Toward Government Strategies for Enhancing Material Innovation Power (Report Compiled by the Strategy Preparation Meeting)

June 2, 2020

Preparation Meeting for Formulation of Strategies for Enhancing Material Innovation Power

Introduction

○ Now, Japan and the world are in the midst of turbulent times. Regarding science and technology innovation alone, significant developments have come in the past several years, including the dramatic advancement of the digital revolution, global environment changes such as the U.S.-China trade disputes, changes in attitudes toward the environment and climate change issues, and the global novel coronavirus pandemic. Because of rapid social changes, the need to agilely formulate strategies for key policy areas for the nation is growing.

○ In February 2020, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Ministry of Economy, Trade and Industry (METI) started discussions toward the enhancement of material innovation power in Japan in response to the increasing importance of materials, including substances and devices, in terms of industries and innovations, and to the current situation where the advantages of Japanese materials are facing a great crisis. In April, MEXT and METI inaugurated a Preparation Meeting for Formulation of Strategies for Enhancing Material Innovation Power to conduct full-fledged discussions with a view to the Integrated Innovation Strategy 2020 and the Sixth Science and Technology Basic Plan. The preparation meeting has recently compiled this report presenting basic stances toward the formulation of government-wide strategies for enhancing material innovation power and directions of future initiatives.

○ Currently, the outbreak and expansion of the novel coronavirus disease is exerting a great impact on the economy and society in Japan and around the world. In such situation, the enhancement of material innovation power to support Japan’s export-oriented industries and contribute to solving various social problems in Japan and other countries will be indispensable for increasing the resilience of Japan’s future economy and society. Materials that directly contribute to countering the novel coronavirus disease or are greatly expected to do so have emerged, including antibacterial and antivirus materials to prevent the expansion of infectious diseases, as well as nanoscale materials to very sensitively detect disease agents. In an increasingly uncertain society, it is becoming more important to prepare knowledge on materials to be quickly implemented in society. Furthermore, the novel coronavirus disease is leading human value and behavior to change, creating opportunities to accelerate the digital transformation of materials research and development, and manufacturing fronts in industry,

academia and government sectors. Japan’s research and development, and manufacturing workplaces are required to enhance their productivity and creativity accompanied by their resilience through the digitalization and the remote, smart and on-demand use of R&D methods and environments. If this report serves as a guideline to allow industry, academia and government stakeholders to integrally and promptly promote initiatives to enhance material innovation power, Japanese materials are expected to powerfully drive global industries and innovations in a new era.

○ In the future, the government would like to clearly position this report in the Integrated Innovation Strategy 2020, promptly launch specific initiatives and continue and deepen discussions toward formulating strategies for enhancing material innovation power in industry, academia and government sectors in line with discussions toward the Sixth Science and Technology Basic Plan.

1．Need for formulating strategies

○ Why are we taking up materials now? When reviewing the history of social innovations, we find materials, including substances and devices, behind social innovations. As far as real society is not a virtual space but a real space where humans and goods move, digital and material technologies are combined to drive society. In recent years, however, hardware development has failed to catch up with the fast advancement of digital technologies, prompting information technology companies in the world to acquire hardware manufacturers. In global business operations focusing on *kotozukuri*, or the creation of events, the need for material innovations following digital innovations has been emphasized. Material innovations that support the virtual-real fusion and digital innovations are indispensable for realizing Society 5.0 as advocated in Japan's Fifth Science and Technology Basic Plan.

○ Material innovations are now required in every domain. They are vital for enhancing artificial intelligence, biology, quantum and other advanced technologies to which Japan gives priority, for achieving United Nations Sustainable Development Goals, or SDGs, for attaining long-term targets for the Paris Agreement, for overcoming resources and environment constraints and for resolving social challenges, such as the realization of a safe, secure society or a society of good health and longevity. To deal with technological challenges regarding important materials that should be developed, Japan must make integral, strategic investments and arrangements covering from basics to applications.

○ In additional developments in recent years, global material supply chains have greatly changed in tandem with U.S.-China trade disputes, and the global novel coronavirus pandemic has indicated the risk of supply chain rupture. From the viewpoint of economic security, material innovations are required to make Japan's supply chains more resilient. Initiatives for materials key to Japan's export-oriented industries would exert a great influence on the future fate of the Japanese economy.

○ Research and development on such materials has entered a phase of major changes. AI and big data development has brought about major changes in R&D approaches, including the global advancement of data-driven R&D initiatives for

shortening R&D periods and cutting costs regarding materials that feature a relatively longer time between R&D and commercialization. Data-driven R&D has realized approaches to explore and develop unknown materials based on needs. At a time when global competition grows fiercer for such initiatives, Japan, which possesses good-quality materials data in industry, academia and government sectors, could exploit materials for leading global industries and innovations by pioneering in developing systems to strategically collect and use data to dominantly increase productivity and create new value.

○ While industrial, academic and government R&D on materials stagnates amid the outbreak and expansion of the novel coronavirus disease, human values and behavior are changing in a manner to create an opportunity to accelerate digital transformation on the R&D and manufacturing fronts. As the world seeks to develop resilient societies and industries amidst the digital revolution, future Japanese materials data utilization initiatives will hold the key to whether Japan will be able to take global leadership.

○ Japan-developed materials have so far generated numerous innovations, supporting Japanese and global economies and societies. As materials undoubtedly represent a technological domain in which Japan is strong, the current situation in which materials are becoming even more important provides a great opportunity for the whole of Japan’s science and technology innovations. On the other hand, Japan has recently faced the risk of losing various strengths. Now that Japan is at such risk, Japan should come up with strategies based on its remaining strengths.

