Application Guidelines Appendix

Chapter 6: Target Technology Areas

6.1 "Energy Storage" Area

Program Officer
WATANABE Masayoshi
(Distinguished YNU Professor, Institute of Advanced Sciences, Yokohama National University)

I. Overview of the Technology Area

Energy storage is an essential technology for aiding in our transition to sustainable energy systems. This technology area will focus on the chemistry of heat and electricity storage. Thermal energy storage, which is a technology used to correct mismatches in time, temperature, and location when handling thermal energy, has made great advances in the use of factory waste heat but leaves room for improvement in the exploitation of unutilized waste heat and other resources at medium and low temperatures. Today, storage batteries and other electricity storage technologies are indispensable for sustaining our livelihood and economic activity, and they continue to increase in importance. More versatile, economical, and environmentally friendly electricity storage methods are needed for a wide range of applications, from small electricity storage devices used in our daily lives to large-scale electricity storage devices in power grids that promote the use of renewable energy sources, such as solar and wind power, having highly variable output.

Therefore, while bearing in mind these societal needs, we will undertake challenging R&D based on free ideas unbound by precedent with the aim of developing technological seeds for innovative energy storage. Through breakthroughs in discoveries of new reaction mechanisms and new materials, we hope to contribute to a transformation in Japan’s energy makeup toward attaining carbon neutrality.

When selecting R&D proposals, an emphasis will be placed on the premise that the proposed technology can contribute to a reduction in carbon dioxide emissions throughout the entire process chain from the perspective of energy and material flows.

This fiscal year, JST is also calling for R&D proposals on storage battery-related technologies for the storage battery technology area that will be conducting team-based research in the Green Technologies for Excellence (GteX) Program. ALCA-Next will not adopt any proposals that could be suitably implemented in the GteX team-based research. Further, GteX is soliciting ideas on potential elemental technologies for team-based research as “innovative elemental technology research.” Therefore, we encourage applicants to refer to the GteX application guidelines and apply to GteX for any topics that could be eligible for a GteX theme. For information on our relationship with GteX, please refer to “1.4 Points of Attention when applying to ALCA-Next” in Chapter 1 of the ALCA-Next Application Guidelines.

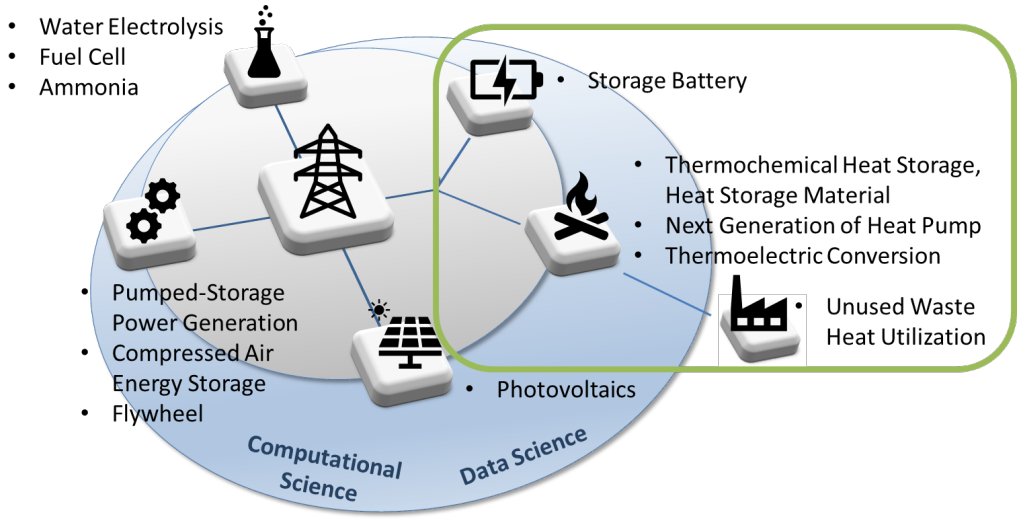

Fig. 1：Technologies targeted in the Energy Storage area

II. Technological Elements Expected to Be Proposed

In the area of energy storage, we anticipate R&D proposals in the following categories.

