Strategic Enhancement of Materials Technology as the Most Important Foundation for Innovation Creation

(Recommendation for the 6th Science and Technology Basic Plan)

October 18, 2019

Committee on Nanotechnology and Materials Science

1. Introduction

The Council for Science and Technology's Special Committee on Comprehensive Policies has been discussing policies to be implemented during the program period of the Sixth Science and Technology Basic Plan (hereinafter referred to as the "Basic Plan"). The Committee has pointed out the need for drawing up a research and development strategy that taps into Japan's strengths, which will help Japan to maintain and strength its competitiveness in science, technology and innovation (STI) into the future.

STI is now being promoted in many countries as one of the most important pillars of national policies. Amid this international competition of STI policies, Japan's 5th Basic Plan presented a new concept called "Society 5.0," which is a human-centered society where economic development and the resolution of social challenges are achieved at the same time by tapping into the power of STI. Through the policies that have since been implemented in accordance with the Integrated Innovation Strategy, Japan has made intensive efforts in the AI, biotechnology, and quantum technology fields, which are three advanced technology fields that are seeing growing investment and increasing R&D competition in many countries.

In addition, STI and the realization of a sustainable and inclusive society are becoming increasingly important as a way for Japan to contribute to the international community as its member in achieving the Sustainable Development Goals (SDGs) and the long-term goals of the Paris Agreement.

As Japan's STI plays an increasingly significant role and attracts greater attention from the international community, there is an urgent need for Japan to innovate and fully tap into materials technology (science and technology related to materials and devices) as a tool essential in both increasing innovation in advanced technology fields, such as AI, biotechnology, and quantum technology, and achieving Society 5.0, the SDGs, and the long-term goals of the Paris Agreement.

It is worth noting that Japan has a great advantage in the research and development of materials technology. To date, Japan has constantly invested in the nanotechnology and materials fields to drive technological evolution, and has created many innovative materials and devices using nanotechnology as the foundational technology, accelerating social change. Materials and devices have become the

most important source of foreign currencies for Japan, as exports grew thanks to international confidence in Japanese products backed by sophisticated technology and meticulous manufacturing. This has become the lifeblood of Japan's international presence and negotiating power. If we look at universities, national laboratories, corporations, and other domestic research institutions, we can find a vast range of talents, knowledge, information, data, know-how, and intangible intellectual property accumulated in an enormous amount throughout the years.

At the same time, we must also recognize that such Japan's strengths have been threatened in recent years. There is a significant shortage of young researchers, including doctoral students specializing in chemistry, materials, and physics, while the research capabilities of universities and other institutions are declining. We also need to make more efforts to turn knowledge created at universities into excellence, and develop a system that allows for the practical application of such excellence in a way commensurate with its value.

Meanwhile, major powers, such as the United States and China, have geared toward materials technology as one of the most important basic technologies for the future, increasing their investments in this area.

It is now, while we still have an advantage built on past investments and efforts from both the industrial perspective and the science and technology perspective, that Japan must strategically enhance the R&D of materials technology—a technology with increasing importance and expectation in many countries around the world—as a new driver for innovation during the period of the Sixth Science and Technology Basic Plan.

Based on such understanding, the Committee on Nanotechnology and Materials Science adopted in August 2018 the R&D Strategy for Nanotechnology and Materials Science and Technology (hereinafter referred to as the "R&D Strategy"), which was aimed at bringing about social revolution via materials ("Material Revolution") that contributes to both industrial revitalization and human wellbeing. One year has passed since then, yet it is still as important to implement the initiatives presented in this R&D Strategy.

Recently, the Committee held a complementary discussion taking into account changes in the situation since the formulation of the R&D strategy, in order to create a recommendation to inform the Special Committee on Comprehensive Policies and other entities involved in the development of the Sixth Basic Plan.