○ Given the above, Japan should urgently formulate government strategies for enhancing material innovation power, or potential to create material innovations, as the driver of the Sixth Science and Technology Basic Plan starting in FY2021 and one of the key strategies following the AI, biotechnology, quantum and environment strategies under the common vision of industrial, academic and government stakeholders.

2. Current situation assessment

○ No cross-departmental policy for the materials domain has been formulated in Japan since a sectoral promotion strategy (for nanotechnology and materials) was formulated along with the Third Science and Technology Basic Plan in March 2006. Since then, strengths of materials have been maintained in some areas and rapidly lost in others. The following summarizes Japan's current situation from the three viewpoints of industries, basics, and their fusion, for linking the strengths of materials to innovations in various domains.

(Industries)

- Representing Japan's export-oriented industries are materials and automobiles (each accounting for more than 20% of total exports in value). There are numerous Japanese materials products that command global market shares above 50%. The coordination-oriented Japanese materials industry's strengths, including advanced manufacturing process technologies of materials companies supported by high technological skills of measurement and analysis instrument, processing and production equipment companies, have become a lifeline for Japan's global presence and international bargaining power.
- On the other hand, Japan has been losing market shares for storage batteries and other combination products, for products easy to imitate and cases where open-close strategies are insufficient. Other challenges include low growth in materials ventures, the lack of sufficient innovation ecosystems meeting user needs that are being diversified and require faster commercialization, and Japan's failure to take full leadership in developing international rules, such as how to handle data to demonstrate the superiority of Japanese materials. Another matter of concern is growth in raw material supply risks as indicated by the concentration of supply sources for some materials in some countries.

(Basics)

- The materials-related field including chemistry and materials science has driven Japan's academic paper production and boasts greater international competitiveness than other fields. Japan has world-level research centers and high-quality researchers. Other Japanese strengths include research facilities

and equipment that are among the best in the world, as well as good-quality materials data.

- In terms of international comparison, Japan's share of materials-related academic papers in the world has declined substantially both in quality and volume in the past decade due partly to the Chinese government's sharp investment expansion. As a decline in the attractiveness of research approaches has been combined with the lack of young researchers and the aging of researchers at universities and other research fronts, Japan's research capacity has been supported partly by foreign researchers. Another problem is that Japan has failed to sufficiently utilize various materials data generated at research fronts.

(Fusion)

- In Japan's materials domain, industry-academia-government relations are relatively close, as indicated by Japanese companies' tendency to proactively utilize knowledge generated at Japanese universities and by opportunities for doctorate holders to actively participate in companies. Materials invented in Japan, including lithium-ion batteries, blue light-emitting diodes and neodymium magnets, have so far driven numerous social innovations and received high ratings around the world.
- On the other hand, Japan has lagged behind major foreign countries in exploring fusion and emerging fields. It is pointed out that Japan has failed to socially implement various materials knowledge commensurate with the value of knowledge or exploit such knowledge for creating innovations or resolving social challenges due mainly to government funding schemes' poor performance and universities' insufficient arrangements for cooperation with the industry sector.

○ Countries around the world are promoting initiatives to back up material innovations. In particular, top priority agenda for major country governments include data-driven R&D (in all major countries), semiconductor development (in China and the United States), and R&D for overcoming scarce resources problems (mainly in the United States and Europe). Regarding data utilization initiatives, it is pointed out that European and U.S. academic paper publishers and information

technology platform companies have begun to develop business models for the strategic collection of materials data. As countries in the world are thus accelerating such initiatives, we must closely watch relevant global trends. At a time when companies in the world are proactively trying to balance environmental constraints with economic growth, materials companies are required more than ever to reduce environmental loads throughout products' life cycles from production to dumping and responsibly manage supply changes.

○ Japan has promoted R&D initiatives regarding such top priority agenda, demonstrating its presence in the world. Under strategies to be formulated by the government, however, industry, academia and government sectors must be united to accelerate such initiatives.

3. Future visions to be pursued

○ Government strategies for enhancing material innovation power should be in line with the government's growth strategy and science and technology innovation policy. Therefore, they should share the realization of Society 5.0, the achievement of SDGs and the formation of a human-centered inclusive society as the final goals with these policies. Based on this concept, the following three future visions are proposed as those for Japan to pursue over a medium to long term to demonstrate the big value of materials.

【Vision 1】 From the viewpoint of industry, pursue a country with high material innovation power, or **a country that would take advantage of materials for driving industries and demonstrating leadership to the world**

(Specific image)

Japan would take advantage of advanced manufacturing process technologies of materials companies supported by high technological skills of measurement and analysis instrument, processing and production equipment companies to substantially improve materials development productivity and provide most of the key materials for supply chains, leading Japanese companies to obtain high competitiveness and reliability in the international market. Japan would create a virtuous cycle in which new materials-related ventures would be

created one after another and would develop various goods and services. As a result, material products exports would expand, with Japanese users of these products improving their international competitiveness.

【Vision 2】 From the viewpoint of basics, pursue a country with high material innovation power, or **a country that would attract excellent researchers with attractive materials**

(Specific image)

Japan would develop the world's most attractive materials R&D environment, create global research and innovation bases attracting excellent Japanese and other researchers and become a global brain circulation center for materials, improving its materials-related research power. Japan would also nurture and secure excellent personnel indispensable for sustaining the strengths of materials.

