Executive Summary

COVID-19 has affected various aspects of human society. The restriction of economic activities and the economic stagnation have been serious and this is also expected to result in a temporary decrease in the emissions of the greenhouse gases (GHGs) generated by human activities. However, that decrease is only a small part of the total emissions. Efforts to achieve the Paris Agreement are still necessary even in this difficult situation. Some countries have green growth strategies as a key element of the COVID-19 recovery plan.

Meeting the targets in the Paris Agreement is a common issue for all humankind. International cooperation is important. However, competition between nations for technological and institutional advantages is intensifying at the same time. In order to achieve net zero GHG emission and transition to a carbon-neutral society, drastic changes in the various elements of society are required. This will be an extremely difficult task, but it will also bring new opportunities. Countries are accelerating their initiatives so that they can obtain benefits from these new opportunities and minimize the losses associated with the transition.

In addition to initiatives to mitigate and adapt to climate change, the world is facing many issues, such as natural disasters that are becoming more serious due to climate change, environmental burdens and the loss of biodiversity. Safe and stable energy supplies are also essential elements as a base of human society. R&D in the environment and energy fields is required to contribute to these various issues and social demands.

COVID-19 has affected not only on the changes in socio-economic activities and the energy supply and demand balance, but also affected on the surrounding environment. Risk management of infection through environmental surfaces is one of the important aspects for preventing the spread of infection. The role of ventilation and air conditioning in indoor environment is important as well. Wastewater-based epidemiology has arisen as a new method for detecting novel coronavirus. Earth observation helps to understand the effects of COVID-19 on a wider scale. The relationship between cities and rural areas is changing.

In this report, the socio-economic trends and R&D trends surrounding the environmental and energy fields were explored. Especially, 30 R&D areas were set and examined their trends. The following three trends were commonly observed across those.

- Integration and synthesis of scientific knowledge and technologies, coordination and harmonization of technologies: There were many cases in which the efficiency and performance of individual technologies were improved for the purpose of upgrading the system as a whole, and in which coordination and harmony among technologies were considered. In addition to scientific and engineering knowledge and skills, the need for scientific knowledge regarding human behavior, values, and socio-economic aspects is increasing. This means that the integration of knowledge is another major R&D issue to be addressed.
- Higher accuracy and higher resolution of observation, measurement, analysis, prediction: The data obtained through observation and measurement is increasing both quantitatively and

qualitatively. The integrated use of such data and improvement of the accuracy and resolution of prediction are also vigorously carried out.

- Virtualization and intelligence with digital transformation (DX) and cyber-physical system (CPS): Advanced analysis of data obtained through observations and measurements brings new discoveries and research approaches. Inductive approaches through the application of AI is also actively introduced in several R&D areas.

R&D capabilities and potentials of Japan that have found from this survey are as follows.

Energy

- Centralized power supply: Japan has accumulated a high level of technology in thermal power generation, but recently socio-economic conditions are harsh against coal-fired power generation both inside and outside Japan. Regarding nuclear power generation, research on safety is being conducted in Japan. R&D on small modular reactor which is actively promoted in the U.S. and other countries, is stagnant in Japan.
- Renewable energy: Japan has strengths in new materials for solar power generation. Global business competition, however, remains intense in the application and development of each power generation method, and the status of Japan in the areas of solar cells, wind power technology and biomass technology are significantly declining.
- Energy utilization: R&D in the fields of electricity, chemistry and mechanical engineering is actively conducted, and some of them are highly recognized internationally in the basic research and have strength in the industrial applications / developments. There are certain international strengths in R&D in the fields of EMS utilizing digital technology, stabilization of power systems, the next generation of rechargeable batteries, heat pumps, toxic materials separation / removal technology, artificial photosynthesis and hydrogen technology. There are few basic researchers in the areas such as regional cooling-heating system, and there is a weakness in improving energy efficiency as a system.
- Fundamental fields: Japan has strengths in thermal efficiency of practical combustion equipment, emission reduction, low friction technology and fracture analysis of composite materials.

Environment

- Research related to COVID-19: Research on wastewater-based epidemiology, satellite observation data analysis, air-conditioning engineering are actively conducted.
- Climate change observation / prediction / evaluation: Rainfall observation, meteorological satellite observation and oceanographic observation are being conducted at high level. Development of the Earth System Model (ESM) contributes to scientific assessment on climate change at IPCC. R&D on global hydrologic cycle, dam operation based on rainfall forecast technology, and regional climate downscaling are also well known.

- Environmental purification, Hygienic Engineering: For water use and treatment, membrane treatment and UV-LED technology are highly competitive. In environmental purification (air, soil, groundwater), there is international high-level technologies on the three-way catalyst for gasoline vehicles and mine wastewater purification.
- Ecosystem and biodiversity observation / evaluation / prediction: In ecosystem and biodiversity observations, Japan participates in global initiatives and contribute to the accumulation of observational data in the East Asia region. However, Japan is behind the US and Europe in the recent trend of comprehensive research using the vast amount of observational data.
- Fundamental fields: In the field of atmospheric environment analysis, research on $PM_{2.5}$ is at higher level. Researches on microplastics, arsenic, and mercury are also actively conducted. In the field of life cycle assessment (LCA) and environmental impact assessment, there are many cases for individual products and specific needs. On the other hand, Japan has been often behind the US and Europe in conducting comprehensive assessment, and regulatory science being conjunction with development of laws and regulations.