Based on the content of the R&D strategy that showed measures for promoting the nanotechnology and materials fields, this recommendation clarifies that materials technology (science and technology related to substances, materials, and devices) is going to be the most important basic technology for Japan in the future. It explains the importance of materials technology and Japan's strengths in this field, while also presenting the direction of future R&D efforts and specific initiatives that will be required.

2. Basic Understanding

(1) Increasing Importance of Materials Technology

- Innovation in materials technology is the key to producing results in advanced technology fields in which R&D competition is accelerating on a global level, such as AI, biotechnology, and quantum technology. For example, there is a need for an innovative, next-generation semiconductor device with high energy efficiency, high density, and high speed to support AI, as we are drawing near to the limit of Moore's Law. In the field of biotechnology, regenerative medicine needs innovative materials to promote cell culture, differentiation and transplantation, as well as innovation in biodevices to embody advanced functions unique to living organisms. In the field of quantum technology, it is vital to innovate quantum sensor materials and materials for superconducting qubits for quantum computers. It is also important to promote the R&D of quantum materials in which new functions are expressed by precise control of quantum states.

- To bring Society 5.0 into reality, it is essential to develop a technological platform that connects cyber space and physical space. The enhancement of cyberspace technology alone is not enough. For example, it is also necessary to innovate and fully tap into materials technology, including environmentally- and human-friendly sensors and devices with significantly improved performance that are capable of coping with diverse physical and chemical data existing in large quantities in physical space.

- Japan's materials technology will also play an important role of contributing to the international community in solving global issues. For example, many of the 17 SDGs, which are aimed at bringing about a sustainable and inclusive society, include targets that cannot be achieved without innovation in materials technology, such as the development of air and water purification systems, and efficient use of solar cells and energy harvesting. Innovative battery technology and new materials that do not rely on scarce resources are also vital in achieving the long-term goals of the Paris Agreement and solving environmental and energy issues. The development of a bioeconomy that Japan aims to achieve in the future requires innovations of new materials, such as high-performance biomaterials and bioplastics, while new high-performance structural materials are coveted for protection from natural disasters and increased mobility.

- In this way, innovations in materials technology is commonly required in almost every policy and technology area that Japan prioritizes. It is important that materials technology researchers work on these challenging technological issues with great potential while improving their capabilities through friendly competition.

(2) Achievements in Materials Technology as Japan's Strengths

- Japan can create a number of innovations by actively promoting materials technology R&D. This is supported by the great technological and industrial potential of materials technology.

○ The source of added value in Japan's leading industry, i.e. the manufacturing industry, is competitive materials and device technology. At present, industrial materials account for about 20% of the total exports of Japan, and there are many products that have a market share of more than 50% in the global market. In today's world, where manufacturing is implemented in the global value chain, the strengths of the materials and device industries have become the lifeblood of Japan's international presence and negotiating power.

○ From the science and technology perspective, there have been many instances where the development of materials and devices drove social change. For example, the development of ceramic technology led to the creation of optical fibers made of highly transparent quartz glass, which helped the rise and advancement of the information-driven society. The advancement of microfabrication technology and the discovery of the tunnel magnetoresistance effect led to the development of ultrahigh-density storage using magnetic recording, which gave rise to AI and big data technology. The explosive spread of lithium-ion batteries installed in mobile devices pioneered the current age of AI, IoT and big data. Materials and devices originating in Japan have not only helped the development of the information-driven society, but also have driven the development of many different fields, including the environmental field. Examples of such materials and devices include neodymium magnets mounted on hybrid vehicles, carbon fiber reinforced plastics, which are widely used in aircraft and automobiles, and blue light emitting diodes that revolutionized lighting technology. It is also worth noting that such achievements were the fruit of long-term investments in R&D activities at universities and companies. The Nobel Prizes for blue light-emitting diodes in 2014 and lithium-ion batteries in 2019 are a testimony to the world's recognition of the strength and contribution of Japan's materials technology. In addition to such contribution to social change, Japan is also currently leading the world in the R&D of different materials with attractive functions, such as nanocarbon and spintronics. Moreover, there has been an increasing number of cases where such materials with attractive functions are practically applied in society in a way that is different from what was initially intended.