a. Research on storage technologies for unutilized thermal energy at medium and low temperatures
b. Research on safe and inexpensive electrical energy storage technologies promoting the use of renewable energy
c. New ideas for energy storage technologies toward realizing carbon neutrality

a. Research on storage technologies for unutilized thermal energy at medium and low temperatures

Turbines and engines that operate at high temperatures can achieve high power conversion efficiency based on the Carnot cycle. However, technologies for utilizing heat energy in the mid-to-low temperature range, which accounts for most energy consumption, have not been sufficiently developed to offset the costs of production and maintenance, with much heat being discarded unused. Consequently, there is strong demand for developing thermal management technologies, such as heat storage, heat reclamation, and heat recovery in the medium-to-low temperature range, that can contribute to a reduction in greenhouse gas emissions. Therefore, we are calling for proposals for clarifying reaction mechanisms and exploring heat storage materials aimed at making use of unutilized waste heat at medium and low temperatures. In addition to conventional sensible and latent heat storage for storing thermal energy, we intend to focus on thermochemical heat storage that uses chemical phenomena, particularly reversible chemical reactions, to store energy as chemical energy. Thermochemical heat storage has greater heat storage density than sensible or latent heat storage and is expected to expand the potential for practical technologies.

For example, we are seeking proposals for resolving the following bottleneck issues, but will also accept other innovative proposals:

- Elucidation of reaction mechanisms and searches for materials to realize high-capacity thermochemical heat storage
- Development of safe, inexpensive, and high-performance latent and sensible heat storage

materials

b. Research on safe and inexpensive electrical energy storage technologies promoting the use of renewable energy

For the large-scale introduction of renewable energies aimed at realizing a carbon-neutral society, such as solar and wind power, there is a need for advances in electrical energy storage technologies suited to electricity grids, including batteries and capacitors for both the medium-to-long-term (supply and demand) and short-term (weather-related output fluctuations) adjustments of these energies. Among these technologies, redox flow batteries have attracted interest as grid storage batteries for such features as their low life-cycle cost and high safety owing to the use of flame-retardant materials and, while the batteries have low volumetric energy density and require a large installation area, we anticipate breakthroughs on these issues. Additionally, nonflammable ionic liquids and aqueous electrolytes, which are being considered for future applications in next-generation electrical energy storage technologies, will require improved ion transport properties and an expanded potential window to enable higher voltages in the storage devices. In this category, we are seeking R&D proposals on low-cost and highly safe electrical energy storage technologies capable of overcoming the above challenges.

For example, we are seeking proposals for resolving the following bottleneck issues, but will also accept other innovative proposals:

- Development of electricity storage materials that contribute to the smoothing of output fluctuations
- Technologies for significantly improving volumetric energy density in redox flow batteries
- Large-scale electrical energy storage technologies using nonflammable ionic liquids or aqueous electrolytes

c. New ideas for energy storage technologies toward realizing carbon neutrality

We welcome any R&D proposals on heat and energy storage technologies that do not fall into the above categories and original as-yet-unnamed battery systems that are based on novel chemical concepts and that will contribute greatly to the realization of carbon neutrality.

6.2 "Energy Conversion" Area

Program Officer
WATANABE Masayoshi
(Distinguished YNU Professor, Institute of Advanced Sciences, Yokohama National University)

I. Overview of the Technology Area

In the Green Growth Strategy for attaining carbon neutrality, making renewable energies our primary power sources and developing innovative technologies that utilize hydrogen energy are considered essential. Expanding the use of renewable energy will require us to reduce the cost of introducing photovoltaic and other power generation systems and to improve energy conversion efficiency. Hydrogen, which is expected to be utilized in a wide range of settings, including power generation, industry, and transportation, will also require significant improvements in conversion efficiency for its generation, conversion to energy carriers, and utilization.

