computers) with particular emphasis, with the participation of companies. Through the development of "quantum/classical hybrid" software that complements and links with "technical and quasi-quantum technologies (see (3) below)", we will promote efforts toward practical application in the short to medium term.

Quantum simulation (cold atoms) is a technological field that is expected to be utilized and applied in the materials and chemical industries in which Japan has a competitive edge, and with the participation of companies, early practical application is based on basic research. Promote initiatives towards such things.

Research and development of annealing-type quantum computers is progressing not only among foreign companies but also among Japanese companies in collaboration and cooperation with national research institutions, and support for practical application and commercialization is in progress. Expand.

ii) Quantum measurement/sensing •

The domestic and international markets for sensors are expanding further, and expectations are extremely high for quantum measurement/sensing as a next-generation fundamental technology. Research and development investment in this area is significantly expanding, especially in Europe and the United States, and international competition with Japan is intensifying.

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Furthermore, the targets of quantum measurement and sensing are wide-ranging, including magnetic fields, electric fields, temperature, and acceleration, and measurement methods are also becoming more diverse and complex.

• In addition, as a spin-out for the practical application of quantum computers, quantum measurement and sensing are technological fields that are expected to be commercialized and implemented in society at a relatively early stage, and Japan However, it is extremely important to engage in internationally competitive research and development with an eye toward commercialization and marketization.

• Solid-state quantum sensors (diamond NV centers, etc.) have the feature of being able to measure magnetic fields, electric fields, and temperature with ultra-high sensitivity at room temperature and in the atmosphere, and are a particularly competitive field among sensor materials. Japan maintains high technological capabilities in developing materials for solid-state quantum sensors (Tokyo Institute of Technology, National Institute for Quantum Science and Technology (QST), National Institute for Materials Science (NIMS), National Institute of Advanced Industrial Science and Technology (AIST), etc.) We provide materials to overseas research groups. It also has internationally high technical capabilities in measurement technology. It is an area that is expected to be utilized in a wide range of industries, and Japanese companies are increasingly participating in research and development. • Quantum inertial sensor is a technology that detects acceleration and angular velocity using quantum effects, and is expected to have a significant ripple effect on a wide range of industries, such as high-precision self-position estimation equipment, as well as improving the safety and security of the country and its people. This is an important core technology from the perspective of safety. Furthermore, optical lattice clocks are clocks that are several orders of magnitude more accurate than conventional atomic clocks, and Japan leads the world by far in terms of accuracy and continuous operating time. This is an area that is expected to contribute to the redefinition of the second in the International System of Units and have ripple effects as an ultra-high-precision spatiotemporal measurement infrastructure. In both cases, there are world-leading researchers in this field, and Japan possesses world-class technology, and it is essential to maintain and strengthen these. • Research and development is progressing regarding quantum entanglement optical sensors, such as "quantum entanglement microscope" which exceeds the measurement precision of conventional optical microscopes, and "quantum OCT" which dramatically improves the resolution of optical coherence tomography (OCT). . Japan is leading the world in developing quantum entangled light sources and using them in applications, in cooperation with universities and other companies. To date, we have successfully demonstrated resolution exceeding existing technology using quantum entangled light, and we will continue to expand our research and development and demonstration efforts with the aim of early commercialization and commercialization. This is very important.

• Quantum spintronics sensor is a technology that uses quantum mechanical effects to detect changes in spin in materials caused by stimuli from the outside world. Companies are increasingly entering the field of magnetic sensors using tunnel magnetoresistive (TMR) elements based on technology related to product development such as MRAM. Venture companies are actively entering the market in Europe and the US, and the search for future practical application and industrialization has begun. Additionally, the spin heat flow sensor is a new sensor that can utilize information on heat flow, and is expected to be used in heat-related industries and social infrastructure. Our country leads the world in terms of basic principles, etc., and we need to steadily advance research and development. • Ultrashort pulse lasers are progressing from femtosecond to attosecond science, and are expected to lead to expanded applications in a wide range of industrial fields, such as elucidation of material properties and development of magnetic devices. Japan has strengths and competitiveness in laser light source technology in both high repetition rate and high intensity types. As competition with Europe, America, China, etc. intensifies, it is important for Japan to steadily advance research and development with future industrial applications and uses in mind.

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<Priority technological

issues> Solid-state quantum sensors (diamond NV center, etc.)

Quantum inertial sensors/optical lattice

clocks Quantum entangled optical sensors

<Fundamental technology issues>

Quantum spintronics sensors, gravity

sensors,

attosecond lasers, etc.

<Individual policy>

Solid-state quantum sensors are a technology that Japan has strengths in manufacturing and are expected to be applied in a wide range of fields including medical and health fields in the future. We will focus on promoting a wide range of research and development. On the other hand, as early utilization and application in device development, etc. are expected, the active participation of companies, etc. will be encouraged, and efforts will be made for practical application and commercialization in the short to medium term.

Quantum inertial sensors and optical lattice clocks are technologies that have prospects for technological establishment and are expected to be used and applied in many fields, so research and development will be focused on them. The government is also involved in strategic initiatives aimed at early commercialization.

For the quantum entanglement optical sensor, we are conducting research and development on a hybrid type that combines quantum OCT and existing (classical) OCT, and we are also conducting research and development on a hybrid type of quantum entanglement optical sensor that combines quantum OCT and existing (classical) OCT. Regarding absorption spectroscopy, by promoting research and development aimed at proof of principle, we will promote the participation of companies and others, while developing initiatives for practical application in the short to medium term.

ÿ) Quantum communications/

ciphers • In recent years, advances in computing technology, AI, medical technology, etc. have led to the creation of highly confidential and important digital information one after another. If such important information were to be leaked, the social and economic impact would be enormous, so ensuring confidentiality and integrity over an extremely long period of time is an extremely important issue.

• With the rapid development of gated quantum computers, there is a possibility that the public key cryptography technology that supports modern Internet security may be cracked, and studies on quantum-resistant computer cryptography are progressing internationally. On the other hand, since there is a risk of compromise in quantum-resistant computer cryptography, the United States, China, and other countries recognize that quantum communication and cryptography, which in principle are secure, are a serious threat to national security. We are rapidly proceeding with research and development on the subject. • In Japan, Toshiba Corporation and NEC manufacture the world's fastest BB84 quantum cryptographic device, and the National Institute of Information and Communications Technology (NICT), the University of Tokyo, Nippon Telegraph and Telephone Corporation (NTT), Mitsubishi Electric Corporation, etc. , is leading the world in theoretical research and demonstration. NICT is leading the world in the development of quantum communication and cryptographic transmitter/receiver equipment, with the metropolitan area testbed ``Tokyo QKD Network'' having the longest operational track record in the world. The University of Tokyo is a quantum computer

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However, we are promoting research on cryptographic algorithms that cannot be broken. Regarding satellite quantum communications, China surprised the world by announcing that it had succeeded in establishing quantum communications with the ground using its independently developed satellite "Mozi." In Japan, NICT has successfully conducted a demonstration experiment between a low-orbit satellite and a ground station.

• Japanese companies are working towards the early commercialization and commercialization of cryptographic transmitting and receiving equipment, and are working on standardization at the European Telecommunications Standards Institute (ETSI) and the International Telecommunication Union (ITU), along with NICT. We are promoting activities and leading the world.

• Quantum relay technology (quantum memory, quantum entanglement, etc.) is being developed by Osaka University, NTT, NICT, etc., and is leading the world in proof of principle of quantum entanglement between atomic quantum memory and photons, and all-optical quantum relay method. . Challenges include verification of long-distance transmission, multiplexing, integration, and scaling up. International competition is intensifying, with numerous research and development projects being launched in Europe, America, China, and other countries. • As for networking technology (construction, operation, maintenance, etc.), quantum memory and quantum relay are at the proof-of-principle stage, so it will still take time to realize a quantum internet that will replace the current internet. For this reason, a trusted node architecture related to quantum communication is being considered, and ITU-T is proceeding with standardization discussions based on this architecture.

• Japan, from the perspective of ensuring the safety and security of the country and its people and strengthening industrial competitiveness, As a means of safely storing important digital information, we will conduct research and development on quantum communications and cryptography, which have confidentiality and integrity, and are highly internationally competitive with an eye toward commercialization, as well as their commercialization and standardization. It is extremely important that the country tackle this issue.

<Priority technical issues>

Quantum communication/encryption link technology

<Fundamental technology issues>

Quantum relay technology (quantum memory, quantum entanglement, etc.)

Networking technology (construction, operation, maintenance, etc.), etc.

<Individual policy>

Among quantum communication/encryption link technologies, quantum communication using optical fibers has established basic technology for transmitting/ receiving equipment, and is at the stage of practical application and commercialization by Japanese companies, so it is being developed in addition to research and development. In addition to promoting strategic initiatives to realize business development both domestically and internationally in the short to medium term, with the involvement of the government, we will also promote international standardization activities through close collaboration and cooperation between industry, academia, and government. Regarding satellite quantum communications, in view of its importance in terms of the safety and security of the country and its people as well as industrial policy, research and development will be promoted intensively from both the short- and medium-term and medium- to long-term aspects, and efforts will be made to improve the communications environment. , we are developing strategic efforts toward practical application.

ÿ) Quantum materials (quantum physical properties/materials) •

“Quantum materials” are physical properties/materials that exhibit functions by precisely controlling their quantum states. Japan has developed theoretical, experimental, and material technologies through years of basic and applied research. In terms of development, etc., it is an area that has strength and competitiveness worldwide. On the other hand, in recent years, condensed matter physics

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The concept of topology has been actively introduced in Japan, and based on this, the search for materials that exhibit new functions and research to understand their functions are rapidly expanding, and the world is expanding internationally, especially in Europe, the United States, and China. Competition is intensifying.

• In addition to high-quality research and development being carried out in Japan's universities and research institutes and a deep pool of human resources, this technology field has a broad base of Japanese industries and companies, and is highly internationally competitive. keeping. It is positioned as a promising technology area that will lead to strengthening the industrial competitiveness of Japan, which has until now lagged behind the rest of the world in internationally growing industrial fields, such as the development of next-generation devices and the creation of new physical materials. .

• Topological quantum materials such as graphene are materials that are expected to be applied to energy-saving devices and new physical materials through the realization of highly efficient spin/charge conversion, etc., and have high industrial ripple effects in the future. It is considered a technical field. While research and development is becoming more active in the United States, Europe, and China, Japan has a core of researchers who are conducting research and development that is highly acclaimed internationally. • Materials that can utilize spin

current (spin current materials) are expected to be innovative materials that can be used in spintronics devices that obtain energy from heat, vibration, light, etc. in a single device. Spintronics technology is a technological field in which Japanese universities and research institutes have accumulated many years of basic research. Sensing using these materials has high expectations as a new sensing technology for measuring heat flow and rotational flow, and it is important to steadily promote it from the basic research stage.

<Fundamental technology issues>

Topological quantum materials (graphene, etc.) Topological magnetic materials Spin current materials, etc.

(2) Quantum fusion innovation area • It is necessary

to advance strategic efforts in each major technology area related to quantum technology based on the measures listed in (1). On the other hand, based on these technological areas in which Japan has strengths, we will develop quantum technology and related technologies (including existing technologies) in order to increase the speed and accuracy of innovation in order to realize the future social image set forth in this strategy. It is extremely important to build and develop a new technology system unique to Japan that integrates and links the following. • Quantum computers are expected to have computational performance that far exceeds

that of classical computers for specific problems, and AI technologies such as machine learning and clustering are highly complementary and are expected to be one of the important killer applications. Expectations are rising. Although it is attracting international attention, research and development is still in its infancy, but Japan maintains strengths in areas such as quantum software development. For this reason, "quantum AI technology," which replaces part of AI technology with quantum computers (including Japan's unique quantum inspired technology) and integrates and utilizes them as accelerators, is positioned as an extremely promising technological field. • "Quantum biotechnology," which combines quantum technology with life and medicine, is a unique academic discipline in Japan, such as elucidating the functions of life phenomena at the cellular level and utilizing solid-

state quantum sensors in the medical and health fields.

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We are at the stage where we have begun to develop the market. On the other hand, it is a promising technological field that is expected to have an extremely large ripple effect in solving the issues faced by Japan, such as the aging of the population, extending healthy lifespans, and rising medical costs, and realizing a healthy and long-lived society. .

• With the progress of quantum computer technology, there is a possibility that current public key cryptography technology will be deciphered. From the perspective of ensuring the safety and security of the country and its people, advanced network security will be developed by combining quantum and classical technologies. "Quantum security technology" is an extremely important technological area. While Europe, the United States, and China are proceeding with large-scale research and development, Japan is also advancing pioneering efforts, and there is an urgent need to develop this into a solid foundational technology. • We have clearly positioned these new technological fields that combine and collaborate quantum technology and related technologies as "quantum fusion innovation fields," and we are aiming to lead the world in these fields as the country's top priority areas. We will strongly promote and develop strategic initiatives.

Goal: Establish the ``quantum fusion innovation area'' as the top priority area for the future development of Japanese industry and innovation, formulate a ``fusion area roadmap'' for each area, and provide research and development support based on these.

Strengthen and promote strategic initiatives <Quantum fusion innovation area> Quantum AI technology (e.g. quantum-classical hybrid computation (supervised/unsupervised learning), algorithm/system architecture development (including use of quantum inspired technology), etc.) Quantum life technology (Quantum bio) (Example: Biological nano-quantum sensor, quantum entangled optical imaging, hyperpolarized nuclear magnetic resonance technology (hyperpolarized/ultra-compact MRI), etc.) Quantum security technology (Example: Quantum secure cloud, optical/quantum network cryptography))

<Overall policy> In the area of quantum fusion innovation, Japan will maintain its strengths and competitiveness, and will contribute to Japan's industry and innovation by realizing practical application and commercialization with high accuracy as early as possible. Targeting technological areas that are expected to make significant contributions.

For each quantum fusion innovation area, from a medium- to long-term perspective, we will promote research and development with the highest priority as a nation, and by combining it with existing (classical) technologies, we will develop related and peripheral technologies in the short to medium term. We will develop strategic initiatives to realize practical commercialization, including spread and expansion (spin-out).

<Specific measures>

The government, in coordination and cooperation with related ministries and agencies, will look at the overall picture of the technology system, including related and peripheral technologies, in the area of quantum fusion innovation, and will develop plans for the next 20 years or so from a medium- to long-term perspective. We have created an "Interdisciplinary Roadmap" that shows strategic and specific measures to be taken in the interim, and have formulated it in conjunction with this strategy.

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Based on the “Interdisciplinary Field Roadmap,” the government will provide focused research and development support for each quantum convergence innovation field through large-scale projects under direct control of the national government and large-scale R&D funding. At the same time, based on these, we will actively attract investment from the private sector and promote and develop a wide range of initiatives for research and development and practical application through industry-academia collaboration and public-private collaboration.

(3) Quantum inspired technology/quasi-quantum technology

• In Japan, companies are mainly developing the ideas and methods of quantum technology, such as annealing technology and technology that uses laser pulses equivalent to quantum bits (utilizing the quantum nature of light). Unique and innovative technological development and products that incorporate existing (classical) technology (classic computers, etc.) and service development is progressing.

• For example, Hitachi Ltd.'s CMOS annealing machine, Fujitsu Ltd.'s digital annealer, Toshiba's simulated branching machine, NTT's LASOLV (QNN during the Cabinet Office's Program for the Promotion of Innovative Research and Development (ImPACT) project), etc. Technological development and commercialization of Ising-type computers, which can process specific combinatorial optimization problems at much higher speeds than classical computers, are progressing ahead. This is a unique movement, and there are no other examples in the world.Also, from a global perspective, efforts are being made to speed up classical algorithms, for example, inspired by quantum algorithms.

• In particular, scaling and practical application of gate-type general-purpose quantum computers requires efforts from a medium- to long-term perspective, and scaling of annealing-type quantum computers based on the same Ising model also requires a certain amount of time. Given the expected demand, these unique Japanese technologies are expected to be applied and deployed in various industrial fields such as finance, insurance, manufacturing, and transportation, in addition to the evaluation and verification of future quantum computers. It should be highly evaluated as a technical field. • For this reason, we will clearly position these technology systems as "quantum inspired technology" and develop efforts such as research and development and social implementation.

Goal: Evaluate and identify promising “quantum inspired technologies” originating in Japan, and promptly enhance and promote strategic research and development and support for practical application.

<Overall policy>

“Quantum inspired technology/quasi-quantum technology” is a unique technology mainly developed by Japanese companies, and we will focus on promoting research and development based on “quantum/classical hybrid” that combines these with quantum technology. At the same time, we will develop strategic initiatives to lead to industrialization and commercialization in the short to medium term.

<Specific measures>

Through support such as research and development funding, the government will promote industry-academia collaboration and collaboration using the "quantum inspired technology" possessed by Japanese companies, such as CMOS annealing machines, digital annealers, simulated branching machines, and LASOLV. Promote innovative research and development (application development, etc.) and social implementation through public-private collaboration.

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The government, with the cooperation of Japanese academia and companies, will develop promising "quantum inspired technology". Identifying and evaluating quasi-quantum technology.

(4) Fundamental research • Although quantum technology is expected to develop dramatically in the future, there are many technological areas that are still at the basic research stage, and from the perspective of increasing the depth of Japan's technology and human resources, a wide range of research is needed. It is extremely important to steadily promote science-based (basic research stage) research and development in these areas from a medium- to long-term perspective. • In addition, in order to develop the technological areas listed in (1) to (3), in addition to quantum technology itself, we must analyze and evaluate Japan's strengths and competitiveness, and develop the fundamental technologies and related technologies that support these. Broad-based fundamental research that includes technology and peripheral technologies (e.g., microstructural analysis, microfabrication technology, light wave control/optical device technology, semiconductor technology, cooling technology such as dilution refrigerators, cryogenic electronics, etc.) analysis/evaluation technology) is required. In addition, we will promote the commercialization and practical application of these basic technologies with a view to strengthening their international competitiveness and domestic production, and will develop and share basic facilities and equipment, such as cutting-edge equipment, to realize them.•It is essential to steadily and proactively promote the securing of strategic materials essential for the operation of equipment, etc. • For this reason, we will further enhance and strengthen such basic research and the development and sharing of basic facilities and equipment, including the technical areas listed in (1) to (3) and related areas. While doing so, we will steadily promote this.

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2. international strategy

(1) Strategic development of international cooperation

• The United States and Europe are promoting science-based (basic research stage) research and development regarding quantum technology through various types of funding, and expectations are high for expanded cooperation with Japan in this field. In particular, the Japanese and U.S. governments discussed accelerating Japan-U.S. cooperation on quantum technology at the ministerial-level Joint High-Level Committee on Science and Technology Cooperation held in May 2019. Furthermore, since last year, the Japanese and EU governments have agreed on the importance of expanding cooperation in the field of quantum technology, and held a joint symposium. Britain, Germany, and other countries are also looking forward to a cooperation agreement with Japan at the government level.

• Under these circumstances, from the perspective of ensuring the safety and security of the country and its people and industrial policy, Japan has established relationships with countries and regions that share common values and have high research and technological standards related to quantum technology. Therefore, it will be extremely beneficial and important for Japan's strategy to develop and build a multilateral cooperation framework at the government level.

• Furthermore, we will consider Japan's strengths and competitiveness as well as the advantages and disadvantages of research cooperation in each specific technology area with countries that have a high level of research and technology related to quantum technology, such as the United States, the United Kingdom, and Germany. Based on this, it is important to build a multi-layered and strategic bilateral cooperation framework among governments, universities, research institutes, etc., and to promote concrete cooperation.

Goal: Within five years, develop and build a multilateral and bilateral cooperation framework on quantum technology at the government level, mainly in Europe and the US <Specific measures> In addition to

considering and agreeing

on a multilateral cooperation framework regarding (quantum information science, etc.), we are also considering and promoting the expansion of research cooperation through holding joint symposiums and workshops.

Actively utilize existing frameworks such as the Joint Committee on Science and Technology Cooperation with the United States, the United Kingdom, Germany, etc., and consider and promote specific bilateral cooperation frameworks (MOUs, etc.) regarding quantum

technology. . Conducting international joint research with specific countries and regions, taking into consideration Japan's strengths and merits, etc. Promote the establishment of joint funding mechanisms and the holding of joint symposiums.

(2) Thorough security trade control • Quantum

technology is an important fundamental technology from the perspective of future industry and security, and the international export control regime is also tightening regulations on quantum-resistant cryptographic technology, etc. . Furthermore, based on the National Defense Authorization Act and other laws, the United States has recently been considering tightening regulations regarding advanced technologies, including quantum technology, from both export and investment perspectives. Additionally, the EU and other countries are also tightening investment regulations for quantum technology.

• Based on the agreement on the international export control regime, Japan is promoting strict security trade controls based on the Foreign Exchange and Foreign Trade Act. Based on this law, we are encouraging universities and research institutes to develop management systems for advanced technology, etc., but it has been pointed out that there are still issues with establishing management systems and ensuring that researchers are fully informed. I am in a situation where I am.

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• For this reason, the government as a whole will promote security trade controls targeting advanced technologies, including quantum technology, and further promote the establishment of systems for legal compliance and appropriate management within organizations. It is essential to strengthen and promote the establishment of management systems at universities, research institutions, etc.

Goal: Strengthen and promote the establishment of management systems, including compliance with foreign exchange and foreign trade laws, etc. at universities and research institutes that conduct research on advanced technologies such as quantum technology

<Specific measures>

National The government will promote and thoroughly implement security trade controls based on foreign exchange and foreign trade laws, taking into account international discussions on strengthening the management of sensitive technologies. Based on the "Guidance for Sensitive Technology Management Related to Security Trade (for Universities and Research Institutions)," the government will further strengthen and promote efforts to strengthen security trade control systems at universities, research institutions, etc. Universities, research institutes, etc. shall establish internal security export control regulations, etc. within the university/institution based on the same In addition to accelerating preparations, we will further strengthen our operational structure by ensuring that researchers are thoroughly informed.

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3. Industrial/Innovation Strategy (1)

Formation of “quantum technology innovation centers (international hubs)”

• In Europe and the US, the formation of centers related to quantum technology is progressing rapidly (e.g. Delft University of Technology (QuTech) in the Netherlands, University of Toronto in Canada, United States•University of California, Lawrence Berkeley National Laboratory, University of Oxford in the UK, etc.), and these bases function as a stage set for attracting outstanding researchers from Japan and abroad. In Japan, a relatively small number of researchers are dispersed across universities, research institutes, companies, etc., and the lack of top-class research centers that are internationally recognized and evaluated is a major issue.

• Regarding quantum technology, from the perspective of further increasing the depth of research and human resources that have been accumulated over many years at Japanese universities and research institutes, and ensuring the diversity of basic and fundamental research, such universities - It is important for the government to continue to enhance and strengthen support for a wide range of research at research institutions.

• On top of that, from the perspective of securing and strengthening international competitiveness, focusing on technological areas where Japan maintains strengths and competitiveness, we will mobilize human resources and technologies according to the characteristics of the technology, and conduct everything from basic research to technology demonstration. It is extremely important to form a base where industry, academia, and government work together on everything from innovation, open innovation, intellectual property management, and human resource development. A new ``Quantum Technology Innovation Center (International Hub)" will be formed as an international research and development base. • Centered on national research institutes and universities, the center will bring together excellent researchers and engineers from Japan and abroad, attract active investment from companies, etc., and promote organic collaboration between universities and companies.•Build a cooperative system. At the same time, we will collaborate and connect with multiple universities, graduate schools, etc., and develop and build a role as a core base for developing human resources in the field of quantum technology, which will play a key role in the future.

Goal: Develop and form at least five "quantum technology innovation centers (international hubs)" in Japan over the five years starting in 2020

<Example

requirements for centers> Core technology with high international competitiveness

It must be a technical field that has the following characteristics.

It is a technological field in which Japan's universities, research institutes, companies, etc. have high potential, and where future dramatic development of industry and innovation is expected. Large investments

are expected from domestic and foreign companies, or there is an accumulation of excellent human resources from overseas.

The technology area is expected to be

It is a technological field where it is beneficial and efficient to integrate human resources, technology, budget, etc.

<Example of base

type> Open platform type that deepens and strengthens collaboration between universities/research institutes and companies (e.g. IMEC, Tohoku University International Electronics Center (cies)). Although placed

under the umbrella of a university or research institution, a base type that ensures a high degree of freedom and independent management

Molding (e.g. Ministry of Education, Culture, Sports, Science and Technology's "World Top Level Research Center Program (WPI)").

A center type (e.g. Rika

Strategic centers such as the National Institute of Advanced Industrial Science and Technology (AIST).

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<Candidate sites>

Superconducting quantum computer research center

Quantum device development center

Quantum software (quantum AI, etc.) research center Quantum life

(bio) research center (solid-state quantum sensor utilization, etc.) Quantum materials

research center Quantum inertial sensor/

optical lattice clock research center Quantum Security Research

Center

<Specific measures>

Based on the above requirements, the government will promote the formation of "quantum technology innovation bases (international hubs)", which are international research and development bases centered on universities,

research institutes, etc. The center will receive medium- to long-term support from related ministries, including financial, tax, and institutional aspects (including the use of the special zone system), as well as attracting appropriate investment from domestic and foreign companies. Developed and promoted as a research and development base by the public and private sectors.

(2) Establishment of the “Quantum Technology Innovation Council (tentative name)”

While quantum technology is highly recognized and expected to be an important technology that will lead to future industry and innovation, it is still technically immature and under development, and has not yet reached the stage where Japanese industry can actively participate. . On the other hand, in the United States, for example, there is a movement to form a new consortium led by NIST to discuss research, development, and utilization of quantum technology among academia and industry based on a bill related to quantum information science.

Under these circumstances, in Japan, various stakeholders, including industry, academia, and government, gather to create a "consortium" where various stakeholders, including industry, academia, and government, gather to consider and discuss the current state of quantum technology, the development of research and development, and its utilization in industry and society. ” is extremely beneficial. Related efforts have already begun, such as the creation of the ``(One Company) Quantum ICT Forum,'' and with these in mind, the ``Quantum Technology Innovation Council (tentative name)'' will be established to target specific technology areas.

At this council, industry, academia, and government collaborate and cooperate to take the lead in considering specific initiatives and roadmaps for individual technological issues, and promote open innovation in cooperative areas based on these ((build an ecosystem). Furthermore, based on the latest research and technology trends, we will consider and promote strategic promotion and support measures for Japanese industry, including collaboration with overseas companies and research institutions.

Goal: Within 5 years, consisting of universities, research institutes, companies, etc. in each specific technology area Establishment of the Quantum Technology Innovation Council (tentative name)

<Example of the council's position/role> This should

be a proactive initiative by academia and industry. Multiple companies are participating,

as well as universities, research institutes, and related ministries, etc., in a project related to quantum technology.

The project must involve the participation of a variety of organizations and institutions that have an interest in a specific area.

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Analysis of the current state of technology, direction of research and development, and utilization in industry and society for the specific area concerned.

The project must be considered and discussed from a wide range of viewpoints, including practical use.

<Council candidates>

Quantum Computer and Software Council Quantum Sensor

Utilization Council, Quantum Materials Utilization Council Quantum Information Communication

and Network Technology Council (Quantum ICT Council)

<Specific measures>

The government will support initiatives related to the creation and activities of the Quantum Technology Innovation Council (tentative name), which is an initiative of academia and industry in each specific technology area (e.g., bridging the gap between Japan and the world, participation of related ministries and agencies, and support through grants, etc.).

(3) Improving the environment for business

start-ups and investment • In Europe and the US, giant IT companies such as Google, IBM, Microsoft, and Intel are

While making huge R&D investments in cutting-edge quantum technology including computers,

Expectations are rising for the creation of new industries, such as the birth of venture companies with advanced technology and high international recognition, such as Rigetti, D-Wave, and IonQ.

• In Japan, large companies have not been able to actively participate in the development of cutting-edge quantum technology due to factors such as quantum technology being at an immature stage and the future outlook uncertain. On the other hand, although there are fewer venture companies based on university technology than in other countries, active movements are emerging, such as the establishment of MDR and QunaSys. From the perspective of linking quantum technology to industry and innovation, it is extremely important to create an environment that further promotes the creation of university- and corporate-based venture companies based on such advanced quantum technology. •

Furthermore, in order to commercialize and industrialize quantum technology, the government should take the lead in promoting the introduction and utilization of the technology, with reference to examples from Europe and the United States, from the perspective of inducing investment from both developing companies and users. It is extremely important to create an environment that promotes investment by companies.

Goal: Within 10 years, a university/research institute or company based on quantum technology

Establish at least 10 new venture companies, including those related to elemental technology. <Specific

measures> Universities,

R&D corporations, etc. will

We actively support the creation of venture companies based on the excellent technology seeds possessed by Japan.

The government is promoting in-house ventures and

Supporting the development and expansion of an environment that fosters corporate ventures.

In order to expand the creation of venture companies based on quantum technology, the government is considering expanding support through government financial institutions and the Industrial Innovation Investment Corporation, as well as entrepreneurial training and startup support. The

government is promoting the advanced introduction and utilization of advanced technologies and products related to quantum technology, including quantum cryptography equipment.

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4. Intellectual property/international standardization strategy

(1) Intellectual property strategy •

Regarding quantum technology, not only the government but also giant IT companies are making active investments and working closely with universities, research institutes, etc. At the same time, we are conducting cutting-edge research and development. These companies are proceeding with strategic intellectual property management, skillfully using open and closed technologies, with a view to future lock-in, especially for important core technologies. • As competition across national and corporate borders intensifies, strategic management of quantum technology-related intellectual property is essential. Furthermore, as industry-academia collaboration and open innovation initiatives in this field are rapidly expanding both domestically and internationally, it is extremely important to strengthen open and closed strategies, primarily at universities and research institutes, prior to starting a project. It is.

Goal: Intellectual property strategy based on open/closed strategy regarding quantum technology <Specific measures> The government will flexibly acquire

rights for the results of

research and development related to quantum technology at universities, research institutes, etc., including related technologies based on open/closed strategies.•Promote utilization, etc.

The government will promote matching of promising quantum technology seeds possessed by universities and the like with the needs of companies, ventures, etc., as well as promote commercialization and bridging among universities and such companies.

(2) International standardization strategy •

In areas close to social implementation, such as quantum computers and quantum cryptography, it is important to advance efforts toward international standardization of quantum technology and related technologies. In the field of quantum information science, the United States has built an industry-academia consortium centered on NIST and has begun considering ways to obtain standardization. In addition, ISO/IEC JTC1 has established a research group on quantum computing, and is proceeding with the extraction of standardization work items mainly in China and Japan. • In order to strengthen international competitiveness and capture markets, Japan will develop strategic initiatives related to international standardization that leverage its technological superiority, with a focus on the quantum technology field, where it has particular strengths. This is essential. In doing so, it is especially important to cooperate with countries such as the United States and Europe, which share common values, and to promote prompt and accurate international standardization strategies.

Goal: Develop quantum technology areas in which Japan has strengths and where large economic ripple effects are expected. Identify areas and consider and promote strategies for acquiring international standards. <Specific measures>

The government will

collaborate with universities, research institutes, etc. to conduct research focusing on priority technological issues, including related technologies.

We support the acquisition of integrated international standards from the research and development stage.

The government will develop standards in collaboration and cooperation with related organizations such as international standardization organizations and certification bodies.

We have established a support system for identifying technologies that require standardization, standardization, and certification.

Regarding quantum technology, the government is promoting the development and securing of human resources who can propose projects and participate in deliberations to international standardization organizations such as the International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), and ITU.

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5. Human resources strategy

(1) Developing and securing excellent human resources • As international competition in quantum technology intensifies, the number of researchers involved in research and development of quantum technology in Japan is thinner than in other countries. be. In particular, as companies in the United States and China are making huge investments in quantum computers and quantum software, and attracting excellent human resources from Japan and abroad with high compensation, there is a risk that they will fall far behind in the international competition to acquire human resources. . • For this reason, in Japan, in order to dramatically increase the quality and depth of human resources in the quantum technology field, we will enhance and strengthen the education and research environment in quantum technology-related fields at the higher education level, including universities. It is extremely important and essential to strategically cultivate and secure excellent young researchers and engineers who will be responsible for research and development in the relevant fields. • Furthermore, with an eye toward post-AI, it is important to appropriately coordinate with human resource development based on the "AI strategy." Targeting students studying AI at universities and young researchers involved in research and development, we will enhance and secure opportunities to acquire knowledge about cutting-edge quantum technology in addition to AI technology, and aim to become familiar with fields related to quantum technology. It is necessary to increase the depth of the human resources.

Goal: As early as within five years, promote human resource development through the establishment of courses and majors related to quantum technology at universities, etc., and the development of systematic educational programs <Specific measures> Collaborate and cooperate with companies, etc. to

strategically develop and

develop researchers and engineers.

Consider a roadmap for securing human resources, and support the development and securing of human resources at universities, etc.

The government will collaborate and cooperate with universities and inter-university research institutes to develop specialized programs related to quantum technology, such as establishing and reorganizing majors and courses that cover a wide range of quantum technology and related fields, while linking it with human resource development measures in the AI strategy. Consider and promote the development of environments and opportunities that provide educational education.

Universities should develop systematic and common educational programs (teaching materials, curricula, etc.) on quantum technology, utilize and implement them in undergraduate and graduate school education at each university, and provide education using the Internet, etc. Consideration and promotion. The government will collaborate and cooperate with universities, research institutes, and even companies to encourage

excellent researchers and engineers to engage in quantum technology through personnel exchanges, transfers, cross-appointments, etc. beyond the boundaries of organizations and fields. Secure opportunities to acquire new knowledge and skills.

(2) Promoting brain circulation • As competition in quantum technology between countries and companies continues to intensify, securing excellent human resources is a common issue, and it is a challenge that transcends the boundaries of nationality. Competition for human resources is rapidly evolving around the world. Japan still maintains world-class research capabilities in fundamental technology, basic theory, and materials development related to quantum technology, but companies and universities in Europe, the United States, and China are already requesting research from Japanese universities. It has also been pointed out that the company is starting to poach talented researchers from its ranks.

• In this way, based on the fact that quantum technology is at the forefront of international competition in the field of cutting-edge technology, we will strive to maintain and strengthen Japan's research capabilities and human resources, as well as ensure future industrial competitiveness. Therefore, in addition to securing domestic researchers, it is extremely important to strategically promote efforts to invite and secure excellent researchers from overseas.

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• Furthermore, in order to improve the knowledge and skills of Japan's outstanding young researchers and engineers, it is necessary to secure opportunities for them to study at overseas universities.

Goal: Based on multilateral and bilateral cooperation frameworks, hold an international symposium on quantum technology innovation every year with the participation of top-level researchers and engineers from Japan and abroad, and realize brain circulation. ÿ Specific measuresÿ

The government is working with universities and research institutes, including the Quantum Technology Innovation Center (International Hub), to invite and secure outstanding researchers and engineers involved in quantum technology innovation from overseas. Support and reinforcement.

Universities, research institutes, etc. are working hard to secure and develop excellent researchers, engineers, etc. from Japan and overseas. In addition to improving the environment, we actively promote promotion through securing posts, etc.

