Executive Summary

The nanotechnology/materials field stands on nanoscience which has developed as a science handling phenomenon occurring at the nanoscale, based on basic science fields such as material science, quantum science, optical science, life science, information science, and mathematical science. On the basis of nanoscience, the common basis of science and technology is built, which include manufacturing techniques such as microfabrication technology with steady progress, additive manufacturing with integrated material processing and molding, measurement technology spanning to sub-angstrom resolution represented by a super-high-resolution electron microscope, prediction of material structure and functions using the first principle electronic state calculation, and analysis techniques by simulation and modeling.

Design and control techniques for materials and their functions such as element strategy and molecular technology, materials informatics, control of interface and gap in materials, phonon engineering have been constructed using the above-mentioned basic technology. By combining these materials and their functions, we can produce new materials and devices and also create cutting-edge technologies in the fields of environment and energy, life and healthcare, ICT and electronics, and social infrastructure, depending on the purpose of its application. The structure of the field mentioned above is shown in the panoramic view on page 1 in Japanese version.

It would not be an exaggeration to say that the development of materials technology has defined the nature of our society and life. In the 21st century, nanotechnology has taken on the role of technology driver together with materials technology. Nanotechnology, in cooperation with materials technology is further accelerating the changes in society and daily life. Furthermore, it is fundamentally supporting the remarkable changes in modern society through the integration of technologies from different fields and the systematization of technologies.

On the other hand, because nanotechnology and materials are used in a very wide range of areas in society, there is increasing concern about their potential negative impact on the human body and the environment. Since the early days of the world's industrialization, there have been safety issues for the human body and the environment, such as various types of pollution caused by industrial waste, food and drug damage caused by food additives and pharmaceuticals, etc. However, the situation is even more complicated in the case of nanomaterials with nanoscale size. Since novel nanomaterials may have new physical and chemical properties different from conventional materials, the risk can hardly be estimated from the chemical composition of materials as with conventional chemicals. Therefore, it is necessary to comprehensively consider a wide range of properties such as size, shape, and surface conditions. Since the scientific assessment of such risks requires enormous resources such as time, money, and equipment, efforts are being made through national initiatives and international cooperative frameworks. There are such efforts from the scientific aspect of the environment, health, safety (Environment, Health and Safety, EHS) and from the ethical, legal, and social (Ethical, Legal and Social Issues, ELSI) aspect. Also, for nanomaterials to be widely distributed in an international market, it is important to promote many aspects of international standards, such as unique terminology, evaluation test methods, and risk assessment methods.

The U.S. was the first country in the world to launch a national technology initiative for nanotechnology, National Nanotechnology Initiative (NNI), which has had a significant impact on R&D strategies around the world in this field. Public investment in the U.S. has totaled more than $30 billion since 2001. Since the Trump administration, the budget for the NNI has been decreasing. However, National Nanotechnology Coordination Office (NNCO) held a "stakeholder workshop" to discuss how to develop the NNI for the next decade in January 2021. We need to closely watch new movement under the Biden administration. 96% of the NNI budget is accounted for by five departments and agencies: NIH, NSF, DOE, DOD, and NIST. For example, NSF's total budget for fiscal year 2020 includes $14.3 million in funding under the CARES (Coronavirus Aid, Relief, and Economic Security) Act for research and development in response to novel coronavirus infections (COVID-19), including vaccines, sensors, masks, filters, and antimicrobial coatings.

Europe has been strengthening its nanotechnology and materials sector within the framework program "Horizon 2020" (2014-2020, €74.8B/7 years). In Horizon 2020 of EU, three priority areas are set up, which are ① Excellent Science (€24.4B), ② Industrial Leadership (€17.0B), ③ Societal Challenges (€29.7B). In the priority area of Excellent Science, following three projects, "Graphene Flagship", "Human Brain Project" and "Quantum Flagship" have been promoted as Future & Emerging Technologies (FET) with a total budget of 1 B € over 10 years.

A new program, Horizon Europe (2021-2027, €95.5B/7 years), will be launched in 2021. The details of this program will become clearer soon, but it is expected that science and technology investments in nanotechnology and materials will be strengthened, as in the previous Horizon 2020. As of July 2020, Horizon Europe has been allocated three pillars: (1) Pillar 1 (Excellent Science): €24.9B, (2) Pillar 2 (Global Challenges and European Industrial Competitiveness): €53.8 B, and (3) Pillar 3 (Innovative Europe): €13.4B.

In Asia, the progress of China is particularly prominent in high-tech industries and academic field. The 13th Five-Year Plan for Science and Technology Innovation (2016-2020), issued in 2016, shows that the Chinese government has directly linked science and technology to the economy and innovation, and is looking at the entire process of innovation creation, from R&D to industrialization. It is clear that the remarkable progress of China's scientific and technological capabilities from the fact that most of the indicators targeted in the plan have been achieved on time or ahead of schedule. Furthermore, at the 5th Plenary Session of the 19th Central Committee of the Communist Party of China (CPC) held at the end of October 2020, the general framework of the medium- and long-term plan up to 2035 and the 14th Five-Year Plan for the whole of China, including science and technology, was announced. The plan emphasizes strengthening the country through science and technology with innovation-led development at its core. The plan lists such advanced fields as artificial intelligence, quantum information, integrated circuits, life and health, brain science, biological breeding, aerospace, and the deep sea as targets for projects.