【Vision 3】 From the viewpoint of fusion, pursue a country with high material innovation power, or **a country that would contribute to the world by exploiting materials for creating new value and industries**

(Specific image)

Excellent materials research findings produced at universities and ventures would be securely and speedily implemented in society to trigger innovations in various fields. This would accelerate the realization of key government strategies for AI, biotechnology, quantum and environment areas, allowing Japanese-developed materials to contribute much to resolving significant challenges in Japan and abroad. Japanese-developed materials would also create new value, research fields and industries one after another.

○ The fusion with digital technologies, or the effective utilization of materials data, is the key to realizing the three future visions. Strengths about which Japan can boast to the world include excellent human resources in industry, academia and government sectors, good-quality data, advanced research facilities and equipment, and mature industry-academia-government cooperation. As the strengths of Japanese materials have been endangered due to a rise of foreign countries, Japan can take full advantage of its strengths regarding materials for securing its lifeline and win. It will become important for industry, academia and

government sectors to be united to sharply accelerate the digital transformation of materials R&D and initiate Japan models for data utilization to enhance Japan's material innovation power.

○ Japan could obtain a great strength regarding international strategies for science and technology innovations by enhancing its material innovation power from the viewpoints of industry, basics, and fusion through the formulation and implementation of government strategies. Material innovation power enhancement initiatives should enhance Japan's overall science and technology innovation power and allow Japan to lead global industries and innovations.

4. Directions of future initiatives

○ To realize the future visions cited in 3. in a decade (to 2030), Japan should promote the following four initiatives in the immediate future. They must be linked closely to each other for their strong promotion.

(1) Developing data-based materials R&D platforms

(2) Promoting important materials technology and social implementation fields strategically

(3) Developing material innovation ecosystems

(4) Nurturing and securing human resources to support material innovation power

○ In promoting these initiatives, Japan should base them on its strengths cited in 2. and consider materials' characteristics: long supply chains from basic research to social implementation, basic research that has a low chance of success and consumes much time, and higher industrial competitiveness secured for more complex production processes and more difficult-to-protect products.

○ Given that initiatives contributing to enhancing material innovations range very widely, we here in principle propose only significant, unique initiatives focusing on materials that fail to be fully considered for the Science and Technology Basic Plan and other policies for all science and technology innovation fields.

4-(1) Developing data-based materials R&D platforms

<Background and challenges>

○ As materials R&D has been required to be shorter and cheaper despite human resources shortages in recent years, it is becoming more important for initiatives to utilize data for enhancing the efficiency, speed and quality of materials R&D and improve the R&D environment through such enhancement.

○ Japan has developed tools for data-driven R&D in industry, academia and government sectors through initiatives at the National Institute for Materials Science (NIMS) and the National Institute of Advanced Industrial Science and Technology (AIST) and government R&D projects, such as the Strategic Innovation Program (SIP). In the future, however, the presence of high-quality industry, academia and government materials data will be vital for successful data-driven R&D. As for materials data,[1] NIMS has taken leadership in developing open databases. However, Japan has yet to make any system ready for collecting, storing, distributing and utilizing industry, academia and government data efficiently. Japan has failed to fully consider any system for materials data to be sustainably created and shared in a manner to stimulate R&D front incentives. While some initiatives to strategically collect open data are promoted around the world, countries are still exploring systems to effectively handle materials data in industry, academia and government sectors.

○ Attention here should be paid to large cutting-edge research facilities and shared facilities developed through the Nanotechnology Platform Program and other projects in Japan. These advanced facilities link materials researchers, engineers and users to play a key role in fostering joint research, bridging technologies and developing human resources. Other Japanese strengths include the widely distributed existence of excellent human resources with knowhow on materials engineering and manufacturing to produce good-quality materials data, as well as the presence of measurement and analysis instrument, processing and production equipment companies with advanced technological capabilities. To enhance material innovation power, Japan is required to take maximum advantage of these strengths to implement initiatives for accelerating the creation and utilization of high-quality materials data.

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1 Materials data are divided into three categories: open data (patents, papers and other data accessible for anyone), closed data (in-house and other data available for a limited range of data holders) and share closed data (closed data that should be strategically shared by multiple units beyond individual units)

○ Furthermore, the global novel coronavirus pandemic has increased the need for Japan to introduce new R&D approaches and environments utilizing data, AI and robots in a full-blown manner. Japan must accelerate digital transformation, including the digitalization and the remote, smart and on-demand use of materials R&D and production fronts.

<Directions and goals>

○ Japan will develop national materials R&D platforms to strategically collect, store, distribute and utilize high-quality materials data in industry, academia and government sectors and to have a system for such high-quality data to be created and shared efficiently and continuously in industry, academia and government sectors based on Japan's strengths.

○ First, it will be important to formulate a common guideline for handling materials data and develop infrastructure for collecting, storing, distributing and utilizing common data. It will be particularly important to increase high-quality share closed data for developing a system to sustainably create and share data. Given that purposes and means for collecting data differ by research institution and technological domain, however, it is desirable to take advantage of the accumulation of existing initiatives to begin with data creation initiatives for R&D projects for shared cutting-edge facilities and key technology and social implementation domains in which Japan has strengths. The future goal is that achievements of the existing initiatives will be organically linked to develop materials digital transformation (DX) platforms for the whole of Japan to sustainably and effectively create, share, store, distribute and utilize data from the upstream to downstream of materials R&D in a manner in which data holders' understanding is gained.