The government will work with universities and research institutes to ensure that young researchers and promising students from universities have opportunities to join overseas research institutes and engage in cutting-edge research and development related to quantum technology. At the same time, we will promote active promotion to universities, etc.

(3) Developing Quantum Natives • Quantum technology is a field that requires strategic research and development over the medium to long term, and nurturing and securing the researchers who will lead the future can be said to be an extremely important policy issue. Already, countries such as the United States and Europe are providing opportunities to learn about quantum technology and related fields from a relatively early stage in order to foster and secure future researchers and engineers. Efforts are underway.

• In Japan, high schools and technical colleges are particularly interested in developing and securing "Quantum Natives" who have the advanced knowledge and skills to use quantum technology from an early stage. It is extremely important to actively provide students with opportunities to learn about quantum mechanics and other related fields.

• Furthermore, through school education and social education, efforts will be made to arouse children's interest in the content of cutting-edge quantum technology and the current status and future of its use in society and industry. It is also important to advance

Goal: To foster and secure the "Quantum Natives" who will lead the future, provide learning opportunities especially for students at high schools and technical colleges, and develop a wide range of science communication activities <Specifics> Measures> The government should enhance science and mathematics education

such as mathematics and physics at high schools and technical colleges, and provide education on quantum mechanics and electronic information to students at these schools who are particularly interested in quantum technology. Promote the provision of opportunities to learn about related disciplines and cutting-edge research such as processing, physical properties, and materials science. The government collaborates and cooperates with universities,

research institutes, companies, science museums, etc. to enhance and secure opportunities for people to come into contact with cutting-edge quantum technologies, including quantum computers, through science communication activities, etc.

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V. Promotion system for this strategy

• It is necessary to develop and build a system to steadily promote initiatives based on this strategy, centered on the “Integrated Innovation Strategy Promotion Council.” In particular, under this strategy, based on a roadmap that includes specific measures to be taken over the next 20 years or so from a medium- to long-term perspective, targeting areas such as the quantum fusion innovation area and priority technological issues. It is extremely important to establish a system to strategically promote research and development. • In addition, from the perspective of ensuring the effectiveness of initiatives based on this strategy, related ministries and agencies will collaborate and cooperate under the "Integrated Innovation Strategy Promotion Council" to consider all measures including tax, financial, and institutional aspects. , it is necessary to ensure that it is put into practice.

• From this perspective, the Expert Council for Quantum Technology Innovation will be progressively reorganized to form the Quantum Technology Innovation Council, which will be composed of experts from the government, industry, and academia, under the Council for the Promotion of Integrated Innovation Strategy. Consider establishing a Technology Innovation Council (tentative name). • In light of the current situation where trends surrounding quantum technology are rapidly changing, the conference will aim to grasp the latest domestic and international trends in a timely and appropriate manner, and steadily implement this strategy (including the technology roadmap and interdisciplinary roadmap). Conduct follow-up. In implementing the follow-up, considering that the strategy is to invest in research and development over the medium to long term amidst the severe financial situation, we will conduct individual follow-up activities from the perspective of promoting an appropriate division of roles between the public and private sectors and proactive participation of the private sector. We will conduct cross-sectional evaluations and verifications of the status of efforts in projects, etc., and flexibly review priority technical issues and roadmaps.

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(Attachment 1)

Regarding the holding of the expert meeting “Quantum Technology Innovation” to promote the strengthening of innovation policies

February 12, 2019 Partially
revised November 26, 2019 Chairman of
the Integrated Innovation Strategy Promotion Council decided

1. Regarding the establishment of the "Expert Council for Promoting the Strengthening of Innovation Policies" (Decision by the Integrated Innovation Strategy Promotion Council on July 27, 2018) Based on the provisions of paragraph 2, the "Expert Council for Promoting the Strengthening of Innovation Policies" ” (hereinafter referred to as the “meeting”).

2. Based on the provisions of Paragraphs 2 and 3 of the same, the chairperson and members of the meeting shall be as shown in the attached sheet.

3. The management of the meeting shall be as specified in Paragraphs 4 to 7 of the same.

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(Attachment)

Expert meeting for strengthening innovation policy “Quantum technology innovation”

<Chairman and members>

Yasuhiko Arakawa Specially Appointed Professor, Nano-Quantum Information Electronics Research Institute, University of Tokyo

Kohei Ito Professor, Faculty of Science and Engineering, Keio University

Makoto Gonokami President of the University of Tokyo

Chair: Yoshimitsu Kobayashi Chairman of the Board, Mitsubishi Chemical Holdings Corporation

Masahide Sasaki, Senior Researcher, Future ICT Research Institute, National Institute of Information and Communications Technology

Tetsuomi Samukawa Director, NTT Advanced Technology Research Institute

Yoshinori Tokura Distinguished Professor, Tokyo College, University of Tokyo

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(Chairman Kobayashi will be the chairperson of the Expert Council until November 26, 2019, and President Gonokami will be the chairperson after that date)

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(Attachment 2)

Discussion process for formulating quantum technology innovation strategy

March 29,
2019 1st Expert Meeting

April 18th 2nd Expert Meeting

May 16, 2019
3rd Expert Meeting

June 11th 5th Integrated Innovation Strategy Promotion Conference

June 19th 45th Science, Technology and Innovation Conference

July 5th 4th Expert Meeting

July 30th “Quantum Technology Innovation Strategy” Interim Report Compilation

September 24th 5th Expert Meeting (rotated meeting related to establishment of working group)

September 30th 1st Quantum Computer Simulation Working Group (closed)

October 2nd 1st Quantum Communication/Cryptography Working Group (closed)

October 4th 1st Quantum Measurement/Sensing Working Group (closed)

October 29th 2nd Quantum Computer Simulation Working Group (closed to the public)

November 5th 2nd Quantum Communication/Cryptography Working Group (closed)

November 6th 2nd Quantum Measurement/Sensing Working Group (closed)

November 27th 6th Expert Meeting

January 21,
2020 6th Integrated Innovation Strategy Promotion Council “Quantum Technology Innovation Strategy” Final Report Compilation

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technology roadmap

• This roadmap is a compilation of the outlook for the development of each technology over the next 20 years or so, based on domestic and international research trends, etc., targeting priority technological issues. • Each roadmap includes (1) technology goals, (2) core technology system, (3) peripheral and related technologies, and (4) social and economic impact that these will bring.

One of the objectives is to share a vision for the future between the public and private sectors.

• Based on this roadmap, the government plans to strengthen research and development support for priority technological issues. Based on this support, new investment from the private sector is expected.

We strongly hope that this project will encourage investment and active participation, and that it will develop into a national industry-academia collaboration and public-private collaboration project.

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ÿGated quantum computer (superconducting quantum bit)

• Realize a general-purpose digital quantum computer that can perform large-scale, complex calculations at high speed, high accuracy, and low power consumption. • Implement around 1,000 physical qubits in 10 years or later. In addition, implement about 50 quantum error-corrected qubits. • Promote scale-up by developing design support technology and refrigeration/low temperature technology for scale-up.

Economic/ Social Impact

- Random number generation using quantum computing
- Development of distributed quantum computers
- Realizing secure distributed quantum computing Blind quantum computing
- Quantum secure network technology development
- Expansion of science and technology frontiers (development to elementary particle/condensed matter physics research, application to quantum life phenomena)
- Utilization in drug discovery, fluidics, structural analysis, etc.
- Advances in computer science triggered by the realization of quantum supremacy
- Development of high-temperature superconductors, artificial photosynthetic materials, innovative devices, high-efficiency catalysts, etc.
- Demonstration of quantum supremacy
- Achieving quantum supremacy with NISQ
- General-purpose digital quantum computing beyond NISQ
- Progress in ultra-low power consumption devices and advanced system control HW/SW technology
- Exploring unexplored areas of IoT by realizing innovative systems in computing, communications, measurement and sensing
- Realizing high-performance quantum sensing

technological progress

Qubit integration

- Arbitrary control of physical qubits (approximately 50 qubits) is possible
- Arbitrary quantum control of physical qubits (approximately 100 qubits) becomes possible
- Quantum computers equipped with 500 to 1,000 physical qubits emerge
- Quantum computers equipped with quantum error-corrected logic bits (10 to 50) appear
- Demonstration of quantum supremacy (with around 50 qubits)
- Demonstration of algorithms for NISQ (with 100-1000 qubits)

cloud service

- Development of quantum cloud service for NISQ
- Development of cloud service for large-scale quantum computation
- Implementation of cloud service for large-scale quantum computation
- Development of error-correcting quantum computer
- Utilizing quantum computer networks Building a quantum internet

System technology

- Development of scalable qubit integrated circuit architecture
- Developing a scalable wiring architecture
- Miniaturization and integration of control electronics
- Building a large-scale quantum computer

Manufacturing technology

- Development of quantum bit manufacturing technology
- Ultra-high density mounting
- Development of scalable chip package
- Development of integrated qubit signal processing circuit
- Development of low-temperature front-end signal processing circuit

Control/ measurement technology

- Ultra-high bandwidth arbitrary waveform generator, analog-to-digital converter
- On-chip control integrated circuit using cryo-CMOS, RFSQ, etc.
- Autonomous AI quantum gate calibration device

Progress in peripheral technologies that support this technology

Refrigeration/ low temperature technology

- Cable connector Microwave parts miniaturization
- Enlargement of dilution refrigerator system

Design support technology

- Development of quantum circuit layout design development environment
- Development of automation technology for all design and inspection processes

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

ÿQuantum software (gate type)

• Physical and chemical calculations of large atomic and molecular systems enable a wide range of applications such as materials, medicine, drug discovery, machine learning, finance, and security. • Demonstration of quantum supremacy and error correction by implementing more than 1,000 qubits. Implemented on a quantum computer that implements the architecture • Create algorithms suitable for quantum computing based on basic theories of physics, chemistry, and computational science, and develop fusion areas

Economic/Social Impact

- Verifiable random number generation using quantum computing
- Quantum secure network technology development
- Realizing secure distributed quantum computing Blind quantum computing
- Direct data input from quantum sensors to quantum computers
- Creating advantages and added value by combining quantum infrastructure (quantum communication network, quantum sensor, quantum computing device, quantum software)
- Direct machine learning from quantum IoT (quantum sensors, etc.)
- Demonstration of quantum supremacy
- Contribution of quantum ICT to ICT
- Expansion of scientific and technological frontiers • Development of elementary particle and condensed matter physics research • Application to quantum life phenomena
- New functional materials (understanding scientific understanding)•High-temperature superconducting materials •Artificial photosynthesis •Interfacial functions •High-efficiency catalysts •Photofunctional materials •Transport phenomena
- Advanced scientific and technological calculations /thermal fluid analysis •Inverse matrix calculation •Structural mechanics analysis •Linear system solver

technological progress

Software implementation

- Demonstrates the usefulness of quantum-classical hybrid algorithm
- Miniaturization of quantum error correction architecture
- The emergence of architectures that enable programmable error correction
- Quantum open source software is available, enabling architectures that integrate quantum technologies

soft

- Software development that brings out the performance of quantum-classical hybrid algorithms
- Demonstrating quantum supremacy with small applications
- Enables automatic optimization of high-speed quantum circuits
- Software that enables efficient use of hardware resources
- Diversification of applications through the development of implementable algorithms
- Establishment of quantum-advantaged quantum algorithms running on error-tolerant quantum computers
- Accelerating compilers for larger scale Automation progresses
- Establishing the fundamentals of quantum programming languages and compilers

architecture

- Quantum software design evaluation Noise compensation • Performance evaluation in conjunction with hardware • Development of quantum classical interface • Evaluation of quantum software using HPC and shortening of development cycle
- Design of a quantum error correction architecture and proof of principle using an actual device • Design of an architecture that reflects the error characteristics of the implementation • Optimization of architecture-dependent arithmetic processing
- Designing a quantum error correction architecture that enables quantum IoT • Resolving incompatibility between quantum information systems
- Developing architecture design according to application

basic theory

- Exploration of computational physics and chemistry using quantum computers, implementation of computational physics and chemical theory
- Creation of fusion fields and implementation on quantum computers
- Applied theoretical research to multiscale/multiphysics Applied theoretical research to quantum chemistry/biomedical chemistry
- Deepening the fundamental theory of quantum computation (integration with computational theory)/Quantum complexity theory research
- Quantum distributed computation/quantum algorithm theory research
- Quantum device system design and evaluation Advances in optimization theory
- Development of quantum system verification theory

Progress in peripheral technologies that support this technology

hardware

- Arbitrary quantum control of physical qubits (approximately 50 qubits) becomes possible
- Arbitrary quantum control of physical qubits (approximately 100 qubits) becomes possible
- Quantum computers equipped with 500 to 1,000 physical qubits emerge
- Quantum computers equipped with quantum error-corrected logic bits (10 to 50) appear

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

ÿQuantum software (annealing type)

• Responds to various optimization problems, from optimization of transportation, factory processes, and manufacturing schedules to application to autonomous driving technology for automobiles • 5 to 10 years from now, modeling of issues to be incorporated into combinatorial optimization problems and Ising models Application of machine learning to transportation, factory processes, automobile technology, etc. • Promote large-scale social implementation by developing tools for users and advancing middleware and software technology that can be applied to a variety of fields.

Economic/Social Impact

The learning speed of machine learning is accelerated, and only necessary items are learned while selecting the necessary learning (clustering)

Significant performance improvements and processing speed improvements in AI inference, information processing, etc.

Apply real-world problems such as control of small-scale automated guided vehicles and other moving objects and process schedules to combinatorial optimization

problems Real-time traffic optimization such as automatic driving support and evacuation route planning in the event of a disaster

Weekly small group job scheduling

Start of application to real-world problems such as large-scale transportation logistics, marketing, streamlining manufacturing processes, network optimization, and autonomous driving.

Emergence of a user environment that can be used without being aware of the hardware model

Development of physical properties research

Solving social issues such as finding the optimal evacuation route in the event of large-scale traffic congestion or disasters

Utilization for energy saving through optimization of manufacturing processes and networks, etc.

Supporting work style reform through optimal job scheduling, facilitating recovery from accidents through real-time optimization of train diagrams, and on-demand transportation

Easier social implementation by lowering the cost of quantum annealing systems

Contributing to the development of new functional devices

technological progress

optimization problem

Some combinatorial optimization problems can now be solved using an annealing computer.

Annealing type computers have begun to be applied to solve some real-world problems

In combination with solver algorithms that solve linear programming problems and quadratic programming problems, annealing becomes an accelerator that can be applied to all optimization problems.

Software middleware

Developing middleware to use annealing

Development of SDK environment that utilizes annealing and diversification of application fields

Research and development of drivers and middleware that use annealing computers as part of general-purpose operating systems

Developed an API to appropriately convert Ising models to suit various hardware architectures

Development of software for hybrid use of quantum annealing machine and classical annealing machine

Construction of basic theory regarding Ising model and graph theory

Research and development of middleware that combines annealing type and gate type hardware

Ising model conversion middleware

Ising model conversion middleware

Typology of theoretical development and sophistication of applicable combinatorial optimization problems

Development of integrated software to use annealing-type computers in combination with other types of computers available at the time, such as classical computers and gate-type quantum computers.

Progress in peripheral technologies that support this technology

Quantum annealing hardware

Manufacturing a 100-qubit annealing system with high coherence performance and excellent scalability

Manufacturing 2000 qubits with high coherence performance and excellent scalability (good solution for medium-scale combinatorial optimization)

Realization of a large-scale quantum annealing machine (10,000 qubits or more) with high scalability and high coherence performance (good solution for medium- to large-scale combinatorial optimization)

Other methods of annealing hard

Realization of hardware (LASOLV) that implements approximately 10k spins with full coupling

Realization of hardware (LASOLV) that implements approximately 100k spins in fully coupled

Miniaturization of LASOLV

Realization of hardware (LASOLV) that implements spins of 1M or more and further scale-up

Utilization and development of annealing hardware (CMOS annealing, digital annealer, etc.) using digital circuits

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

ÿQuantum simulation (cold atoms)

• We are developing two types of physical property quantum simulators that help elucidate new material phases and optimization quantum simulators that accelerate the resolution of social and industrial issues. • Through the development of optical space control technology and the exploration of cold atomic properties, In 10 years, a quantum simulator with 106 or more qubits will be realized . Application to gate-type general-purpose quantum computers; Deployment of high-precision optical control technology to medical care, life sciences, and optical microfabrication.

Economic/Social Impact

- Enabling scientific understanding of new material phases (high-temperature superconductivity, quantum magnetism, topological properties, high-energy physics, non-equilibrium dynamics)
- New devices will be developed based on the understanding of material phases using quantum simulators (high-temperature superconductors capable of low-loss power transport, high-performance memories that utilize quantum magnetism, etc.)
- Social recognition of quantum superiority over classical
- Possible to solve industrially meaningful problems
- Solving social issues such as truck delivery, traffic congestion relief, and predictive health management. Quantum chemical calculations of complex molecules. Acceleration of industrial problem solving such as materials and drug discovery design
- Application to gate-type general-purpose quantum computers
  Deploying high-precision optical control technology to medical life sciences and optical microfabrication

technological progress

simulation

- Realize many-body ground state and many-body excited state and explore the mechanism of the emergence of new material phases
- Feedback of knowledge obtained through quantum simulation to materials science and demonstration of the emergence of new material phases in solid materials
- Achieve quantum simulation with 10 to 100 qubits Solve optimization problems Demonstrate quantum superiority
- Realize quantum simulation with 1,000 qubits Solve small-scale quantum chemistry problems Solve small-scale social issues
- Implementation of a quantum simulator with more than 106 qubits
- Improving the efficiency of quantum simulation by reducing simulation time and automatically optimizing parameters

simulation

- Cooling to many-body ground state, generation of many-body excited states, and observation of non-equilibrium quantum many-body dynamics
- Development of quantum gas microscope
- Development of observation methods for new material phases (methods for measuring correlations of time, space, momentum, spin, etc.)
- Development of methods for implementing physical/chemical models
- Hybridization technology with classical computers
- Fully coupled scaling of physical qubits
- Implementation of quantum error detection and correction mechanisms
- Developing high-fidelity qubits
- Exploring challenges that demonstrate quantum superiority
- Developing quantum-superior algorithms to solve industrial problems

common

- Development of single-atom optical tweezers
- Development of theoretical methods to verify quantum simulation results

Progress in peripheral technologies that support this technology

Fundamentals of cold atomic systems

- Search for atomic properties in cold atomic systems
- Control of new atomic species and mixed systems in cold atomic systems

Light source/ optical system technology

- Development of spatial shape control of light (array technology to arbitrary multiple sites, trap shape control technology)
- Development of an integrated light source system capable of fully automatic, computer-controlled, high-speed operation, and phase-intensity modulation
- Implementation of on-premises quantum simulator

Mounting technology

- Building a user interface that implements the problem in hardware
- Development of a fully integrated cold atomic quantum simulator

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

ÿAnnealing quantum computer (superconducting quantum bit)

• After 10 years, the practical application of annealing-type quantum computers with high coherence performance of about 10,000 qubits will lead to optimization of logistics and transportation, acceleration of machine learning speed, Improving real-time performance of searches,

etc. • Increase the scale of annealing-type quantum computers by creating a development environment that supports low-temperature electronics and 3D wiring design. • In the long term, we will develop machines that enable control similar to gate operations. We will also pursue development

Economic/Social Impact

- The learning speed of machine learning is accelerated, and only necessary items are learned while selecting the necessary learning (clustering)
- Significant performance improvements and processing speed improvements in AI inference, information processing, etc.
- Apply real-world problems such as control of small-scale automated guided vehicles and other moving objects and process schedules to combinatorial optimization problems.
- Start of application to real-world problems such as large-scale transportation logistics, marketing, streamlining manufacturing processes, network optimization, and autonomous driving.
- Solving social issues such as finding the optimal evacuation route in the event of large-scale traffic congestion or disasters
- Utilization for energy saving through optimization of manufacturing processes and networks, etc.
- Supporting work style reform through optimal job scheduling, facilitating recovery from accidents through real-time optimization of train diagrams, and on-demand transportation
- Real-time traffic optimization such as automatic driving support and evacuation route planning in the event of a disaster
- Emergence of a user environment that can be used without being aware of the hardware model
- Easier social implementation by lowering the cost of quantum annealing systems
- Weekly small group job scheduling
- Development of physical properties research
- Contributing to the development of new functional devices

technological progress

hardware systemization

- Manufacturing a 100-qubit annealing system with high coherence performance and excellent scalability
- 2,000 qubit production (improving coherence performance is essential)
- Manufacturing 2000 qubits with high coherence performance and excellent scalability (good solution for medium-scale combinatorial optimization)
- Realization of a large-scale quantum annealing machine (10,000 qubits or more) with high scalability and high coherence performance (good solution for medium- to large-scale combinatorial optimization)

Qubit integration

- Development aimed at significantly improving the coherence performance of qubits
- Evolution to general-purpose quantum computers
- Development toward large-scale integration of qubits
- Hybridization technology with classical computers

Manufacturing technology

- Development of 3D packaging technology for quantum circuits
- Development of bit integration technology using large-scale circuit manufacturing equipment
- Process manufacturing technology development for large-scale quantum circuits
- Yield improvement, evolution of mass production technology
- Technology to improve yield rate and stabilization technology

Control/ measurement technology

- Control technology using superconducting digital circuits and microwave devices
- Development of on-chip quantum classical interface integrated circuits using cryo-CMOS, superconducting digital circuits, etc.

Progress in peripheral technologies that support this technology

Refrigeration/ low temperature

- Cable connector microwave component integration
- Enlargement of dilution refrigerator system

technology Design support technology

- Quantum circuit layout design and development of operation simulation technology
- Automatic low-temperature test inspection technology for efficient selection of non-defective products

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

ÿSolid quantum sensor (diamond NV center, etc.)

• By realizing a compact, robust, ultra-sensitive solid-state sensor, it is expected to be used in magnetoencephalography measurement (medical/healthcare), extreme environments, life fields, etc. • 10-12T (Tesla) in 5 years, 10 years later Achieved observation of weak magnetic field at room temperature of 10-14T. Furthermore, we will establish technology to simultaneously measure temperature and current, etc. • In order to increase the sensitivity of sensors, we will develop advanced quantum state control technology and improve the quality of sensor materials.

Economic/Social Impact

Contributing to energy saving, safety and security, etc.
• Saving energy through high-precision control of power electronics and batteries, and improving safety through temperature monitoring •
Detection of trace amounts of foreign objects in foods, drugs, battery materials, etc.

Contributing to healthcare, medical care, and BMI through compact and wearable magnetoencephalography/neurometry • Elucidating the structure and function of the brain, immune mechanisms of the nervous system, dementia, depression, etc. • Uses in psychosomatic medicine and health through the spread of magnetoencephalography measurement systems , use in drug discovery • Electrode-free brain machine interface realized

Infrastructure, space, resource exploration, exploration in extreme environments using robust ultra-sensitive sensors • Failure prediction by monitoring infrastructure such as electricity • Use for oil and other resource exploration, space situation monitoring and exploration

Application to quantum cryptographic communication, quantum computation, and quantum networks: Realization of distributed and secret quantum computers connected by quantum entanglement

Development in the field of quantum life science: Contribution to medical care through cell screening using bio-nano quantum sensors, hyperpolarized MRI, etc.

technological progress

Solid-state quantum sensor (magnetic)

• Establishment of simultaneous temperature/current measurement technology • Environment-resistant (under high temperature/radiation) sensor • Biocompatible (non-cooled, non-toxic) sensor • Realization of cell measurement sensor

• Single molecule level biological dynamic measurements • Realization of room temperature, high spatial resolution NMR • Realization of quantum memory

• Realizes a compact and wearable biomagnetic measurement system • Realizes room temperature, high spatial resolution, and compact MRI • Realizes a robust ultra-sensitive magnetic sensor in extreme environments • Standard measurements using bio-nano quantum sensors and nano-quantum probes • Cell/biological measurements Contribution to efficient cell screening, etc.

Achieving sub-pT magnetic field sensitivity

Achieved 10fT wide-

Achieving ultra-high sensitivity in the aT region

quantum measurement

Realization of environmental spin-noise decoupling Development of

field high-precision synchronous quantum phase detection, realization of ensemble nuclear spin transfer Development of

Exceeding the shot noise limit Deepening integration with quantum optical measurement

device

electrical detection technology Development

current/spin injection technology Realization of quantum manipulation using spin waves, etc. Achievement of larger area and faster growth

material

of high orientation, high density, high coherence, and time processing technology High

efficiency Development of highly controlled electron/ion beam irradiation technology Single

photon source, quantum entangled light source Development of high-

Quantum relay Quantum network Deployment to quantum computation

performance, high-speed growth, research on emission centers other than NV centers Deepening of quantum

Quantum physics/theory

measurement principles and techniques using quantum hybrid systems Advanced quantum state control

such as quantum entanglement, nuclear spin hyperpolarization technology, phonon manipulation Realization of etc.

Development of high-sensitivity technology using quantum memory

Quantum relay using quantum memory Quantum network Integration with quantum computing

Elucidation of noise mechanism, demonstration of low-noise signal detection method, and highly efficient spin control method Development

Progress in peripheral technologies that support this technology

system

of 3D measurement inverse problem analysis technology (cell-neural tissue-brain function, etc.)

Application of AI deep learning, etc. (noise reduction processing, image recognition, anomaly sign detection, internal estimation, etc.) Microwave

Implementation/inte

antenna technology Development of integrated circuit technology Development of active shield technology Realization of on-chip technology

Development of shieldless technology

Realization of chip array

Development of nanophotonics integration technology

Advancement of optical technology (green VCSEL, high-performance high-sensitivity image sensor, etc.)

Current (2019) | 5 years later (2024) | 10 years later (2029) | 20 years later (2039)

Machine Translated by Google

ÿQuantum inertial sensor

• Achieved a navigation device that surpasses the accuracy of current devices. Ensuring multi-level safety for self-driving cars and ships, use for earthquake disaster prevention in combination with optical lattice clocks, etc. • Highly sensitive operation of gyros in a ship environment will be realized in 5 years, and a quantum inertial navigation system demonstration device will be developed in 10 years. • Demonstrate the principle of a cooled ion type gyro, and proceed with the establishment of technology for precisely measuring angular velocity under ship-level acceleration and rocking conditions for a cooled atomic type gyro.

Economic/Social Impact

- Improving the efficiency of marine resource exploration using autonomous unmanned underwater vehicles (AUVs) (enabling precise linking of resources with latitude and longitude information)
- Establishment of technology to safely navigate self-driving ships (advanced logistics) (countermeasures against piracy using GPS deception)
- Establishment of technology to ensure multiple safety in highly automated passenger transport (measures against terrorist acts using GPS deception)
- Technology has been established to measure geoid height changes in real time in the sea area around Japan using a ship, making it possible to assess the risk of plate earthquakes (in conjunction with optical lattice clocks and star trackers).
- Establishment of technology to ensure multiple safety for self-driving cars (measures against aging population) (measures against GPS failure/GPS deception), countermeasures against cyber attacks on connected cars
- Technology has been established to continuously acquire Japan's geoid in real time and space using probe cars, self-driving cars, etc., making it possible to evaluate risks including direct earthquakes.

*RLG: Ring laser gyro

technological progress

Cold atom gyro

- Demonstration of 1-2 orders of magnitude higher sensitivity than RLG
- Ship-level acceleration and highly sensitive operation under rocking motion
- Automotive-level acceleration and high-sensitivity operation under vibration

Cooled ion type gyro

- Achieves 1-2 orders of magnitude higher sensitivity than RLG
- Prototype demonstration of quantum inertial navigation device with two-digit higher positional accuracy than conventional technology

(Cold atom gyro / Cooled ion type gyro)

- Realizes a quantum inertial navigation device compatible with platforms with high mobility Position accuracy: 2 to 3 orders of magnitude higher (compared to conventional models) Size: 100L or less
- Realizes a quantum inertial navigation device compatible with a small, lightweight, and highly maneuverable platform Position accuracy: 2 to 3 digits (compared to conventional models) Size: 10L or less

Furtensol gravity gradiometer

- Sensitivity (10n/m/$\sqrt{\text{Hz}}$) prototype
- Operates under ship-level acceleration and rocking (10n/m/$\sqrt{\text{Hz}}$)
- Achieves high sensitivity operation (1n/m/$\sqrt{\text{Hz}}$) under ship-level acceleration and rocking
- Achieves high sensitivity operation (100p/m/$\sqrt{\text{Hz}}$) under ship-level acceleration and rocking

High precision High exercise resistance

- Established technology to separate acceleration and angular velocity from the output of a cooled atomic/ion interferometer under ship-level acceleration and rocking conditions.
- Established technology to separate acceleration and angular velocity from the output of a cooled atom/ion interferometer under automobile-level acceleration and oscillation.
- Demonstration of compact and portable atomic wave waveguide technology that guarantees high coherence
- Realization of highly sensitive gyro using cooled atomic wave waveguide
- Proof of principle of cooled ion type gyro
- Established basic technology to improve gyro sensitivity in a practical way using quantum entanglement (spin squeezing)
- Establishment of quantum entanglement technology compatible with atomic wave waveguide technology
- Achieving a compact and portable coherent continuous atomic wave source

Gravity gradient correction

- Introduction of gimbal structure to gravity gradiometer
- Miniaturization of gravity gradiometer considering application of quantum technology

Progress in peripheral technologies that support this technology

soft

- Establishment of hybrid quantum navigation algorithm
- Exploring quantum navigation based on new concepts

High performance

- Development of highly sensitive classical accelerometer
- Consideration of hybridization with quantum technology

Downsizing and portability

- Atomic source Downsizing and weight reduction of vacuum equipment
- Maturation of atomic wave waveguide creation technology
- Downsizing and weight reduction of light
- Minimization of light sources by introducing PLC technology, etc.
- sources Downsizing and weight reduction of control circuits

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

ÿOptical lattice clock

• By widely supplying ultra-high precision time to society, we will capture new time business markets such as next-generation communications and relativistic positioning. • Work to further miniaturize and popularize optical lattice clocks, and expand the use of atomic clocks. Demonstrate standardization and relativistic geodesy • In addition to developing elemental technologies to improve the precision of optical lattice clocks, proceed with elemental technology development that will lead to miniaturization, portability, and geodesy.

Economic/Social Impact

- Large-scale earthquake risk assessment (linked with quantum inertial sensors)
- Asynchronous high-speed, high-capacity communication •High-speed, high-precision advanced location information services (VLBI, radar, etc.) •High-speed optimization of power grid smart grid (stable operation in the event of a potential major disaster)

technological progress

light lattice clock

- Demonstrated optical lattice clock with 19-digit accuracy, which is 4-digits more accurate than conventional atomic clocks (with this accuracy, it is possible to detect height differences on the millimeter level)
- volumetric optical lattice clock device Downsized to 400L
- GNSS-independent spatiotemporal network, high-precision distributed system (18-digit accuracy) Real-time mapping of gravitational potential (cm order)
- Redefining the second using a high-precision optical atomic clock (18-digit precision)
- Field demonstration of relativistic geodesy (displacement observation on mm order)
- Optical lattice clock device downsized to 200L volume
- Portability of optical lattice clock device Lower price (spread)

Higher precision (higher reliability)

- Capturing atoms, miniaturizing cooling technology, and increasing reliability
- Uniform, zero magnetic field high precision control technology
- Highly stable and robust optical frequency control technology
- Improving the reliability of optical lattice clock devices
- Mass production technology for optical lattice clock devices

Geodetic/ mapping

- 19-digit optical lattice clock with long-term stable operation, high reliability, and unmanned operation
- Geodetic mapping system using optical lattice clock

Progress in peripheral technologies that support this technology

Downsizing and portability

- Higher performance, higher reliability, and stable supply of semiconductor lasers
- Narrow line width, highly integrated compact optical circuits Optical module technology, high reliability
- Compact and highly reliable optical-electrical circuit technology
- Uniform magnetic field high precision control technology
- Optical lattice clock device technology including in-vehicle use

networking

- Long distance optical link (1000km class)
- Optical lattice clock optical link repeater technology, higher reliability, lower cost
- Lower cost of optical fiber network

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

ÿQuantum entanglement optical sensor

• Contributing to a safe and secure society through advances in medical technology such as non-invasive observation of cells and precise measurement of retinal thickness, as well as highly sensitive detection of chemical substances. •

Volumetric resolution of 1 ÿm3 or less will be achieved with quantum OCT in 10 years . In addition, we have realized quantum infrared absorption spectroscopy up to the far infrared region using a visible light detector. • Development of

visible and infrared quantum entangled light sources, faster photon detectors, longer wavelengths in the infrared region, and integrated high-speed signals. Proceed with processing development

Economic/Social Impact

- Dispersion tolerance High-resolution quantum OCT will revolutionize the evaluation and inspection technology of transparent electronic devices (image elements and optical ICs), etc.
- Three-dimensional high-resolution quantum OCT enables in-situ observation of cells, contributing to the development of regenerative medicine, etc.
- Ultra-high resolution observation using quantum OCT enables early detection of diseases and contributes to healthy longevity.
- A compact dangerous goods identification device using mid-infrared quantum absorption spectroscopy will help create a safer and more secure society.
- Detection, identification, and analysis of chemical substances and drugs using far-infrared quantum absorption spectroscopy can now be performed anywhere, which will have a major ripple effect in environmental monitoring, drug manufacturing, medical care, etc.
- Quantum life science research spread to solid-state quantum sensors

technological progress

Quantum optical coherence tomography (quantum OCT)

- Realizes quantum OCT with a vertical resolution (1 ÿm or less) that is 3 to 5 times better than the current classical technology (OCT)
- Realizes 3D quantum OCT with volumetric resolution (1 ÿm3 or less), which is two orders of magnitude better than current technology (enables cell shape recognition)
- Realization of three-dimensional quantum OCT with volumetric resolution (0.1 ÿm3), which is three orders of magnitude better than current technology . Also realizes multifunctional quantum OCT, such as 3D measurement of concentration of specific substances.