Therefore, while bearing in mind these demands, we will undertake challenging R&D based on free ideas unbound by precedent with the aim of developing technological seeds for innovative energy conversion. By developing technologies that could lead to the stable procurement and large-scale use of next-generation energy and technologies related to hydrogen energy carriers, we hope to contribute to a transformation in our energy makeup aimed at carbon neutrality.

When selecting R&D proposals, an emphasis will be placed on the premise that the proposed technology can contribute to a reduction in carbon dioxide emissions throughout the entire process chain from the perspective of energy and material flows.

This fiscal year, JST is also calling for R&D proposals on hydrogen-related technologies for the hydrogen technology area that will be conducting team-based research in the Green Technologies for Excellence (GteX) Program. ALCA-Next will not adopt any proposals that could be suitably implemented in the GteX team-based research. Further, GteX is soliciting ideas on potential elemental technologies for team-based research as “innovative elemental technology research.” Therefore, we encourage applicants to refer to the GteX application guidelines and apply to GteX for any topics that could be eligible for a GteX theme. For information on our relationship with GteX, please refer to “1.4 Points of Attention when applying to ALCA-Next” in Chapter 1 of the ALCA-Next Application Guidelines.

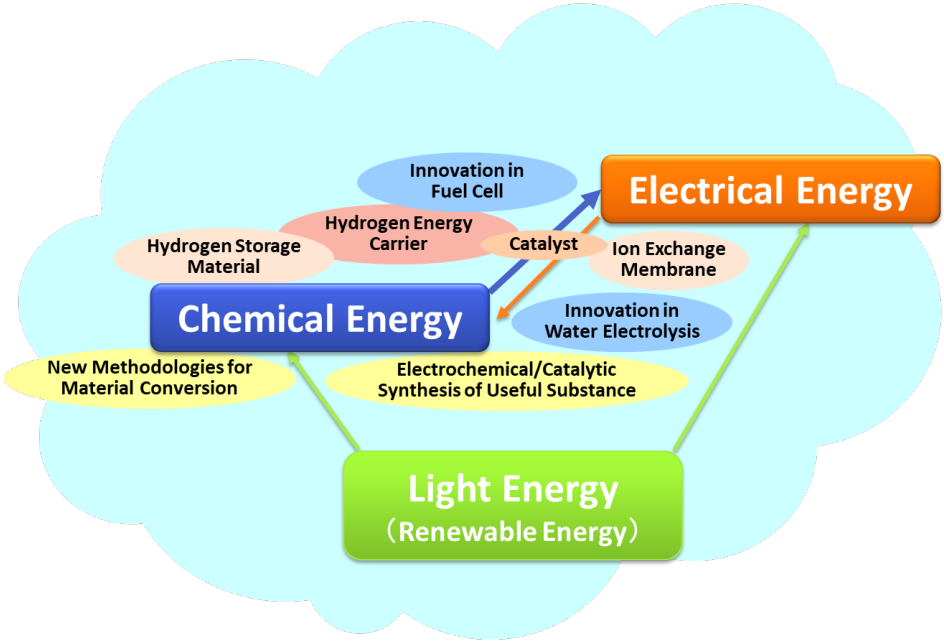

Fig. 2：Technologies targeted in the Energy Conversion area

II. Technological Elements Expected to Be Proposed

In the area of energy conversion, we anticipate R&D proposals in the following categories:

a. Inexpensive, efficient, and convenient technologies for converting solar energy
b. Inexpensive, energy-saving technologies for the synthesis and use of hydrogen energy carriers
c. New ideas for energy conversion technologies toward realizing carbon neutrality

a. Inexpensive, efficient, and convenient technologies for converting solar energy