○ Data-driven R&D using high-quality industry, academia and government data to be generated from the platforms will be accelerated to dominantly improve productivity in the creation of R&D achievements. This will not only cut R&D time and costs but also provide attractive R&D environments for young and other researchers to promote the production of new excellent research findings. Platform activities will be enhanced to accelerate collaboration and fusion between industry, academia and government materials researchers and users. The digital

transformation of materials R&D throughout Japan will be promoted to accelerate the creation of material innovations and establish Japanese models for utilizing data.

<Specific major initiatives to become necessary>

○ **Developing a common guideline for handling industry, academia and government materials data**

It is indispensable for Japan to consider and formulate a common guideline for handling industry, academia and government materials data. Specifically, the development of common data structures (including data formats; hereinafter the same) and rules for export control regarding data distribution and rights regarding data should be considered sequentially. Then, how to handle data based on their characteristics should be clarified for each of three materials data categories: open, closed and shared closed. To this end, the government should form a panel of experts for formulating the guideline.

It is important to develop databases covering patents, academic papers and other open information for AI learning to increase open data available for data-driven R&D.

○ **Developing materials data centers and networks**

Japan's materials data centers and networks must be developed as infrastructure for data-driven R&D. Specifically, industry, academia and government data utilization centers to accumulate and manage open materials data and data structures and share closed ones in a secure environment should be quickly developed at NIMS and AIST. Those materials data centers should cooperate with the research data infrastructure system that the National Institute of Information is developing for the whole of Japan and with existing data storage and control centers for technological domains featuring unique strengths. Japan as a whole should effectively and efficiently develop highly reliable materials data utilization infrastructure available for industry, academia and government sectors.

Data structures developed at the centers are expected to be used for promoting the digitalization and utilization of closed data in industry and other sectors.

○ **Developing or upgrading shared facilities allowing high-quality data to be created and utilized**

Japan's existing shared cutting-edge facilities and equipment available for materials R&D in industry, academia and government sectors, including large synchrotron and neutron radiation facilities, as well as advanced fine processing and analysis equipment developed through nanotechnology platforms and other projects, should be utilized and upgraded to develop and enhance shared infrastructure for creating high-quality data and data structures for the whole of Japan. In this respect, it is important to make effective use of facilities and equipment made available for preemptive data utilization initiatives and promote initiatives to nurture and secure data structure design experts and engineers required for maintaining, managing and upgrading facilities and equipment.

To promote the acquisition and discovery of high-quality data and the creation of new value, industry, academia and government sectors should be united to build next-generation synchrotron radiation facilities, electronic microscopes and other cutting-edge research facilities and equipment, to develop, upgrade and introduce cutting-edge research instruments and to promote the sharing and networking of such research facilities, equipment and instruments.

○ **Developing and standardizing common data formats for measurement and analysis instruments vital to creating high-quality data**

Towards the promotion of high-quality data production, initiatives should be accelerated to develop and standardize common data formats for measurement and analysis data that differ by instrument manufacturer and instrument. If instrument manufacturers respond to such initiatives beyond their competition, new materials are expected to be developed through unified or integrated analysis on a platform and data-driven R&D. Common data formats should first be developed into Japanese industrial standards for Japanese instrument manufacturers. At the same time, international standardization initiatives should be promoted.

○ **Promoting R&D projects to create and utilize data in key technology and social implementation domains**

It is important to implement strategic R&D projects to fuse data creation and utilization with theories, computation and tests, and to expand achievements in key materials technology and social implementation domains (see (2)) for the purpose of continuing to create high-quality materials data and using them for creating excellent research achievements. Given that it is important to design data structures for open data and share closed data for each project and each R&D agendum, data structure designers should participate in those R&D projects, with overall human resources development enhanced through those projects.

It is also important to promote smart laboratory initiatives to introduce automation technologies, such as robotics and IoT, on R&D fronts for efficient cutting-edge tests, measurement and AI analysis to create high-quality data.