Infrared quantum absorption spectroscopy

- Realization of quantum absorption spectroscopy in the mid-infrared region (2 to 5 ÿm), which eliminates the need for conventional infrared detectors (quantification of specific molecules)
- Achieves quantum absorption spectroscopy in the far infrared region (5 to 20 ÿm) (enables identification and identification of complex molecules)
- Miniaturization through modularization of quantum entangled light sources (A4 size)
- Further miniaturization (palm-sized) by making entangled light sources into chips, etc.
- Advanced functionality for infrared quantum absorption spectroscopic imaging, etc.

light source

- Increasing the intensity of quantum entangled light sources using waveguide-type quasi-phase matching elements
- Development of modular quantum entangled light source Development of far-infrared quantum entangled light source
- Development of quantum entangled light source integrated with excitation light source Development of semiconductor-on-chip quantum entangled light source

photon detection

- Longer wavelength and faster superconducting photon detector
- Realization of ultrahigh-speed signal processing by combining superconducting photon detectors and superconducting circuits
- Miniaturization of superconducting photon detectors
- Longer wavelength for upward conversion photon detection (mid-far infrared)
- Miniaturization of upward conversion photon detection and systemization as evaluation equipment (cooperation with quantum network)
- Arraying semiconductor photon detectors Higher sensitivity Higher speed

Image processing/ theory

- Creation of quantum entangled optical adaptive optics technology and fusion with AI technology
- Higher resolution Deepening of optical quantum sensing data processing to support multi-functionalization
- Quantum optics Nonlinear optics Development and deepening of optical quantum measurement theory
- Creation of new measurement and imaging methods Expansion of quantum entangled light wavelength range (X-ray terahertz)

Progress in peripheral technologies that support this technology

signal processing

- Advances in high-speed electrical processing technology such as photon detection signals (~50GHz) Development of new technologies such as superconducting circuits High-speed parallel signal processing of large numbers (~1 million) of detection signals

Light source/light

- Miniaturization and sophistication of excitation laser light sources On-chip optical circuit technology Progress in integration technology with laser light sources, etc.

low temperature technology

- Downsizing and lowering the cost of small cryogenic equipment for photon detectors (table-top)

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Ten

Machine Translated by Google

yQuantum spintronics sensor (tunnel magnetoresistive sensor/spin heat flow sensor)

•Tunnel magnetoresistive (TMR) sensor: Application to social infrastructure, buildings, farmland, and biological monitors by realizing safe, high-performance, and inexpensive magnetic field sensors with low cost and mass productivity Spin heat flow sensor: Information on heat flow It can be used and is expected to be used in heat-related industries such as plants and social infrastructure.

•In 10 years, power-saving, self-oscillation TMR sensors, compact, portable, matrix-type spin heat flow sensors, etc. will be realized. •Improvements in ferromagnetic tunnel junction fabrication technology, quantum rectification mechanisms and topological electronic structures based on spin will be realized. Proceed with the development of thermoelectric conversion technology using

Economic/Social Impact

Industrial applications include inspection of infrastructure such as tunnels, bridges, and piping, high-precision flaw detection on metal surfaces, and management of factory production line equipment.

Sensors are placed everywhere, such as automatic driving support and smart grid power monitoring. Connect to the cloud and use it as big data

Applications to healthcare such as simple human body function measurement, wearable sensing such as pulse waves and fetal movements

Achieving magnetocardial measurement and applying it to medical and healthcare

Realizing the measurement of brain magnetism, spinal magnetism, etc., and realizing the advancement of medical care

technological progress

TMR sensor (magnetic)

Achieved an inexpensive, high-performance, implantable magnetic sensor with high sensitivity and low noise Achieved electrical detection of 100

fT low frequency magnetic field

Achieved a magnetic sensor that can transmit data in any environment by saving power Achieved electrical detection of 10 fT low frequency

magnetic field

Realizes a sensor that combines multiple functions such as light and magnetism, vibration and magnetism, and heat and magnetism. NMR measurement is now possible, creating a system that can simultaneously measure the shape of the magnetic field Achieving

electrical detection of a 1fT low-frequency magnetic field

Higher sensitivity/ higher functionality

Development of high-performance tunneling magnetoresistive materials

Improving magnetic tunnel junction fabrication technology

Development of noise reduction technology

Improving the functionality of ferromagnetic tunnel junctions (development of elements with power generation function and elements with self-excited oscillation function)

Established mutual information transmission technology between ferromagnetic tunnel junctions and other physical

quantities Established NMR measurement technology using ferromagnetic tunnel junctions

A coherent magnetoresistive sensor is realized by realizing a tunnel magnetoresistive element incorporating NV centers.

Progress in peripheral technologies that support this technology

Design/control technology, etc.

Design of magnetoresistive characteristics Progress in control technology

Development of peripheral circuit technology to reduce noise Development of

uniform element processing technology

Fusion of single spin quantum sensor and magnetoresistive device Integration of power

supply and measurement circuit packaging/system cost optimization

Economic/Social Impact

Realization of abnormal heat flow detection Realization of smart air conditioning

Development of constant monitoring and operation optimization services for large-scale plants using heat flow sensor information (1 trillion yen/year in Japan) Use for infrastructure maintenance/ management, crime prevention/disaster prevention

Achieving disease prevention and detection Building a wide range of IoT infrastructure Data utilization services are being rolled out (several trillion yen/year in Japan)

technological progress

Spin heat flow sensor

Achieves a flexible thin film sensor (film) with dramatically low parasitic thermal resistance

Achieved heat flux sensitivity of 10mV/(W/m2)

Compact, portable, matrix-type, and other highly functional heat flow sensors

Realizes the key component of an autonomous sensing node that collects various sensing data including heat flux data Achieves large area/mass production

Achieves heat flux sensitivity of 100mV/(W/m2)

Achieving compactness and high integration through three-dimensional layering

Thermoelectric conversion element development and advancement

Exploring the Weyl structure of materials Development of thermoelectric conversion technology using spin-based quantum rectification mechanisms and topological electronic structures (spin Seebeck, anomalous Nernst effect, etc.)

Advancement of material development technology using AI

Progress in topological electronic structure control technology

Advances in manufacturing and packaging technology for thermoelectric conversion elements that surpass the conventional Seebeck effect and are inexpensive

Advances in technology that uses AI to obtain high-level environmental information from thermoelectric noise

Development of a self-contained environmental sensor element that has both thermoelectric conversion and heat flow sensor functions

Progress in sensor embedding technology that is in harmony with the environment

Progress in peripheral technologies that support this technology

Fusion technology etc.

Progress in dramatic cost reduction of cloud computing

Development of fusion with simulation technology such as real-time visualization technology of heat flow distribution Development of security

infrastructure monitoring technology by fusion of heat flow magnetic field information and AI

Development of medical diagnostic methods using weak heat flow and weak magnetic field

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

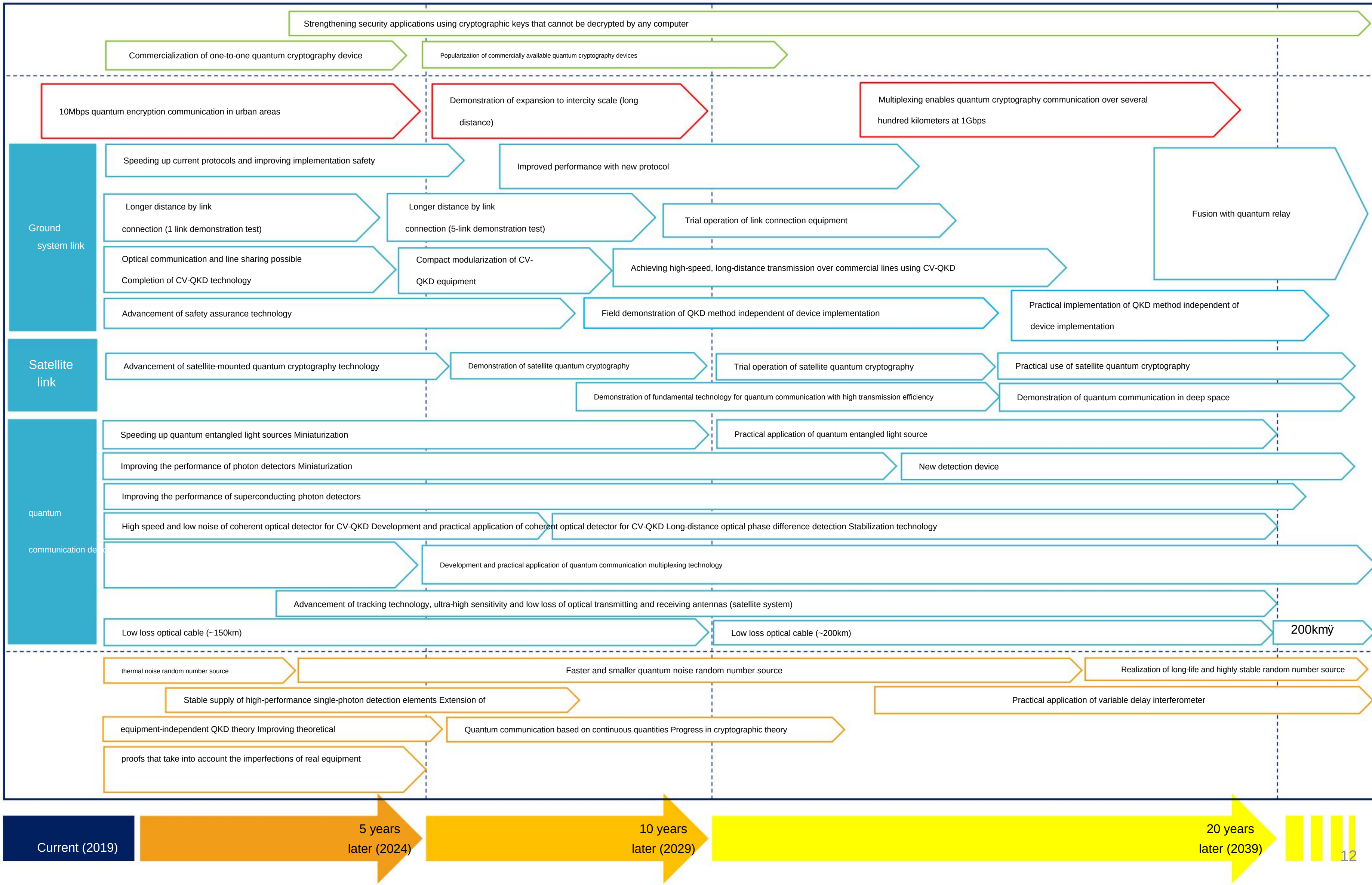
ÿQuantum communication/cipher link technology

• Enhance the safety of various security applications by commercializing quantum cryptographic devices • 10Mbps quantum cryptography communication in urban areas by 5 years, expansion to intercity scale (long distance) by 10 years Demonstration • Research and development of high-performance single photon detectors, quantum entangled light sources, random number sources, etc. In addition, research and development of new methods of QKD

Economic/Social Impact

technological progress

Progress in peripheral technologies that support this technology



Machine Translated by Google

ÿQuantum relay technology (quantum memory, quantum entanglement, etc.)

• Accelerate data processing by realizing secure quantum computation and distributed quantum computation using quantum internet connections.

• 3-point quantum entanglement distribution by 10 years, and 1 kbps using quantum entanglement distribution by 20 years. • Research and development of quantum memory implementation, quantum entanglement generation, connection technology with light, etc. to realize quantum repeaters.

Economic/ Social Impact

- Enables quantum encrypted communication by connecting users via the quantum internet Enables secure quantum
- calculations by connecting quantum computers and users via the quantum internet Enables distributed quantum computation by connecting quantum
- computers to each other via the quantum internet Quantum sensors connect to quantum computers Quantum sensor network becomes possible
- by connecting to the Internet

technological progress

quantum entanglement delivery

- Demonstration experiment of quantum relay function in field environment
- Improving operability, reducing costs, and ensuring stability of quantum relay using quantum memory Enables long-distance (>500km)
- Enables quantum entanglement distribution between three points via quantum relay
- quantum entanglement distribution via quantum relay Multi-body quantum entanglement at multiple points via
- Using quantum entanglement distribution, it is now possible to generate keys at a rate exceeding 1 kbps New

quantum entanglement

- Quantum entanglement generation between photons and quantum memory realized by light emission
- Quantum entanglement generation between quantum memories realized by light emission and light reception
- Quantum entanglement generation between quantum memories realized via communication photons
- quantum memory generation is realized
- applications that utilize global multipoint quantum entanglement have emerged

quantum memory

- Realization of quantum memory that achieves quantum media conversion and operability equivalent to semiconductor memory
- Achieved operational fidelity of over 99.9% for quantum entangled gates
- Quantum memory of 100 to 1000 qubits capable of individual quantum manipulation is realized Fault-tolerant logical
- Realization of a scalable and reconfigurable quantum relay system by combining quantum memory method and all-optical quantum relay method
- Quantum memory of about 10 bits with memory time of more than 1 minute realized
- Achieving complete bell measurement between different media
- quantum memory is realized by quantum encoding

quantum interface

- Quantum media conversion between photons and quantum memory realized
- Quantum media conversion between qubits and quantum memory, which perform quantum calculations, is realized
- Quantum entanglement distribution and connection with quantum computer and quantum sensor realized
- Progress in quantum wavelength conversion
- technology Progress in single photon fiber coupling technology
- Fiber modularization of quantum wavelength converter realized
- Wavelength multiplexed quantum communication realized by quantum wavelength converter

light source

- Realization of single photon source, quantum entanglement light source
- Progress in single photon sources and quantum entangled light sources
- Demonstration of all-optical quantum relay

Progress in peripheral technologies that support this technology

optical circuit

- Progress in quantum circuits using optical integrated circuits
- Non-destructive measurement of the number of photons and gate operation between photons are now possible
- Quantum communication experiment using new light source

System development

- Automate system calibration
- Progress in quantum authentication technology
- Improving the performance of control microwave lasers
- Modularization of quantum repeaters
- Long-term maintenance-free, including the quantum relay system's refrigerator

material development

- High purity and high functionality of diamonds, semiconductors, dielectrics, etc.
- Advances in microfabrication technology
- array integration
- Mass production of quantum relay element modules

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

ÿ Networking technology (construction, operation, maintenance, etc.)

• Build a quantum cryptography network that integrates terrestrial and satellite systems, a deep space quantum communication network, and a quantum internet to realize a secure and highly efficient network. • Urban area mesh by 10 years and global quantum cryptography by 20 years. Realize a network and demonstrate deep space quantum communication and quantum internet • Research and development on quantum communication/encryption networking technology and quantum internet infrastructure technology that makes full use of link technology and quantum relay technology

Economic/ Social Impact

- Introducing a quantum technology service platform that integrates functions such as quantum computing, quantum sensing, quantum communication, and cryptography
- A secure communication network covering all of Japan has been realized.
- Turning global quantum cryptography network into a service

technological progress

quantum middle Tsugi, quantum internet

- Demonstration of basic functionality of quantum internet
- Standardization of quantum internet connection specifications, routing, address management, etc.
- Trial operation with quantum internet testbed
- Establishment of elemental technology for quantum relay
- Development of quantum internet architecture
- Longer distance and multi-point quantum relay

Quantum cryptography network, quantum communication

- Practical implementation of global quantum cryptography network
- Trial operation of a global quantum cryptography network that integrates satellite and terrestrial networks Construction and trial operation of a
- Stable operation and practical use of metropolitan area quantum cryptography network
- metropolitan area mesh backbone quantum cryptography network between cities
- Deep space quantum communications, satellite-to-ground quantum communications interconnection
- Advancement of key management technology and quantum cryptography network control management technology
- Relaxing node safety requirements using next-generation quantum cryptography technology and improving resistance to service outage attacks through link redundancy
- Introduction of CV-QKD technology to access networks
- Installing quantum communication devices on satellite and developing architecture for satellite quantum communication networks

Progress in peripheral technologies that support this technology

Network control/ management technology and protocols

- Advances in software-defined network control technology and its introduction into the field of quantum communication and cryptography
- Advances in photonic network technology, lower loss in optical routing
- Progress in quantum multiparty protocol theory and development of implementation methods

satellite communication technology

- Improving the performance of satellite optical communication technology and accumulating space demonstration results
- Improved performance, miniaturization, and portability of optical ground stations
- Downsizing of satellite buses and progress in satellite constellation technology

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

Fusion area roadmap

• This roadmap is a compilation of prospects for the development of each area over the next 20 years or so in the quantum fusion innovation area, taking into account domestic and international research trends. • Each roadmap describes (1) the progress of the interdisciplinary field, (2) the technological system that supports the interdisciplinary field, and (3) the social and economic impact these will bring, with the aim of sharing future visions between the public and private sectors. It is one of the • Based on this roadmap, the government plans to strengthen research and development support for the quantum fusion innovation field. Based on these supports, etc., from the private sector We strongly hope that new investment and active participation will be encouraged, and that this will develop into a national industry-academia collaboration and public-private collaboration project.

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Machine Translated by Google

ÿQuantum AI technology

• Maximize the potential of AI by elucidating and demonstrating quantum mechanical elements in future neural networks and human learning mechanisms • Quantum AI systems that combine quantum infrastructure (quantum communication/internet, quantum sensors, quantum computers) • By combining machine learning (AI) and quantum information processing, we will build the basic principles of quantum machine learning, apply quantum AI methodologies to chemistry, materials, and physical property calculations such as materials informatics, quantum simulation, and control of quantum systems.
application

Economic/Social Impact

- The learning speed of machine learning is accelerated, learning only the necessary items while selecting the necessary learning (clustering)
- Significant performance improvements and processing speed improvements in AI inference, information processing, etc.
- Expansion of scientific and technological frontiers • Development in particle and condensed matter physics research • Application to quantum life phenomena
- New functional materials (academic understanding) •High-temperature superconducting materials •Artificial photosynthesis •Interfacial functions •High-efficiency catalysts •Photofunctional materials •Transport phenomena
- Advanced scientific and technical calculations •Thermofluid analysis •Inverse matrix calculation •Structural mechanics analysis •Linear system solver

Progress in the field

Annealer type hard/soft

- Application of Ising model to quantum machine learning
- Development of quantum AI functions from machine learning
- Elucidating the computability of quantum neural networks
- Application of quantum Boltzmann machine learning theory
- Establishment of calculation methods to accelerate AI
- Actual computational performance when facing NP-hard problems
- Application of classical impossible dynamics
- Academic exploration of the mathematics of quantum AI
- Challenging complex phenomena such as elucidating the mechanism of glass in nature
- Elucidation of quantum mechanical elements in human learning mechanism

Gate type hard/soft

- Development of quantum machine learning frameworks such as quantum circuit learning, quantum kernel method, and quantum generative models
- Construction of advanced quantum machine learning algorithms capable of exponential acceleration
- Application of quantum machine learning to real data and real problems
- Application of quantum AI approach to quantum control
- Building quantum machine learning by combining quantum sensing and NISQ machines
- Application of quantum machine learning combining quantum sensing and NISQ to quantum life science
- Application of quantum AI approach to quantum many-body systems (materials chemistry)
- Implementation of quantum machine learning using NISQ machines
- Quantum materials informatics and quantum chemoinformatics using quantum machine learning and quantum chemical calculations
- Performance evaluation of quantum machine learning algorithms
- Interfacing classical and quantum data: Building data structures
- Dequantization and construction of quantum-inspired algorithms
- Academic exploration of the mathematics of quantum AI (configuration of quantum models, information geometry of parameter spaces, development of parameter adjustment methods, analysis of representation ability and separation ability of quantum feature spaces)

Advances in technology supporting this area

Annealer type hard/soft

- Manufacturing 100 qubits with high coherence performance and excellent scalability
- Manufacturing 2000 qubits with high coherence performance and excellent scalability
- Realizing a large-scale quantum annealing machine with high scalability and high coherence performance
- Some combinatorial optimization problems can now be solved using annealing-type computers
- Annealing type computers begin to be applied to solve some real-world problems
- In combination with solver algorithms that solve linear programming problems and quadratic programming problems, annealing becomes an accelerator that can be applied to all optimization problems.

Annealer/ Gate common

- Establishing the fundamentals of quantum programming languages and compilers
- Accelerating compilers for larger scale Automation progresses

Gate type hard/soft

- Arbitrary control of physical qubits (approximately 50 qubits) is possible
- Arbitrary quantum control of physical qubits (approximately 100 qubits) becomes possible
- Quantum computers equipped with 500 to 1,000 physical qubits emerge
- Quantum computers equipped with quantum error-corrected logic bits (10 to 50) appear
- Demonstration of superiority of quantum-classical hybrid algorithm
- Design of quantum error correction architecture and demonstration of quantum superiority using actual equipment
- Emergence of architecture that enables programmable error correction
- Quantum open source software is available, enabling architectures that integrate quantum technologies

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

ÿQuantum life science (biological nanoquantum sensor)

• It will become possible to screen cells with specific properties and abilities, which is expected to lead to more efficient production of biopharmaceuticals and more efficient regenerative medicine. • Measurement range will be at the individual cell level in 5 years and at the individual organism level in 10 years. • Promote the expansion of measurable items, delivery technology to specific sites within cells, wide range observation, and development of deep biological observation technology.

Economic/Social Impact

Achieving efficient production of biopharmaceuticals and streamlining regenerative medicine through cell screening and cell quality control using biological nanoquantum sensors

AI diagnosis, wearable devices, and "quantum smart vesicles/quantum smart cells" enable early detection of various diseases, self-care at pre-symptomatic stages, and prevention of aggravation and recurrence.

Measurement using biological nano-quantum sensors has become the standard measurement technology for cell measurement and analysis in all bio-related industries, regardless of basic application.

By understanding "how matter becomes life" based on biodata infrastructure, it becomes possible to construct life from atoms and molecules, predict the behavior of life, and understand the evolution of life.

Progress in the field

Biological nano quantum sensor

Converting information obtained from a wide variety of cell types, physiological conditions, and measurement items into big data and unifying data interpretation International standards Comprehensive research to understand the molecular processes occurring within living cells Establishment of AI diagnostic technology Basic biology Build an open database for development (fusion of biotechnology and digital) Completely elucidate physically Commercialization of sensor reading system that targets the whole body and

Commercialized as a general research sensor kit for measurement purposes such as temperature and pH.

deep parts of the body. Promote research on cancer cell proliferation and metastasis, etc. Realize efficient screening technology for cells with specific properties and

abilities

Advances in technology supporting this area

Measurement items

Expansion of measurement items such as temperature, hardness, magnetic field, pH, amount of specific physiologically important substances, etc.

Build a system that reads data on a large

number of measurement items from a wide range of 3 or more simultaneous measurement items at once and tracks changes over time.

Development of a biological nano-quantum sensor that autonomously learns the items to be quantified and returns appropriate measurement information depending on the purpose (life phenomena or pathological conditions)

delivery technology

Developed technology to deliver to specific sites within cells (nucleus, mitochondrial membrane, etc.) Elucidated noise

Developing specific delivery technology for sensors at the whole body level, such as to tumors or specific organs

High sensitivity •Measurement range

mechanism, demonstrated low-noise signal detection method, and high-efficiency spin control method Number of cells:

approximately 5,000-10,000

Developed an ultra-wide-field optical detection magnetic resonance microscope that can measure large numbers of cells

Development of whole-brain imaging technology and whole-body measurement technology at the single-cell level

Achieved magnetic field sensitivity on the nanotesla order at the nanometer level

at once. Achieved sub-nanoTesla magnetic field sensitivity at the nanometer level.

Advancement of optical systems and high-frequency irradiation technology and realization of environmental spin noise decoupling

Development of multi-functionalization technology for biological nano-quantum sensors through 13C concentration and surface functionalization

Development and global expansion of integrated diagnosis and treatment technology through fusion with hyperpolarized MRI/NMR

Development of highly efficient and highly controlled electron/ion beam irradiation technology

Achieving observation of the deep parts of the living body of about

2 mm Development of sensor materials that emit light in the infrared region

Established a reading method that does not rely on fluorescence,

such as magnetic fields or sound waves, to enable whole-body measurements

Quantum manipulation technology for deep observation of 10 mm or more, deepening of the principles and technology of quantum measurement

Self-care medical application of "quantum smart vesicles/quantum smart cells"

Cell function artificial manipulation

Developing cell introduction technology for nanosystems/quantum nanosensors that control gene expression on and off

at a depth of about 10 mm. Developed fundamental technology for "quantum smart vesicles/quantum smart cells" that enable artificial control of cell functions .

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Machine Translated by Google

ÿQuantum life science (ultra-high sensitivity MRI/NMR using quantum technology)

• It is expected that drug screening will contribute to the development of new drugs, and metabolic imaging will be used to determine the effectiveness of deep cancer treatments, diagnose intractable diseases, and early detection. • In 5 years, drug screening using room temperature hyperpolarization and long-term visualization of metabolic processes will be realized. 10 years later, medical diagnosis will become a reality and clinical trials will begin. • Ultra-high sensitivity will be achieved through the development of hyperpolarization, quantum coding, nanosensor imaging technology, etc. We also developed hyperpolarization technology for various molecules.

Economic/Social Impact

High-speed drug screening based on molecular structure information has spread to biochemistry and pharmaceutical laboratories and drug discovery manufacturers, greatly contributing to new drug development.

Metabolic imaging has spread to biomedical science laboratories and has greatly contributed to the elucidation of biological phenomena and pathologies.

Immediately determines the effectiveness of treatment for cancers deep within the human body, such as pancreatic, prostate, and kidney cancers. Diagnosis of intractable diseases such as cardiovascular and brain disease diagnosis is also possible.

Safe and environmentally friendly nano-contrast technology has been put into practical use as a contrast agent

Through easy and evidence-based diagnosis using MRI using hyperpolarization, nano-contrast imaging, and AI technology, we will realize a social system that seamlessly performs early detection at the pre-symptomatic stage and prevention of severe disease and recurrence.

Progress in the field

Room temperature hyperpolarization technology

Room temperature hyperpolarized biomolecular structure

analysis Room temperature hyperpolarized drug screening

Realization of long-term metabolic process visualization using quantum coding

Room temperature hyperpolarized drug efficacy pharmacology kinetic study

Realization of room temperature hyperpolarized metabolic imaging in large animals

Realization of biomolecular analysis and in-vivo analysis using large-scale quantum entanglement of various molecules

Conducting clinical trials to determine the effectiveness of anticancer drug treatments using room temperature hyperpolarized probes

Low temperature hyperpolarization technology

Metabolic imaging of long-lived probes achieved by high-polarization and low-temperature hyperpolarization

Practical application of biological metabolic imaging through the development of polarization technology that contributes to lower costs

Conducting clinical trials of high-speed disease diagnosis technology using hyperpolarized probes/sensors of various molecules

Clinical application of hyperpolarized probes/sensors for various molecules

composite technology

Nanosensor contrast material and hyperpolarization technology enable clear observation of early stage cancers of 1 mm or less and pancreatic cancer deep in the body, which is difficult with conventional methods.

Using multivariate measurement and AI analysis using hyperpolarized nanosensor contrast material, we have established technology for in-situ pathological diagnosis and cancer onset prediction that does not require a cancer biopsy.

Advances in technology supporting this area

Hyperpolarized probe

10,000 times higher sensitivity for small-volume samples 1,000 times higher sensitivity for large-volume samples

10,000 times higher sensitivity for large-volume samples

Large capacity, 10,000 times higher sensitivity for multiple molecules

Room-temperature superpolarization of pyruvic acid for anticancer drug efficacy determination

Development of hyperpolarization technology for various molecules

Development of high-polarization, long-life molecular probes Practical use of longer-life probes

Development of quantum encoded sensor technology

Development of quantum encoded entanglement sensor technology

Development of more advanced quantum encoded sensors by utilizing large-scale quantum chemical calculations using quantum computing and quantum AI Development of highly sensitive magnetic resonance devices that

Hyperpolarization device

Development of a small-capacity, room-temperature hyperpolarization device Development of a low-cost, low-temperature hyperpolarization device with high polarization rate

combine hyperpolarization and small magnets Development of devices for social implementation Improvements such as increased capacity, improved polarization efficiency, lower price, and GMP compliance

Nanosensor Contrast technology

Developing nanoparticle delivery to lesions and imaging technology to develop multiple nanosensor contrast agents

Clinical application development of nano-contrast technology

Algorithms and databases

Pathology estimation algorithm using multivariate measurements Developed a database for the purpose of automating pathological estimation of cancer, brain diseases, etc.

Realizing pathology estimation technology using multivariate measurement, nano-contrast technology, and AI

Establishment of information technology that enables "MRI pathological diagnosis" using large-capacity multivariate image analysis

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Machine Translated by Google

ÿQuantum life science (elucidation and imitation of quantum life phenomena)

• By realizing technology that mimics biological functions such as photosynthesis, it is expected to contribute to energy saving, production of useful substances, sustainable primary production, improvement of the global environment, etc. • In 5 years, the functionality of quantum effects will be elucidated at the molecular level, 10 Expansion to the cellular level in 2020 • Proceed with integrated analysis using information science, measurement of quantum states in living organisms, dynamic structure analysis of biomolecules, such as quantum coherence in photosynthesis

Economic/Social Impact

- Achieving ultra-efficient and low-cost drug discovery by simulating biological reactions to candidate substances Imitating the sense of smell Ultra-early disease detection using improved ultra-sensitive substance sensors
- Imitating and improving the enzyme functions of fermentation microorganisms and medicinal plants to create high value-added foods. Create useful crops through smart breeding that controls mutations at the quantum level and contribute to sustainable primary production.
- By imitating living organisms and using common elements, artificial photosynthesis, artificial enzymes, and ultra-energy-saving fertilizer production, etc., we will produce sustainable energy that is both economical and environmentally friendly, and produce useful substances (biofuels, biomaterials, biopharmaceuticals, etc.)) production and agricultural production Spread and improve the global environment Elucidation of the most fundamental academic question, "How
- do materials come together to form life?" Reconstruction of life from atoms and molecules and the behavior of life It is now possible to predict (human consciousness, etc.)

Progress in the field

Elucidation of life phenomena in the nanoscale world that can only be explained by quantum physical laws and the mechanism of their spread to the macroscale world

Development and commercialization of technology that mimics biological functions

Elucidation and imitation of quantum theoretical life phenomena

- Mechanism elucidation at the quantum to cellular level such as photosynthesis, respiratory chain system, biological nitrogen fixation, etc.
- Elucidation of the mechanisms of environmental reception such as olfaction and magnetism at the quantum to cellular level
- Elucidation of the mechanisms of mutation, evolution, and gene expression at the quantum to cellular level
- Precise elucidation of molecular interactions such as enzymatic reactions and information transmission by receptors
- Mechanism elucidation based on quantum to individual level measurements of brain functions arising from various neural circuits
- Organs Elucidation of the mechanism of spread to the individual level Realization of artificial photosynthesis systems, solar cells, and ultra-energy-saving nitrogen fixation technology that imitate the mechanisms of biological functions and used elements Development of olfactory sensors, etc., and application to detection of pathogenic substances, etc. Quantum effects Development of material production technology using controlled artificial enzymes
- Prediction of brain function

Advances in technology supporting this area

quantum state measurement

- High-precision observation of quantum coherence in photosynthesis and respiration using ultrashort pulse lasers, quantum measurement of biological nitrogen fixation reactions, Spectroscopic analysis of quantum effects in biological
- magnetic and olfactory receptor mechanisms
- Molecular design that mimics biological functions using quantum effects
- Measurement and theoretical analysis of quantum superposition states in DNA mutations, enzyme reactions, etc.
- Quantum measurement of biomolecules by pump-probe method using high-intensity synchrotron radiation soft X-rays Theoretical calculation
- of wave functions of biomolecules

Dynamic structure analysis of biomolecules

- Neutron structure analysis system capable of molecular structure analysis with high resolution of 1 or less
- Quantum-level structural analysis combining X-ray complementary data, expanding the analysis target to high molecular weights of 100,000 or more
- Seamless high-precision dynamic structural analysis that integrates quantum-level structural analysis and experimental dynamics analysis with quantum simulation analysis
- Structural analysis of supramolecular sub-resolution and sub-picosecond time division in a wide variety of biological species Quantum chemical
- calculations for over 100,000 electron orbitals in 1 to 2 hours

Information science

- Build an open database for unified analysis of biodata from each level of living organisms obtained using new measurement technology Application of quantum probabilistic framework to life sciences
- •Integrative analysis of biodata using information science •Chemical understanding of life functions based on the understanding of material functions and chemical reactions deepened by quantum computers •Life science applications of quantum sensing and quantum machine learning using NISQ ÿ System Toward an understanding of life phenomena as

Current (2019) → 5 years later (2024) → 10 years later (2029) → 20 years later (2039)

Machine Translated by Google

ÿQuantum security technology

• Realization of use by early adopters such as government agencies and high security communication services for corporate users and general users • Realization of quantum secure cloud by 5 years, integration of quantum secure cloud and legacy authentication infrastructure by 15 years • Promote the organic fusion of quantum cryptography technology and security technology that does not depend on the amount of calculation (secret sharing technology, etc.), and link these with authentication infrastructure.

Economic/Social Impact

- Use by Arya adapters such as government agencies
- Used in cases requiring high security
- Global high security communication service launched
- Launch of high security communication service for corporate users
- High security communication service launched for general users
- Practical implementation of communication protocols using quantum entanglement, application to higher precision of GNSS, higher security, higher precision of VLBI, etc.
- Safe and convenient communication commerce based on preshare quantum random numbers
- Quantum secure cloud service, establishing a data storage and exchange platform that will be unbreakable even 100 years from now

Progress in the field

- International standardization of quantum cryptography
- International standardization of quantum security technology
- Standardization of quantum cryptography network framework, security evaluation, and key supply API
- Establishment of standards for integrated architecture between IP networks and quantum cryptography networks
- Formulation of operational guidelines and commencement of certification by certification bodies and third-party organizations
- Establishment of operational guidelines for connection specifications between autonomous networks in quantum secure networks, route control, address management, authority management, etc.
- Realization of quantum secure cloud (quantum cryptography + secret sharing)
- Expansion of quantum secure cloud (intercity scale)
- Integration of quantum secure cloud and legacy authentication platform, and expansion to cover all of Japan

Advances in technology supporting this area

Security technology fusion, application creation

- Quantum Communication Organic fusion of cryptography, modern cryptography, and network technology
- Basic theory of multipoint quantum secure networks
- Multipoint quantum secure network architecture
- Expansion of multipoint quantum secure networks incorporating quantum relay and quantum multi-party protocols, test bed demonstrations, and establishment of quantum security technology infrastructure
- Maturity of secret sharing technology
- Progress in secure computing technology
- Improving the performance of key distillation processing (error correction + secrecy enhancement)
- Quantum communication of classical cryptographic functions such as quantum signatures and quantum mutual authentication
- International standardization of quantum-resistant computer cryptography
- Transition to quantum-resistant computer cryptography and launch of services with the advancement of quantum computers in mind

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Reference materials

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Trends in other countries surrounding quantum technology

• Overseas, particularly in the United States, Europe, and China, "quantum technology" is positioned as an important technology that will bring major changes to the economy and society, and governments are taking the lead in formulating research and development strategies. In recent years, we have significantly expanded our R&D investments and strategically expanded our R&D base formation and human resource d

•Major IT companies in various countries are also actively investing, and venture companies are also being established and raising funds.

•Government initiatives

ü In September 2018, the National Science and Technology Council formulated a national strategy outline for quantum information science. ü In December 2018, a law was passed regarding investments of up to $1.3 billion (approximately 140 billion yen) over five years starting in 2019 (Excluding DOD and CIA) ü Formation of around 10 bases for research and development and human resource development, mainly at DOE and NSF.