With improved efficiency and lower costs, crystalline-silicon solar cells have seen an expansion of applications primarily in mega solar power projects and other large-scale facilities to more recent consumer uses, such as home roofs. However, in order to further expand the use of solar cells, it will be vital to increase installations on factory rooftops, walls of buildings, noise barriers and slopes along highways, agricultural greenhouses, and other structures whose load bearing is too small to install current crystalline-silicon solar cells. One important research challenge for attaining this goal is how to drastically improve the efficiency and lifespan of new solar cells, such as organic thin-film and lead-free perovskite solar cells, which can be lightweight and flexible and produced inexpensively. Other important challenges are the development of methods to convert stable small molecules, such as water and carbon dioxide, to hydrogen, methane, methanol, and other useful substances using sunlight to activate the small molecules and the development of catalysts to facilitate this conversion process. Yet another important challenge will be the development of fundamental technologies for converting solar energy to energy carriers with high energy density using only solar energy.

For example, we are seeking proposals for resolving the following bottleneck issues, but will also accept other innovative proposals:

- Development of inexpensive, thin, lightweight, and flexible solar cells that can dramatically expand potential installation sites
- Development of technologies for producing useful substances using solar energy that are less

expensive and more efficient than existing technologies

b. Inexpensive, energy-saving technologies for the synthesis and use of hydrogen energy carriers

Energy carriers that enable hydrogen, which is inefficiently stored and transported over long distances in its gaseous state, to be stored and transported efficiently in its liquid form or as a hydrogen compound are a key technology for the construction of a hydrogen energy society. Studies have been conducted on such energy carriers as ammonia, organic hydrides, and formic acid, but have yet to establish an energy carrier that is both cost-effective and convenient.

Common challenges to hydrogen energy carriers are their synthesis from hydrogen and utilization technologies involving dehydrogenation. Ammonia is one hydrogen energy carrier that has shown promise. However, since conventional methods of industrial synthesis consume a large amount of energy, an entirely new method of synthesis is needed for an energy carrier that is carbon neutral. One challenge with utilization is to reduce costs and energy consumption in the process of dehydrogenation, which removes hydrogen from organic compounds. Also important are technologies that directly utilize hydrogen energy carriers without the need for dehydrogenation. In this category, we are seeking innovative proposals that can fundamentally solve the above challenges.

For example, we are seeking proposals for resolving the following bottleneck issues, but will also accept other innovative proposals:

- Exploration of high-performance, inexpensive catalysts and new processes for the synthesis and dehydrogenation of ammonia and other hydrogen energy carriers
- Development of technologies for the direct utilization of hydrogen energy carriers

c. New ideas for energy conversion technologies toward realizing carbon neutrality

We welcome any R&D proposals on energy conversion technologies that do not fall into the above categories if they are based on novel chemical concepts and will contribute greatly to the realization of carbon neutrality.

6.3 "Resource Circulation" Area

Program Officer
WATANABE Masayoshi
(Distinguished YNU Professor, Institute of Advanced Sciences, Yokohama National University)

I. Overview of the Technology Area

This technology area conducts R&D on technologies, materials, and chemical processes that will enables us to recycle resources efficiently with low environmental impact, contributing greatly to a reduction in greenhouse gas emissions. Recovering and recycling carbon and other resources has become increasingly important worldwide for achieving carbon neutrality. For example, the capturing and recycling of greenhouse gases from industrial exhaust, which is a massive source of greenhouse gas emissions, is expected to contribute significantly to carbon neutrality. For this reason, we must study energy-saving and efficient technologies for the capture and separation of carbon dioxide gas and other greenhouse gases and establish new processes for the synthesis of high-performance, highly functional chemicals and fuels, either directly from greenhouse gases or from biomass that has absorbed and fixed greenhouse gases. We anticipate an increase in the production and distribution of storage batteries, fuel cells, and solar cells aimed at reducing greenhouse gas emissions, but the supply of metal resources used for their production is limited, as are the countries that produce them. Consequently, recycling existing resources will be important to ensure a stable supply of such raw materials. Our aim is to develop technologies, materials, and chemical processes that will make a significant contribution to a reduction in greenhouse gas emissions by enabling the recycling of organic and inorganic resources.