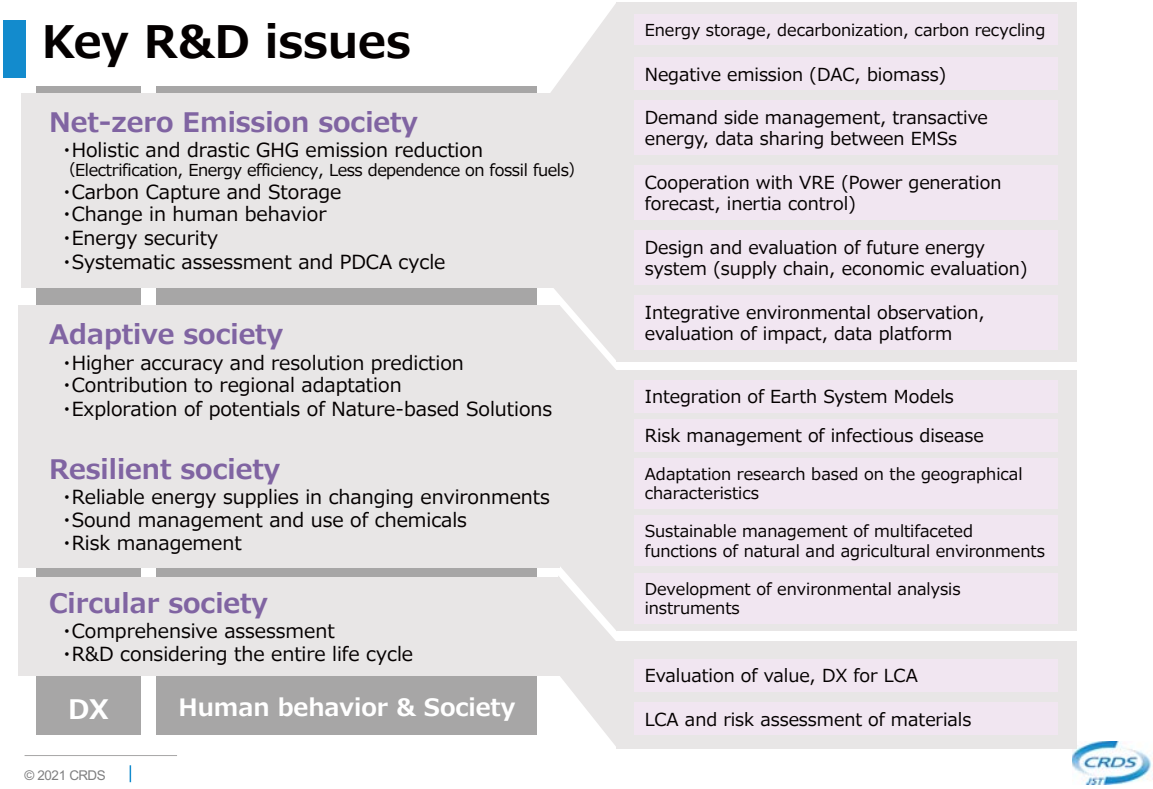
Based on the above domestic and international R&D trends and socio-economic trends, it is likely to be that the future direction of R&D in the environment and energy field is "R&D to promote society transition". As each country accelerates the transition, the importance of R&D that promotes the transition will increase more than ever.

So, what kind of society are we aiming for? There are four main directions being taken: "Net zero emission society (climate change mitigation)", "Adaptive society (climate change adaptation)", "Resilient society (resilience)", and "Circular society (circular economy)". Sustainability and inclusiveness are the common values at the core. Especially with regard to the net zero emission society, an ambitious goal achieving carbon neutral by 2050 has been set by the Japanese government. Counting backwards from 2050, the energy system in the society must be changed significantly by 2030. Since it is not a problem that can be solved by a specific industry or individual pieces of technology alone, it is necessary to tackle it comprehensively beyond the boundaries of the field.

"DX" and " human behavior and relationships with society" are key drivers to promote the society transition. The “DX” here includes not only DX in R&D but also DX in the society. Regarding the "human behavior and relationships with society", this means that we need to understand more about human behavior and society itself, and also means that collaborations with various stakeholders are necessary to implement and disseminate the results of R&D to society.

Toward the transition to the four societies, issues to be focused are shown in the figure below. Here, the correspondence is shown for each society, and they are also related to each other. Climate change mitigation and adaptation are issues that should be tackled in an integrated manner. Adaptation to climate change is closely related to response to natural disasters such as extreme weather, so there is something in common with efforts toward a resilient society. The circular economy also needs to be promoted integrally with net zero emissions and a resilient society.

Efforts to realize net zero emissions must include: accelerating social implementation with agile R&D and some incentives; running the PDCA cycle by grasping the status of GHG emission reductions; encouraging integrated and cross-cutting efforts that promote collaboration with multi-stakeholders; development of the next-generation human resources and technologies; strengthening the basis of science and technology at national level; and promoting international collaboration. Efforts to realize climate change adaptation and a resilient society must include: building a system to promote the integration and synthesis of scientific knowledge and technologies; and creating and accumulating model cases of implementation in a society. Efforts to realize a circular economy or four societies as a whole must include building a platform for DX. In this platform, various types of data such as earth observation data and data relating to energy consumption must be stored, processed and analyzed by professional data scientists and engineers.



R&D in the environment and energy fields is extremely broad. Along with the development of the society, we also have a responsibility to build better society and the global environment for the future generations. Faced with COVID-19, the situation is still uncertain, but it is necessary to strongly promote R&D as a pillar for overcoming these difficult situations and development a robust society.