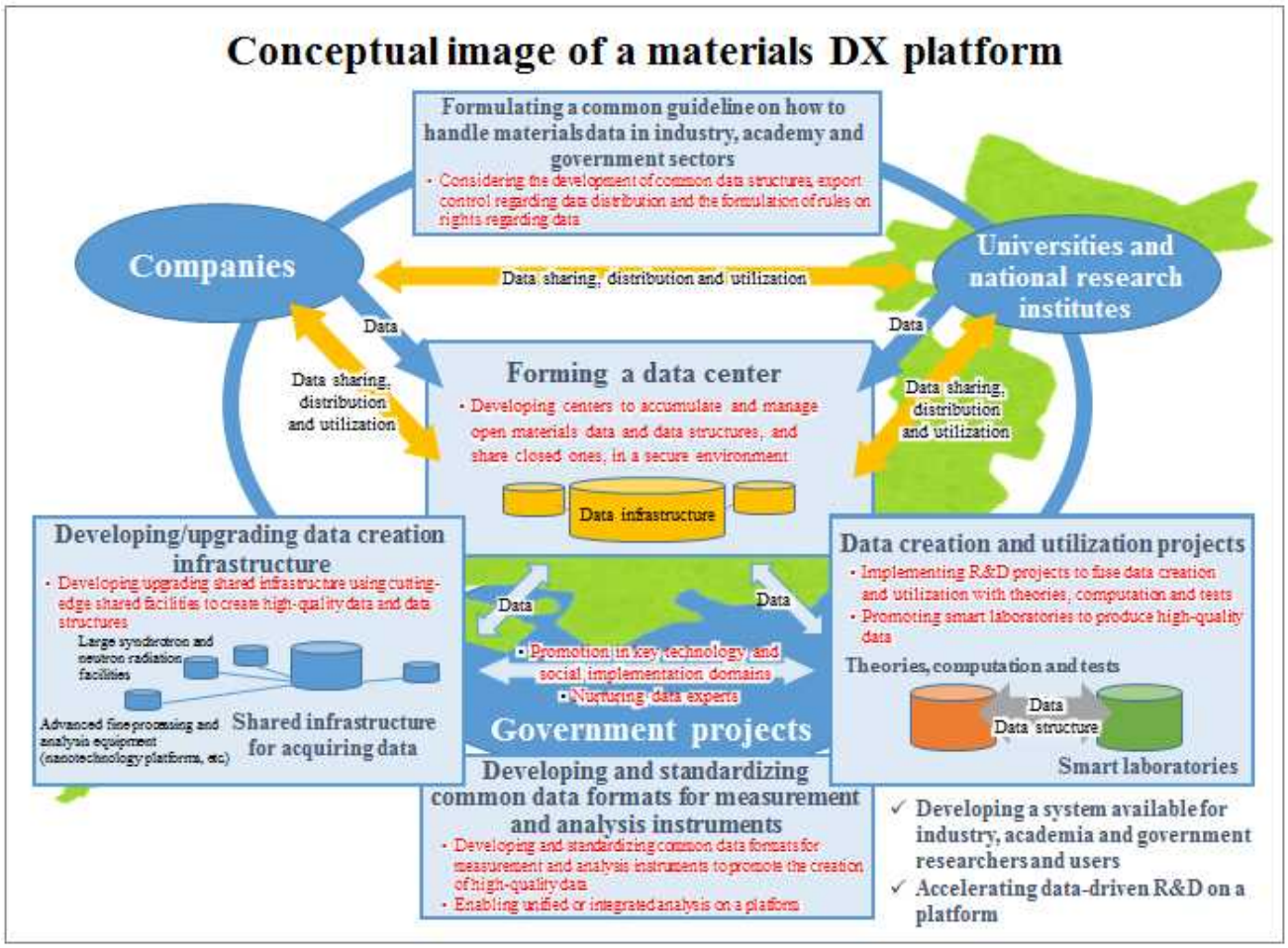
Furthermore, it is important to upgrade materials analysis and development initiatives through collaboration and fusion between simulation and AI/data sciences while making maximum use of domestic supercomputers, including Fugaku.

○ **Promoting digital transformation of materials R&D**

Japan is required to comprehensively promote the above specific initiatives to develop national materials DX platforms to create various materials data and data structures that could be utilized by industry, academic and government materials researchers and users indispensably for developing materials and relevant products and systems. This is expected to accelerate data-driven R&D on industry, academia and government R&D fronts. In the future, it would be ideal if data created generally through government-led materials-related R&D projects could be stored and structuralized autonomously and utilized. Relevant measures, including incentives, should be considered in the future.

It is also important to nationally promote the digital transformation of materials R&D, including data-driven R&D and smart laboratory development. The national promotion is expected to not only cut time and costs for industry, academia and government R&D but also realize the effective utilization of intellectual property, including knowhow and implicit knowledge accumulated by

R&D front researchers and engineers, the expansion of opportunities for efficient use of research time and creative research activities, and the reduction of risks of R&D stagnation amid new and conventional infectious disease outbreaks and large-scale natural disasters.



4－（2） Strategic promotion of key materials technology and social implementation domains

<Background and challenges>

○ As Japan’s policy resources are limited against a wide range of social implementation domains requiring material innovations, we must clarify priority domains for social implementation and strategically focus investment on key technology domains that Japan should develop truly.

○ Given that materials hold the key to the enhancement of Japan's science and technology innovation power, it is important to give priority to the realization of Society 5.0, the resolution of social challenges in AI, biotechnology, quantum and environment domains subject to existing government strategies, and the enhancement of industrial competitiveness. Regarding the enhancement of industrial competitiveness, an important point is that critical materials will be secured for supply chains. Another important point is whether materials manufacturers and users could dominate future global markets.

○ As it is noted that knowledge fusion and social implementation in materials-related fields are insufficient, some systems are required to accelerate interdisciplinary fusion and industry-academia-government cooperation for investment in key technology domains.

<Directions and goals>

○ We select key technology domains from the following viewpoint. In this respect, it is important for industry, academia and government stakeholders to share social innovation domains where material innovations in those domains would bring about great value through systemization, or the future picture that would be realized through materials.

・ Contributions to resolving social challenges and enhancing industrial competitiveness at home and abroad, including contributions to realizing the social implementation (future picture) of material innovations bringing about great value

・ Strengths (including potential) possessed by Japanese materials companies in international markets

・ Japan's basic research power and human resources potential

・ Hopefulness of innovative achievements to be created through data utilization for the digital transformation of research approaches

○ In promoting key technology and social innovation domains, Japan should combine the following approaches in line with the characteristics of the domains to implement integrated, strategic investment and systems for basics to applications taking full advantage of Japan's strengths, such as materials data and process technology, to create innovations felt by society and citizens as valuable:

(1) Approach promoting industry, academia and government R&D and innovation activities for a social implementation domain speedily and integrally (backcast approach)

(2) Approach mobilizing Japanese and other researchers for multiple social implementation domains to nurture technologies for implementation in various domains through interdisciplinary fusion (forecast approach)

○ It is important to promote investment not only in strategic research to be promoted in a top-down manner over the next decade, but also in various basic research studies anticipating industrial and social innovations over a longer term. To this end, we will sit down and tackle some materials research agenda over a certain period of time based on researchers' intrinsic motivation and promote emergent research for creating destructive innovations to accumulate various excellent materials research findings for the whole of Japan.