○ The reasons why Japan has been able to achieve such outstanding results on a global scale include the historical background that Japan was one of the first Asian countries to develop a higher education system, which allowed it more time to nurture human resources and basic research capabilities. Another reason that some have pointed out is that research methodology for materials technology is compatible with the temperament and characteristics of Japanese people, such as caring for details and perseverance in experiments.

○ Another strength of Japan is its R&D environment for materials technology, especially the shared advanced research facilities like SPring-8. There are nationwide frameworks (such as Nanotechnology Platform Japan) that allow researchers to efficiently use shared advanced research facilities and equipment for microstructure analysis, microfabrication, and molecular/substance synthesis. The sharing of research facilities and equipment has promoted

interdisciplinary fusion and industry-academia-government collaboration, while also providing opportunities for young researchers who are incapable of procuring large-scale facilities and equipment themselves. In addition, the National Institute for Materials Science (NIMS), which is responsible for materials R&D, has been designated as one of the three national R&D corporations in Japan. Since its foundation, NIMS has continuously achieved world-class research achievements. This is also another reason why Japan has an advantage in materials R&D.

○ Furthermore, materials technology is one of the research fields with the highest number of researchers and the greatest amount of research funds acquired in Japan. This tendency is especially remarkable among high-level R&D activities, suggesting that many excellent domestic researchers exist in this field in Japan. There are also many universities that position materials technology as their core R&D activities. This suggests that, in addition to the importance of strongly promoting materials technology initiatives, the way in which materials technology is promoted itself may have a great impact on the future of STI activities in Japan.

○ Nanotechnology has played a significant role to date. Japan's constant investment in nanotechnology since the 21st century nurtured nanotechnology into a world-leading basic technology and one of Japan's strengths, while also promoting the fusion of different fields, such as science and engineering, and medicine and engineering. As a result, the initial mission in this technological field was achieved, which was to elucidate phenomena and pioneer new functions on the nanoscale. Since then, nanotechnology has evolved into a systematic tool and a platform for creating new innovations. Looking into the future, there is great expectation that new innovations could be further created through the fusion of different fields and tapping into the accumulated investment in the nanotechnology field, by further refining the scale from the nano level to the quantum level and by gaining comprehensive understanding and control on the nano to macro level.

(3) Situation Surrounding R&D

○ There is concern that Japan's international competitiveness in R&D may be declining. In particular, qualitative and quantitative indicators and Japan's international shares of papers in chemistry, materials science, and physics, which are the basic disciplines for materials technology, have been declining over the past decade. This is a serious concern, although these three disciplines still have relatively high international competitiveness compared to other disciplines. While mid-career and senior Japanese researchers have a strong presence at international conferences on materials, many have pointed out that young researchers need to increase their presence. It is becoming more difficult for universities to secure doctoral students and postdoctoral fellows, who are core human resources for R&D activities. In particular, the number of students pursuing an academic career has been significantly decreasing in recent years. It is necessary to address such shortage of next-generation human resources at R&D institutions. It is considered that university faculty members have not been able to secure enough research time,

which has led not only to a decline in research capabilities, but also to a decrease in the number of students pursuing an academic career.

- As the period of R&D projects by private companies is becoming shorter, the corporate environment for nurturing human resources and technologies is being lost. For this reason, companies are looking to universities and national laboratories to play more roles than before. The creation of industry-academia-government collaboration to accelerate open innovation and swift decision-making procedures for establishing university-initiated ventures is becoming more important than ever in promoting the practical application of knowledge. However, it has been pointed out that excellent knowledge created at universities has not always been swiftly and practically applied in society in a way commensurate with its potential value due to the absence of enough support for industry-academia-government collaboration projects conducted by researchers at universities. It has also been pointed out that the fostering and securing of young human resources in the chemical engineering and welding engineering fields is in a critical situation when considering corporate demand for such human resources.