ü In June 2017, the European Commission 's expert panel formulated an R&D strategy. ü In the 10 years starting in 2018, In addition to launching projects worth around 125 billion yen, each country carries out research and development using its own budget.In particular , countries such as the Netherlands and Great Britain are forming international research centers. Attracting private investment

ü In the 13th Five-Year Plan for Science, Technology and Innovation (2016) , quantum communications and quantum computers are positioned as important science and technology projects, and we are actively investing in them ü We are building a national laboratory for quantum information science in Hefei City, Anhui Province. Under construction at a cost of 7 billion yuan (approximately 120 billion yen) (scheduled for completion in 2020) üFocusing on efforts in the cryptography and communication fields, such as quantum cryptography using satellite communications

• Efforts by representative companies

<Major IT company>

Established

Google Quantum Artificial Intelligence Research Institute (2013-)

IBM

Research investment of $3 billion over 5 years (from 2014)

Microsoft

Established Station Q (2005-)

阿里巴巴 Alibaba **(Alibaba)**

Established quantum computing laboratory at Chinese Academy of Sciences (2015~, 30 million yuan/year)

<Venture>

D-Wave The Quantum Computing Company

Launched **the world's first commercial quantum annealing machine .** Raised $200 million.

rigetti

Developed a superconducting quantum computer. Raised **approximately $120** million.

Note: Exchange rates are calculated based on the standard foreign exchange rate and arbitrage foreign exchange rate announced by the Minister of Finance of Japan for the month in question at the time of announcement.

As global competition intensifies, we are at a crossroads in how to promote quantum technology

Machine Translated by Google

Current status of Japan's quantum technology efforts

•**Quantum technology was positioned as an important fundamental technology for the first time in the Fifth Science and Technology Basic Plan, but**

Subsidiary technology strategy has not yet been formulated. Each ministry conducts research and development individually.

•**Japan has advantages in basic theory and basic technology, but there are challenges in efforts toward practical application and industrialization (systemization) of technology.**

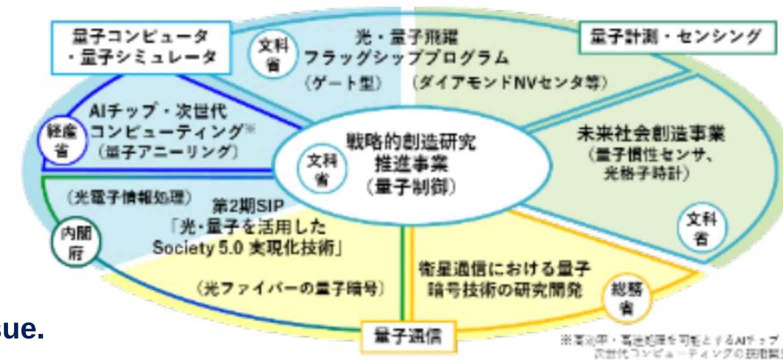
• In the 5th Science and Technology Basic Plan (Cabinet decision in January 2016), the integrated innovation strategy is positioned as optical/quantum technology for the first time

(Cabinet decision in June 2018) . Because it is an innovative technological field that makes possible what was previously impossible and brings about changes in society , research and development is actively underway in Europe, the United States, and China. **In order to** realize Society 5.0, Japan will work to maintain and improve the international competitiveness of optical and quantum fundamental technologies, in which Japan has strengths.

• Each ministry carries out research and development individually.

ü Cabinet Office Quantum Cryptography (Optical Fiber), Optoelectronic Information Processing ü Ministry of Internal Affairs and Communications Quantum Cryptography (Satellite Communications)

ü Ministry of Education, Culture, Sports, Science and Technology Quantum Information Processing (Gate Type), Quantum Measurement/ Sensing ü Ministry of Economy, Trade and Industry Quantum Information Processing (Quantum Annealing)



• Japan has an advantage in basic theory, etc., but systemization of technology is an issue.

1998Professor Hidetoshi Nishimori (Tokyo Institute of Technology) and others publish a paper on "quantum annealing method" as a quantum calculation method

2010Canadian venture company D-Wave announces the world's first commercial machine

(Source: D-Wave)

1999 Yasunobu Nakamura and Chao-Shin Cai (at the time at NEC) published a paper on quantum bits using superconducting circuits.

2016 IBM releases the world's first gated quantum computer to the cloud

(Source: IBM)

If things continue like this, we will fall far behind other countries and the foundations of the country's future growth will be threatened.

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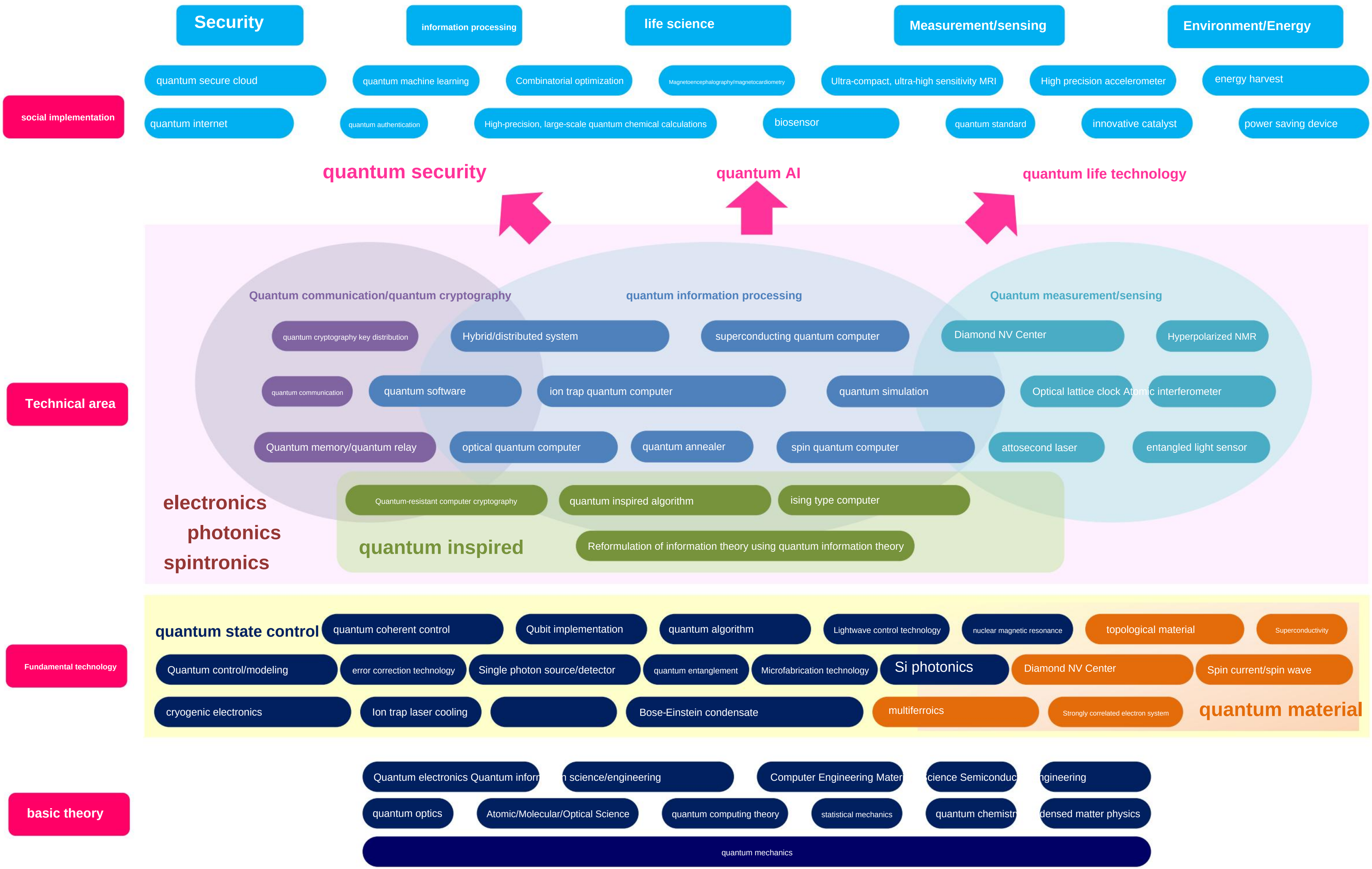
Scope of technologies covered by the "Quantum Technology Innovation Strategy" (draft)



Machine Translated by Google

Main technology area ÿ Quantum computer/quantum simulation

•Although there are technical challenges in realizing gated quantum computers and quantum simulations, they contribute to streamlining the development of novel materials and drugs and improving security technology, resulting in dramatic innovation in all fields of industry and society. • Quantum annealing brings about this , **and there is active movement toward solving real problems, including in companies. By solving combinatorial optimization problems, which is our spe**

Contributing to productivity improvements by eliminating traffic congestion and optimizing factory production processes.

Gate-type quantum computer (superconducting qub...)

ü **Computers that use quantum mechanical states as units of information processing (qubits) ü Japan was the first in the world to succeed in producing superconducting qubits . Maintains high technological capabilities in** the production and control of high-quality superconducting qubits

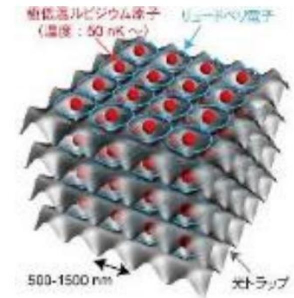
ü Large scale with high quality superconducting qubits

assignment

ü It is expected that large-scale massively parallel computing will make it **possible to calculate problems such as factorization, search, and quantum deep learning in a short time and with** ultra-low qubit cooling and control equipment costs (Professor Nakamura, University of Tokyo)

Quantum simulation (cold atoms)

ü Technology for conducting simulation experiments by controlling the quantum states of many artificial particles **for** problems specific to the behavior and interactions of quantum many-body systems **ü Japan is engaged in theoretical research on strongly correlated electron systems. Leading the world ü** There are challenges related to **implementation of long-range interactions between multiple atoms, etc.** ü Expected for **theoretical elucidation of quantum many-body physics and high-temperature superconductivity .** Expectations for the spread of peripheral technologies such as light and cooling



Concept of ultrafast quantum simulator
(Professor Omori, Institute for Molecular Science)

quantum software

ü Research and development of the OS, system architecture, algorithms, and applications required to perform calculations on quantum computers

ü In **addition** to universities and research institutes, **development is being carried out in both gate-type and annealing-type mainly by venture companies. Intensification**

ü **Expectations for innovation in industry and society due to faster and larger-scale** quantum calculations such as machine learning and quantum chemical calculations

Quantum computer hardware/ software hierarchy

quantum annealing

ü Using quantum mechanical "superposition" to derive the optimal combination

A **computer** specialized **for**

—

Quantum annealing machine developed by D-Wave (Canada) (Source: D-Wave)

Inspired hardware development becomes active ü Efforts to solve real-world problems such as traffic problems take the lead

Machine Translated by Google

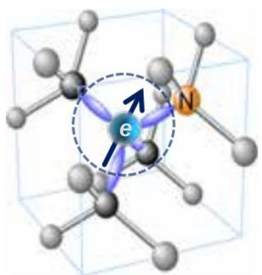
Key technology area ÿ Quantum measurement/sensing

•**Quantum measurement/sensing is a technology that takes advantage of the fragility of the quantum state to achieve sensitivity and accuracy that exceeds conventional technology.** Contribute to the creation of a safe and secure society through improvements in **life and medical** technology, such as a healthy and long-lived society and disaster prevention.

solid state quantum sensor

ü**Highly sensitive magnetic field sensor that utilizes electron spin states.** Compared to **conventional** magnetic field measurement methods (Hall elements), high sensitivity (100,000 **times) and high spatial resolution (approximately 100 times) are achieved at room temperature ü Japan has strengths in material manufacturing technology .** Comprehensive research and development is required from basics to device development.

ü Expectations are high for **healthcare, safe driving, prevention and treatment of brain diseases,** etc. through advanced measurement of **brain magnetic** nerve fields.



quantum inertial sensor

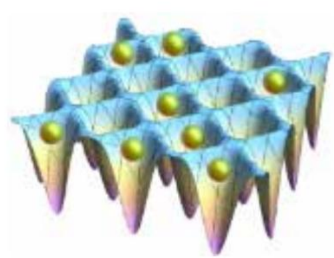
ü**A** sensor that measures acceleration and rotational speed using the wave nature of atoms . **Expected to improve accuracy by two orders of magnitude over the** currently widely used ring laser gyro **ü While Japan has a high level of optical technology, it remains at the proof of principle ,** and it is important to make it smaller and more portable for practical use **ü** GPS **For example ,** it is possible to realize fully self-driving cars and autonomous unmanned underwater vehicles (AUVs) that can confirm one's location and reach a destination even without a signal.

(Source: JAMSTEC)

light lattice clock

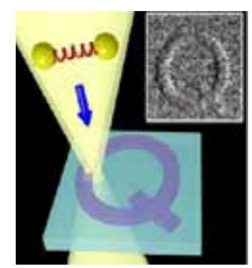
ü **A clock that uses laser light to measure time with precision several orders of magnitude higher than conventional atomic clocks ü Japanese researchers propose a principle. Japan's optical lattice clocks lead the world in accuracy** and continuous operating time. **Further downsizing and portability Improving environmental resistance is important**

ü **Candidate for a new definition of the second ü Earthquake** measurement by measuring weak gravitational changes Expected to be useful for disaster prevention related to volcanoes and verification of constancy of physical constants



entangled light sensor

ü Highly sensitive sensor that utilizes quantum entanglement , which has an effect even when two photons are separated **ü Japan has realized a high-quality, high-intensity entangled photon source, and** proof of principle for practical applications is now underway. It is being done. **ü**It is possible to create **highly sensitive compact infrared spectrometers necessary for** non-invasive observation of cells, **precise measurement of tissue thickness such as the retina, and** drug manufacturing management at chemical plants.



Machine Translated by Google

Key technology area ÿ Quantum communication/ciphering

• Quantum cryptography provides an absolutely unbreakable cryptographic service, so highly confidential information can be accessed without fear of compromising security.

A society where people can communicate on the Internet will be realized.

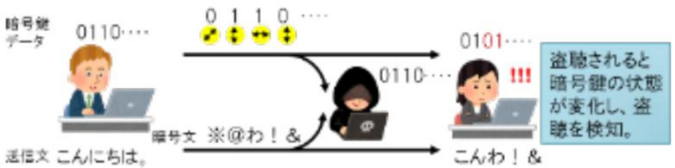
Quantum Cryptography | Optical Fiber

ü **Encryption key data is loaded onto photons and the quantum key is delivered via optical fiber .**

The only encryption method **that detects all eavesdropping attacks and has proven information-theoretic security.**

ü**Japan 's strength is high-performance quantum cryptography equipment. On the other hand, issues include lower prices and integration with applications.**

üIt is important to develop a unique **system** in Japan that combines data storage and confidential calculations and connect it to social implementation.



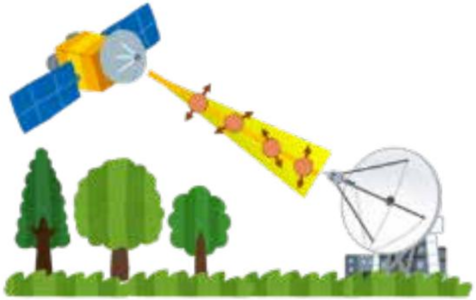
Quantum cryptography | Satellite communication

ü **Perform quantum key distribution between satellites and between satellites and ground stations, ar**

Technology that enables highly confidential communication in

ü In Japan, we will develop **the world's smallest microsatellite in the field of optical communications** and conduct preliminary experiments. **ü** To realize this technology, we will develop high-speed photon transmission , **high-precision laser capture and tracking technology, etc.**

Important



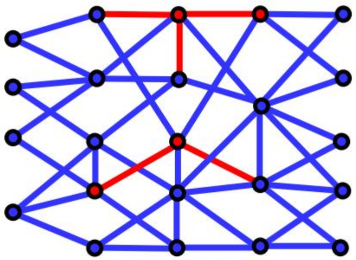
quantum communication

ü **For transmission and control of photon superposition, quantum entanglement, etc.**

Technology that realizes ultra-high efficiency communication

ü **Issues include development of network architecture and integration, and research and development of quantum receivers for ultra-high efficiency communication.**

ü**In** addition to ultra-high-efficiency communication, it is also expected to be applied to methods of transmitting quantum **information** to quantum computers.

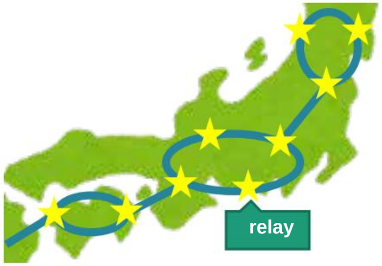


quantum relay

ü**Quantum cryptography has a limited communication distance of about 100km due to optical loss.**

Currently, relays are carried out using classical methods that do not allow eavesdroppers to physically intrude , **and theoretically safe relay technology has not been established .**

There is a technology that can be a strength in the integration of quantum relay devices. ü On the other hand, there are issues such as transmission speed and error correction **that need to be addressed from a** long-term perspective.



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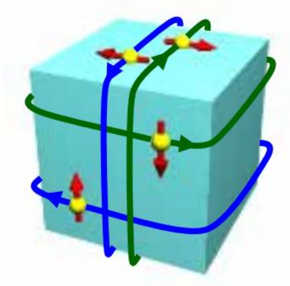
Key technology area ÿ Quantum materials

• Advances in nanotechnology have made it possible to control things on the single nano-order and atomic layer level, making it possible to access quantum phenomena that were previously unobservable. • **Control of these phenomena will enable not only innovations such as quantum information processing but also current technologies such as energy conversion and electronics innovations. It is expected to achieve a level of functionality that is impossible to achieve at the technical level.**

topological quantum matter

ü Highly efficient spin-to- **charge conversion is possible** by utilizing **topological insulators, which are new materials that are insulators in the bulk but metal on the surface . ü Furthermore, Majorana particles, which are topological superconductors,** are expected to be used as robust quantum bits, and research is being carried out around the world. **ü Contribute to the realization of ultra-low power consumption devices and new types of quantum computers**

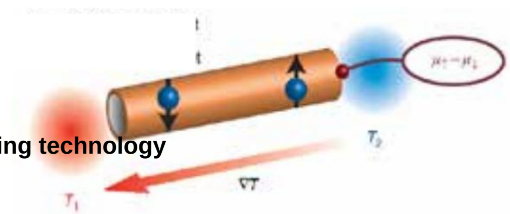


topological insulator

energy conversion materials

ü Utilizes the spin Seebeck effect, which is a thermoelectric effect caused by spin-charge conversion

ü Enables thermoelectric conversion that can be produced at low cost in large quantities, and multi-source energy harvesting that obtains energy from heat, vibration, light, etc. with a single device **ü Energy Contributing to the realization of power-free IoT sensors using harvesting technology**

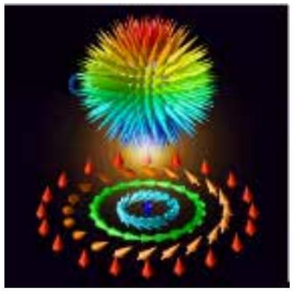


spin Seebeck effect

spintronics materials

ü Research is progressing on skyrmions, which are nanoparticles consisting of multiple spins, as they can be used as information carriers that can be driven with a small amount of current. Enables **ultra-low consumption and large-capacity memory**

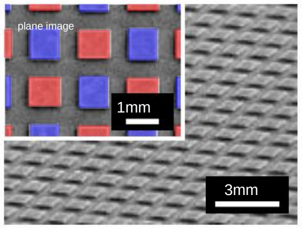
contribution



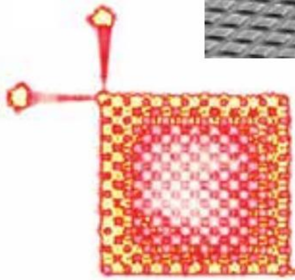
Skyrmion

photonics materials

ü **Development of high-efficiency lasers using new concepts such as single-photon emission from quantum dots and topological photonic crystals** is progressing **ü Also, by using metamaterials, devices and devices that exceed optical limits are being** developed. Achieves **electromagnetic wave shielding ü Contributes to the realization of energy-saving light sources and next-generation quantum communications**



metamaterial



topological photonic crystal

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Quantum fusion innovation area ÿ Image of quantum AI technology

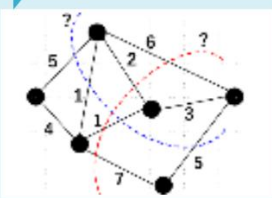
•Advanced artificial intelligence is an important key to realizing Society 5.0. AI is being deployed one after another in the real world, and we need to support this development in the future. The development of next-generation computing technology will also be an important factor in achieving this goal. •

Machine learning is attracting attention as a candidate for the killer app for quantum computers. It has been pointed out that in the future, when quantum computers become more sophisticated, they may have an advantage. Lead the world by carrying out intensive research and development ahead of the rest of the world.

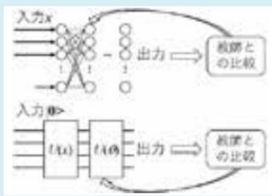
Unsupervised learning/Supervised learning

ü We are developing initiatives that will contribute to practical applications with the aim of developing unsupervised learning, supervised learning, and reinforcement learning based on QAOA and quantum circuit learning as a computational base. ü Expectations are high for fields such as image diagnosis, materials development, and drug discovery.

Contributing to the realization of artificial intelligence based on large scale and complex data



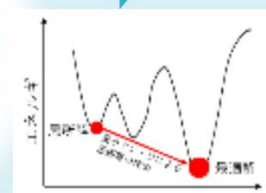
Example of MAXCUT problem (unsupervised machine learning)



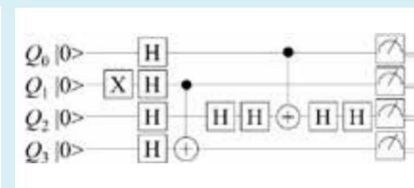
Comparison of neural networks and quantum machine learning

New algorithm development

ü Develop new algorithms that will lead to more advanced and highly accurate artificial intelligence ü Evaluate and verify the performance of the developed algorithms, including quantum superiority, using quantum computers, etc. Application of quantum computers to AI Achieved expansion of usage



Principle of Ising machine solution



Quantum computer gate operation image

Quantum technology quantum algorithms, quantum computers etc...

×

Information science machine learning, system architecture, etc...

system architecture

ü Identify areas where quantum **computers** are good at information processing in artificial intelligence ü Optimize computational resources of quantum computers and modern computers

Contributing to the advancement and precision of artificial intelligence

Cooperation image

Using quantum AI technology, we will realize faster and more accurate artificial intelligence, which is the key to economic and social development, and contribute to the creation of highly competitive industries and the resolution of Japan's various issues!

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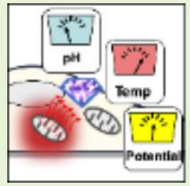
Quantum fusion innovation area ÿ Image of quantum biotechnology

•**With the recent development of quantum technology, quantum technology is being applied to life science, and the knowledge gained by elucidating life phenomena using quantum theory. Research aimed at linking these observations to innovations in medical and environmental technology is beginning to begin.**

• Important innovations will be brought about, such as the realization of a healthy and long-lived society through ultra-early diagnosis and treatment, anti-aging, and the creation of highly functional materials that **imitate** the quantum effects of living organisms such as quantum entanglement and superposition. **There is great potential, and we need to be the first in the world to tackle this issue.**

Biological nano quantum sensor

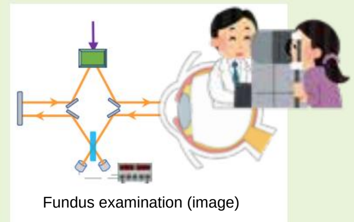


Diagnosis with single cell accuracy (image)

ü Applying nano-quantum sensors to living cells ü It is now possible to obtain parameters inside cells and cell tissues that were previously impossible to measure, such as local pH, temperature, and current, such as the nucleus and mitochondria.

New diagnostics such as aging status and pre-prediction of cancer have been realized.

Quantum entangled optical imaging


Fundus examination (image)

ü Imaging quantum entangled light

Utilization ü High sensitivity exceeding the S/N ratio of conventional l High-definition measurements enable detailed observation of capillaries, etc.

Realizing ultra-early diagnosis of ophthalmological diseases and arteriosclerosis

Quantum technology

quantum entanglement, superposition, tunnel effect, etc...

×

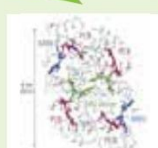
Life science

Structural biology, cell biology, developmental biology, etc...

quantum biomimetics

ü Elucidation of the mechanism of "quantum effects" that enable living organisms to have a high sense of smell and highly efficient photosynthesis and respiration ü Provide **clues for the development of** olfactory sensors that surpass drug detection dogs and artificial photosynthesis

Highly sensitive detection of drugs and explosives and realization of artificial photosynthesis


A light-harvesting protein that achieves 100% energy transfer through the “superposition effect”

Hyperpolarized nuclear magnetic resonance technology

ü Utilizes spin-polarized compounds that align the direction of nuclear spins in MRI examinations ü **Sensitivity is more than 1,000 times higher than conventional methods.** Enables **shortening of MRI examination time and real-time** metabolic imaging


Innovative MRI diagnostic technology

Introducing MRI examinations into health checkups and determining the effectiveness of cancer treatment

Contributing to the realization of a healthy and long-lived society and the innovation of environmental technology through quantum biotechnology!

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Quantum fusion innovation area ÿ Image of quantum security technology

•In recent years, studies have been conducted on quantum-resistant computer cryptography, which is difficult to break even with quantum computers, and on transition technology from the current public key authentication
It's becoming more active. In addition, secret sharing and secure computation for cloud services are being put into practical use.

•By integrating these technologies with quantum cryptography, it is possible to realize "quantum security technology that has ultra-long-term confidentiality, tamper resistance, availability, and computational capabilities," creating a cyberspace with robust security for the future. be able to.

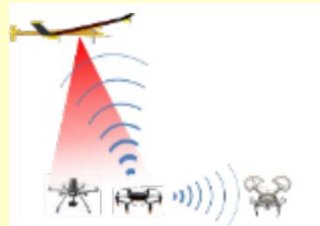
quantum secure cloud

(Source: NICT)

ü Integrates quantum cryptography, secret sharing, secure computation, and quantum-resistant computer cryptography ü Prevents eavesdropping and tampering in the future, and executes calculations while maintaining confidentiality

Achieving data backup with business continuity and safe secondary data usage, reducing social security costs and creating new services

adaptive physical layer cryptography



ü Developed wireless encrypted communication technology based on the quantum and electromagnetic properties of light and radio waves ü Achieved information-theoretically secure encrypted communication using the optimal **electromagnetic wave** band depending on the communication channel conditions

IoT devices, drones, etc. provide services that allow high-speed and safe communication anytime, anywhere.

Quantum

cryptography uncertainty principle, physical random numbers

×

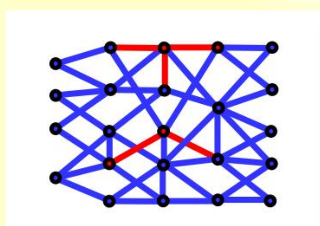
Information security

Modern cryptography,

computer science, network theory

Optical/Quantum Network Encryption

ü Integrates quantum cryptography, secret sharing, and network theory **ü Develops optical/quantum network encryption technology that performs decentralized encoding and encrypted communication using multiple nodes and links**



Realizes a scalable secure communication network with excellent resistance to service outage attacks and high availability.

Quantum secure mobile communication netwo

ü Implement quantum security technology in mobile objects such as **satellites, drones, and connected cars ü** Develop mobile communication technology with excellent mobility, connectivity, and safety **High-capacity and safe communication technology that covers everything from space, the stratosphere, and high altitudes to terrestrial networks Realizing a mobile communication network**

(Source: NICT)

Build a cyberspace with permanent security using quantum security technology!

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Image of quantum technology innovation center (international hub)

•In Europe and the United States, the formation of hubs for industry-academia collaboration related to quantum technology is rapidly progressing (Delft University of Technology (QuTech) in the Netherlands, Tokyo in Canada).

London University, Oxford University in the UK, etc.) It functions as a stage set that attracts excellent researchers from Japan and abroad.

•From the perspective of securing and strengthening Japan's international competitiveness, we will bring together human resources and technologies centered on technological areas in which we have strengths, and conduct everything from basic research to technology demonstration, open innovation, intellectual property management, etc. An international collaboration base (international

Base type (example)

open platform type

Open platform type that deepens and strengthens collaboration between universities/research institutes and companies (e.g. Tohoku University CIES)

Institutionally independently

operated type A center-forming type that is placed under the umbrella of a university or research institution but ensures a high degree of freedom and independent operation (e.g. WPI center)

In-house center type An in-house **center type** that has been developed and strengthened as an organization of a research department under the umbrella of a research institute (e.g. strategic centers at RIKEN, AIST, et

Center requirements

• **Japan has outstanding researchers with high international reputation, and the technology field has core technologies with high international competitiveness.**

•Japanese universities, research institutes, companies, etc. have high potential. •Technology that is expected to attract significant investment **from overseas companies, or that is expected to attract excellent overseas human resources.** • **It is a technical field where it is beneficial and efficient to integrate human resources, technology, budget,** etc.

Center scheme (draft) • Project

period is approximately 10 to 15 years (clear milestones will be set and changes or cancellations will be made depending on the evaluation results) • **Development as an industry-academia collaboration center funded and borne by both the public and private sectors (stage** Establish a gate and gradually increase the proportion of private investment)

• **A board will be set up in the government to oversee the entire project, and detailed progress management will be carried out through hands-on** support, etc. •A center director will be appointed at each base to handle necessary **base functions** such as management, research, intellectual property, and commercialization. **and established a management system.**

Centers

• Superconducting quantum computer research center • Quantum device development center • Quantum software (quantum AI, etc.) research center • Quantum life (bio) research center • Quantum materials research center • Quantum inertial sensor center • Quantum security research center, etc.

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Image of human resources development

•As international competition in quantum technology intensifies, the number of researchers and engineers involved in research and development of quantum technology in Japan is thinner than in other countries, and there is a large gap in the international competition for human resources. Risk of falling behind •In order to dramatically improve the quality and depth of human resources in fields related to quantum technology, strategically improve the education and research environment at the higher education level. need to be administered

Image of the initiative

Create a roadmap

ü Clarify what kind of human resources are needed for each major technology area and create a roadmap for strategically developing and securing researchers and engineers (Examples of items that need to be specified) Need to learn academic studies and technologies, requirements for the center, measures necessary for training and securing, etc.

Center development/ program development

ü The government will collaborate and cooperate with universities, research institutes, etc. to develop human resource development bases that correspond to major technical fields. ü The bases will play a **central role in developing common educational programs (teaching materials, curriculum, etc.).**

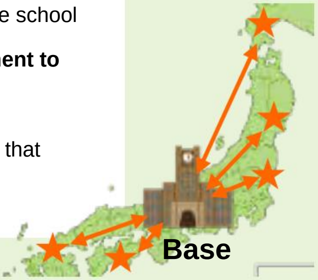
Provide the developed educational program to desired universities, etc. across the country.

strategic initiatives

<Human resource development base> ü Develop human resources using the developed educational program ü Collaborate with universities across the country that utilize the developed educational program , **and follow up on areas that cannot be handled by local universities alone** (intensive lectures, tutoring, etc.)

alignment

<Universities and graduate schools in each region> The educational programs developed by the center will be utilized in undergraduate and graduate school education at each university. **Develop an environment to provide** specialized education in quantum technology ü Work with centers to cover areas that cannot be covered by individual universities, etc.



Strategically cultivate and secure excellent researchers and engineers, and maintain and improve Japan's research and development capabilities.

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Quantum future society vision

~ Vision of the future society that should be aimed at through quantum technology and strategies for realizing it

April 22, 2020

Integrated Innovation Strategy Promotion Council

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1.First of all

<Quantum technology innovation strategy initiatives>

In January 2020, the government formulated the Quantum Technology Innovation Strategy, and established a base where industry, academia, and government work together on everything from basic research on quantum technology to technology demonstration, open innovation, intellectual property management, human resource development, etc. In February 2021, eight quantum technology innovation hubs (QIH) were established. Additionally, in July of the same year, the Quantum Innovation Initiative Council (QII Council), based at the University of Tokyo, introduced the first overseas commercial quantum computer to Japan. In the industrial world, the Council for Creating New Industries Based on Quantum Technology (Q-STAR) was established in September

of the same year, and the

A new system was put in place to promote research, development, and industrialization of quantum technology.

In addition, at the same time as formulating this strategy, we have also formulated a technology roadmap with an eye to the future.Based on this roadmap, research and development will be carried out in various fields such as quantum computers/quantum simulation, quantum measurement/sensing, quantum communication/ciphering, etc. Progress is being made steadily.

Furthermore, we are expanding our international collaboration between the Quantum Technology Innovation Center (QIH) and overseas research bases in Europe, America, and other countries. ``International Symposium on Quantum Science, Technology and Innovation'' where people from industry, academia and government from Japan and abroad gather for joint research and

(Quantum Innovation 2021)'' is also steadily progressing.

<Changes in the environment since the formulation of the quantum technology innovation strategy>

Based on the formulation of the Quantum Technology Innovation Strategy in January 2020, Japan is steadily undertaking research and development efforts. However, since the formulation of this strategy, the environment surrounding quantum technology has been changing rapidly.

Overseas, there are moves centered on private companies to accelerate research and development and commercialization of quantum computers with ambitious goals. Additionally, technologies and services that combine quantum computing and conventional (classical) computing systems are rapidly developing. As international competition intensifies, Japan is also drastically accelerating and strengthening research and development of quantum computers, and industry, academia, and government are working together to make full-scale and strategic efforts to strengthen industrial competitiveness. It is expected that it will go.

In addition, the coronavirus pandemic has led to rapid progress in DX across the entire social economy, and it is expected that the movement toward Society 5.0, which highly integrates cyberspace and physical space, will progress further in the future. Along with this, the amount of data and communication has increased explosively, and security is also required to be ensured, making quantum technology, which has excellent computational capacity and confidentiality, even more important.

Furthermore, in response to the increasingly serious problem of climate change, efforts to realize a carbon-neutral society are gaining momentum. Quantum technology is expected to dramatically improve computing performance in the future, and is expected to make a major contribution to the realization of a carbon-neutral society, including decarbonization through the development of unprecedented environmental materials.

be done.

In order to scale up and put quantum computers into practical use, there are many technical challenges such as stable generation of quantum bits, and various breakthrough technologies are required. In recent years, innovations in computer science including AI and cutting-edge

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Fundamental technologies for controlling and elucidating these physical phenomena are making remarkable progress, including the development of precise control techniques for quantum states that make full use of laser technology. To advance strategic research and development toward future breakthrough technologies, we will mobilize knowledge from many academic fields to strongly promote broad-based basic research and human resource development, including young researchers. is important.

In recent years, in addition to the global semiconductor supply shortage caused by the coronavirus pandemic, economic security has become increasingly important due to the emergence of geopolitical issues. Quantum technology is an extremely important technology in terms of economic security, and it is important that advanced quantum technology It is important to have the necessary skills in one's own country and to develop stable and continuous human resources for this purpose. It is also important to take measures to protect important data and information systems that form the basis of industry and society, including technical information, from cyber attacks.