<Specific major initiatives to become necessary>

○ **Identifying key technology and social implementation domains**

Based on the future visions given in 3., the following are cited as social implementation domains in which material innovations would bring about great value or as key technology domains Japan should promote truly. It is hoped that these domains would be identified in discussions toward the formation of government initiatives.

(Social implementation domains in which materials would bring about great value (future picture) (examples))

- **Realizing Eco-Society 5.0, driven through very low power consumption** by innovating low-power and private power generation devices, and energy conversion and storage devices
- **Transitioning effectively from a country dependent on overseas resources to a resources-producing country** by innovating rare resources substitution and recycling technologies

- **Realizing the world's most safe, resilient country** with high-strength, high-function materials that can control their durability and degradation on their own
- **Realizing a well-being society in which everyone can feel healthy, secure, comfortable and happy** with sensitive sensor systems and innovative materials restoring and enhancing physical functions
- **Accelerating a mobility revolution** with ultra-lightweight, ultimate functional and energy conversion materials
- **Realizing sustainable industries and livelihoods independent from fossil resources** with biological and biofunction-using materials and innovative catalysts
- **Realizing the world's most creative, productive and resilient R&D and manufacturing fronts** through materials-digital R&D approaches and environmental innovations

(Key technology domains (examples))

- **Materials allowing high-level device functions to be performed**

(Power electronics devices, microelectromechanical system (MEMS) devices, ceramic devices, light and heat controlling materials, IoT sensors, actuators, etc.)

- **Materials using quantum and electronic control to perform innovative functions**

(Quantum sensors, superconductive materials, nanoelectronics devices, nanophotonics devices, spintronics devices, etc.)

- **Materials enabling innovative energy conversion**

(High-output, large-capacity storage batteries, high-performance solar cells, energy conversion materials, energy storage/transportation materials, high-performance motors, thermoelectric elements, etc.)

- **Advanced materials recycling technologies**

(Resources substitution technologies, resource consumption reduction technologies, engineering technologies for easily recyclable materials, technologies for effective use of untapped resources including by-products, advanced materials identification/separation/refining technologies, etc.)

- **Next-generation biomaterials, next-generation high-molecular materials**

(High-strength biodegradable plastics, bioadaptive materials, guided tissue regeneration materials, antiviral materials/devices, self-restoring materials, biosensors, wearable devices, etc.)

- **Next-generation nanoscale materials**

(Two-dimensional thin films, nanocarbon materials, nanoparticle materials, nanowire/nanofiber materials, nanoporous materials, etc.)

- **Ultimate functional materials**

(Ultimate environment structural materials, ultra-heat-resistant materials, lightweight high-strength materials, ultra-low friction/abrasion materials, stimulus-responsive materials, etc.)

- **Multi-material technologies**

(Multi-material bonding technologies, three-dimensional lamination technologies, multi-material design/assessment/analysis technologies, composite materials, etc.)

- **Materials and device design/control technologies**

(Surface/interface/grain boundary control technologies, reaction control technologies, new element function creation technologies, atom/molecule control technology, materials space/crystalline control technologies, etc.)

- **Common materials infrastructure technologies**

(Materials data structuralization technologies, data-driven R&D, smart laboratory technologies, high-throughput technologies, measurement/analysis technologies, fine processing technologies, precision process materials/technologies, safety/reliability/risk assessment technologies, etc.)

○ **Promoting R&D in key technology and social implementation domains**

Regarding the abovementioned backcast approach, Japan should promote leading projects concentrating the wisdom of industry, academia and government sectors through the New Energy and Industrial Technology Development Organization (NEDO), the Japan Science and Technology Agency (JST) and each government agency. A system should be established for both the government and private sectors to provide adequate funding, with high-risk cooperation areas specified for each project. Adequate open and close strategies should be designed.

As for the forecast approach, Japan should promote R&D and the creation of R&D centers (including networks) mobilizing and fusing excellent industry, academia and government researchers at home and abroad through JST, MEXT and other projects. To adequately absorb domestic and foreign research capacity,

Japan should strategically promote international cooperation for each technology domain.

In implementing such R&D initiatives, Japan should proactively introduce data creation and utilization initiatives, as well as enhancing R&D and center creation initiatives for process technologies and process sciences, to link the strength of Japan's knowledge to that of the industry sector.

In addition, Japan should adequately promote competitive research cost reform and cooperation between resource distribution organizations, enhance strategic and emergent research projects, and increase public and private sector investment in such projects in order to enhance material innovation power.