- Many have pointed out that social problem-solving R&D projects supported by the government tend to aim to solve a single problem and rush to produce research results and put them into practical application, failing to promote the fostering of enough excellent knowledge that can be a seed for innovation.

- Material development methods have been innovated with the rise of AI and big data due to the digital revolution. Since the launch of the Materials Genome Initiative by the United States in 2011, countries around the world have promoted efforts to develop data-driven materials aimed at reducing development time and costs. In this situation, the world-leading database of high quality, abundant materials data built and maintained throughout the years by NIMS has become a major strength of Japan.

(4) Foreign Policy Trends and Their Impacts

- Japan should also pay attention to policy trends in other countries. Major countries and regions around the world, including the United States, Europe, China, and South Korea, have recognized the importance of materials technology as a key to innovation in various policy and technology areas, and have begun to make focused investment. In particular, China has made large investments in materials technology in accordance with Made in China 2025, published in 2015, which set out the goal of increasing the self-sufficiency rate of semiconductors and other components to 70% by 2025. With its significantly increased science and technology budget, China has made active efforts to take in highly skilled human resources and excellence from all over the world, including Japan. The United States has also strengthened its initiatives related to semiconductor and electronic materials in recent years, as represented by the Electronics Resurgence Initiative launched by the Defense Advanced Research Projects Agency in 2018. The

United States is also developing new measures for rare-earth minerals. Korea announced in 2019 that it would significantly increase government investment from 2020 onwards to achieve independence concerning materials, components and equipment. This is expected to impact the global value chain of the materials and devices industry into the future. Recently, movements surrounding technology security triggered by the U.S.-China battle over technological hegemony have spread throughout the world. Under such circumstances, the strategic procurement of scarce resources and materials from domestic sources is becoming ever more important.

3. Basic Principles of Promotional Measures

○ Japan's materials technology has strengths in terms of science and technology, such as a world-class research base with a wealth of human resources and investment, and in terms of commerce, such as the existence of highly competitive export industries. For this reason, investments in materials technology are estimated to be highly cost-effective. With the growing importance of materials technology, we can expect to see further innovation in this area in the future.

○ In this view, it is essential for the government to promote related science and technology innovation activities in a strategic and integrated manner by positioning materials technology as one of the most important fundamental technologies for creating innovation in the Sixth Basic Plan. It is necessary to take advantage of the intellectual potential of materials technology, a field where Japan's outstanding researchers are concentrated, and strongly lead the creation of innovation through the promotion of interdisciplinary fusion and industry-academia-government collaboration. At the same time, as the strengths of Japan's materials technology are under threat, such as the shortage of next-generation human resources, it is important to accumulate the capability to create a variety of knowledge that will become Japan's strength in the future by creating an environment that attracts outstanding human resources and allows them to demonstrate their abilities to the fullest extent.

○ From this point of view, the government is required to proceed with the following four initiatives in the future. In promoting research and development, there are two basic approaches: cultivating and implementing important technical areas derived from specific needs for materials technology, and steadily promoting research and development that pursues attractive materials. In addition, it is vital to maximize the potential for innovation to be created from Japan's materials technology by comprehensively promoting the necessary related initiatives, including initiatives to improve the productivity of R&D activities. The government is required to promote these four initiatives organically and in an integrated manner, rather than separately.

(1) Promotion of key technology areas in materials technology that will drive innovation

(2) Development of infrastructure for the creation of attractive materials

(3) Improvement of productivity through more efficient, faster, and more sophisticated research and development

(4) Promotion of measures necessary to strengthen materials technology

4. Direction of Specific Measures

(1) Promotion of key technology areas in materials technology that will drive innovation

○ In order to support the major role of materials technology innovation, it is necessary to strategically and intensively cultivate diverse knowledge generated from universities and other R&D institutions, and to link it to practical application with a sense of urgency.