Based on "Made in China 2025" issued in 2015, they are promoting several policies aimed at gaining domestic and international market share in 10 key areas covering most of the nanotechnology and materials fields, as well as producing components at own country. As a result, the competition of the research and development in the advanced technologies of semiconductor, AI, quantum technologies, and advanced materials is becoming fierce, particularly between China and the USA. In addition, the global outbreak of COVID-19 and the resulting global economic and industrial turmoil has accelerated this trend. This may affect the research and development planning in Japan.

In other areas in Asia including Taiwan, Korea, and Singapore are also building R&D platforms of nanotechnology and materials and are trying to attract human resources and funds from all over the world.

Japan has high potential in the field of materials, both in basic and applied research. This is because Japan has been actively engaged in materials research for many years. As a result, there are many examples of inventions and industrialization in Japan, such as Neodymium magnets, lithiumion batteries, blue LEDs, photocatalysts, and carbon fibers. The global dominance of the Japanese electronics industry in the 1980s and 1990s was supported by the presence of a group of domestic companies in the materials and manufacturing equipment industries, from large corporations to small and medium-sized enterprises, that supplied the inexpensive, high-quality parts and materials used in those devices. Many of the functional materials, components, and equipment provided by these companies continue to hold a large share of the global market even today when much of the electronics industry has lost its old momentum.

Even if the size of the market for individual materials and devices is not so large, Japanese industry as a whole can be said to have captured a large global market and maintained its industrial competitiveness. At the same time, however, it should be noted that in areas where future market growth is expected, such as electrode materials for lithium-ion batteries, color films for LCDs, and power transistors, there is a downward trend in market share due to the rapid growth of other countries. In the conventional material development method, it usually takes more than 10 years to develop a new material. But under this global competition, the challenge is to increase the speed of materials development more than ever before.

When the importance of nanotechnology began to be recognized around 2000, GAFA (Google, Apple, Facebook, and Amazon), the dominant players in the global information industry today, either did not exist or were just one of the many information processing companies. The cradle that nurtured these giants of the information processing industry was electronic equipment, which continued to make remarkable progress of its performance through the miniaturization of semiconductors according to Moore's Law for 20 years before and after that point. Such a dramatic progress of device performance has been supported by the evolution of nanotechnology and materials technology. In order to continue this evolution at the same speed for the next 20 years, it is necessary to develop hardware technology as well as software one for information processing and communication areas. It is well known that the microfabrication that has supported the evolution of semiconductors up to now is approaching its limits, and there is a growing demand for technological innovation that will support the Post Moore era. It is necessary to continue research and development of innovative information processing technologies, such as neuromorphic computing, which attempts to realize flexible and low-energy information processing learned from the brain, and quantum computing, which uses the principles of quantum mechanics to solve certain complex problems that are almost impossible to solve in a reasonable time on present computers.

Based on the above background, in the first chapter of the report, we summarize the overview of these trends and prospects and describe especially issues in Japan and grand challenges in this field derived through related workshops and trend surveys organized by CRDS. We identify 31 major research and development areas from the panoramic view shown in the above. In addition, we described six social needs that we are facing and set the "13 Grand Challenges" to tackle strategically to solve those needs. In extracting the 31 areas, we focused on the following three perspectives: "innovativeness: a degree of rapid technological progress," "social and economic impact: impact of technology on society and economy," and "continuity: technological importance needed for continuous attention". By taking these perspectives, it is possible to avoid overlooking important new areas that emerge and to avoid technical investigations in areas that have lost their technological and industrial importance. In setting the grand challenges, three perspectives were taken into account: "the demand for new science and technology brought about by changes in society," "the need for strategic investment in line with the emergence of new trends in science and technology," and "securing technology that will be the basis of Japan's industrial competitiveness and national security". Since these ideas are complementary to each other, we can select both strategic R&D aiming to clear targets and curiosity-driven-research opening up to new academic fields as grand challenges.

In chapter 2, we will allocate about 10 pages for each of the 31 major research and development areas, which summarizes surveys on the significance of the area, historical background, current advanced technology trends, present science and technology issues, and international comparisons (Japan, the US, Europe, China, and Korea). In these review processes, we gathered information and opinions with the cooperation of about 170 experts from industry, academia and government, made intensive discussions at workshops and summarized the views from the standpoint of CRDS.

At the time of writing, in early 2021, COVID-19 is still raging around the world. Nanotechnology and materials will not only contribute directly to countermeasures against infectious diseases, such as prevention and treatment, but will also contribute as fundamental technologies to various changes in society caused by infectious diseases. Although this report does not have a special chapter related to new infectious diseases, the outline of the two workshops held on this topic is given in Chapter 1, and the basic technologies that contribute to countermeasures against infectious diseases are described in Chapter 2.