○ **Promoting integrated projects to enhance material innovation power**

In promoting key technology and social implementation domains, Japan should seamlessly and spirally link backcast-type R&D for speedy social implementation and forecast-type R&D for technological development, as well as implementing integral projects, to comprehensively promote initiatives for promoting materials data creation and utilization, developing innovation ecosystems and nurturing and securing human resources. It is important for various industry, academia and government stakeholders taking part in integral projects to share project-wide visions. In this respect, governing boards covering MEXT, METI and other relevant government agencies as well as fund distribution organizations should be established along with consortiums of industry, academia and government stakeholders. Then, those stakeholders should identify and extract backcast- and forecast-type R&D challenges for data creation and utilization projects expected to achieve major breakthroughs and closely cooperate with data centers, data creation infrastructure and process innovation centers in intensifying support for the R&D challenges to realize social implementation (a future picture) through material innovation.

Such integral projects would precede the diffusion and development of R&D initiatives for data creation and utilization cooperating with materials DX platforms in numerous materials fields.

○ **Enhancing science and technology intelligence**

To implement strategic investment in materials, Japan should enhance the functions and cooperation of its core science and technology intelligence bodies – the JST Center for Research and Development Strategy (CRDS) and the NEDO Technology Strategy Center (TSC) – to lead them to promote their activities as the world's top-level science and technology intelligence bodies. In the future, the JST CRDS and the NEDO TSC are required to step up their collection and analysis of overseas information to make further contributions to formulating an international strategy for enhancing material innovation power.

4-(3) Developing material innovation ecosystems

<Background and challenges>

○ Materials technology innovations gain great value when they lead to industrial innovations. In fact, Japan-developed materials have so far generated numerous innovations, contributing to enhancing Japan's industrial competitiveness. Thanks to this, industry-academia-government relations in the materials domain in Japan are closer than in other domains. On the other hand, it is pointed out that universities and other research organizations in Japan have numerous excellent research findings that are left idle without leading to social implementation or have failed to be identified adequately as valuable. At a time when business corporations tend to reduce basic research or shorten basic research cycles, it has become more important for them to obtain and use research findings produced at universities and other research organizations. Industry-academia-government cooperation and technology assessment should be enhanced further.

○ As social and technological changes accelerate sharply, with user needs being diversified, flexible R&D ventures and companies' use of outside knowledge for the open innovation approach have become important. As indicated by sluggish growth in the number of materials-related ventures, however, Japan has failed to create or establish players and systems for the speedy creation of new markets. In preparation for dealing with new social challenges, such as the current outbreak and expansion of the novel coronavirus disease, Japan should develop systems to quickly put materials knowledge into social practices.

○ In the global economy, emerging markets and other countries are competing for leadership in making international rules on the assessment of materials

specifications, measurement and analysis data and safety. While keeping global trends in mind and attempting to cooperate with Western and other countries, Japan should develop systems for its companies to win international markets.

<Directions and goals>

○ Japan would further deepen industry-academia-government cooperation in the materials domain and develop new innovation ecosystems where various industry, academia and government stakeholders participate and fuse with each other to produce ventures and other players that would induce new innovations. At the same time, Japan would further pave the way for its companies to strategically win international markets.

○ Through these initiatives, Japan would seek to put materials knowledge produced at universities and ventures into social practice securely and quickly, and to pave the way for strong Japan-developed material products and materials companies to be generated and create innovations in various social implementation areas.

<Specific major initiatives to become necessary>

○ **Developing materials process innovation centers**

Japan should develop centers that should have systems for enhancing process technologies among the Japanese materials industry's strengths and core functions of material innovation ecosystems. Specifically, such innovation centers should have cutting-edge process foundries and analysis systems available for small and medium-sized enterprises and ventures, and integrate and provide information and support functions regarding materials technology seeds, needs, systems and human resources in order to accumulate, utilize and recycle various industry, academia and government resources, including technologies and human resources. Given that materials contribute to promoting numerous regional industries and that regional universities and companies conduct unique R&D projects, AIST and universities should cooperate in creating centers based on the characteristics of regional industries and be united with various social implementation stakeholders to contribute to regional vitalization.

○ **Enhancing the creation of ventures based on materials' characteristics**

Japan should promote initiatives to enhance the creation of ventures with consideration given to materials' characteristics, including long R&D time scales. Specific initiatives include the promotion of cooperation with materials DX platforms in allowing ventures to proactively utilize high-quality data, the development of systems for supporting the demonstration and commercial production of new materials developed by ventures and the enhancement of tax incentives for creating ventures. These initiatives should be considered sequentially.

○ **Accelerating mature industry-academia-government cooperation based on materials' characteristics**

Japan should promote initiatives to enhance universities' cooperation with the industry sector to further solidify industry-academia-government cooperation in the materials domain. Specific initiatives include the development of cutting-edge facilities and data centers for rallying industry, academia and government sectors, the nurturing and securement of industry-academia coordinators and project managers, the securement of university research administrators and intellectual property experts, the promotion of matching between entrepreneurs and university researchers, and the multiaxial assessment of university researchers. They should be considered sequentially.

Given that even innovative technology seeds from materials R&D projects that take much time and consume massive costs for technology verification before commercialization are frequently left idle without being able to attract business investment, it is important to promote pacesetting R&D projects to explore and nurture innovative seeds at universities and ventures, and find ways for their commercialization.

○ **Leading international rulemaking and promoting institutional reforms to accelerate innovations**

In order to allow Japanese materials R&D achievements to be adequately rated and utilized in global markets, Japan should implement joint research with European, U.S. and other research institutes on the measurement and specifications of materials and lead international standardization while trying to

form international consensus. Japan should also promote the standardization of benchmarks and approaches for the quick assessment of safety required for the social implementation of new materials in a bid to lead discussions on regulations in global markets.