○ In selecting key technology areas, it is important to identify areas where materials technology innovation is the key to solving important domestic and international challenges, such as innovation in advanced technology fields including AI, biotechnology, and quantum technology, bringing about Society 5.0, achievement of the SDGs, response to environmental and energy issues including the achievement of long-term goals of the Paris Agreement, ensuring the safety and security of Japan and its citizens, creation of a healthy and long-lived society and bio-economy, and innovation in agriculture. In doing so, it is also important to look at the accumulation of investments (including human resources) and achievements, and whether or not these accumulations can be effectively utilized.

○ For example, the following technical areas were identified. These areas will need to be further examined in detail in line with the progress of the 6th Basic Plan.

・Innovative and integrated sensor technology for the age of trillion sensors, which holds the key to the realization of Society 5.0.

・Innovative element and device technologies that bring about orders of magnitude lower power consumption, high durability, environmental friendliness, and multifunctionality that will contribute to innovations in AI and quantum technology, and to the construction of an infrastructure that connects cyber and physical spaces.

・New biomaterials and devices that will lead to the integration of materials and living organisms and the expansion of human capabilities, etc., with a view to contributing to extended healthy lifespans through regenerative medicine, advanced diagnostic devices, etc.

・Next-generation battery technology that enables significant energy conversion, storage, and high-efficiency use, and contributes to the reduction of carbon dioxide emissions

・Extreme performance materials with high heat resistance, strength, and reliability, which are indispensable for ensuring safety from natural disasters, building national resilience, bringing about next-generation energy technologies, such as nuclear fusion, and developing science and

technology innovation activities in space and the ocean.

・Adhesion and bonding technology aimed at advanced understanding and control of the interface of composite materials, which is indispensable for the advancement of mobility and bringing about an energy-saving, low-carbon society.

・Separation and decomposition technology used for recycling, circulation, refinement, and purification of various materials for bringing about a sustainable society and a bio-economy.

・The next-generation element strategy aimed at pioneering new, untapped functions of elements, which will lead to a society where elements and materials are recycled and a strategic breaking away from dependence on rare elements.

・Molecular technology and space and gap control technology to create new functions by freely designing and controlling materials, which will lead to innovations in a wide range of applications

○ In promoting these technological areas, it is necessary to set technological goals from a medium- to long-term perspective. However, it is desirable to set flexible goals for each technology, taking into account that each technology has potential for various applications, rather than solely aiming to solve a single problem.

○ In fostering knowledge in key technology areas, it is important that universities and national research institutions play a central role in fostering excellent knowledge that will become the seeds of innovation by bringing together and fusing outstanding human resources in different fields in an open environment, both at home and abroad, and through friendly competition.

○ For the practical application of knowledge in key technology areas, it is important to promote R&D under cross-sectional collaboration between industry, academia, and government, where R&D for practical application and basic research mutually stimulate each other.

○ In order to effectively and efficiently connect innovative materials to practical applications, it is necessary for innovative functions to be successfully demonstrated in devices and systems that are actually used in companies. Process technology for expanding the scale of production of these new materials and systematizing them requires new scientific principles and science foundations (so-called process science), as materials become more complex. Therefore, it is also important to promote process science efforts through an open innovation mechanism centered on universities and national research institutions.

○ From these perspectives, the government’s current efforts are insufficient to support materials technology R&D activities in a strategic and integrated manner. Further strengthening of these efforts is required.

(2) Development of infrastructure for the creation of attractive materials

○ Pursuing the appeal of materials based on the inquiring minds of researchers is a fundamental activity of materials technology. Attractive materials with attractive functions can lead to innovations in areas of application that no one could have envisioned at the outset, and sometimes to disruptive innovations that are game changers. In addition, these materials continue to be the core of Japan's strength.