<Response to environmental changes>

Since the formulation of the Quantum Technology Innovation Strategy in January 2020, society has been undergoing rapid changes, including intensified international competition in quantum computers, the rapid progress of DX due to the coronavirus pandemic, and moves toward realizing a carbon-neutral society. Quantum technology is expected to play an increasing role in the economic environment. In addition, as economic security becomes

increasingly important, quantum technology is also extremely important for economic security.

technology, and it is important to possess advanced technology in one's own country and to develop human resources.

For this reason, we will accelerate and strengthen efforts such as research and development, social implementation, and industrialization of quantum technology more than ever to ensure international competitiveness, create growth opportunities for Japan's industry, and solve social issues. etc.
can be said to be an urgent issue.

As the use of data continues to become more sophisticated and expanded due to the rapid progress and spread of AI, quantum technology will serve as a catalyst to further accelerate this progress, leading to dramatic improvements in future computing performance. Furthermore, quantum technology is expected to dramatically improve sensing and communication performance, including much more sensitive sensing and highly secure communications than before.

Quantum technology, which will dramatically improve future computing, sensing, and communication performance, will be used in drug discovery and medical care, materials, finance, energy, lifestyle services, transportation, logistics, factories, safety and security, and more. Value for society and economy can only be created by utilizing it in a variety of fields. For this reason, research and development related to quantum technology
When promoting initiatives such as quantum technology, social implementation, and industrialization, it is important to have a bird's-eye view of incorporating quantum technology into the entire socio-economic system.

In addition, quantum technology is applicable to computer science such as AI and advanced simulation, and information and communications such as 5G/Beyond 5G. Technology, semiconductors, measurement/sensing technology, etc. are closely related to conventional (classical) technological systems, and it is important to promote efforts while integrating and integrating them.

Based on this background, industry, academia, and government will work together to improve Japan's industry, including a productivity revolution, while also linking AI strategy, Beyond 5G promotion strategy, semiconductor strategy, etc., and keeping in mind cooperation with like-minded countries. Utilize quantum technology to create growth opportunities and solve social issues such as carbon neutrality, and transform society as a whole.

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We have formulated this vision as a new strategy with an eye toward future society in order to realize this vision.

<Relationship between this vision and quantum technology innovation strategy>

``Quantum technology innovation strategy'' (so to speak, ``quantum technology research and development'') that focuses on research and development of quantum technology and related areas. Research and Development Strategy”), this vision aims to create growth opportunities for Japan’s industry and solve social issues. In order to realize the transformation of society as a whole by utilizing quantum technology, we will formulate a vision for the future society that should be aimed at through quantum technology and a strategy for realizing that vision, so to speak, as a "strategy for social transformation using quantum technology." It is. For this reason, this vision (a strategy for social transformation through quantum technology) and the The government's efforts will be promoted in tandem with the Quantum Technology Research and Development Strategy (quantum technology research and development strategy).

Therefore, going forward, we will continue to promote research and development efforts based on the "Quantum Technology Innovation Strategy" (roadmap has been partially revised) formulated in January 2020, and improve productivity based on this vision. We will utilize quantum technology to create growth opportunities for our country's industry, such as revolutions, and to solve social issues, such as carbon neutrality. Promote initiatives to realize the transformation of society as a whole with an eye toward future society.

This vision was formulated with an eye to the vision of the future society that quantum technology should aim for and the situation that should be achieved in 2030, but the environment surrounding quantum technology will continue to change rapidly. As the environment is expected to continue to change dramatically, we will take precautions against future changes in the environment, including reviewing this vision. We will respond accordingly.

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2. Changes in the environment surrounding quantum technology, etc.

(1) Intensifying international competition in the quantum industry

Since the formulation of the Quantum Technology Innovation Strategy in January 2020, there have been moves overseas, mainly by private companies such as Google, to accelerate research and development and commercialization of quantum computers with ambitious goals. There is [1]. In addition, technologies and services that combine quantum computing and conventional (classical) computing systems are rapidly developing. are doing.

Furthermore, overseas, there are cases in which basic research directly leads to commercialization, such as when a private company acquires an entire university research laboratory and commercializes it. Furthermore, university-originated venture companies based on basic university research are rapidly growing, with university-originated venture companies going public on the back of huge investments from venture capital, and being acquired by large corporations. In this way, compared to the conventional linear model of basics, applications, and practical use, the interval between basic research and commercialization is narrowing, and efforts toward the practical application of quantum computers are accelerating worldwide.

As international competition intensifies in this way, Japan is also drastically accelerating and strengthening research and development of quantum computers, and is also promoting the use of the quantum industry (hardware and software vendor companies) and quantum technology. Industry, academia, and government will work together to improve industrial competitiveness, with a view to promoting industries in related fields (drug discovery/medical care, materials, finance, energy, lifestyle services, transportation, logistics, factories, safety and security, etc.). It is hoped that full-fledged and strategic efforts will be made to strengthen the system. For this reason, it is necessary for industry, academia, and government entities to work together more closely to accelerate initiatives such as research and development, social implementation, and industrialization, and to strongly promote the creation of a business environment that will serve as the basis for this. .

In addition, in the field of quantum communications and cryptography, there is an accelerating movement overseas to establish long-distance quantum cryptographic communication testbeds and conduct demonstration tests by utilizing space assets such as terrestrial communication networks and satellites. . Furthermore, beyond that Research and development aimed at realizing a quantum internet is also gaining momentum. As international competition intensifies in the field of quantum communications and cryptography, in Japan, industry, academia, and government are working together to integrate existing information and communication systems, taking into account the Beyond 5G promotion strategy. It is necessary to accelerate efforts to strengthen international competitiveness. be.

(2) Rapid progress in DX due to the coronavirus pandemic

Since the formulation of the Quantum Technology Innovation Strategy in January 2020, the coronavirus pandemic has led to rapid progress in DX in all social and economic activities such as daily life, medical care, education, entertainment, and transportation, and in the future, it is expected that DX will expand into cyberspace. It is expected that the movement toward Society 5.0, which highly integrates physical spaces, will progress further.

In the future, in a post-corona society, new lifestyles such as telework will become established in society, and 5G/

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1 Google (US) will achieve 1,000 logical qubits in 2029 (announced in May 2021), and IonQ (US) will achieve 1,024 logical qubits in 2028 (announced in December 2020). In Japan (Moonshot R&D System) (announced in January 2020), the number of logical qubits will be several tens to 100 in 2030 (acceleration planned).

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With the development of Beyond 5G information and communication systems, IoT, edge computing, and other technologies, DX,
It is expected that the movement towards Society 5.0 will further accelerate.

In a society where DX and Society 5.0 are progressing, the amount of data handled and the amount of communication on networks is increasing explosively, and there is also a need to ensure security, which cannot be handled by conventional (classical) technology systems alone. Since this may be difficult, it is essential to utilize quantum computers, quantum communications, and cryptographic technologies, which have excellent computational complexity and confidentiality.

(3) Contributing to a carbon neutral society/SDGs, etc.

In response to the increasingly serious problem of climate change, countries around the world are making full-fledged efforts in the environmental field, such as carbon neutrality/beyond zero (negative emissions). Japan will reduce greenhouse gas emissions by 46% in 2030 (compared to 2013), and in order to achieve this goal, we are working hard in each sector such as industry, civil life, and transportation.
A fundamental transformation of the socio-economic system is required in order to achieve decarbonization.

In addition, in order to realize the Sustainable Development Goals (SDGs), there are many complex social issues that need to be resolved, including health and medical care, food, and poverty. Furthermore, in Japan, there are social issues that need to be overcome in order to create a sustainable society, such as an aging society with a declining birthrate and an accompanying decline in the working-age population.
do.

Quantum technology will enable dramatic improvements in future computing, sensing performance, etc., unprecedented
Complex social issues such as the realization of a carbon-neutral society and the SDGs, such as decarbonization through the development of environmental materials, the realization of a healthy and long-lived society through early diagnosis and treatment of diseases, and the improvement of productivity as the working-age population declines. It is expected that the project will make a significant contribution to solving the problem.

(4) Progress in fundamental technology supporting quantum computers

In order to scale up and put quantum computers into practical use, there are many technical challenges such as stable quantum bit generation and error correction, and various breakthrough technologies are required. For the research and development of these breakthrough technologies, in addition to strategic efforts, we need to develop the foundations that will lead to future breakthrough technologies based on academic approaches.
Broad basic research is also required. For example, in order to generate and utilize stable qubits, it is necessary to have a basic understanding of dissipation phenomena and many-body interactions in quantum systems in non-equilibrium states such as decoherence and in open systems. . In the field of physics, understanding these phenomena while taking into account the influence of the external environment has generally been a difficult problem, but in recent years, innovations in computer science including AI and quantum simulation using cold atomic systems have made progress.
Fundamental technologies for controlling and elucidating these physical phenomena are showing remarkable progress, including advances in simulation experiments and the development of sophisticated control techniques for quantum states that make full use of cutting-edge laser technology.

In addition to promoting strategic research and development toward breakthrough technologies that will be essential for the large-scale and practical application of quantum computers in the future, we will mobilize knowledge from many academic fields to conduct broad-based basic research and engage young researchers. It is important to strongly promote human resource development, including human resources.

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(5) Economic security of quantum technology

In recent years, in addition to the global semiconductor supply shortage caused by the coronavirus pandemic, economic security has become increasingly important due to the emergence of geopolitical issues. Quantum technology is a technology that will play a role as the foundation for supporting social and economic systems in the future, and will also be extremely important for economic security, and will play a central role in the future struggle for supremacy between nations. It can be said that this is an important technology.

For this reason, from the perspective of economic security, it is necessary to acquire advanced quantum technology domestically, including acquiring cutting-edge technology to ensure technological superiority in quantum technology and securing supply chains for important basic components and materials. It is necessary to maintain and secure human resources in a continuous and stable manner for this purpose. In addition, measures are taken to protect important information systems and data that form the basis of industry and society, including technical information, from cyber attacks. Response is also important.

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3. Basic idea

In light of changes in the environment surrounding quantum technology, we will incorporate quantum technology into the socio-economic system and improve our country's production.

In order to utilize quantum technology to create business growth opportunities and solve social issues, industry, academia, and government will work together to promote initiatives based on the following three basic ideas.

ÿ Incorporating quantum technology into the entire socio-economic system and integrating it with conventional (classical) technological systems. (Hybrid), creating growth opportunities for Japan's industries and solving social issues ÿ Promoting the utilization of cutting-edge quantum technology (establishing testbeds for quantum computers, communications, etc.) ÿ New industries/start-up companies that utilize quantum technology Creation and revitalization of

(1) By incorporating quantum technology into the entire socio-economic system and merging it with conventional (classical) technological systems (hybrid), we will create growth opportunities for Japan's industry and resolve social issues.

Quantum technology will be utilized throughout the entire socio-economic system, and will be used in drug discovery and medical care, materials, finance, energy, and lifestyle services.

It is expected to contribute to the creation of industrial growth opportunities and the resolution of social issues in a wide range of fields such as services, transportation, logistics, factories, and safety and security.

For this reason, when proceeding with research and development, social implementation, industrialization, etc. related to quantum technology, various companies

It is important to take a bird's-eye view of incorporating and utilizing quantum technology in the entire socio-economic system in collaboration with the socio-economic field.

In addition, it is important to think in an integrated manner by integrating computer science such as AI, information and communication technology such as 5G/Beyond 5G, measurement/sensing technology, and conventional (classical) technological systems such as semiconductors.

In this way, by incorporating quantum technology and research results into the socio-economic system and fusing and integrating them with conventional (classical) technological systems, we can create growth opportunities for Japan's industry, such as a productivity revolution, and achieve carbon neutrality.

Realize the realization of society and solve social issues such as SDGs.

(2) Promoting the utilization of cutting-edge quantum technology (development of testbeds for quantum computers, communications, etc.)

In order for the entire society and economy to utilize quantum technology, it is important to create an open environment where a variety of users can access quantum technology. In addition, in this environment, users can utilize quantum technology to develop use cases.

Efforts to explore and create are also important. For this reason,

we are developing state-of-the-art quantum computers, quantum communication/ciphering, and

We will also develop an environment for the use of quantum technology, such as establishing test beds for quantum measurement and sensing.

In addition, various users will be able to make full use of these testbeds to develop quantum technology use cases that will lead to future killer applications that will greatly contribute to creating growth opportunities for Japan's industry and solving social issues.

We support efforts to explore, create, and demonstrate use. Furthermore, in order to spread and expand quantum technology, we will

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We will strongly promote efforts to disseminate and disseminate information on use cases.

(3) Creation and revitalization of new industries/startup companies using quantum technology

Quantum technology is expected to be utilized in a wide variety of industrial fields, and the future will include quantum computers and quantum software. The market size for both software and software is expected to be huge, [2] However, at present, the technical method of quantum computers and the but the outcome, including the business model and major players, has not yet been determined.

The quantum field market is a growing market in its infancy, where the outcome is not yet decided.In other words, Depending on Japan's future responses, it can be said that this is a market with a chance to win international competition and realize growth for Japan. For this reason, we aim to strengthen industrial competitiveness by encouraging private businesses to enter the quantum field and stimulating investment. We will strongly promote key initiatives.

Furthermore, in the business field of developing new markets, startup companies that are resilient to environmental changes, have flexible thinking and ideas, and are adept at creating new businesses are expected to play an active role. Furthermore, it is also expected that existing companies will create new businesses/industries, such as spin-offs and spin-out ventures. It is also expected to utilize corporate venture capital (CVC) to invest in startup companies.

be caught.

For this reason, industry, academia, and government are working together to develop new industries and businesses that utilize quantum technology, which will serve as the engine of future economic growth. We will strongly promote efforts to improve the business environment to create and revitalize start-up companies.

2 The global market size related to quantum computers in 2040 is predicted to be 10 trillion yen to 19 trillion yen for hardware and 40 trillion yen to 75 trillion yen for software. (Source: “What Happens When “If” Turns to “When” in Quantum Computing?” (BCG, July 21, 2021))

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4. Vision of future society (image of future society)

In order for industry, academia, and government to work together to promote research and development, social implementation, and industrialization of quantum technology, and to utilize quantum technology throughout society and the economy, it is necessary for all concerned parties to develop ideas for future society. It is important to promote initiatives while sharing a vision (image of future society). For this reason, the vision of the future society that should be achieved through quantum technology is settings, etc.

(1) Vision of the future society that should be achieved through quantum technology (image of future society)

In recent years, values such as SDGs and ESG investment that simultaneously achieve not only economic growth but also sustainability and people's happiness have become more important than ever, and the image of a society in which the economy, environment, and society are in harmony has become more important in modern times. This is becoming a common understanding. Looking ahead to future society, these values and initiatives based on them will continue to become more and more important. It is thought that it will continue.

For this reason, the ultimate future society that we should aim for through the use of quantum technology is one in which the economy, environment, and society are in harmony. Establish an image of future society. Specifically, based on the values of "economic growth innovation," "harmony between people and the environment," and "well-being," industry and academia are working toward a vision of a future society in which the economy, environment, and society are in harmony. The government aims to work together as one.

In this case, for example, since there is a risk of harm to society if quantum technology is used inappropriately, such as in code-breaking, we need to consider the institutional and ethical aspects that arise when quantum technology is newly used in society. In order to respond to issues such as social acceptance, we will proceed with efforts while utilizing "comprehensive knowledge" that includes not only the natural sciences but also the humanities and social sciences, depending on the stage of social implementation and development of the technology.

ÿ Economic growth Innovation ÿ Harmony

between people and the environment Sustainability ÿ Spiritual

enrichment Well-being

(i) Economic growth InnovationNext -generation

high-speed computing, which combines quantum computers and conventional (classical) computing, will dramatically accelerate the innovation creation cycle of hypothesis and verification, leading to a productivity revolution by utilizing quantum technology. Achieve economic growth by creating growth opportunities for Japan's industries.

(ii) Harmony between people and the environment SustainabilityWe

will use quantum technology to harmonize people and the environment, such as by developing next-generation environmental materials using quantum computers and realizing a carbon neutral and circular economy through the best mix of energy. A company that develops sustainably Realize the meeting.

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(iii) Living a spiritually rich life Well-being Safe and

secure living through quantum cryptographic communication, health and longevity through next-generation medical care using highly sensitive quantum sensing, etc. Hybrid computing of quantum and classical, including fusion with AI, etc. Quantum technology can be used to improve people's minds, such as disaster prediction using quantum sensing, and resilient societies using evacuation guidance systems.

Realize a rich life.

(2) Value created by quantum technology in future society (image of quantum technology utilization)

Quantum technology will realize dramatic improvements in future computing, sensing, and communication performance, and will be used in a variety of fields such as drug discovery and medicine, materials, finance, energy, lifestyle services, transportation, logistics, factories, and safety and security. It can be used in various fields to create value for the social economy. In order to realize the vision of future society, we have listed some possible usage examples below. Shown below. Please note that these are current use cases, and it is expected that new use cases will be created in the future as use cases are discovered and technology advances.

<Drug discovery/medical care>

Drug discovery/pharmaceuticals (development and manufacturing of new drugs with higher functionality and more complex structures than conventional drugs, etc.), tailored medical care (providing tailor-made drugs and treatments tailored to each patient's symptoms and constitution, etc.), optimization of chemical reactions/design of catalysts and enzymes (faster and more efficient drug discovery/pharmaceutical processes, etc.) Highly accurate diagnosis (early detection of dementia and heart disease, etc.), highly sensitive and compact MRI (an MRI that aligns the nuclear spin direction and is significantly more sensitive and smaller than conventional ones), highly secure communication and secure Cloud (encrypted communication of medical records, personal data, etc.)

Security cloud, etc.)

<Materials>

Development of new functional materials (functional materials with higher functionality than conventional ones (energy saving, recyclability, light weight, toughness, etc.), alternative materials for scarce resources, etc.), optimization of chemical reactions/design of catalysts and enzymes (decarbonization) efficient chemical processes that contribute to society and the circular economy), etc.

<Finance>

Trading strategies (planning financial trading strategies under complex conditions, etc.), market forecasting (customer needs and market forecasting using quantum machine learning, speeding up derivative price calculations, etc.), portfolio optimization (optimizing financial assets held) risk analysis (analysis that includes various risk factors by speeding up Monte Carlo simulation, etc.), fraud detection (building models to identify normal/fraudulent financial transactions, etc.), highly secure communication/secure

Accloud (information regarding loans and banking transactions, etc.), etc.

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<Energy>

Smart grid (a smart system that connects and controls fluctuations on the demand side and supply side in real time, real-time optimal power allocation of highly variable renewable energy, etc., and search for combinations such as energy mix)
etc.), high-performance batteries (development of highly efficient and highly functional batteries using new battery materials and chemical reactions, etc.), EV energy conservation (reducing the distance traveled per unit of energy through highly accurate current sensing and control within EVs). stretching, etc.), secure infrastructure information management (SCADA), etc.

<Lifestyle services>

High-precision weather forecasting (high-precision forecasting at a smaller regional level, etc.), advertising strategy (setting of advertising space that is optimal for each customer's profile and needs, etc.), consumer behavior (real-time recommendation of optimal products, environmental brain machine interface (BMI) (non-invasive and highly sensitive measurement of brain magnetism using quantum sensing), secure video conferencing (confidentiality using quantum cryptographic communication, etc.) high video
meetings, etc.) etc.

<Transportation> Multimodal sharing/MaaS (optimization of car sharing, on-demand dispatch, etc.), traffic simulation (simulation that takes into account complex conditions, traffic control to alleviate congestion, etc.), autonomous driving (route searching, etc.)
optimization, etc.), improved convenience for EVs (search for charging stations and parking lots, etc.), aircraft operation network planning (aircraft allocation, crew scheduling, fuel, response to operational troubles, etc.), and aircraft materials (lightweight, strong new materials, etc.), wind tunnel simulations (energy-saving aircraft design, etc.), etc.

<Logistics>

Placement and operation planning of delivery vehicles such as cars, ships, aircraft, and drones (maximizing loading capacity and operation rate, transportation cost) route optimization (minimizing travel distance, maximizing number of deliveries, minimizing transportation costs, etc.), inventory
Management (optimal inventory management to maximize production efficiency, efficient linkage of multiple factory inventories, etc.), etc.

<Factory>

Smart factories (optimization of production resources such as personnel, robots, materials, etc. in factories), IC manufacturing and design (combining complex circuit patterns, etc.), secure infrastructure information management (SCADA), inventory management (product production, etc.)
Optimal inventory management to maximize production efficiency, efficient linkage of multiple factory inventories, etc.)

<Safety and security>

Highly secure communications/secure cloud (highly confidential communications in all fields, highly secure storage of data to be protected), disaster countermeasures (optimization of evacuation routes in the event of a disaster, planning for the placement of personnel and supplies at evacuation centers)
etc.), earthquake and volcanic disaster prediction (observation of the Earth's crust using optical lattice clocks, etc.), and use in the defense field (command and control).

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speeding up control (selecting the optimal means of responding to multiple simultaneous attacks), supplying supplies (transporting supplies efficiently), Warning and surveillance using UUV (continuous surveillance without using GPS), etc.

(3) The situation we should aim for in 2030 towards the future society vision

When industry, academia, and government stakeholders promote initiatives such as research and development, social implementation, and industrialization, it is important to set concrete numbers and work towards them. For this reason, the situation that we should aim for in 2030 toward the image of future society is We will proceed with our efforts based on the following assumptions.

- ÿ **Raise the number of domestic users of quantum technology to 10 million**
- ÿ **Raise the production value of quantum technology to 50 trillion yen**
- ÿ **Create quantum unicorn venture companies that open up future markets**

(i) Raise the number of domestic users of quantum technology to 10 million

In developed countries, past examples suggest that when the Internet user rate exceeds 5-10%, the spread of the Internet will accelerate explosively. We aim for a similar ratio for domestic users of quantum technology (including quantum applications, quantum inspired, etc.) (including those who use it without knowing it is quantum technology), and assume 10 million domestic users.

As an effort to support this, we will strongly promote the development of a usage environment such as a quantum computer testbed, so that the diverse users mentioned above can access it and explore and create use cases. Also a killer We support the search and creation of use cases that lead to applications, and take measures to disseminate and disseminate information on use cases. We will strongly promote the group.

(ii) Raise the production value using quantum technology to the scale of 50 trillion yen

Population in 2030 (119.13 million people) [3] Considering the ratio of 10 million users of quantum technology to Industrial production value to which technology can contribute (2030) approximately 615 trillion yen [Four] Set. It should be noted that this figure is based on production value.

Furthermore, the amount of domestic added value in 2030 is predicted to be approximately 1.2 trillion yen. [Five] (Quantum computer 294 billion yen,

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3 Source: Japan's future population projections (estimated in 2017) (National Institute of Population and Social Security Research)

Of the 4 input-output tables (FY2015), manufacturing industry 302.8 trillion yen, electricity 20.3 trillion yen, and commerce 95.5 trillion yen Calculated assuming a CAGR of 1% from FY2022 onwards for the total production value of 35.5 trillion yen for finance and insurance, 53.6 trillion yen for transportation, 50 trillion yen for information and communications, 45.8 trillion yen for medical care, and 7.2 trillion yen for advertising ((Reference to the annual real GDP growth rate of +1.0% in the Japanese Medium-term Economic Forecast (FY2022-FY2031) (Daiwa Institute of Research, January 24, 2022). 5 Source: Yano Research Institute, Inc. “2021 Current Status and Future Prospects of the Quantum Computer Market” (September 2021), “2022 Current Status and Prospects of the Quantum Technology Market” (February 2022)

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Quantum simulation 48 billion yen, quantum sensing 110.2 billion yen, quantum cryptography 65.3 billion yen, quantum life 32.3 billion yen, quantum physics 135 billion yen, quantum materials 371 billion yen, quantum AI 109.8 billion yen), plus overseas acquisitions ((approximately 0.1 trillion yen), the total added value in Japan and overseas is expected to be approximately 1.3 trillion yen.[6]

Initiatives to support this include the Quantum Technology Innovation Center (QIH), the Council for Creating New Industries Using Quantum Technology (Q-STAR), and the Quantum Innovation Initiative Council (QII Council), which paves the way for the use of actual quantum computers through industry-academia collaboration.), relevant ministries, and other relevant ministries in industry, academia, and government will work together more closely to further strengthen full-fledged and strategic efforts to strengthen industrial competitiveness by supporting private business activities, and the public and private sectors will work together. Ta Aiming for overseas expansion.

(iii) Creating a quantum unicorn venture company that opens up future markets

In Japan, unicorn companies (unlisted startups with a valuation of over $1 billion (approximately 105 billion yen) The number of companies (technology companies) is increasing year by year, and as of December [7]. In addition, following these five companies, 2021 there are five companies, including HIROTSU Bioscience (cancer early detection testing) (102.6 billion yen) and Astroscale Holdings (space business), which is involved in the emerging space business. (garbage removal service) (81.8 billion yen) and iSpace (lunar lander and exploration vehicle development) (75.3 billion yen) are also rapidly growing, approaching the valuation of unicorn venture companies of $1 billion.

In the emerging market of quantum business, we aim to create unicorn companies (at least several companies in each field) that will open up future markets in the three major quantum fields (quantum computers, quantum cryptographic communications, and quantum measurement/sensing) by 2030. and stimulate the entry of venture companies.

In order to support this, the public and private sectors are working together to foster entrepreneurs, support R&D, match investors, A comprehensive entrepreneurial environment will be developed, including the provision of risk money using government funds.

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6 Based on the 2015 Input-Output Table (Ministry of Internal Affairs and Communications) of the domestic final demand for all industries at 92.3% and the export portion at 7.7%, the overseas market portion is assumed to be approximately 0.1 trillion yen. 7Preferred Networks (AI development) (356.1 billion yen), Smart News (information gathering app) (201.7 billion yen), Smart HR (cloud-based human resources and labor management software) (173.1 billion yen), TBM (plastic/paper alternative material) (133.6 billion yen), Spiber (next-generation material) (131.2 billion yen) (Source: Nihon Keizai Shimbun "NEXT Unicorn Survey", December 2021)

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5. Future initiatives

Based on the basic concepts and vision of future society described above, we will conduct research and development in the technological areas of quantum computers, quantum software, quantum security networks, quantum measurement/sensing/quantum materials.

We will promote initiatives related to social implementation, industrialization, etc., and fundamental initiatives for creating innovation as follows.

I. Initiatives in each technical area

(1) Efforts related to quantum computers

<Points>

ÿ Realization of hybrid computing systems and services using quantum technology and conventional (classical) computing systems (including semiconductors, etc.), and the fundamental strength of research and development of domestically produced quantum computers comparable to those of other countries.

transformation

ÿ Creating an environment and supporting standardization for commercialization through collaboration with domestic and foreign companies, including volunteer countries. Comprehensive support for industry, such as assistance (new center established at AIST)

ÿ Strategic research and development of breakthrough technology and foundations for large-scale and practical use of quantum computers. Promotion of basic research

(i) Realization of hybrid computing systems and services using quantum technology and conventional (classical) computing systems (including semiconductors, etc.), and drastic strengthening of research and development of domestically produced quantum computers comparable to those of other countries.

ÿOverseas , technologies and services that combine quantum computing and conventional (classical) computing systems are rapidly developing. For example, overseas companies are providing services that connect multiple quantum computers to the cloud and rapidly execute hybrid quantum/classical algorithms that combine quantum computers and conventional (classical) calculation systems. In order to respond to these trends, Japan is also developing hybrid computing systems and application services that integrate quantum computers with conventional (classical) computing systems such as supercomputers, through collaboration (co-creation) between industry and academia. Research and development related to

Promote it extremely.

ÿQuantum computers are a cutting-edge science and technology department store, and the scientific knowledge and cutting-edge technologies obtained from their development are expected to have many technological implications. Therefore, if we are looking to the future of Japan's science and technology, the significance of developing a domestically produced quantum computer is extremely significant, and we must proceed steadily. In addition, from the perspective of the need for developers of quantum computers/fundamental software to quickly grasp problems faced by actual machines, it is important to understand that real machines that can tune hardware, middleware, etc.

This is essential, and in order to establish a de facto standard for elemental technology, a testbed with an environment where actual equipment can be used is also necessary. To this end, while building supply chains with companies from like-minded countries, we will vigorously advance research and development of domestically produced quantum computers, and steadily advance efforts to establish test beds that can be widely applied. Specifically, we will develop the first unit in FY2020, and will continue to advance the sophistication of the test bed and carry out necessary research and development based on international trends, progress in research and development, needs for test bed usage, etc.

We are really moving forward.

ÿ**As** international competition intensifies with overseas companies setting ambitious goals one after another for the large-scale and practical application of quantum computers, Japan is also setting ambitious goals comparable to those of other countries and Type (classic)

We will strategically and radically strengthen and accelerate research and development efforts toward the realization of future error-tolerant domestically produced quantum computers, with a view to linking them with computational systems and in cooperation with like-minded countries. .

(ii) Environmental preparation and standardization support to support commercialization through collaboration with domestic and foreign companies, including volunteer countries.

Comprehensive support for industry, such as assistance (new center established at AIST)

ÿ**For** private companies to research and develop quantum computers, it will take a long period of time and require huge investments. In the future, research and development of prototyping and manufacturing technology for large-scale chips with thousands or tens of thousands of quantum bits, as well as the development of equipment for commercialization, will require the research and development resources of Japanese companies and research institutes.

It has been pointed out that it is difficult and risky to deal with this situation by relying solely on resources.

ÿ**Overseas ,** countries like IMEC (Interuniversity Microelectronics Center) in Belgium have research bases for the world's most advanced semiconductor manufacturing process technology, and are conducting joint research with domestic and foreign companies.

There are also good examples of cities becoming core centers for industrial support in terms of research and development, prototyping, and manufacturing.

ÿ**Based** on these, the National Institute of Advanced Industrial Science and Technology, in collaboration with domestic and international companies, including volunteer countries, will provide private companies with support for prototyping, manufacturing, and evaluation of quantum chips and peripheral devices, as well as quantum-classical hybrid technology. We will develop new user markets, including service businesses, by providing opportunities to use computing resources, develop an environment that supports commercialization, and provide support for standardization. Form a "Global Industry Support Base (tentative name)" to provide comprehensive support. At this time, we will also develop semiconductor prototyping and manufacturing facilities, as well as quantum computer chips and peripheral control devices in collaboration with semiconductor technology and measurement technology.

Prototyping, manufacturing, and evaluation of devices, introduction of excellent parts and electronics technology owned by private companies and research institutes, including small and medium-sized enterprises such as domestic and foreign venture companies, and materials information aimed at creating a user market.

Efforts will be promoted with an eye toward mutual collaboration and advancement of various technologies such as quantum technology, semiconductors, and energy, such as by integrating efforts in other fields such as matics and energy management.

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(iii) Strategic research and development of breakthrough technologies and foundations for large-scale and practical use of quantum computers.

Promotion of basic research

ÿ**In** order to scale up and put quantum computers into practical use, there are many technical challenges such as stable quantum bit generation and error correction, and various breakthrough technologies are required. Furthermore, in addition to quantum computer technology methods that are currently considered promising, such as superconductivity, ion traps, photons, and silicon qubits, there will also be breakthrough technologies in which new technology methods that have never been seen before will be devised. Be expected. In order to develop these breakthrough technologies, we will develop a broad foundation that will lead to breakthrough technologies based on academic approaches, such as strategic research and development, as well as theoretical exploration of quantum systems in non-equilibrium states and open systems. Research is important.

ÿ**For** this reason, we will advance strategic research and development toward breakthrough technologies that will be essential for the large-scale and practical application of quantum computers in the future, and we will mobilize knowledge from many academic fields to conduct broad-based basic research. We will strongly promote human resource development, including researchers and young researchers.

ÿ**In** addition, optical science and technology such as lasers can be used for advanced control of quantum states, high-precision microfabrication, material development, etc. It has brought about major innovations in quantum computers, quantum networks, quantum measurement/sensing, etc., as well as the manufacturing of their parts and materials (quantum chips, quantum repeaters, etc.) and peripheral semiconductors. Because it is an essential and important technology base that supports subsidiary technologies cross-sectionally, strategic research and development and human resource development are necessary. We will strive to enrich and strengthen basic research in a wide range of fields, including research and development.

(iv) Others (points to note, etc.)

ÿ**When** researching and developing quantum computers, it is important to strategically and flexibly accelerate, enhance, and change research and development, taking into account international trends. ÿ**When** drawing up business strategies for quantum computers in the future, it is important to take into account the creation of an environment that allows access to quantum computers. It is also expected that Japan will formulate a balanced business strategy that includes not only vertical integration but also horizontal division of labor that takes advantage of Japan's strengths and also envisages collaboration with overseas countries.

ÿ**In** research and development of quantum computers, we will steadily promote the provision of services that utilize quantum annealing (Ising machines) in the short term, and further utilize testbeds to develop NISQ (Noisy Intermediate-Scale Quantum Computer) (gate-type machines).), and the knowledge gained there is expected to be utilized in the provision of full-scale services using large-scale gated quantum computers in the future. ÿ**In** research and development of quantum computers, from a long-term perspective, human resources from companies and universities interact and collaborate, create a framework for open innovation that involves many companies, create an environment for developing human resources such as working adults, and develop non-quantum technologies. Encourage the participation of researchers and engineers from surrounding areas, and further promote personnel exchange with overseas countries.

is important.

ÿ**The** equipment, commercialization, maintenance at the operational stage, etc. that are necessary for users to use quantum technology, including peripheral equipment technology, must be based on conventional (classical) technology rather than quantum technology.

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Therefore, in the practical application and commercialization of quantum computers, it is necessary to obtain commitment from private companies and to establish a system for collaboration between private companies and quantum technology experts.

ÿIn order to expand and promote investment from industry in the future, we need to explore use cases and develop their economic and It is also important to quantitatively demonstrate social effects.

(2) Efforts related to quantum software

<Points>

ÿ Developing a quantum computer usage environment that can be accessed by a variety of users to explore and create use cases (Test bed preparation, etc.)

ÿ Software development (industry-academia co-creation) by integrating other fields such as drug discovery/medical care, materials, and finance, as well as conventional (classical) technology fields such as AI, with a view to quantum/classical hybrid computing services. ÿ Quantum Drastically enrich and strengthen national software-related projects, discover and support excellent ideas. Support system

(i) Establishment of a usage environment for quantum computers that can be accessed by a variety of users to explore and create use cases (Test bed preparation, etc.)

ÿIn order to utilize quantum technology throughout society and economy, we will develop a usage environment such as a quantum computer testbed that will allow a variety of users from industry, academia, and government to access, explore, and create use cases. To go. In this case, we will utilize the most advanced quantum computers, while also making flexible use of overseas quantum computers. Prepare the environment.

ÿFurthermore , a wide variety of users will be able to fully utilize these testbeds and develop quantum technology applications that will lead to future killer applications that will greatly contribute to creating growth opportunities for Japan's industry and resolving social issues. We will support efforts to explore and create case studies and demonstrate their use.

ÿIn addition, in order to improve user literacy and promote the participation and utilization of user companies, we will We will strongly promote efforts to disseminate and disseminate case information.

(ii) Software development (industry-academia co-creation) by integrating other fields such as drug discovery/medical care, materials, and finance, as well as conventional (classical) technology fields such as AI, with an eye toward quantum/classical hybrid computing services.