Furthermore, Japan should sequentially consider its adequate intellectual property strategies based on materials' characteristics and how to find companies' institutional reform requests effectively and quickly.

4-(4) Nurturing and securing human resources to support material innovation power

<Background and challenges>

○ Material innovations are produced by humans. In recent years, however, human resources shortages in the materials domain have been pointed out along with a decline in the attractiveness of the materials R&D environment. While more industry-sector researchers and engineers are working in the materials domain than in other domains, there is reportedly a shortage of young Japanese researchers, such as postdoctoral researchers and doctoral students, in the materials domain, with foreign researchers covering some of the shortage. Basic research capacity in the whole of the materials domain has been decreasing.

○ While the significance of materials increases, Japan is required to secure relevant human resources and promote their active performance. First, it is important for Japan to steadily implement a comprehensive package for enhancing research capacity and supporting young researchers, as formulated by the Council for Science, Technology and Innovation (CSTI) in January 2020. At the same time, industry, academia and government sectors should be united to promote the nurturing and securement of human resources peculiar to materials.

○ As the digital transformation of materials R&D becomes indispensable in the future, the need for human resources who can adequately handle materials data will substantially increase. Initiatives to nurture human resources with expertise in materials and data sciences have been promoted in the industry sector and graduate schools in the past several years and should be diffused and expanded promptly. Japan still attracts some global attention with its numerous achievements regarding materials research findings and innovation creation. If

initiatives cited in (1) to (3) further enhance Japan's materials R&D capacity and industrial competitiveness, Japan could rally excellent human resources in the world.

<Directions and goals>

○ Industry, academia and government sectors will cooperate in quickly nurturing human resources fusing materials and digital expertise, while implementing the comprehensive package for enhancing research capacity and supporting young researchers. In addition, these sectors will adequately nurture and secure their respective materials-related researchers and engineers for the whole of Japan, while encouraging foreigners to perform well and settle in Japan.

○ Japan, equipped with research facilities at the world's highest levels, will accelerate digital transformation, including data-driven R&D and smart laboratory diffusion, to develop the world's most attractive materials R&D environment that will be highly creative, productive and resilient. Such environment will attract excellent human resources from throughout the world and provide and communicate the attractiveness of materials R&D to students who will lead the next generation. In this way, Japan will sustainably secure human resources supporting its material innovation power qualitatively and quantitatively.

<Specific major initiatives to become necessary>

○ **Enhancing the nurturing of human resources fusing materials and digital expertise**

It is indispensable to substantially enhance the nurturing of human resources fusing materials and digital expertise to accelerate the digital transformation of industry, academia and government materials R&D. Specifically, various materials DX platform initiatives are required to nurture data experts who can design data structures and materials researchers who can use data-driven R&D as a tool. It is also important to promote human resources development initiatives in the industry sector and universities to lead numerous materials-related human resources in industry, academia and government sectors to acquire mathematical, data science and AI expertise.

○ **Promoting the nurturing, securement and excellent performance of researchers and engineers in the materials domain**

Japan should steadily promote human resources-related initiatives in the comprehensive package for enhancing research capacity and supporting young researchers, including the securement of excellent young researchers' stability and independence, the expansion of their career paths and flow to the industry sector, the improvement of doctoral courses, the creation of globally competitive researchers and the enhancement of their international networks, and the expansion of diversity.

In the materials domain, it will remain important in the future to proactively promote foreign researchers' excellent performance. Therefore, we will have to consider developing attractive research environments for foreign researchers and promoting their invitation to and settlement in Japan, while studying measures to thoroughly implement national security trade control at universities and other research fronts. It is also important to use digital tools for remote exchanges and cooperation between domestic and overseas researchers and students.

Furthermore, Japan should enhance initiatives to nurture students who will lead the next generation's material innovation. In this respect, we will have to consider the specifics of these initiatives along with measures for improving the attractiveness of the materials domain's R&D environment and for enhancing and promoting public relations strategies.

Japan should also resolve the mismatch between the industry sector's human resources development needs and university/graduate school education. In particular, we must consider how best to reform university/graduate school education regarding disciplines supporting the industry sector's infrastructure technologies. In this respect, it is hoped that the industry sector will enhance industry-academia cooperation initiatives, such as joint research and lectures sponsored by the industry sector, and proactively engage in the university/graduate school side's consideration of human resource development measures.

Initiatives are also required to nurture and secure engineers in charge of the maintenance and management of cutting-edge facilities and the development and

advancement of relevant instruments. The development of materials DX platforms should include the enhancement of such initiatives.

5. For the future

○ In the future, the government is required to clearly position this report's recommendations in the Integrated Innovation Strategy 2020 to be formulated this summer and promptly launch specific initiatives.

○ The entire government is also required to continue and deepen consideration toward the formulation of government strategies for enhancing industry, academia and government material innovation power, while being strongly conscious of the Sixth Science and Technology Basic Plan to be formulated late this year.

○ In formulating the government strategies, the government will have to enhance government and private sector investment in initiatives subject to the strategies, further specify initiative implementers and implementation schedules, and set benchmarks for verifying the achievements of the strategies. Cited as benchmarks to quantitatively and continuously verify progress toward the realization of the three future visions given in 3. are industrial materials exports in terms of value, the materials industry's shipments and value added, the number of materials and chemicals domain academic papers and their share of the global total, and the number of materials-related ventures from universities. Benchmarks should also be considered and set for each of the four specific initiatives. The government should combine the above to adequately set benchmarks and targets in its strategies and establish true execution strategies.