○ In order to maximize the possibility of creating disruptive innovations, it is important to create an environment in which outstanding researchers, especially young researchers, who are willing to take on challenges, are able to conduct research for a certain period of time without being constrained by the presence or absence of short-term results, and to secure sufficient time for their own research. In doing so, it is also important to actively promote international collaboration and exchange among researchers, and to create opportunities for the fusion of different disciplines, which help researchers obtain ideas from a variety of applied fields. The government is required to make efforts to increase the number of researchers who can pursue the appeal of materials at universities, and at other research and development institutions.

(3) Improvement of productivity through more efficient, faster, and more sophisticated research and development

○ It is necessary to strategically reform the research environment and research methods to bring about more efficient, faster, and more sophisticated R&D activities by introducing new approaches to the accumulation of research infrastructures, which is Japan's strength, in line with the development of cyber technologies, such as AI, IoT, and big data. This should thoroughly enhance the productivity of materials technology R&D activities and make the R&D environment in Japan more attractive to all researchers across generations, genders, sectors and nationalities.

○ Advanced facilities and equipment used in materials technology R&D activities are extremely important, and it is essential to continuously strengthen the sharing and networking of such facilities and equipment while taking advantage of the achievements of the nanotechnology platform and the accumulation of highly specialized human resources to date. In the future, the fusion of different fields will become mainstream in research and development, and a comprehensive understanding and control of nano-to-quantum and nano-to-macro scales will be required. Under such circumstances, there will be a need for state-of-the-art research equipment that is capable of measuring and analyzing more complex phenomena than ever before. Therefore, in addition to dealing with the aging and obsolescence of existing facilities and equipment, it is important to promote efforts for the improvement of the network of shared equipment in line with efforts for the development of state-of-the-art measurement and analysis equipment, and of processing and process equipment. It is also necessary to consider initiatives that meet new needs and trends in research and development, such as the establishment of an efficient regional equipment sharing system, and the strengthening of collaboration with initiatives in computational and data infrastructure, and in software development, as well as the promotion of

high-throughput screening.

- ○ It is necessary to disseminate smart laboratory initiatives using AI, IoT, robotics, etc., which aim at both creating an environment where researchers can maximize their creativity and accelerating the creation of research results. It is important to liberate researchers from simple and repetitive work in the laboratory and promote a shift to an attractive research style suitable for the next era, and to accumulate exemplary cases where the creation of research results is accelerated through the efficient collection and accumulation of high-quality experimental data, and where such quality data is further utilized for advanced R&D activities.
- ○ It is important to strengthen data-driven research and development to accelerate the creation of materials. Japan should take the lead in data-driven research and development of materials by promoting R&D institutions' efforts for developing applications to promote data utilization and for the R&D of innovative materials development methods, while fully tapping into the global advantage of NIMS' database.

(4) Promotion of measures necessary to strengthen materials technology

- ○ In strengthening materials technology, it is necessary to comprehensively promote efforts to solve various issues in the field of research and development and to respond appropriately to social and economic changes, including the international situation.
- ○ In terms of innovation creation, universities' support system for industry-academia collaboration has not yet been fully developed, which is one of the reasons why the new knowledge of materials technology produced at universities has not always been practically applied, failing to fully exert its value. It is necessary to strengthen related organizational efforts, such as considering and introducing multifaceted evaluation of faculty members and researchers, and cultivating and securing human resources to help university faculty members with the practical application of their research results, such as research administrators, intellectual property personnel, and project managers.
- ○ With regard to international efforts, it is important to continuously study and analyze international trends in materials technology, and to clarify the nature of appropriate international cooperation, while actively participating in open global activities. In addition, since diversity is essential for the promotion of outstanding research activities, it is also important to enhance efforts to attract and retain outstanding foreign researchers in Japan. On the other hand, in view of the characteristics of materials technology, industry, academia, and government are required to properly prevent the outflow of sensitive technology from Japan based on security and trade control rules.
- ○ Promoting materials technology means that there will constantly be new and unknown materials arising. It is important to estimate and evaluate the impact of such materials on society, and to

build consensus across disciplines, generations, and countries.