ÿ Quantum applications can create growth opportunities for industries in a wide range of fields, including drug discovery and medicine, materials, finance, energy, lifestyle services, transportation, logistics, factories, and safety and security, as well as solve social issues such as carbon neutrality. It is hoped that they will continue to contribute. In addition, hybrid computing services that integrate conventional (classical) technological systems such as computer science such as AI and information and communication technology such as 5G/Beyond 5G,

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In addition to bringing new industrial value, it has great potential to produce unprecedented scientific results that go beyond the boundaries of existing physics. **ÿIn** research and development of quantum applications,

universities, research institutes, etc. that have advanced specialized knowledge in quantum information science, such as quantum algorithms, work closely with various companies (software vendors and user companies). , application development (= co-creation) is essential.

ÿFor this reason, universities and research institutes in the field of quantum information science work together with industry stakeholders in many fields to create opportunities for industry-academia co-creation (open innovation) to promote research and development and social implementation. Both quantity In addition to aiming for fundamental reinforcement, we are also developing application algorithms, etc., with an eye toward hybrid computing services that combine future quantum technology and conventional (classical) technology under a co-creation system between industry and academia. We will strongly promote efforts such as software research and development and social implementation.

(iii) Drastically enrich and strengthen national projects related to quantum software, discover and support excellent ideas. Support system

ÿIn the research and development of quantum computers, we conduct research and development not only on hardware but also on software such as application algorithms, and by providing services with customer value to users, we secure direct and indirect profits. It is important to realize a virtuous cycle of funds that can be used to invest in next-generation research and development.
It is essential. Furthermore, it is important to carry out research and development with hardware and software as two wheels, in order to mutually improve the sophistication of hardware and software by feeding back software knowledge to hardware. **ÿCurrently ,** compared to national

projects related to research and development of hardware such as quantum computers, there are fewer national projects related to research and development of quantum software in both quality and quantity. We will strengthen our efforts.

ÿTo be responsible for the research and development of quantum software, young human resources with flexible and innovative ideas, startup companies, people from other fields such as drug discovery/medicine, materials, finance, etc., and conventional (classical) technology fields such as AI are required. As more people are expected to enter the industry, we will consider and implement a system to discover and support excellent ideas through ideas contests and other means in order to widen the door as much as possible and incorporate ideas from society as widely as possible.

(iv) Others (points to note, etc.)

ÿIn the research and development of quantum software, the need for actual machines varies greatly depending on the position, purpose, and application, so flexible strategies including the use of actual machines in Japan and overseas, and a quantum computer usage environment that attracts diverse human resources are required. Maintenance is required.

ÿFor user companies, it is often difficult to work on quantum technology, which has a highly uncertain future, from the perspective of accountability to investors, so it is important to first create and accumulate small results (utilization examples). is important. In particular, we are researching and developing quantum applications by identifying fields with many potential users, low barriers to implementation, fields with high marketability and impact, and fields in which Japan has strengths.

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Perspective is also important.

ÿIn disseminating and disseminating information on future quantum computer use cases, create a common language for stakeholders in the quantum and non-quantum fields by expressing customer journeys through illustrations, stories, etc., and increase social demand and private investment. It is also important to encourage **ÿFor** research and development of quantum applications, it is extremely important to have private companies stationed at universities and an environment where researchers can interact face-to-face. Furthermore, in order to utilize flexible and free thinking to create unprecedented ideas, it is important to create an environment that respects the playfulness and ingenuity of researchers and developers.

It is essential.

ÿWhen holding an idea contest, for example, a system that discloses an open issue for each use case and awards a prize, or a PoC (Proof of Concept) of the use case itself for customer value is also considered as a valuable idea. Therefore, a system for creating and discovering these ideas is also effective.

(3) Initiatives related to quantum security and quantum networks

<Points>

ÿ Expand and enhance quantum cryptography communication testbeds and usage demonstrations, and expand and enhance quantum technology and quantum cryptography, including quantum-resistant computer cryptography.

Realization of comprehensive security that integrates conventional (classical) technology

ÿ Support for evaluation and certification systems to support the introduction of quantum cryptographic communication technology ÿ Establishment of a national project for quantum internet research and development that enables communication that maintains the qu

raise

(i) Expanding and enriching quantum cryptography communication testbeds and usage demonstrations, and developing quantum technologies including quantum-resistant computer cryptography.

Realization of comprehensive security that integrates conventional (classical) technology

ÿInternational competition in quantum cryptographic communications is intensifying, with moves overseas accelerating to establish test beds for long-distance quantum cryptographic communications and conduct demonstration tests using space assets such as terrestrial communication networks and satellites. ing. From the perspective of economic security, it is necessary for Japan to secure advanced quantum cryptography communication technology and accelerate its social implementation. **ÿFor** this reason, we are expanding and enriching the open test bed for quantum cryptography communication networks, expanding usage demonstrations that allow a wide range of users to participate toward commercialization, and developing future networks that connect cities.

We will also consider the use of space assets such as satellites. **ÿIn** addition, public and private users, vendors, service providers, telecommunications/cloud providers, etc. are closely collaborating and discussing, building up a track record of use demonstrations, and promoting standardization in response to required security requirements. Computers Comprehensive quantum security that integrates quantum and classical systems, including the use of cryptography, secret sharing technology, etc.

Promote the creation and accumulation of usage examples of security technology.

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(ii) Support for evaluation and certification systems to support the introduction of quantum cryptographic communication technology

ÿ**In** Japan, some private companies have already started services that utilize quantum security technology.
It is expected that this service will be provided by multiple operators in the future.

ÿ**At** this time, when users are considering the introduction of services, objective and uniform indicators should be used to determine the extent to which these services can ensure security and whether they meet user needs. It is important to be able to understand and evaluate.

ÿ**For** this reason, in order to support the introduction of services that utilize quantum security technology, we will continue to promote standardization and conduct evaluations and evaluations of quantum cryptographic communication devices, etc., which are being put into practical use, in order to build next-generation industrial security. Consider the support necessary for initiatives such as introducing a certification system.

(iii) Establishment of a national project for quantum internet research and development that enables communication that maintains the quantum state raise

ÿ**In** the future, the quantum internet, which is the ultimate form of quantum network that enables communication that maintains the quantum state, will include secure communication, large-scale and distributed computing of the number of qubits by connecting multiple quantum computers, and quantum sensors. The communication technology that forms the basis for the utilization of various quantum technologies, such as network connections, It is expected.

ÿ**In** recent years, quantum infrastructure has been developed overseas, including the development of quantum repeaters that can relay quantum states, quantum memories that can store quantum states, and testbeds to demonstrate these. Research and development of elemental technologies for the realization of the Internet is intensifying.

ÿ**In** Japan as well, in collaboration with efforts to realize next-generation communication systems such as Beyond 5G, based on the roadmap for the development of the quantum internet, we are working to realize the large-scale quantum computers of the future.
The fundamentals of the quantum Internet will be realized as a quantum communication infrastructure that will realize the technological infrastructure and the advancement of quantum cryptographic communication.
Started research and development of basic technology.

(iv) Others (points to note, etc.)

ÿ**Communication** networks become more functional and meaningful when they are used by everyone, so the public and private sectors should collaborate, including cooperation with information and communication systems such as 5G/Beyond 5G, and optoelectronic convergence technologies. We will advance our efforts with an eye toward the grand design of future security networks and the contribution and positioning of quantum technology. It is important to go.

ÿ**For** commercialization, it is important to look at the user's perspective rather than the technical one, and it is important to provide services that allow users to easily use quantum cryptographic communication. For this reason, it is expected that a service system will gradually be applied to quantum key distribution (QKD) networks without changing the user interface. ÿ**In** the absence of enforcement, security measures tend to be postponed, making it difficult for vendor companies to invest in them and difficult for user companies to implement them.In the future, guidelines will be developed to increase incentives for using quantum security.

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Mechanisms such as infrastructure and institutional development are also expected.

ÿIn order to popularize quantum cryptographic communication, it is important to create a system that allows stakeholders such as users, academia, and engineers to foster common understanding and cooperate to address issues. ÿWe will steadily advance the demonstration and advancement of quantum key distribution (QKD) network technology, in which Japan currently has strengths, and its overseas expansion, and at the same time, we will develop next-generation quantum network/quantum internet technology. It is important to maintain and improve the international competitiveness of technologies related to quantum security and quantum networks with an eye toward the future, such as conducting research and development on quantum security and quantum networks.

(4) Initiatives related to quantum measurement/sensing/quantum materials, etc.

<Points>

ÿ Expanding the application fields and usage examples of quantum measurement/sensing technology, and improving the usage environment (test bed preparation) (e.g., preparation, etc.), enrichment and strengthening of the technological base that supports its utilization ÿ Discovery and commercialization support for companies (users and vendors) with an eye on future business strategies ÿ Research and development of quantum materials that exhibit the world's most advanced quantum functions Establishment of supply base

(i) Expansion of application fields and usage examples of quantum measurement/sensing technology, improvement of usage environment (test bed preparation) equipment, etc.), enrich and strengthen the technological infrastructure that supports its utilization.

ÿQuantum measurement and sensing technology is expected to realize measurement and sensing with much higher precision and sensitivity than conventional methods, and will be widely used in fields such as life science, medicine, mobility, energy, and disaster prevention.

Ru. Furthermore, in the future, it is expected that it will develop in combination with AI, big data, IoT, etc. ÿOn the other hand, as there are still few application fields and usage examples envisaged at present for these latent needs, it is necessary to expand further application fields and create usage examples. is important. Also, this

It is also important to enhance and strengthen the advanced technological infrastructure that supports such utilization.

ÿFor this reason, we will promote the creation of an environment that will enable industrial and academic users in many fields to understand and utilize quantum measurement and sensing technology, as well as support the creation of usage examples and usage demonstrations that will become future killer applications. do. Furthermore, we will conduct basic research that supports technological sophistication in order to respond to new utilization needs and strengthen international competitiveness, as well as conventional (classical) technologies such as AI, big data, and IoT, life science, medicine, and mobility. R&D that integrates with a wide range of fields such as energy, disaster prevention, etc., and technology bases that include training and securing human resources.

We aim to enhance and strengthen the board.

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(ii) Discovery and commercialization support for companies (users and vendors) with an eye on future business strategies

ÿ**Although** quantum measurement and sensing have the potential for various applications, there are technical hurdles for many companies.

is high, making it difficult for new entrants to enter the market.

ÿ**In** addition, potential needs for new applications are expected by taking advantage of the characteristics of quantum measurement and sensing technology.

Currently, user companies have not been fully discovered because there are not enough places where needs and seeds can meet, and companies tend to be less

aware of the technology. ÿ**For** this reason, universities, research institutes,

etc. will actively provide technical support and information to potential vendors and user companies interested in quantum measurement and sensing technology, as well as

provide user companies (needs) We will build a system to match researchers with universities, research institutes, etc. (seeds). We will also consider building a system

to discover and support new ideas through ideas contests, etc.

(iii) Establishment of research and development and supply infrastructure for quantum materials that exhibit the world's most advanced quantum functions

ÿ**Quantum** computers, quantum/measurement sensing, quantum networks/quantum internet, and other quantum materials

Quantum materials that exhibit state-of-the-art quantum functions are essential for the research and development and practical application of next-generation devices

using nanotechnology, as well as for promoting basic research.

ÿ**Also ,** from the perspective of economic security, we have the most advanced quantum material manufacturing technology in our country and

It is extremely important to build a reliable supply base.

ÿ**For** this reason, we will strengthen research and development on the creation and advancement of quantum functions using high-precision quantum beam technology, and

through the creation and advancement of quantum functions, we will develop the world's best quantum materials that exhibit high-performance quantum functions.

We are committed to cutting-edge research and development, establishing a supply base for world-leading advanced quantum materials, and ensuring a stable supply.

A core ``Quantum Function Creation Center (tentative name)'' will be formed.

(iv) Others (points to note, etc.)

ÿ Quantum measurement/sensing has high technical hurdles and tends to be less well known to companies, etc., so it is necessary to have an interpreter (interpreter/

explainer) who can explain how it can be used as an application, or a business person. It is important to consider how to secure human resources who will be

responsible for this. ÿ**In** order to select a killer application and establish it as a business, vendor companies

and user companies must

It is thought that it is effective to collaborate and have user companies plan and lead the business.

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II. Fundamental efforts to create innovation

(1) Creation and revitalization of startup companies

<Points>

ÿ Entrepreneur development, commercialization support, matching with investors, comprehensive start-up environment development including the use of government funds, etc., discovery and support of new businesses such as idea contests/pitch contests, etc. ÿ Quantum technology for startup companies Support for computer usage and application research and development, etc. ÿ Improving the procurement of products and services for small and medium-sized enterprises, including start-up companies (for example, procurement that emphasizes things other than track record and price for research projects, and technological sophistication

(i) Entrepreneur development, commercialization support, matching with investors, comprehensive development of the entrepreneurial environment including the use of government funds, etc., discovery and support of new businesses such as idea contests/pitch contests, etc.

ÿIn the business field where we are developing new markets, we need people who are resilient to changes in the environment, have flexible thinking and ideas, and Start-up companies that are good at creating new businesses are expected to play an active role. **ÿIn** order to create and revitalize startup companies in the quantum field, we will provide entrepreneurial training, commercialization support, matching support with investors, supply of risk money using government funds, research and development support, and quantum computer usage environment. To create and revitalize start-up companies, such as provision support and collaboration with incubation bases. Develop a comprehensive entrepreneurial environment.

ÿIn addition, in order to create new businesses that utilize quantum technology, we will hold idea contests/pitch contests, etc. for startup companies and young human resources, and discover and support new businesses.

(ii) Support for quantum computer usage and application research and development for startup companies

ÿApplication businesses are knowledge-intensive and do not require large-scale investments, and sometimes require the flexibility to customize and localize services for each customer, so startup companies that can move quickly and flexibly respond. It can be said that this is a promising business field.

ÿHowever , for startup companies that are considering or have already developed quantum applications as a business, capital strength is not necessarily sufficient, creating barriers to quantum application research and development and the use of quantum computers for this purpose. may be high.

ÿIn order to support the business activities of such start-up companies, support will be provided for promising start-up companies with research and development of quantum applications, demonstration tests, and the use of quantum computers.

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(iii) Improving the procurement of products and services for small and medium-sized enterprises, including start-up companies (for example, procurement that emphasizes things other than track record and price for research projects, procurement that includes technological sophistication rather than mere purchasing, etc.)

ÿ**Quantum** business requires long-term investment, and in a small market in its infancy, it may be difficult to establish a business based on market principles alone, so we are working with small and medium-sized enterprises, including startups, from a long-term perspective. It is important to nurture them. Additionally, it is effective for small and medium-sized enterprises to secure a certain market size and increase business viability, targeting not only the domestic market but also overseas markets. ÿ**On** the other hand, in projects run by the government or research institutes, procurement of equipment, devices, etc. is often carried out with emphasis on performance and price, which may be disadvantageous for small and medium-sized enterprises such as startups. There are many. In addition, it is not just a matter of shopping, but it is a place that does not lead to securing or improving international competitiveness.

There are also cases.

ÿ**For** this reason, from the perspective of nurturing small and medium-sized enterprises including start-up companies, the government and research institutes will focus on future growth potential other than performance and price in order to play the role of stimulating demand as early adopters. We will strive to implement appropriate procurement. In addition, when procuring equipment, devices, etc. from small and medium-sized enterprises, with an eye toward strengthening international competitiveness and expanding into overseas markets, we do not simply purchase goods, but also use strategies such as incorporating research and development toward sophistication as necessary. work on the target.

(iv) Others (points to note, etc.)

ÿStart-up companies overseas are often supported by researchers in some form of technical support, so in order to increase the number of start-up companies in Japan, we need to work together with researchers in the quantum field , It is important to increase the number of students. We also provide comprehensive support to support university-based startup companies.

(Intellectual property strategy, legal affairs, business strategy, etc.) are also important.

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(2) Strengthening the structure of the quantum technology innovation center

<Points>

ÿ New base for strengthening industrial competitiveness, economic security, utilization of quantum technology, strengthening international competitiveness, etc.

Point formation/functional enhancement

ÿ Dramatically strengthen the headquarters functions that represent Japan's quantum technology innovation base (rational

Chemical Research Institute)

(i) New bases for strengthening industrial competitiveness, economic security, utilization of quantum technology, strengthening international competitiveness, etc.

Point formation/functional enhancement

ÿ8 quantum technology innovation hubs [8] was launched in February 2021, and each base takes on a role that leverages its own strengths, and is responsible for research and development, international collaboration, industry-academia-government collaboration, human resource development, etc. We are promoting initiatives. **ÿIn** order to invigorate and intensify activities for the commercialization of quantum technology in the industrial world, we will continue to work with the industrial world to ensure Japan's international competitiveness in both hardware and software. It is necessary to strengthen support for

ÿWith regard to hardware, as it is expected that quantum bit development will become more sophisticated and diversified in the future, we will raise the standard to industrial technology level rather than laboratory level, and domestically produce quantum computers and other key technologies. It is necessary to aim for To this end, it is necessary to comprehensively and seamlessly support industrial activities such as prototyping, manufacturing, evaluation, and standardization of quantum chips. In addition, from the perspective of economic security, efforts will be made to improve the sophistication of quantum materials, which are essential for research and development and industrialization of quantum devices, and to develop and strengthen the supply chain infrastructure. It is also necessary to

ÿ Regarding software, new business activities such as services that integrate quantum and classical technologies are expected to become more active and full-scale, and advanced hybrid computing that seamlessly connects quantum and classical It is necessary to prepare an environment for using Google. In addition, in order to utilize quantum technology in socio-economic systems, It is also necessary to support the creation of solutions using quantum technology and to develop industrial human resources who will play a leading role. **ÿFurthermore ,** in order for Japan not to fall behind in the fierce international competition in the quantum field, it is necessary to incorporate the latest academic principles and technologies from overseas industry and academia. To this end, it is necessary to strengthen international research and development, education, etc., as well as develop centers of excellence at the international level and increase the unifying force of Japan.

8 Quantum computer development/Headquarters of all bases (RIKEN), quantum computer utilization (University of Tokyo-Corporate Alliance), Quantum Device Development (National Institute of Advanced Industrial Science and Technology), Quantum Software (Osaka University), Quantum Security (National Institute of Information and Communications Technology), Quantum Life (Bio) (National Institute of Quantum Science and Technology), Quantum materials (National Institute for Materials Science), quantum sensors (Tokyo Institute of Technology)

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ÿ**Based** on these, aim to strengthen industrial competitiveness, economic security, utilize quantum technology, strengthen international competitiveness, etc.

From this perspective, we will strengthen the system by forming new bases and strengthening functions as follows.

ÿ **“Global Industry Support Center (tentative name)” (National Institute of Advanced Industrial Science and Technology (AIST))**

A service business that provides private companies with opportunities to prototype, manufacture, and evaluate quantum chips and peripheral devices, and utilize quantum/classical hybrid computing resources in collaboration with domestic and international companies, including volunteer countries. A base that provides comprehensive support to industry with a view to future commercialization from a global perspective, such as developing new user markets, including development of new user markets, creating an environment that supports commercialization, and supporting standardization. form a point.

ÿ **“Quantum Function Creation Center (tentative name)” (Quantum Science and Technology Research and Development Organization (QST))**

Developing high-performance quantum functions through the creation and advancement of quantum functions using highly precise quantum beam technology The world's most advanced research and development of quantum materials, and the world's leading advanced quantum materials. Establish a base that is responsible for developing the supply infrastructure and ensuring stable supply.

ÿ **“Quantum Solutions Center (tentative name)” (Tohoku University)** collaborates with

many user companies and vendor companies to support the utilization of quantum computers, support research and development of valuable solutions that meet corporate needs, and develop quantum solutions. We will support the utilization of quantum technology and provide support for the industrial world by building classical hybrid computing environments and developing industrial human resources through these. Form a base that supports research and development of valuable solutions and fosters industrial human resources.

ÿ **“International Education and Research Center (tentative name)” (Okinawa Institute of Science and Technology Graduate University (OIST))**

It is a center that is responsible for the world's most cutting-edge international research, development, and education, attracting excellent quantum researchers from Japan and overseas, promoting cutting-edge international joint research, and providing international education on quantum technology. form a point.

(ii) Fundamentally strengthen the headquarters function that represents Japan's quantum technology innovation center

Chemical Research Institute)

ÿ**In** order for Japan not to fall behind in the fierce international competition in the quantum field, it is necessary to ensure a system that incorporates the most cutting-edge theories and technologies advanced by overseas industry and academia without delay. To this end, we must promote internationally advanced research and development and education in both basic and applied quantum technology, increase Japan's unifying force, and establish an internationally visible base that will form the core of this. It is necessary to create

ÿ RIKEN is positioned as the headquarters that oversees and represents all quantum technology innovation centers in Japan (RIKEN Center for Quantum Computer Research).

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Quantum Computing)).

ÿSince quantum technology will spread to various fields in the future, the headquarters center will need to have a system that can cover a wide range of science and technology fields. To this end, we will create and strengthen an environment in which top domestic and international researchers can gather together to promote world-class, cutting-edge research under a system that allows for a broad perspective from both science and technology. In particular, we will deepen collaboration with industry, academia, and government research institutes both domestically and internationally, and develop cutting-edge science and technology that Japan should possess. Aim to maintain and improve overall strength. In addition, we will promote international collaboration across sectors, including industry, dissemination of information, and We will fundamentally strengthen headquarters functions such as coordination and coordination among bases.

ÿIt will also be responsible for providing a wide range of advanced scientific calculations and data utilization methods, including the realization of hybrid computing systems and services through the fusion of quantum computers and conventional (classical) calculation systems. Therefore, while strengthening this center, it is important to develop a system to strengthen research collaboration in related fields such as quantum, supercomputers, AI, and biotechnology.

(iii) Others (points to note, etc.)

ÿIn order to make quantum technology innovation centers more attractive and appealing to domestic and international industries and researchers, we will promote internationally competitive R&D and promote industry-academia collaboration and international collaboration. It is important to further enhance functions and strengthen the structure of each base (including improving posts and benefits). ÿThe quantum technology innovation bases will leverage their respective strengths and collaborate with each other to maximize functions such as industry-academia-government collaboration and international collaboration, and actively disseminate information to increase their presence both domestically and internationally. It is also important to go.

(3) Developing and securing human resources

<Points>

ÿ Providing educational programs to a wide range of people, including industry, using private businesses (recurrent education) etc.), central provision of related information

ÿ Human resource development that integrates other fields such as drug discovery/medicine, materials, and finance, as well as conventional (classical) technological fields such as AI (e.g., hybrid human resources of "••×quantum" who have quantum as a second language, etc.)) ÿ Developing broad-based young research personnel who will be responsible for future breakthrough technologies, and nurturing quantum natives by utilizing science museum exhibitions, video content, etc. (creating an environment where they can come into contact with quantum science from an early age,

(i) Providing educational programs to a wide range of people, including industry, using private businesses (recurrent education etc.), central provision of related information

ÿIn recent years, there has been a movement to develop and provide educational programs in the quantum field, mainly among researchers at universities and research institutes.

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It's becoming more active. However, because the resources of universities, research institutes, and other providers are limited, in order to provide educational programs to a wider range of people in the future, private businesses will be used to implement them.

It is also considered effective to do so.

ÿ**For** this reason, we will utilize private businesses to provide educational programs to a wide range of people, including industry, in other fields such as drug discovery/ medical care, materials, finance, and conventional (classical) technology fields such as AI. At the same time, we will create a system to match human resources from industry and academia so that young human resources can smoothly choose the quantum field as an attractive future career path. In the future, there will be a certification system to certify (visualize) technical proficiency.

We are also considering the introduction of

ÿ**It** also provides information on educational programs provided by multiple institutions in a unified and systematic manner.

Build a system to

(ii) Human resource development that integrates other fields such as drug discovery/medicine, materials, and finance, as well as conventional (classical) technological fields such as AI (e.g., a hybrid of "••×quantum" where quantum is a second language) human resources, etc.)

ÿ**Quantum** technology can create and provide user value only when integrated with other fields such as drug discovery, medical care, materials, finance, and conventional (classical) technology fields. Kata (Classical) It is important to have a perspective that works in collaboration with the technical field.

ÿ**Also ,** from the perspective of enriching human resources in the quantum field, we will develop human resources who can bridge seeds and needs (users).

Developing human resources with knowledge of both the quantum field, other fields, and conventional (classical) technology fields is also important from the perspective of achieving future results. In the future, when the use of quantum technology becomes commonplace, other fields and

There are also expectations for ``••×quantum'' hybrid human resources who are primarily specialized in conventional (classical) technology fields but can also master quantum technology, so to speak, with quantum as their second language.

ÿ**In** order to develop such hybrid human resources, a system will be created to provide an integrated educational program that combines the quantum field, other fields, and conventional (classical) technical fields. In addition, research and development projects

Even if the current situation is low, human resource development will be promoted by actively introducing research and development themes that integrate the quantum field with other fields and conventional (classical) technology fields.

(iii) Developing broad-based young research personnel who will be responsible for future breakthrough technologies, and nurturing quantum natives by utilizing science museum exhibitions, video content, etc. (creating an environment in which they are exposed to quantum science from an early age, etc.)

ÿ**Many** breakthrough technologies, such as stable qubit generation and error correction, are needed to increase the scale and put quantum computers into practical use. ÿ**Promote** broad-based basic research for future breakthrough

technologies and strongly promote human resource development, including young researchers. At this time, we will create an environment that allows for the development of a wide range of human resources at many universities, research institutes, etc., including those other than quantum technology innovation centers. In addition, the National Research and Development Agency, which is responsible for policy-based research and development, and the universities, etc., which are responsible for education and research, collaborate, leveraging the characteristics and strengths of both parties.

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We will promote further exchanges with researchers, teachers, and students, and strengthen the development of research personnel.

ÿ**Furthermore ,** we will create an environment where children can come into contact with quantum science from an early age by utilizing science museum exhibits and video content.

We will also strive to develop quantum natives.

(iv) Others (points to note, etc.)

ÿ**Since** developing and securing human resources is a serious issue for both industry and academia, both universities and research institutes are actively expanding the number of positions, and industry is also actively accepting new employees. It is hoped that efforts will be made.

(4) Intellectualization and standardization of quantum technology

<Points>

ÿ Formation of a patent pool led by the private sector and establishment of a private management organization based on an open/close strategy

Ge

ÿ Mainly focused on intellectual property, standardization, and international rule-making for quantum technologies such as quantum computers and quantum cryptography communications.

Creating a system and structure to guide

ÿ Sophistication of practical technology, world-leading intellectual property and standardization through demonstration of the use of quantum cryptographic communication, establishment and standardization of practical technology including peripheral technologies

(i) Formation of a patent pool led by the private sector and establishment of a private management organization based on an open-close strategy

Ge

ÿ**Quantum** computers and quantum cryptographic communications are comprehensive systems that integrate a variety of technologies, including quantum technology and conventional (classical) technology, and are expected to involve a variety of intellectual property and rights in a complex manner in the future.

ÿ**In** the future, in order for private companies to smoothly utilize these intellectual properties in their business activities and research and development, it is expected that an international patent pool will be formed led by the private sector to license multiple intellectual properties at once.

Waited. At this time, it is also important to have an open/close strategy to secure intellectual property related to quantum technology and consider and identify patents that should be shared among the parties involved. ÿ**For** this reason, the government, in collaboration with private companies, should promote such an open-close strategy and encourage private-sector initiatives.

We will provide the necessary support for the creation of a patent pool and the launch of an organization to operate it.

(ii) Mainly involved in the creation of international rules and intellectual property rights and standardization of quantum technologies such as quantum computers and quantum cryptography communications.

Creating a system and structure to guide

ÿ Regarding the intellectual property rights of quantum technology, Japan ranks third in the number of patents acquired after China and the United States, and ranks among the international

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It is at a relatively high level. However, over the past 10 years, China and the United States have shown rapid growth, and it is important for Japan to strengthen its efforts toward intellectual property rights. Regarding standardization, in addition to de jure standards such as the International Telecommunication Union-Telecommunications Standardization Sector (ITU-T) and the International Electrotechnical Commission (IEC), there are forum standards discussion forums such as the Institute of Electrical and Electronics Engineers (IEEE). Japan is actively participating in this, and it is expected that Japan will play a leading role in the future.

ÿ**For** this reason, we will continue to promote the intellectual property and standardization of quantum computers and quantum cryptographic communications with an eye to future computer and communication systems, as well as develop a system for this purpose in which the public and private sectors work together, and promote standardization activities in the private sector. We will build a system and mechanism that will take the lead in international rule-making, including support.

ÿ**Furthermore ,** a specialized group will be organized to support intellectual property and standardization activities in each organization forming the quantum technology innovation hub. Additionally, efforts will be made to create incentives to promote the creation of intellectual property at universities, research institutes, etc.

(iii) Sophistication of practical technology through demonstration of the use of quantum cryptographic communication, creation of intellectual property and standardization ahead of the world, establishment and standardization of practical technology including peripheral technologies

ÿ Regarding quantum technology, in parallel with research and development, use of the technology will be demonstrated by users as early as possible, and the knowledge from the use demonstration will be fed back to research and development to establish and improve practical technology, and to create intellectual property and trademarks. It is important to proceed with standardization.

ÿ**In** particular, with regard to quantum cryptographic communication, which is becoming more and more practical, we will utilize the open test bed of the quantum cryptographic communication network to improve the practical technology by having many users demonstrate its use, and be the first in the world to do so.

Promote intellectual property and standardization.

ÿ**In** addition to improving core components such as longer distances and miniaturization, we will establish practical technologies (architectures, frameworks, interfaces, etc.) including peripheral technologies, and promote intellectual property and standardization.

(iv) Others (points to note, etc.)

ÿ**Many** of the markets in the quantum field are in their infancy, so in some cases, a certain level of market has been formed, with the aim of social implementation in an open innovation format, utilizing public funding and government procurement. It is also important to consider open/close strategies depending on the growth stage of the market, such as closing after

The key point.

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(5) International collaboration/industry-academia-government collaboration

<Points>

ÿ Strengthening strategic international joint research, sending researchers, mainly young researchers, overseas, and attracting excellence from overseas. Improving international exchange and international mobility, such as attracting outstanding researchers

ÿ Revitalizing international exchange and cooperation in industry and supporting overseas expansion of industry

ÿ Establishment of collaboration/cooperation system between industry, quantum technology innovation centers, and related ministries (exchange of opinions) opportunities, personnel exchanges, joint research, etc.)

(i) Strengthening strategic international joint research, sending researchers, mainly young researchers, overseas, and Improving international exchange and international mobility, such as attracting excellent researchers

ÿIn recent years, many researchers have been faced with the issue that international research personnel exchanges, especially among young researchers, have been sluggish. It has been pointed out by researchers. Furthermore, this issue is becoming even more serious due to the effects of the coronavirus pandemic.

ÿFor this reason, we actively support the dispatch of researchers, mainly young researchers, overseas in a wide range of fields from basic research to applied research, and we also promote international exchange and exchange by inviting excellent researchers from overseas. international Increase liquidity.

ÿIn addition, we will promote the construction of a framework for cooperation between countries, and the Center for Quantum Technology Innovation will play a central role. We collaborate with overseas universities, research institutions, private companies, etc. that have cutting-edge technology, and acquire the latest overseas technology. We will strongly promote international joint research in order to

(ii) Activating international exchange and cooperation in industry and supporting overseas expansion of industry

ÿIn order for private companies to develop and manufacture quantum computers and quantum cryptographic communication systems, it is important to build an international supply chain and an international joint research and development system. International exchange and cooperation between the worlds is essential.

ÿFor this reason, the government will actively support international exchange and cooperation in industry centered on the Council for the Creation of New Industries Based on Quantum Technology (Q-STAR), while also utilizing forums for national cooperation as necessary. ·Assist. ÿAlso , while identifying Japan's strengths that can be applied overseas, the public and private sectors will work together to develop commercial products that utilize quantum technology. Promote the overseas expansion of products and services.

(iii) Building a system of collaboration and collaboration between industry, quantum technology innovation hubs, and related ministries (exchange of opinions) opportunities, personnel exchanges, joint research, etc.)

ÿEight quantum technology innovation hubs (QIH) will be launched in February 2021, and in the industry, the Council for Creating New Industries Based on Quantum Technology (Q-STAR) will be established in September of the same year . A new system was established to promote research and development and industrialization of quantum technology.

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ÿIn addition, the Quantum Innovation Initiative Council (QII Council) was established in July 2020 as a collaboration between the University of Tokyo, Keio University, IBM USA, IBM Japan, and industry, and the A real computer has been installed for the first time in Japan, and members of industry and academia are now using real quantum computers.

It started in July 2021. **ÿIn** order for industry,

academia, and government to work together on research, development, and industrialization, the Quantum Technology Innovation Center (QIH), the New Industry Creation Council (Q-STAR), and related ministries will collaborate systematically in the future.•Build a system for cooperation. We will also utilize industry-academia collaboration through the Quantum Innovation Initiative Council (QII Council). Furthermore, under this system of collaboration and cooperation, we will proactively promote initiatives that meet the mutual needs of all parties involved, such as exchanging opinions between industry, academia, and government, joint research, personnel exchanges, and holding various events.

(6) Promotion of outreach activities

<Points>

ÿ Enhance and strengthen public relations activities through media and content such as science museum exhibitions, SNS, videos, etc., and create an environment where young people can

come into contact with quantum technology ÿ Information such as mechanisms to centrally provide information on quantum technology (portal sites, etc.) Fulfillment of provision fruit/strengthen

ÿ Play-up of human resources who connect quantum and society (evangelists, ambassadors, etc.), front-runner human resources such as entrepreneurs and researchers (also contributing to career development for young people), etc.

(i) Enhance and strengthen public relations activities through media content such as science museum exhibitions, SNS, videos, etc.

Creating an environment where people can come into contact with child technologies

ÿSince quantum technology is generally difficult to understand and difficult to understand, it is important to communicate quantum technology in an easy-to-understand manner to a wide range of people. It is important to further enhance and strengthen public relations activities to achieve this goal. **ÿFor** this

reason, we will use media such as SNS, YouTube, videos, and other content to explain how quantum technology is useful. Explain quantum technology in an easy-to-understand manner.

ÿAlso , through science museum exhibitions and the creation of teaching materials that allow students to experience quantum technology, we will also engage young people such as children, students, and students. We will also create an environment where people can come into contact with quantum technology.

(ii) Improving the provision of information, such as mechanisms (portal sites, etc.) that centrally provide information on quantum technology. fruit/strengthen

ÿCurrently , the Quantum Technology Innovation Center (QIH) and the Council for Creating New Industries Based on Quantum Technology (Q-For information on the activities of STAR), educational programs provided by related organizations, etc., please see individual websites.

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Information is provided through websites, etc.

ÿHowever , for users, there is a problem that they need to access it individually, which makes it inconvenient and difficult to understand.

Furthermore, as the number of stakeholders continues to increase, there is a risk that things will become even more complex.

ÿBased on these, in order to widely provide information on quantum technology to society in an easy-to-understand format, we will

We will aim to enrich and strengthen information provision, such as by creating a portal site that centrally provides information.

(iii) Human resources who connect quantum technology and society (evangelists, ambassadors, etc.), entrepreneurs, researchers, etc.

Play-up of runner talent (also contributes to career development for young people), etc.

ÿSince quantum technology is generally difficult to understand, it is important to translate the content of quantum technology and what it can do in an easy-to-understand manner to society.

We need a system and people to translate and convey the message.

ÿFor this reason, we will appoint human resources (evangelists, ambassadors, etc.) who connect quantum technology and society, and

We will raise social awareness by utilizing media such as YouTube.

ÿAlso , in order to contribute to the career development of young people, there is a system to play up front-runner human resources such as entrepreneurs, researchers,

and engineers who are creating and providing new value using quantum technology. (Information provided

and award systems) will also be considered.

(7) Economic security/business environment improvement, etc.

<Points>

ÿ Ensuring and strengthening economic security (acquisition of cutting-edge technology to ensure technological superiority, securing supply chains for

important basic parts and materials, responding to cyber attacks, etc.) ÿ Promoting government funds, etc.

Promote demand stimulation by supplying risk money and early adopters (political

prefectural procurement)

ÿ Improving the operation of national projects, such as using a fund system that enables long-term investment

(i) Ensuring and strengthening economic security (acquiring cutting-edge technology to ensure technological superiority, securing supply chains for

important basic parts and materials, responding to cyber attacks, etc.)

ÿ Acquire cutting-edge technologies to ensure technological superiority, including quantum computers, quantum networks, basic materials necessary for quantum

measurement and sensing, semiconductor elements, control and measurement equipment, peripheral equipment, manufacturing equipment, etc. We will work

strategically to secure the supply chain for important basic parts and materials. In particular, single photon detectors, which are essential for quantum

communications, are highly dependent on overseas production, so it is difficult to domestically produce them.

Work toward this goal.

ÿResearch and development elements related to quantum technology require the latest technology, and the Beyond 5G promotion strategy,

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Since there are many things in common with semiconductor strategies, etc., research and development based on these strategies can be integrated and effective.

We will strengthen cooperation to move forward.

ÿ**We** also provide support for important information systems and data that form the basis of industry and society, including technical information.

We will take measures such as protecting against cyber attacks, etc.

(ii) Promotion of demand stimulation through the supply of risk money and early adopters through the use of government funds, etc. (government

prefectural procurement)

ÿ**There** are many technical issues that need to be resolved before the practical application of quantum technology, including quantum computers, and it will take a long time.

Requires period investment.

ÿ**In** Japan's private companies (including financial institutions), private investment tends to be sluggish when the future market is uncertain and the investment is over a

long period of time. This will reduce risks and stimulate private investment.

From this perspective, government-affiliated funds, etc. will be used to supply risk money.

ÿ**In** addition, if a private company develops or releases a new product or service (including a prototype) that utilizes quantum technology, the government or related

organizations will proactively procure it as an early adopter to stimulate demand. Tsutomu

Melt.

(iii) Improving the operation of national projects, including the use of fund systems that enable long-term investment

ÿ**Since** quantum technology requires long-term and challenging R&D investment, moonshot-type It is expected that efforts will be made to improve the operation of

national projects, such as by utilizing funding systems such as research and development systems in national projects.

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6. Finally

The 20th century, when quantum technology was born, brought about nuclear power, semiconductor electronics originating from transistors, and lasers. New technologies based on quantum mechanics were created one after another, leading to scientific and technological innovation and social progress.

However, quantum mechanics includes principles unique to quantum mechanics, such as the superposition state being determined to a single value upon observation (contraction of wave packets) and quantum entanglement. These are things we usually use. It was qualitatively different from the world of classical physics, and it was an academic subject that needed to be examined, such as observational problems in quantum theory. Eventually, in the latter half of the 20th century, it was positioned as a dream technology that would bring about new technological innovations. Now I can get kicked.

Since the beginning of this century, quantum technology has rapidly progressed from "verification" to "control" due to advances in both experiments and theory. For example, with quantum computers, the dream technology of a while ago is becoming a reality: controlling the quantum state of each atom or electron as desired and using it for quantum calculations.

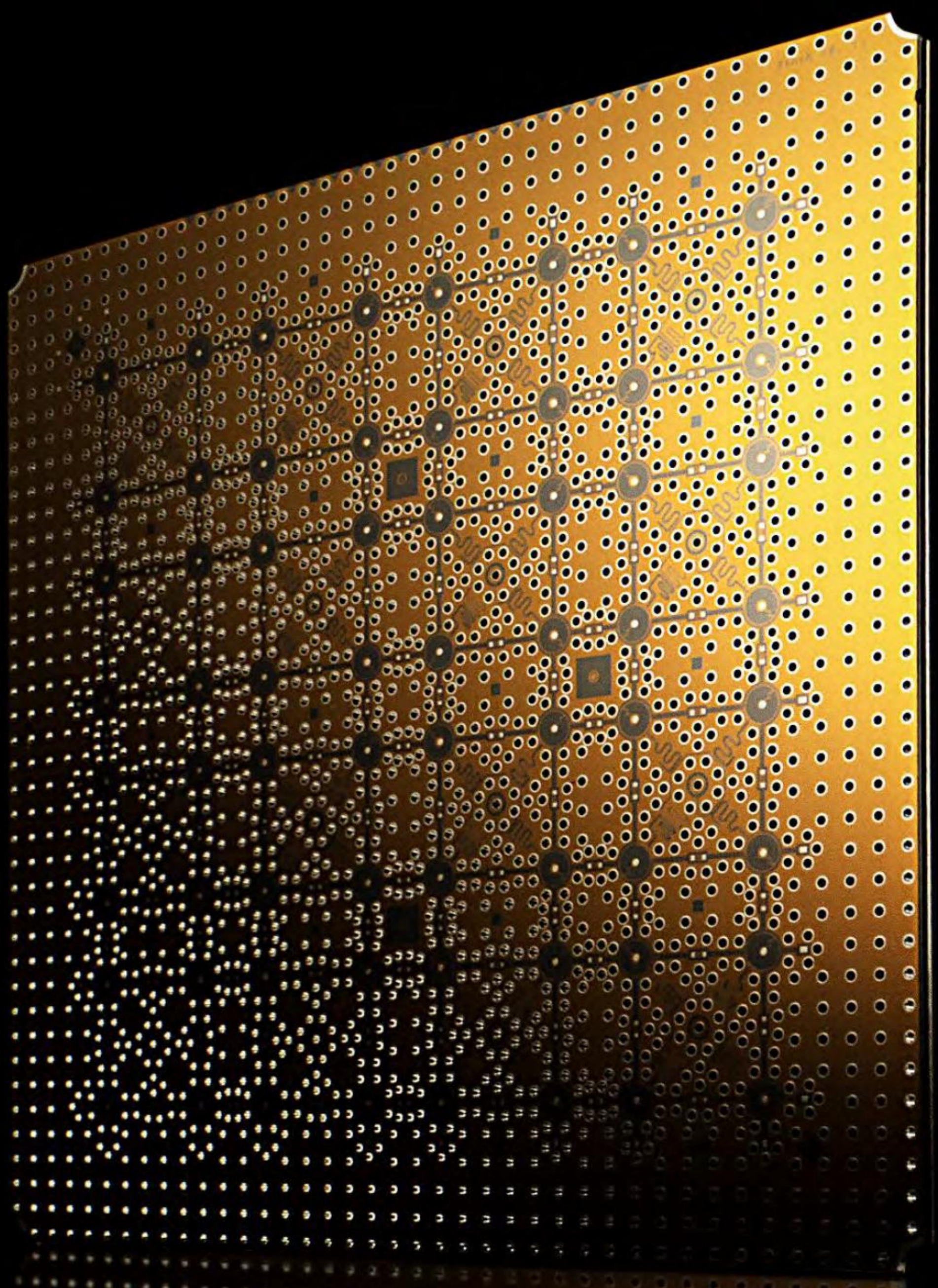
In the future, it will also be possible to control even larger quantum systems. This will usher in an era in which quantum technology will be fully utilized for information processing, secure communications, ultra-sensitive sensing, and more. This vision is as follows. In this new era, we have shown the basic idea and direction of efforts to effectively utilize quantum technology. It is something.

These are technologies that humankind has not yet obtained, and are expected to change the face of society and economy in the future and bring unprecedented benefits. However, if used maliciously, there is a risk of causing serious harm. Ru. Therefore, we will study the essence of new technology ourselves, and strive to achieve not only economic growth but also harmony between people and the environment. With an eye on people's happiness (spiritually rich lives), we proactively take steps to ensure that our products are utilized as a common asset of humanity. should lead the innovation.

The development of quantum technology to date is the result of researchers' curiosity and steady efforts. From now on, industry will It will play a major role in delivering the benefits of quantum technology to society.

In the future, industry and academia will work together to further develop quantum technology and bring great benefits to society and the economy. I hope it goes.

Quantum future industry creation strategy



April 14, 2020

Integrated Innovation Strategy Promotion Council

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Cover photo: Quantum computer chip (provided by RIKEN)

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1. Introduction

ÿ The "Quantum Future Society Vision" (April 22, 2020, Integrated Innovation Strategy Promotion Council) presents a vision of aiming for a sustainable society, economy, and environment through the utilization of quantum technology. The goal is to increase the number of domestic users of quantum technology to 10 million in 2030, increase the production value of quantum technology to 50 trillion yen, and create quantum unicorn venture companies that will open up future markets. **ÿIn** order to achieve this goal, it is important to work on the practical application and industrialization of quantum technology and to connect quantum technology to the creation of value such as improving productivity, creating new industries, and resolving social issues. In particular, in order to achieve the target number of users and production value, industries in a variety of fields must utilize quantum technology in their businesses and services to form a wide-ranging market. becomes important.

ÿIn order to promote the use of quantum technology in a variety of industries, it is important to work toward creating use cases that are valuable to each industry. For example, industrial fields (e.g. materials, chemistry, finance, health/medical care, manufacturing, logistics/transportation, AI, information and communication, etc.) and social issues (e.g. environment, water, food, energy, urban development, defense, etc.) Examples of use cases include: It is also important to actively disseminate information about the results and value of use cases, and to create an environment where managers can understand the value and utilize quantum technology in their business activities. Furthermore, it will be important to create an environment in which industries in a variety of fields can utilize quantum computers. **ÿThe** value market created by the utilization of quantum technology is expected to grow enormously in the future, leading to increased international competition, with active public and private investment overseas and private companies actively and quickly expanding globally. is intensifying. Furthermore, since it is an industry that requires advanced technological capabilities, there are many cases where private companies develop business in close collaboration with universities, research institutes, etc., and basic research and industrial applications are becoming more common than in the past. It can be said that this is an area that is becoming closer.

ÿFor this reason, in practical application and industrialization, industry, academia, and government will work together, and in parallel with basic research, we will strategically consider future business development from an early stage, with an eye toward global collaboration and expansion. It is important to accelerate efforts more than ever.

ÿIn emerging markets where new value is created by quantum technology, startups/venture companies that develop unprecedented new businesses and services can also become important players. On the other hand, many quantum technologies require long-term investment before they can be put to practical use or industrialized, so startups should be developed from a long-term perspective, taking into account the characteristics of the market in the quantum technology field, which requires long-term investment. It is important to form a venture ecosystem by attracting investment and human resources. **ÿIn** the future, as technological innovations and markets such as AI technology, Beyond 5G, and semiconductors change rapidly, we will develop society and economy by combining these with quantum technology.

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It is expected. Furthermore, there is a greater need than ever for efforts to realize a sustainable society and economy, such as the SDGs and a decarbonized society, and it is expected that quantum technology will make a major contribution. In the practical application and industrialization of quantum technology, it is also important to take a flexible approach to responding to such technological innovations and future changes in the economy and society.

ÿ**Based** on these, in order to realize the goals set forth in the Quantum Future Society Vision, we will develop policies and priorities for the practical application and industrialization of quantum technology through collaboration between industry, academia, and government. Indicates specific initiatives that should be taken.

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2. Position of this report

In contrast to the “Quantum Technology Innovation Strategy” (January 21, 2020, Integrated Innovation Strategy Promotion Council), which focuses on research and development of quantum technology and related areas (in other words, the “R&D strategy for quantum technology”), The Future Society Vision is a vision of the future society that should be aimed at through quantum technology, in order to utilize quantum technology to create growth opportunities for Japan's industry and solve social issues, and to realize the transformation of society as a whole. It has been formulated as a strategy for realizing this, so to speak, a ``strategy for social transformation through quantum technology.'' In order to realize the

goals set forth in the Quantum Future Society Vision, this report outlines the policies that should be pursued for the practical application and industrialization of quantum technology, and the priorities for the time being, under collaboration between industry, academia, and government. It is a strategy that shows specific initiatives that should be taken on a priority basis, so to speak, as a ``strategy that shows policies and action plans for the practical application and industrialization of quantum technology.''

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3. Direction of future industry that should be aimed at

(1) Participation, collaboration, and co-creation of diverse industries (soft and hard)

(i) Creation and development of services through the participation of diverse users

ÿ Future quantum industry[1] The majority of the market/value chain is expected to be in the services sector. For this reason, in the future, user industries that provide services in various fields will participate in the field of quantum technology, and through the collaboration and co-creation of various stakeholders from industry, academia, and government, we will develop new technologies that utilize quantum technology in each field. It is expected that services will be created and developed. As a result, it is expected that a model will be formed in which funds are circulated from services to hardware.

ÿAlso , for user industries, quantum technology is just one of the tools to advance business activities. From this perspective, managers can fully understand the benefits of introducing quantum technology compared to other technologies, and utilize quantum technology in their respective business activities to improve productivity and create new industries. It is hoped that an environment will be created that will enable this.

ÿFurthermore , it is important to create a system in which investors can actively evaluate and invest in companies that are effectively utilizing such quantum technologies in their business activities.

(ii) Hardware/system manufacturing through participation and co-creation of a wide range of industries

ÿ When manufacturing hardware/systems such as quantum computers, we need to manufacture devices, parts, materials, electronics, semiconductors, architecture/systems, and refrigeration. It is expected that a wide range of industries, including small and medium-sized enterprises, will participate and co-create everything from machines to manufacturing process equipment. Furthermore, it is important to co-create with users from an early stage and feed back user needs to the hardware system. **ÿIt** is also expected that Japan will strategically capture the global market in fields

where Japanese industries can take advantage of their strengths, such as the materials and device fields, and in strategically important technology fields (choke point fields). Furthermore, it is expected that they will build strong and stable supply chains while collaborating globally with companies from like-minded countries.

ÿIn the future, hardware and system-related businesses will shift from businesses that combine software and services (cloud computing resource provision services, calculation/solution provision services, etc.) to hardware sales (operational

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1 This report covers a wide range of industries that create value through the use of quantum technology, including industries that provide products and services based on quantum technology, industries that utilize quantum technology as users, and industries that support these uses. Refers to industry.

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There are a variety of business models to choose from, including provision of quantum computers on premises, parts/component manufacturing, foundries, circuit design services, manufacturing process equipment, etc.).

ÿ**Currently ,** as the market is in its infancy, the technology and business have not yet been determined, but while keeping an eye on future developments, we must be resilient and quick enough to pivot at any time in order to maximize our chances of winning. (Agile) is important. Furthermore, companies are working together to reduce business risks and ensure a stable supply chain, such as by manufacturing common parts and materials for multiple technology methods, or by adopting parts and materials that are compatible with general-purpose products. It is also expected that the government will make strategic efforts towards building a network.

(2) An environment where many industries can access and utilize quantum technology

ÿ**Currently ,** when using quantum technology such as quantum computers, specialized knowledge is required or the development environment differs depending on the computer. This can be said to be a difficult situation for user companies to overcome.

ÿ**In** order to lower these hurdles, companies that provide user-friendly environments for the use of quantum computers, etc., and services that support user companies' utilization of quantum technology (education services, consulting, etc.) are encouraged. Development is expected. ÿ**In** the future, it will be important to make quantum technology

available to everyone without being aware of it. To this end, it is important to maintain as much of the traditional user interface as possible while building services that have good usability, such as automatically sorting calculations between conventional (classical) technology and quantum technology in the background for a given calculation problem. Be expected.

ÿ**In** addition, rather than making everything quantum, we will also discuss the perspective of building and utilizing a quantum/classical hybrid that complements the strengths of conventional (classical) technology and quantum technology, and the state of progress in technology. It is also important to consider migration (system transition), such as gradually replacing some conventional technologies in services with quantum technology, depending on the situation.

(3) Creation and growth of startups/venture companies and new businesses ÿ**Startups /**

venture companies will be important players in emerging markets such as those in the quantum technology field. It is hoped that by taking advantage of its speed and flexibility, it will be able to follow the rapidly changing market and capture domestic and overseas markets. In the future, it is also expected that a venture ecosystem will be formed in which the profits from commercialization are reinvested in the development of the next business and the creation and cultivation of startups. ÿ**For** the success of startup companies, etc., not only researchers and

engineers but also developers are required.

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It is also important to develop and secure entrepreneurs and managers who can design and develop businesses by making full use of deep tech. Furthermore, it is necessary to cultivate and secure investors who understand deep tech and can provide financial support from a long-term perspective. **ÿAlso ,** existing companies such as large companies are expected to demonstrate their strengths while leveraging their comprehensive strength and capital strength and launch new business divisions/carve-out ventures (intrapreneurs).

(4) Global collaboration and expansion **ÿ** The market for quantum technology has active investment worldwide, and the global market is expected to grow dramatically in the future. While the future of technology and business has not yet been determined, and the winner has not yet been determined, there is a great chance that Japan's industry can capture the global market depending on its future strategies. **ÿFor** this reason, it is expected that they will expand their business globally while actively collaborating both horizontally and vertically with companies from like-minded countries in terms of services and technology. Furthermore, depending on the characteristics of each service, it is expected that they will strategically expand overseas by demonstrating services in Europe, America, Asia, etc. **ÿAlso ,** in order to secure a global market, active efforts to obtain standardization are also important. Regarding intellectual property, it is also a long-term technology field, so it is important to thoroughly implement an open-close strategy while keeping an eye on the period for obtaining rights and carefully distinguishing between what should be patented and what should not be patented, including know-how. Be expected.

(5) Promotion of industrialization through industry-academia-government collaboration

ÿSince the quantum industry requires advanced technology, there are many cases in which the results of basic research at universities and research institutes are used for industrialization, and in recent years, the movement to bring basic research and industrial applications closer together has accelerated. It's coming.

ÿTo this end, the Council for the Creation of New Industries through Quantum Technology (Q-STAR) and the Quantum Technology Innovation Center (QIH) are collaborating organizationally to share visions and values and collaborate. It is expected that systems and mechanisms will be built for collaboration between industry, academia, and government in all aspects such as research, personnel exchange, and information exchange. **ÿIn** national projects as well, efforts will be made to enhance and strengthen efforts from research and development to industrial application, while creating a system in which industry, academia, and government collaborate.

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4. Three perspectives for promoting practical application and industrialization effor

The basic idea of the direction of future industry and the quantum future society vision mentioned in the previous chapter direction [2] Based on this, when moving forward with efforts to commercialize and industrialize quantum technology, efforts will be made based on the following three perspectives. At this time, we will accelerate our efforts even more than ever before, taking into account the intensification of international competition.

ÿCollaboration "Participation, collaboration, and co-creation in the field of quantum technology in various industries, global collaboration and deployment, and industry-academia-government collaboration" As stated in the Quantum Future Society Vision, the number of users of quantum technology and the amount of production In order to expand, it is important to have the participation of a wide range of industries in the quantum technology field and to expand the market base by utilizing quantum technology in various fields.
Ru.

To this end, we will work with the participation of user companies in diverse fields such as materials, chemistry, finance, health and medical care, manufacturing, logistics and transportation, the environment, agriculture, energy, urban development, defense, AI, and information and communications. It is essential that diverse companies collaborate to create and co-create new value. In addition, in order to implement quantum computers, etc. in the real world, it is necessary to have participation not only in the field of quantum technology, but also by companies in the field of conventional (classical) devices, parts, materials, electronics, semiconductors, etc. hybrid) will also be required.

In order to encourage the participation of such diverse companies, we will support the creation of attractive use cases (killer applications) that will appeal to user companies, clarify their effects, and provide support for the creation of attractive use cases (killer applications) that will appeal to user companies. It is important to build a system in which a variety of companies, including those in the (classical) technological fields, can participate, collaborate, and co-create. Furthermore, it is also important to build stable and resilient supply chains and develop global markets while collaborating globally both horizontally and vertically with companies from like-minded countries.

In addition, as basic research and industrial applications become closer and closer together, industrial
It is also important to further strengthen collaboration between academia and government.

ÿAccessibility "Realization of a quantum technology usage environment open to industry"

In order to encourage participation in the field of quantum technology by a wide range of industries, we need to create an environment where user companies in a variety of fields can utilize quantum technology and create new value (quantum computers, quantum measurement/sensing, quantum security network, etc.)

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2 "Incorporating quantum technology into the entire socio-economic system and merging it with conventional (classical) technology systems (hybrid) to create growth opportunities for Japan's industry and solve social issues", "Utilizing cutting-edge quantum technology" ``Promotion of utilization (development of testbeds for quantum computers, communications, etc.)'', ``Creation and revitalization of new industries/start-up companies that utilize quantum technology''

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It is necessary to go.

In addition, it has been pointed out that quantum technology is difficult for ordinary companies to enter into, and there is a strong sense that it is a technology of the future.•Technical support, educational support, etc.) is also important.

Furthermore, when utilizing quantum technology in various fields, it is important to actively disclose and provide information such as its superiority and effectiveness (performance, cost, convenience, etc.) over existing technologies. be.

ÿIncubation "Proactive startup/venture company/new business creation support" In emerging

markets such as those in the quantum technology field, we provide unprecedented business and services. Start-ups/venture companies that develop these areas can also become important players.

For this reason, we will stimulate long-term and stable investment, support market development, and create and support startup companies that open up new markets, as well as form a future venture ecosystem. It is also important to go. Furthermore, it will also be important to create new business divisions and carve-out ventures from existing companies. Start-ups/venture companies are emerging in Japan as

well, both in terms of software and hardware, and they are being developed through close collaboration between industry, academia, and government, including matching with financial institutions, nurturing young entrepreneurial talent, discovering and creating business ideas, and supporting overseas expansion. Therefore, it is important to form a comprehensive innovation platform that creates and supports startup companies, etc. according to their respective stages and characteristics. Furthermore, it is important to form a global ecosystem that includes like-minded countries, with an eye toward promoting investment from abroad and the global market.

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5. Main industrial issues and basic response policies

(1) There are few excellent use cases that provide an opportunity to enter the quantum technology field

(Issue) ÿIn quantum computers, quantum measurement/sensing, and quantum security networks, there are no effective use cases by utilizing quantum technology. The reality is that there are fewer of them. **ÿIn** particular, user companies

are interested in the extent to which quantum technology benefits compared to existing technologies, including performance, cost, and convenience. There are few use cases that clearly demonstrate superiority. **ÿFurthermore ,** there is a lack of accurate information that user companies need to make commercialization decisions

regarding the effects of utilizing quantum technology (benefits for user companies from a management perspective, etc.), including current status and future prospects. .

(Basic response policy)

ÿIn anticipation of future developments in quantum technology, encourage the participation of various user industries in order to expand the market base, and provide support and information for creating use cases that are appealing to users. We will actively disseminate information. When creating use cases, it is necessary to create a system in which diverse user companies, vendor companies, universities, research institutes, etc. can co-create while exchanging information, opinions, and human resources. For this reason, we will build a system that allows industry, academia, and government to work together to create use cases, taking into account the cooperative/competitive areas and the characteristics of each use case.

ÿIn addition, accurate benchmarks should be set regarding the effects of utilizing quantum technology from a management perspective, including not only performance but also cost, convenience, etc., and superiority and effectiveness over existing technologies. We will provide information widely. In this case, we will take into consideration the current state and future prospects of technologies such as quantum computers, which are still in the development stage, and provide information on TRL (Technology Readiness Level) and BRL (Business Readiness Level) that are necessary for users to make commercialization decisions.) We

will also provide information such as: **ÿAlso ,** for users, quantum technology is just a means, and they do not view it as special. Therefore, we will incorporate quantum technology into conventional (classical) technology systems (including migration from conventional (classical) technology to quantum technology), create use cases for quantum-classical hybrid systems, and benchmark against existing technologies. It is also important to conduct comparisons and clarify the effects of using quantum technology.

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(2) High technical hurdles for quantum technology (Issue)

ÿ**Commercialization** and industrialization of quantum technology often requires advanced knowledge and technology, creating barriers to entry from companies outside the quantum technology field (The hurdles tend to be perceived as high.

ÿ Regarding the software aspect, it is expected that user companies in a variety of fields will participate, but many companies do not have the equipment or environment that can utilize quantum technology, nor do they have knowledge or human resources related to quantum technology. .

ÿ Regarding the hardware side, it is essential to involve stakeholders in traditional (classical) devices, parts, materials, electronics, etc., but there is a lack of information on what areas there are opportunities for entry and marketability. in many cases

stomach.

(Basic response policy)

ÿ**In** order to encourage a wide range of industries to participate in the quantum technology field, create an environment where user companies in various fields can utilize quantum technology (quantum computers, quantum measurement/sensing, quantum security networks, etc.) . ÿ**In** addition, since many industries outside of the quantum technology field do not have knowledge or human resources related to quantum technology, it is important to expand opportunities for interaction and collaboration with researchers, engineers, etc. in the quantum technology field. We will provide support for participation in the areas of information, technology, and human resources, while also actively providing educational programs.

ÿ**In** order to commercialize and industrialize quantum technology in the future, we will organize and clarify the necessary conventional devices, parts, materials, electronics, information and communication technology, etc. We will provide information on opportunities for new entry and whether there is market potential.

(3) Future technologies and markets are unclear and business risks are high

(Challenges) ÿIn the future, industries in the field of quantum technology are expected to have a huge market, but at present the winner of the technology and industry has not been decided. It is difficult to predict future technology and markets, and it also requires long-term investment, so it can be said that the industry currently has higher business risks than other industries. ÿ**In** particular, Japan's industry is focusing on fields that require long-term investment. In contrast, investment tends to be sluggish.

ÿ**Furthermore ,** some argue that it is risky for a single company to invest in highly opaque basic research and huge amounts of manufacturing equipment when it is difficult to predict future technology and markets.

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(Basic response policy)

ÿIn order to reduce such business risks as much as possible, the public and private sectors will work together to develop prototyping, testing, and evaluation equipment that can be shared by multiple companies, and use public and private resources effectively and efficiently. We will build a system

that can be used effectively. **ÿIn** addition, we will support the construction and activities of open innovation systems in which multiple companies co-create in co-creation areas (common

parts, etc.). **ÿEven** at the basic research stage, the government will proactively provide necessary support while responding to industrial needs and clarifying the division of roles between the public and private sectors.

(4) Insufficient environment for the creation and growth of startups/venture companies and new businesses

(Issue)

ÿIn emerging markets such as the quantum industry, startups/venture companies (existing companies (including new business units and carve-out ventures) could become important players. **ÿOverseas ,** many startup companies, both soft and hard, are starting up and raising huge amounts of funding from

VCs, etc., and the movement is becoming more active. On the other hand, for start-up companies with limited capital, businesses in the quantum technology field, which require a so-called long-term strategy such as long-term investment, technological development, and market development, are considered high-risk areas with a private-sector-only market mechanism. I can say it.

ÿIn addition, in the domestic investment environment, the creation and growth of start-up companies, etc. is hindered due to the fact that the total amount of investment in start-up companies, etc. is small, and financial institutions, etc. tend to avoid investments with long investment recovery periods. It has also been pointed out that there are insufficient business environments and opportunities for this. Furthermore, some argue that it may be difficult for start-up companies, etc., that lack capital, structure, and information dissemination capabilities to smoothly advance overseas expansion.

(Basic response policy)

ÿSince the quantum technology field requires long-term investment and technological development, industry, academia, and government should work together to encourage private investment through active government projects. Support the creation and development of start-up companies through support from a long-term perspective.

ÿ Creation and support of startup companies through matching with financial institutions and partner companies, etc., development of young entrepreneurs who will take on the role, and mechanisms for creating business ideas using quantum technology (pitch contests, idea-thons, etc.) Promote hackathons, etc.).

ÿFurthermore , collaboration with existing companies, collaboration between venture companies,

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We will form an innovation platform that comprehensively supports startup companies, etc. by forming an ecosystem, disseminating information on business activities domestically and internationally, and supporting overseas expansion.

(5) Lack of industrial human resources

(Issue) ÿThere is a worldwide shortage of industrial human resources in the field of quantum technology, and competition to acquire human resources is intensifying. In order to put quantum technology into practical use and commercialize it, we need not only research and technical personnel in the field of quantum technology, but also a variety of technical fields (devices/components/ materials, electronics, semiconductors, architecture/systems, software). , information and communications) will also be needed.

ÿFurthermore , it is important to develop and secure human resources in user fields as well as business human resources who support commercialization and industrialization, such as management, intellectual property, and legal human resources.

ÿThe shortage of human resources is a serious issue for both vendor and user companies, and it is necessary to develop and secure industrial human resources in the quantum technology field in a long-term and strategic manner.

(Basic response policy)

ÿIndustry and academia, including universities, research institutes, and industry, will work together to create and provide educational programs for human resources in various fields, including industrial human resources and students. Furthermore, we will promote human resource exchange and mobility between industry, academia, and government, both domestically and internationally, such as human resource matching between industry and academia (intern system, etc.) and human resource exchange between different fields.

ÿAlso , in national research and development projects, we will actively form mechanisms and set themes that allow human resources from various fields to participate.

ÿFurthermore , efforts will be made to enhance and strengthen educational programs for young people in junior high and high schools, who are a source of industrial human resources, and outreach activities through science museum exhibitions, etc.

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6. Direction of efforts

(1) Quantum computer (software, usage environment preparation, etc.)

ÿ Support the creation of appealing and attractive use cases with the participation of many user companies, and aim to expand and promote the user industry. Furthermore, we will continue to examine the performance and effectiveness indicators (performance, cost, convenience, low carbonization, etc.) of quantum technology utilization from the user company perspective, including management and ESG perspectives, and encourage managers and investors to use these indicators. We will consider building a system that can be used for management and investment.

ÿ Promote the development and provision of environments (applications, middleware, development environments, etc.) that allow users to easily use quantum/classical hybrid computing environments, and through this, foster and promote software and usage support service providers. Plan.

ÿ In addition to utilizing domestically produced actual machines for a variety of applications in industry, academia, and government, we will also collaborate with domestic and international quantum computers and conventional (classical) computers to build a practical environment that will lead industrialization and advance the frontiers of industry and science. Build and provide a cutting-edge quantum/classical hybrid computing environment.

ÿ Creation and promotion of user industries

ÿSupport for creating use cases, etc.

ÿIn order to create and expand a service market that utilizes quantum computers, user companies in various fields should take the lead in discovering appealing values and needs from an industrial perspective. , it is important to create new services. For this reason, with the participation of many user companies, we will support efforts to create appealing use cases and expand and promote the user industry. This will include the use of AI technology that is progressing in actual industrial sites.

We will promote the participation of new user companies and support the creation of use cases while also working to integrate quantum computers with the trend of DX. **ÿIn** order to develop a sustainable industry, sustainable capital circulation (ecosystem) is important.

ÿFor this reason, in the short term, quantum annealing machines and simulated animation

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Issues that urgently need to be solved using ring machines [3] In response to this, we aim to quickly create new markets and expand our business. In the medium to long term, we will be able to solve problems that cannot be solved in a realistic amount of time using conventional (classical) computers, quantum annealing machines, etc. by using large-scale gate-based quantum computers that are expected to be used in industrial applications. We aim to further expand and promote the market by expanding the scope and scale of application of quantum computers. **ÿIn** addition, in order to utilize quantum computers in promising fields such as biotechnology and materials, the "Bio Strategy 2020" (June 26, 2020 (fundamental measures), January 19, 2021) Bio x Quantum, Material x We will promote fusion between industrial fields such as quantum. **ÿFurthermore ,** multiple user companies can exchange information and opinions at consortiums such as Q-STAR, where multiple companies participate in each use case field, and create use cases in collaborative areas as necessary. We also support efforts to advance

ÿ Consideration of performance and effectiveness indicators for the use of quantum technology from the perspective of user companies ÿIn order to promote the use and investment behavior of quantum computers in a wide range of industries, it is necessary to compare performance with existing technologies as well as to consider management perspectives such as ROI, etc. It is important to demonstrate to the managers of user companies and investors what effects the use of quantum computers will have on business activities from an ESG perspective, including SDGs, decarbonization, etc. **ÿFor** this reason, in order to enable user companies to understand and judge whether quantum computers have a performance advantage compared to existing technologies, it is necessary to consider quantum computers and software (appliances) while also taking into account the results of use cases. We will examine performance indicators (advantages over existing technologies, benchmarks in actual use, etc.) of quantum/classical hybrid systems. **ÿFurthermore ,** from a management and ESG perspective, we will not only consider performance, Effects of using quantum computers on business activities, including low carbonization

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3For example, optimizing logistics/transportation and personnel allocation where staff shortages are an issue, effective use of renewable energy to solve energy problems, supply and demand forecasting and network control in virtual power plants (VPPs), and 5G communication networks. Anticipated improvements include traffic control and lower power consumption, more efficient simulations in drug discovery, and shorter learning times and higher accuracy for large-scale

language models. In the four areas of cooperation, for example, by comprehensively creating use cases in various fields such as urban development to solve social issues, we will promote cross-disciplinary and cross-organizational efforts and involve public institutions such as local governments. It is also effective to link this to future public procurement (utilization by local governments, etc.).

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We will also consider effect indicators that can appropriately evaluate (including future effects). In addition, we will also consider building a system that allows managers, investors, etc. to accurately evaluate business activities that utilize quantum computers, etc., using these effectiveness indicators, and utilize them for management and investment.

ÿ**Furthermore ,** we will proceed with the construction of a system that will allow user companies to compare the performance of multiple quantum computers, software, etc. (development of software that allows performance comparisons, etc.). Furthermore, when considering performance indicators, since the performance of quantum computers at present is limited, we will also consider the prospects for improving performance indicators due to future technological developments.

ÿPromotion of the software industry

ÿDevelopment and promotion of software and usage support service providers ÿFor quantum computers, middleware that connects applications and quantum computers, and software development environments (software development kits (SDKs), etc.) differ depending on the actual device or platform. Furthermore, it is difficult for general users to use, as it often requires a certain level of specialized knowledge. **ÿIn** order to expand the use of quantum computers in the future, it will be important to create an environment in

which users can use various machines without being aware of them. Furthermore, from the perspective of future practical application, an integrated computing environment (quantum/classical hybrid computing environment) that skillfully selects and utilizes quantum computers and conventional (classical) computers in the background for a given computational problem will be developed.) is also expected.