○ In order to secure human resources for the next generation, it is necessary to strengthen the communication from the research and development field about the fascination of materials technology research and the appeal of materials, while the government should also portray materials technology as a promising science and technology field that creates the future. In addition, personnel with degrees related to materials technology are active throughout industry, academia, and government, and there is no so-called postdoctoral problem; rather, postdoctoral and doctoral students are in short supply at materials technology R&D institutions. In light of this situation, those involved in this field must do everything in their power to convey the appeal of doctoral degrees and research jobs to society and the public. In addition, it is also important for Japan to improve the treatment of doctoral students and researchers working on materials technology at universities and other institutions to a level on a par with those in Europe and the United States in order to maintain and improve Japan's international competitiveness.

5. Conclusion

This recommendation was tentatively compiled for the purpose of serving as a reference for the development of the Sixth Basic Plan. The Committee plans to further discuss this recommendation by the summer of 2020, focusing on the specific measures described in 4.

In order for Japan to strengthen materials technology in earnest, it is important for the government as a whole to examine measures to promote materials technology, which should also show the direction of initiatives at universities, national research institutions, and companies under a common vision shared by industry, academia and government.

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○Committee on Nanotechnology and Materials Science

1. Current Situation and Challenges

- The innovation and utilization of materials technology, which is a science and technology related to materials and devices, are greatly needed in order to bring about innovations in advanced technologies, such as AI, biotechnology, and quantum science, and to achieve Society 5.0, the SDGs, and the long-term goals of the Paris Agreement.
- What is important here is that Japan has significant strengths in materials technology, both in terms of science and technology, and in terms of industry. Materials and devices originating from Japan have produced numerous innovations and driven social change. As the most important foundation of the export industry, they have also become the lifeline of Japan's international presence and negotiating power. Excellent human resources, knowledge, information, data, research facilities, and equipment are widely accumulated at R&D institutions in this field.
- On the other hand, there is a lack of young researchers specializing in chemistry, materials, and physics, which has led to a decline in research capabilities at universities and other institutions. There is concern that Japan lacks a system that allows knowledge created at universities to be practically applied in a way commensurate with its value.
- Major countries and regions around the world, including the United States and China, are beginning to focus on materials technology as one of the most important technologies for the future and are stepping up their investments.
- Under these circumstances, it is essential for the Japanese government to strategically and integrally promote related science and technology innovation activities by positioning materials technology as one of Japan's most important fundamental technologies for the creation of innovation in the Sixth Basic Plan.

2. Efforts to Be Promoted in the Future

(1) Specific R&D areas and topics to be promoted

- It is important to take advantage of the diverse intellectual potential of materials technology, which is an area where Japan's outstanding researchers are concentrated, and strongly lead the creation of innovation. After identifying key technology areas, the government will effectively promote the cultivation and practical application of excellent knowledge by promoting the fusion of different fields and the collaboration among industry, academia, and government.
- Given the demands of various policy areas and the accumulation of human resources and investment, the following can be key technology areas: sensor technology, element and device technology, biomaterials and devices, battery technology, extreme performance materials, adhesion and bonding technology, separation and decomposition technology, elemental strategy, and molecular technology, and space and gap control technology. The Committee will have to further hold detailed discussion to identify key technology areas.

- It is also important to accumulate into the future the ability to create a variety of knowledge that will lead to disruptive innovation, which will be Japan's strength. It is necessary to increase the number of researchers who can steadily and consistently pursue the appeal of materials.

(2) Specific matters that should be addressed in each field regarding the R&D system

- Through the introduction of new approaches in line with the development of cyber technology, etc., Japan will strategically reform the research environment (e.g., strengthening the sharing and networking of advanced research facilities and equipment, and the spread of smart laboratories, etc.) and research methods (e.g., strengthening data-driven research and development) to enhance the attractiveness of the research environment in Japan and improve productivity by achieving more efficient, faster, and more sophisticated research and development.
- Japan will integrally promote the strengthening of the industry-academia collaboration system, international activities, and the securing of the next generation of human resources.