ÿFor this reason, we are making it easy for users to create a quantum/classical hybrid computing environment by creating a development environment such as common applications, middleware, and SDKs that can handle multiple quantum computers in combination with conventional (classical) computers. We will build and provide an environment that can be used for **ÿFurthermore ,**

as the performance of quantum computers improves, the processing of conventional (classical) computers used to control them is also rapidly becoming more sophisticated. Since the use of quantum/HPC collaboration platforms is also essential,

Develop software to realize the form.

ÿIn recent years, in order to support user usage, there has been an active movement of private companies to provide comprehensive usage support services, including consulting and education, as well as software services that provide applications, middleware, development environments, etc. . In Japan, many of these private companies are venture companies that contribute to improving the usability of quantum computers and play a key role in serving as a hub connecting users and the use of quantum computers.

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It's also Yah. When the government moves forward with developing the usage environment for quantum computers as mentioned above, it will make full use of such private companies, develop and provide a highly convenient usage environment for users, and develop software.•We will foster and promote usage support service providers.

ÿ Establishment of a quantum computer usage environment for software development ÿ

Establishment of a flagship computing environment to explore new frontiers ÿIn

March 2020, the National Research and Development Agency RIKEN (hereinafter referred to as "RIKEN") established the first in Japan A domestically produced actual machine (a superconducting quantum computer test bed) was announced and operation

began. **ÿThis** test bed machine takes advantage of the characteristics of a domestically produced actual machine and is capable of controlling the deep layers of the hardware, so once operation begins, it will be possible to control everything from software (error suppression/correction, etc.) to middleware (architecture/systems) and hardware. We will build an environment in which industry, academia, and government can utilize technology for a variety of purposes, including the cultivation and sophistication of core technologies (control devices,

etc.) and the development of quantum/classical hybrid technologies. **ÿFurthermore ,** at RIKEN, we will collaborate not only with quantum technology but also with the computational science and mathematical science communities by linking cutting-edge quantum computer machines, including this testbed, with conventional (classical) computing such as Fugaku. We will continue to develop an advanced computation center that will provide a quantum/classical hybrid computing environment that will serve as a cutting-edge flagship to explore the frontiers of industry and science.

ÿEstablishment of a practical computing environment that will

lead industrialization ÿIn order to create use cases that utilize quantum computers and promote industrial use, we will create a quantum-classical hybrid system that will lead industrialization and that can be easily accessed by a wide range of users. Develop a practical computing environment. **ÿIn** the near future,

we will use simulated annealing machines, and later we will also use quantum computers (annealing method). Furthermore, in the future, we envision industrial use of quantum computers (gate type) from a medium- to long-term perspective. **ÿIn** addition, various types of quantum computers made overseas are ahead of commercialization.

Five It

is also beneficial to utilize the actual machines necessary for creating use cases, and flexibly utilize them by examining and selecting them from the perspectives of user needs and effectiveness.

5 Regarding overseas-made quantum computers (gate type), superconducting type, ion trap type, cold atom type, photon type, etc. are available for commercial use through the cloud, etc.

(2) Quantum computer (hardware, basic technology, etc.)

ÿ We will strengthen and accelerate technological development and commercialization of the superconducting type, which is the leading technology for quantum computers (gate type). Furthermore, we will accumulate operational experience and know-how and develop human resources who will be responsible for this, and we will also build a system that allows the results of operations to be fed back to hardware development. Regarding other methods, efforts will be made to promote the participation and activities of private companies, including start-up companies.

ÿ With regard to quantum computers (annealing), we will clarify the quantitative superiority in terms of performance, proceed with early demonstration of actual machines, and operate them in an integrated manner with various computer resources such as HPC and simulated annealing machines. By utilizing it as a practical computing environment that leads industrial use, we aim to improve our competitive advantage in industrial use.

ÿ In order to build a stable and resilient supply chain, we will collaborate with like-minded countries to identify the equipment, parts, materials, etc. necessary for future quantum computer systems, clarify the technical content, and become a leader in this endeavor. Promote the participation of companies, including small and medium-sized enterprises. At the same time, we will identify priority technological fields where Japanese industries can demonstrate their strengths, as well as technological fields that will become choke points, and secure and secure equipment, parts, materials, etc., and necessary technologies for these technological fields. We will continue to improve the sophistication. ÿ We will create an environment that can support the activities of private companies in basic research on elemental technologies such as quantum chips, and in processes such as prototyping, testing, and evaluation for large-scale production.

ÿQuantum computer (gate method)

<Superconducting quantum computer>

ÿSupport for technological development of quantum computers ÿSuperconducting type is the leading technological method for quantum computers, and overseas countries are actively promoting technological development and commercialization. Meanwhile, in Japan, industry, academia, and government are working together to develop domestically produced machines. The development of domestically produced actual equipment is of great significance, as it contributes to the development and sophistication of elemental technologies from software to hardware and various related technologies for the entire system, as well as the design of hardware and architecture for the development of quantum-classical hybrid technology. has. **ÿIn** March 2020, RIKEN began operating the first domestically produced actual machine in Japan, and domestic vendor companies are planning to collaborate with RIKEN to unveil the actual machine in FY2025. In order to achieve this goal, we will continue to strengthen and accelerate technological development. Furthermore, since the control of quantum computers requires knowledge of basic science such as the control of quantum many-body systems and dissipative systems, RIKEN is responsible for the research and development of core technologies such as quantum state control technology based on scientific principles. Vendor co

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It is expected that these core technologies will be used to expand the scale and systemize the technology.

ÿ**Furthermore ,** since the domestically produced actual machines will enter the operation phase, we will accumulate operational experience and know-how and develop the human resources who will be responsible for them, as well as convert the results of operations and user experience into hardware. We will also build a system to provide feedback to research and development.

ÿ**Support for commercialization of private commercial machines, strengthening international competitiveness, etc. ÿAlthough private** commercial machines have been released for superconducting quantum computers, the superconducting method, like other methods, has not been established as a technology. It requires long-term research and development, and furthermore, it requires enormous costs to put it into practical use and to scale it up. For this reason, some point out that research and development, practical application, and industrialization by private companies alone is risky, but it is a new market for quantum computer vendors and related parts and materials supplier companies. It also creates business opportunities. ÿ**For** this reason, the National Institute of Advanced Industrial Science and Technology (hereinafter referred to as ``AIST'') is conducting basic research on elemental technologies such as quantum chips, and conducting processes such as prototyping, testing, and evaluation for large-scale production (We will continue to create an environment that can support the activities of private companies in the prototyping, testing, and evaluation of quantum chips, testing of peripheral components at extremely low temperatures, etc.). ÿ**In** addition, at RIKEN and AIST, which are the main bases, RIKEN supports research and development at the basic stage, and AIST supports industry with processes such as prototyping, testing, and evaluation for large-scale development. Both parties will cooperate and collaborate to support the activities of private companies by clarifying the division of roles.

<Other gate methods (ion trap, light, silicon, atom, etc.)>

ÿ**Promote industrial participation and strengthen collaborative systems ÿIn** Japan, in addition to superconducting systems, ion traps, light, silicon, Regarding atomic and other methods, research and development is being strongly accelerated and promoted mainly through national projects (such as the Moonshot R&D System).

ÿ**Overseas,** private companies are promoting commercialization of various technological methods, and in Japan, we are actively building partnerships with private companies and creating startup companies with an eye toward future practical application and industrialization. efforts to promote the participation and activities of private companies, including ÿ**In** addition, Japan's first startup company in the field of quantum computers (hardware) was launched in 2020, and plans to develop and release quantum computers/quantum networks in the future. Ideal for startups/ventures pursuing advanced technology methods that require long-term investment and are high risk.

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Therefore, utilizing national project support is also an effective means. Therefore, in order to support the activities of such startups/venture companies, we will work to enhance support through national projects and build a system.

ÿQuantum computer (annealing method) ÿTechnical development and commercialization support for quantum annealing machines, etc. ÿIn Japan, we will develop a quantum annealing machine that is close to practical use and industrialization, and use it to create new markets and expand business. This is of great significance from the perspective of quickly forming an industrial market for quantum computers and realizing a sustainable financial cycle (ecosystem) that connects profits from industrial use to investments in technology research and development. be.

ÿDomestic companies are collaborating with AIST to develop a quantum annealing machine, and the actual machine is scheduled to be released around 2026, and a 1,000-qubit class actual machine will be available in 2020. We are aiming to achieve this goal.

ÿCurrently , Canada's D-wave Systems is leading the way in providing services for commercial equipment in the 5,000 qubit class, but since the size of the qubit does not necessarily determine performance, it is difficult to quantify the performance. We will clarify the superiority and support early demonstration of actual equipment, and steadily advance support for technological development and commercialization.

ÿIn addition, it can be used in conjunction with conventional (classical) computers to solve large-scale problems, and can be operated in an integrated manner with various computer resources such as HPC and simulated annealing machines, making it a practical computing environment that leads industrial use. By doing so, we aim to improve our competitive advantage in industrial applications.

ÿCommon platform technology

ÿ Securing and upgrading the parts, etc. that are essential for the global commercialization of quantum computers, and strengthening the supply chain ÿ In order to stably proceed with the research and development and commercialization of quantum computers, etc., it is necessary to have high-performance devices and It is essential to build a strategic supply chain that provides a stable supply of parts and materials. Regarding quantum computers, each company has indicated a [6],the roadmap for scaling up in the 2020s, and in order to realize the system, a stable and resilient supply of related equipment, parts, materials, etc. is required. It is necessary to build a chain. **ÿFor** this reason, we have developed the necessary equipment in anticipation of future large-scale quantum compute

6Fujitsu in Japan, and overseas companies such as IBM, Google, Rigetti Computing, IonQ, and Quantinuum have announced development roadmaps.

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Identification of equipment, parts, materials, etc., and clarification of [7] After carrying out the technical content.Identify leading industrial fields and companies, including small and medium-sized enterprises, that will serve as a resource, and encourage the participation of these companies. At the same time, we will identify priority technological fields where Japanese industries can demonstrate their strengths and technological fields that are strategically important choke points in the supply chain, and develop equipment, parts, materials, etc. for these technological fields, as well as necessary equipment. Consider and implement strategies to secure and advance technology. Through this, we will encourage the participation of many existing companies in the electronics field, etc., and build a stable and resilient global supply chain through collaboration between companies in Japan and like-minded countries.

ÿIn order to put quantum computers into practical use and increase their scale, it is necessary to develop and commercialize a wide variety of parts and materials, but this also creates barriers to entry for new companies as it requires huge costs and human resources. It becomes. Therefore, AIST is conducting research and development of elemental technologies such as quantum chips, prototyping control devices, peripheral parts, materials, etc. for large-scale production, and conducting evaluations at extremely low temperatures. Promote the construction of a global supply chain by supporting the activities of private companies such as private companies and quantum computer vendors.

7New Industry Creation Council through Quantum Technology (Q-STAR) (Japan), Quantum Economic Development Consortium (QED-C) (USA), Quantum Industry Canada (QIC) (Canada), European Quantum Industry Consortium (QuIC)) (Europe), a consortium of four quantum industries is jointly researching and creating a supply chain map.

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(3) Quantum security network

ÿ In order to discover and expand user industries both domestically and internationally, we will create appealing use cases and promote use as anchor tenancy/early adopters by public institutions.

ÿ In order to support the business of domestic vendor companies, we will provide support for technological development through operation in wide-area testbeds, accumulate experience in operation and use (use cases), and encourage public and private sectors to work together. We will expand overseas. Furthermore, we will promote the construction of a domestic authentication infrastructure for quantum cryptography communication equipment to expand and popularize its use.

ÿ Also, aim to build a comprehensive architecture using quantum/classical hybrids and enrich and strengthen wide-area testbeds for quantum cryptographic communication. Furthermore, we will proceed with research and development of the quantum internet and consider a roadmap for implementation with an eye to t

ÿPromotion of industry for quantum security networks ÿ

Promotion and expansion of user

industries ÿIn order to discover and expand user industries in Japan and overseas, we will utilize quantum cryptography communication wide-area testbeds (QKD networks), etc. to attract new users. We will support the creation of attractive use cases (killer applications) that will appeal to customers.

ÿEspecially in promising business fields such as finance, medical care, manufacturing, and security. We will continue to promote its use. At this time, it is important to consider the balance between safety, cost, and usability when creating use cases.

ÿWith a view to full-scale use and dissemination in the future, efforts will be made to improve incentives for users to use quantum security, such as by recommending the use of quantum security in rules and guidelines for each field, taking into account use cases, etc. We will also support the promotion of use as anchor tenancies/early adopters in public institutions such as local governments.

ÿSupport for commercialization of quantum security networks/strengthening

international competitiveness ÿOne domestic vendor company has already released a commercial device for quantum cryptography communication, and is actively working on business development with an eye on international expansion. I'm here. Furthermore, one new domestic vendor company is scheduled to enter the market and

release commercial machines from FY2025 onwards. ÿIn order to support the business of domestic vendor companies, we will actively support technological development through operations in the wide-area testbed mentioned above. Furthermore, we will steadily accumulate a track record of operation and usage (use

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The public and private sectors will work together to support overseas expansion while leveraging our track record. Furthermore, by vigorously promoting standardization and intellectual property rights, we will expand and popularize this technology both domestically and internationally.

ÿ**At** this time, we will take into account not only the development of hardware vendor companies, but also the development of private companies that will be responsible for future usage support services (applications).

ÿ**Promoting the construction of a domestic authentication infrastructure for quantum cryptography communication equipment** ÿ**In** recent years, there have been several serious cases in Japan where cyber-attacks have made business continuity difficult, and ensuring security has become an extremely important issue for users. Considering the importance of ensuring security, when users introduce quantum cryptography equipment, they need a mechanism that allows them to determine whether each equipment reliably guarantees the desired performance. Additionally, from FY2025, there will be multiple domestic vendors of quantum cryptography communication equipment, and users will need a system that allows them to compare the performance of such equipment using objective indicators. Ru.

ÿ**Based** on the above, in order to expand and popularize the use of quantum cryptography communication devices, it is necessary to develop a device certification system by a third-party organization. We will work towards building a domestic certification infrastructure including systems. ÿ**In** this case, we will build a system to make the certification system autonomous

as an ecosystem by using private companies as evaluation institutions, and we will develop and secure human resources who will be in charge. Furthermore, when considering the certification system, we will pay attention to international collaboration and cooperation in terms of the system, with an eye to future overseas expansion.

ÿ **Improving the usage environment and expanding the usage demonstration of quantum security networks**

ÿ**Construction and verification of comprehensive architecture** using quantum-classical hybrid (system migration) is necessary. ÿ**At** this time, we will consider the best mix by complementing the strengths and weaknesses of various quantum and classical cryptosystems, such as quantum cryptography, quantum streaming cryptography, quantum-proof computer cryptography (PQC), secret sharing, and secure computation. Perspective matters. ÿ**In** order to create an environment that can verify the best mix of quantum and classical, we will build and verify a quantum integrated architecture (quantum technology platform) that includes quantum cryptography, quantum secure clouds, quantum computers, etc.

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ÿEnhancing and strengthening the wide-area testbed for quantum cryptographic communications ÿThe wide-area testbed for quantum cryptographic communications (QKD network), which is maintained by the Ministry of Internal Affairs and Communications and the National Institute of Information and Communications Technology (NICT), is designed to provide a wide range of users with the opportunity to learn about quantum cryptographic communications. It has become a valuable platform that can be used for various purposes. There is.

ÿIn order to expand various usage demonstrations in the future, we will build an intercity quantum cryptography communication network that includes space assets such as satellites, and expand from intercity to nationwide scale.

ÿAt this time, we will build and improve the sophistication of the testbed, keeping in mind that we will contribute to the creation of use cases that provide the best mix of quantum and classical techniques.

ÿ Sophistication of quantum security networks ÿ Research and development of quantum internet, etc. ÿThe quantum internet, which communicates over long distances in a quantum state, is capable of performing large-scale calculations by connecting multiple quantum computers in addition to highly confidential quantum cryptographic communication. It is expected that this technology will become possible in the future.

ÿAdditionally , new startup companies are emerging to realize the quantum internet of the future. **ÿWith** an eye toward the promotion of future industries,

including these start-up companies, we will promote research and development and technology demonstrations including devices, architectures, and protocols, as well as develop the road toward the introduction of quantum internet. We will proceed with discussions to make the map more concrete.

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(4) Quantum measurement/sensing/Quantum materials

ÿ In order to promote the quantum measurement/sensing industry, we will actively provide information on quantum measurement/sensing technology and its utilization to a wide range of industries, and provide support for technology development and commercialization. We will create a system such as a consortium of industry, academia, and government that can share information and exchange opinions. ÿ We will provide many companies with an environment where they can easily use and develop quantum measurement and sensing, and provide technical and usage support. Furthermore, we will actively support the creation of attractive use cases that appeal to users and the development and demonstration of technologies for commercialization.

ÿ With the participation of industries in the material field, we will promote a system that allows hardware and software to work together to promote technological development and commercialization. Furthermore, industry, academia, and government will work together to build a system that can stably supply the quantum materials that Japan should strategically secure.

ÿ Promotion of the quantum measurement/sensing industry ÿSupport for technological development and commercialization of quantum measurement sensing ÿQuantum measurement/sensing has applications in a variety of fields such as medical care, energy, communications, mobility, and security, and has many applications. It is important to advance technology development and commercialization with the participation of companies.

ÿFor this reason, the main centers are the Quantum Technology Infrastructure Center (tentative name), the Quantum Life Center (National Institute for Quantum and Radiological Science and Technology (hereinafter referred to as ``QST'')), and the Quantum Sensor Center (Tokyo Institute of Technology).), etc., will actively provide information on quantum measurement, sensing technology, and utilization, including the stage of practical application and advantages over existing technologies, to a wide range of industries including user and vendor companies. At the same time, we will support technology development and commercialization. Furthermore, in addition to basic research in pursuit of top performance, industry, academia, and government will work together to advance technology development and commercialization, including engineering technology for practical application, such as miniaturization of modules and chips. Furthermore, we will proceed with an integrated perspective that combines existing systems with quantum measurement and sensing. **ÿIn** addition, in order to promote the participation of many companies and realize an industrial ecosystem where multiple companies collaborate and collaborate (horizontal division of labor, vertical integration, etc.), various industry, academia, and government stakeholders will share information and exchange opinions. The government will also promote the creation of systems such as industry-academia-government consortiums that can carry out these activities.

ÿProviding an environment for the use and development of quantum measurement and sensing ÿFor many companies, quantum measurement and sensing technology poses technical obstacles.

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The barriers are high, and unlike quantum computers, many require hardware, so support in terms of technology and usage is also important. **ÿFor** this reason, major centers such as the Quantum Technology Infrastructure Center (tentative name) and the Quantum Life Science Center (QST) will play a central role in making quantum measurement and sensing easily available to many companies, including users and vendors. We will prepare and provide an open environment for development (in particular, solid-state quantum sensors that can be used for a wide range of industrial applications, hyperpolarization technology, optical lattice clock networks, etc.), as well as provide necessary technology and usage according to user needs. We will continue to support the

ÿIn addition, in order to fully utilize and popularize quantum measurement and sensing, efforts will be made to standardize quantum measurement and sensing technology and to create measurement standards that utilize quantum measurement and sensing.

ÿ Expansion and promotion of user industries ÿIn order to promote the quantum measurement and sensing industry, it is important to expand the user market by discovering and expanding various user companies that use quantum measurement and sensing.

ÿFor this reason, we will actively support the creation of attractive use cases that will appeal to many users and the development and demonstration of technologies for commercialization, while also providing an environment for the use of quantum measurement and sensing. I'm going to **ÿIn** this case, in order to make it easier for users to adopt quantum measurement/sensing technology, we will consider the performance of quantum measurement/ sensing and its superiority/effectiveness over existing sensing (performance, cost, convenience, etc.) to ensure accurate and accurate information. Providing easy-to-understand information
We will actively provide this.

ÿPromotion of quantum material industry

ÿSupport for technological development and commercialization of quantum materials ÿQuantum materials are the foundational technology for quantum computers, quantum measurement/sensing, and quantum networks. Furthermore, materials fields such as quantum materials are areas where Japan's industry can demonstrate its strengths. On the other hand, because quantum technology has not yet been established, or use cases and markets have not been established, it is currently difficult to predict sales and business risks, and the barriers to entry in the quantum material industry are high. There is also a point that. **ÿFor** this reason, when researching and developing quantum technology and creating use cases, it is important to discover and demonstrate use cases that have the potential to be realized at an early stage, and to clarify the prospects for future marketability and effects from an early stage. We will strive to become a leader in this field and disseminate information widely to related industries.

ÿIn addition, from the perspective of rapidly promoting industrialization efforts, we will promote the participation of private companies that can play a leading role in the quantum materials field from an early stage, and provide hardware and

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Build a system that promotes technology development by integrating software.

ÿBuilding a supply chain for quantum materials ÿQuantum

materials are the foundation of quantum technology, and it is important for Japan to build a stable and strategic supply chain for the important quantum materials that we need to secure.

ÿFor this reason, the main bases are the Global Center for Quantum and AI Fusion Technology Business Development (AIST), the Quantum Technology Infrastructure Center (tentative name) (QST), the Quantum Materials Center (National Institute for Materials Science), etc. Industry, academia, and government will work together to consider quantum materials that Japan should strategically secure, taking into account user needs, and then build a system that can provide a stable supply of quantum materials.

ÿFurthermore , with an eye on the future quantum industry, we will work towards forming an industrial ecosystem in which quantum materials (upstream/upstream) and quantum device-related industries (downstream/downstream) collaborate and collaborate.

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(5) Innovation platform ÿGlobal

collaboration and development of quantum industry

ÿIn the future, a huge global market for the quantum industry is expected, and in order to capture overseas markets, it is necessary to form a Memorandum of Understanding (MoU)8 between quantum industry organizations and to collaborate globally through a global network of 9 Inter-industrial collaboration where the public and private sectors come together private companies . It is important to promote (technical cooperation, business alliances, etc.) and overseas expansion. It is also effective to proactively demonstrate services overseas (Europe, America, Asia, etc.) with an eye toward future overseas expansion. **ÿFor** this reason, the public and private sectors will work together to promote the

international expansion of products and services, as well as global information, by utilizing the know-how and track record accumulated through the use and technology demonstration of quantum technology, including the leading QKD network. We will continue to promote communication. In this case, local networks will also be utilized through foreign government-related organizations (embassies in Japan, etc.). Furthermore, since there are cases where small and medium-sized enterprises such as startups/venture companies lack opportunities to expand overseas, the government will provide detailed support such as exhibiting at overseas trade fairs and disseminating information.

ÿFurthermore , we will work toward global industrial collaboration, overseas market expansion, and the acquisition of international standards through international cooperation, dialogue, and exchange at various levels of industry, academia, and government.

ÿEstablishment of foundation for creation of startups/venture companies, new businesses, etc.

ÿIn Japan, the number of startups/venture companies (including new business divisions of existing companies and carve-out ventures, etc.) is increasing, both in terms of software and hardware.
are doing.

ÿSince the quantum technology market requires long-term investment, industry, academia, and government should work together to form a future venture ecosystem while enhancing various types of support according to each stage and characteristics. It is important to create and support startups and venture companies.

ÿFor this reason, we will create and support start-up companies through matching with financial institutions, incubation companies, partner companies, etc., develop young entrepreneurs who will be the leaders of start-up companies, and match human resources (research personnel and management personnel). (matching, etc.), business eye using quantum technology

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8New Industry Creation Council through Quantum Technology (Q-STAR) (Japan), Quantum Economic Development Consortium (QED-C) (USA), Quantum Industry Canada (QIC) (Canada), Four European quantum industry consortiums, the European Quantum Industry Consortium (QuIC), signed a memorandum of understanding to establish an international council aimed at promoting the growth of the global quantum industry (February 1, 2020)).

9 It is also assumed that the know-how and track record of global collaboration accumulated through the use and technology demonstration of quantum technology, including the leading QKD network, will be utilized.

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Mechanisms for discovering and creating new ideas (pitch contests, ideathons/hackathons, etc.), ecosystem formation such as collaboration with existing companies and collaboration/cooperation between start-up companies, and dissemination of information domestically and internationally regarding business activities. We will form a comprehensive innovation platform that creates and supports startup companies through close cooperation between industry, academia, and government, including support for overseas expansion.

ÿDeveloping and securing industrial human resources

ÿ**There** is a global shortage of human resources in the field of quantum technology, and competition to acquire human resources is intensifying.Industry, academia, and government should work together to develop industrial human resources in the quantum technology field in a long-term and strategic manner, in cooperation with like-minded countries. It is important to develop and secure Ru.

ÿ Looking to future industries, we will develop and cultivate human resources not only in research and technical fields in the field of quantum technology, but also in related technical fields (devices, parts, materials, electronics, semiconductors, architectures and systems, software, information and communications, etc.). It is important to ensure this. In addition, it will be necessary to develop and secure human resources who can fully utilize quantum technology in user fields through reskilling and other means. Furthermore, in order to commercialize and industrialize quantum technology, it is also necessary to develop and secure business human resources such as management, intellectual property, and legal personnel. Additionally, synergy effects are expected in DX-related industries in the fields of AI, cloud, and IoT through collaboration with quantum computers, etc., and reskilling of human resources in these industries is also considered to be effective. **ÿFor** this reason, while determining what skills are needed for human resources at each level of these industries, we will consider and create effective educational programs, and then provide training programs for human resources at various levels of industry. We will strongly promote educational support for developing and securing industrial human resources, such as by providing educational programs. Furthermore, we are working to expand our outreach activities through educational programs and science museum exhibitions aimed at young people, such as university students and junior high school and high school students who may become future industrial human resources. Provide seamless educational opportunities to industry. **ÿAlso ,** consider a system to expand opportunities for employment and entrepreneurship by guaranteeing the quality of human resources through a certification system for those who have completed educational programs.

ÿFurthermore , human resource matching between industry and academia and between different fields (for example, industry-academia human resource matching events, human resource pools and matching mechanisms for managers and engineers, internship systems for students working on industrial issues, etc.)), and promote the exchange and flow of human resources between industry, academia, and government, both domestically and internationally, to form an ecosystem for human resource development.

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ÿBuilding a new partnership system between industry, academia, and government **ÿIn** order for industry, academia, and government to strengthen collaboration and work together, Q-STAR, an organization centered on industry, and public research institutes, universities, etc. should play a central role. It is expected that the QIH organization will share information, interact, and collaborate more than ever before. **ÿFor** this reason, we will establish a new partnership system (Q-Partnership (tentative name)), such as establishing a regular venue for Q-STAR and QIH to systematically share and exchange information, and exchanging personnel. Promote efforts to strengthen collaboration between industry, academia, and government. **ÿThe** progress and results of research on national projects will be actively shared in such forums, and efforts will be made to enhance and strengthen efforts toward technology development and commercialization through collaboration between industry, academia, and government.

ÿStandardization, intellectual property creation, benchmark setting, etc. **ÿAs a** huge market for the quantum industry is expected in the future, international competition is essential in order for Japan to capture overseas markets and use quantum technology as an impetus for economic growth. It is important to strategically work on standardization and intellectual property in order to strengthen our capabilities.

Ru.

ÿFor this reason, industry, academia, and government should work together to consider the technologies that should be standardized for quantum devices (including materials and parts, etc.) such as quantum computers, quantum sensors, and quantum communication equipment, and then consider the existing standardization technologies. We will strongly and strategically promote efforts toward standardization while collaborating with frameworks and related parties, and will be strongly involved in the formation of rules in the market.

ÿIntellectual property promotion plans, etc. are also implemented at quantum technology innovation centers, etc. Ten

We will strengthen our efforts by proactively and strategically promoting the creation of intellectual property in the same way as with other cutting-edge technologies, while referring to the policies of the Government of Japan.

ÿAlso , benchmark indicators (performance, cost, convenience, low carbonization, etc.) regarding the effectiveness and performance of quantum devices from a management and technical perspective (including the superiority of quantum technology over existing technologies), which are important for users. We will also actively consider, set up, and provide information related to this.

ÿ Efforts toward building a strategic supply chain

ÿIn order to stably advance the research, development, and commercialization of quantum computers, quantum measurement/ sensing, quantum materials, and quantum networks, we need a strategic supply chain that stably supplies advanced devices, parts, materials, etc. It is important to make efforts to build a **ÿFor** this reason, industry, academia, and government are working together to secure important

devices and

10 “Intellectual Property Promotion Plan 2022” (June 3, 2020, Intellectual Property Strategy Headquarters), etc.

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After considering parts, materials, etc., we will consider a supply chain map and build a stable supply chain from a strategic perspective. **ÿAt** this time, we will also consider the development of unique and common devices for quantum computers, quantum measurement/sensing, and quantum networks, as well as the use of general-purpose products, to reduce business risks, build a stable supply chain, and improve the economy. Consideration will be made based on rationality, etc. **ÿFurthermore ,** we will build a broad-based industrial ecosystem by identifying companies (including small and medium-sized enterprises) that can play a leading role, and form a broad-based market with high economic ripple effects.

ÿPlatform strategy/construction of co-creation environment ÿTechnology methods and winning strategies for quantum technologies such as quantum computers have not yet been determined, and it is necessary to develop common fundamental technologies (platform technologies) regardless of future technology methods. Strategies for securing this market (platform strategy) are also important. For this reason, industry, academia, and government should work together to consider the platform technologies that Japan's industry should focus on, in parallel with the discussion on the supply chain map mentioned above, and to develop the development and manufacturing infrastructure for these technologies. We will consider the platform strategy, including the way it should be. **ÿAlso ,** in order to commercialize and scale up quantum computers in the future, a huge amount of investment will be required, and furthermore, given the uncertainty of the future technology, it would be risky for a single private company to work on it alone. Since there are cases, it is also important to take into consideration the areas of cooperation and competition and proactively provide industrial support. For example, it is effective and efficient for multiple companies to collaborate in sharing processes such as prototyping, testing, and evaluating semiconductors, developing common technologies, building supply chains for common parts, setting benchmarks, and standardizing. Areas can also be considered. **ÿFor** this reason, under the cooperation of industry, academia, and government, while taking into account the initiatives that should be implemented in the cooperative and competitive areas, we will create a system and mechanism that allows multiple companies to collaborate and work on open innovation in the cooperative areas. We will provide necessary support.

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ÿBy leveraging the strengths of Japan's industry, such as strengthening quantum technology innovation bases , and integrating and linking quantum technology with each industrial field, we will create new value in the industry, such as creating new industries, improving productivity, and solving social issues. In order to strongly support the creation of new technologies, we will strengthen quantum technology innovation centers as follows.

" Global base for business development of quantum/AI **convergence technology (tentative name)" (AIST) (strengthened)** In addition, a global development base for the industrialization of quantum technology will be established at AIST, keeping in mind the involvement of global companies such as user companies in Southeast Asia and start-ups/venture companies. Specifically, while utilizing available quantum computers, we will quickly develop and provide a quantum/AI hybrid practical computing environment for the creation of new businesses, and aim to create use cases and develop human resources. . In addition, regarding the supply chain of quantum computers, we will be the first in the world to develop and provide a low-temperature test environment, collect needs and know-how through collaboration with quantum computer vendor companies in Japan and overseas, and systemize quantum computers. The government will improve the international competitiveness of domestic companies by supporting the development and evaluation of products, parts, and materials. Furthermore, we are conducting comprehensive industrial activities related to quantum computer chips, including not only research and development, but also providing environments and services that provide the development and prototyping functions of quantum devices and integrated circuits toward the realization of large-scale commercial devices. Assist.

"Quantum Computation Development Center (tentative name) (Headquarters Center)" (RIKEN) (strengthened) ÿA company that strongly promotes cutting-edge and wide-ranging basic scientific research in quantum technology, including quantum computers, and produces research results. Promote technology transfer to In addition, by linking cutting-edge quantum computers with conventional (classical) computing such as Fugaku, we will involve not only quantum technology but also the computational science and mathematical science communities to create a state-of-the-art flagship quantum computer. - Proceed with the development of an advanced computation center that provides classical hybrid computing environments, etc., and utilize this to explore new industrial and scientific frontiers.

"Quantum Technology Infrastructure Center (tentative name)" (QST) (strengthened) ÿIn addition to continuing to develop and supply quantum materials that exhibit advanced quantum functions, we will also continue to develop and supply quantum materials that exhibit advanced quantum functions, as well as quantum measurement and sensing that utilize them. Develop and provide an environment where industry can use, test, and evaluate quantum materials, and provide usage support and technical support to industry regarding quantum materials, quantum measurement, sensing, etc.

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provide assistance. Furthermore, while making full use of optical science and technology, we will promote research and development and industrial support that form the basis of quantum technology, such as the development of technologies and devices that realize advanced observation and control of quantum states.

“Quantum Frontier Industry Creation Base (tentative name)” (Tokai National University Organization) (additional candidate) 11 ÿ

Through the fusion of technology in fields such as chemistry and materials, in which Japanese industry has strengths, and quantum technology, under industry-academia-government collaboration. We will use new approaches to explore cutting-edge technologies such as chemicals and materials, as well as new business and service frontiers, and support the creation of new industries and the sophistication of industrial activities. Furthermore, we will promote the development of human resources who are familiar with both the chemical/materials field and the quantum technology field and who will be responsible for collaboration and fusion between fields.

11The Quantum Technology Innovation Council will confirm whether it meets the requirements for a quantum technology innovation center, and then formally decide on the new center.

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7. Finally

Quantum industry is an industrial field that requires the combined efforts of various fields, from hardware to software to services, and can be called a comprehensive art. For this reason, it is important that organizations and human resources from industry, academia, and government in various fields collaborate closely and co-create new value. Furthermore,

since many industrial sectors are involved, it can be said that this is an area with extremely high economic ripple effects on related industries. Based on this, we can expect that the growth of quantum technology will be used as a catalyst to realize comprehensive growth for Japan.

A huge market for the quantum industry is expected in the future, and investment is increasing globally. Ru. However, there is a certain degree of investment enthusiasm (boom) in technology, and there may be times when investment enthusiasm will slow down in the future. To this end, it is important for industry, academia, and government to strengthen their unity from now on, to steadily and continuously develop technology and human resources from a long-term perspective, and to work toward future blossoming without worrying about joy or despair. It is. Additionally, from the perspective of attracting investment and human resources in a sustainable manner, it is important to strive to disseminate accurate information based on scientific evidence.

The quantum industry is an emerging market, and it is important to create an environment where young people can start businesses and boldly take on new business challenges with free ideas. Furthermore, even in existing companies, it is expected that managers will take the lead in creating an environment in which young human resources can take on new business challenges as intrapreneurs.

In the future, technological innovations and markets such as AI technology, Beyond 5G, and semiconductors will change at a dizzying pace, and efforts toward a sustainable social economy such as the SDGs and a decarbonized society are expected to be required more than ever. When practicalizing and industrializing quantum technology, it is also important to flexibly respond to future technological innovations and economic and social changes.

Approximately 100 years have passed since the birth of quantum technology, and quantum technology is moving into the stage of full-scale practical application and industrialization. We hope that each industry will use quantum technology as an opportunity to find a winning path to future growth and enrich the economy and society.