When selecting R&D proposals, an emphasis will be placed on the premise that the proposed technology can contribute to a reduction in carbon dioxide emissions with low environmental impact throughout all processes using the proposed technology from the perspective of energy and material flows.

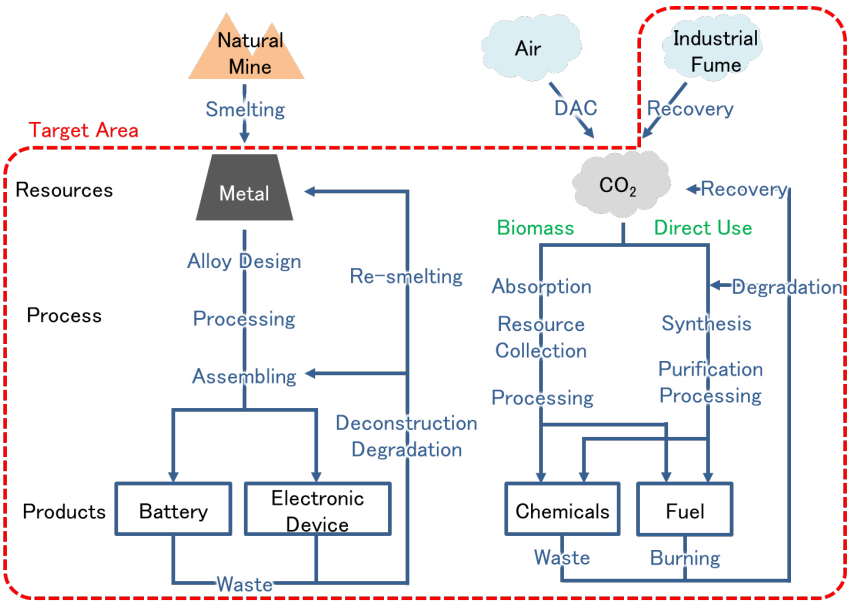

Fig. 3：Technologies targeted in the Resource Circulation area

II. Technological Elements Expected to Be Proposed

In the area of resource circulation, we anticipate R&D proposals in the following categories.

a. Research on efficient, energy-saving technologies for the capture, separation, and utilization of greenhouse gases
b. Research on new synthesis technologies for producing high-performance, highly functional materials from biomass with high efficiency and low environmental impact
c. Research on the development of recycling processes using degradable and easily dismantled materials for contributing to a reduction in greenhouse gases
d. Research on new chemical concepts for resource circulation aimed at realizing carbon neutrality

a. Research on efficient, energy-saving technologies for the capture, separation, and utilization of greenhouse gases

The use of fossil resources emits an enormous amount of greenhouse gases, but we are now seeing a shift toward carbon dioxide-free renewable energy and the development of energy-saving technologies aimed at reducing these emissions. An urgent matter that must be addressed to realize carbon neutrality, however, is the need to separate and capture greenhouse gases from large-scale sources and to convert the recovered greenhouse gases to resources. Although some technologies for separating and capturing greenhouse gases are already being considered for practical applications, we still need to develop technologies that can outperform conventional techniques in all such methods in order to achieve significant improvements in performance and reductions in cost for a wider range of applications. We must also establish new processes for synthesizing compounds having high industrial demand from greenhouse gases and promote the conversion of greenhouse gases, particularly carbon dioxide, into resources.

Therefore, we are soliciting R&D proposals on the development of innovative adsorption materials and separation membranes for greenhouse gases and the construction of new technologies for synthesizing high-value-added compounds from carbon dioxide. Proposals that clarify the envisioned operating conditions and scale and whose development can contribute to a reduction in greenhouse

gas emissions throughout all processes of capture, separation, and utilization will be given greater consideration.

For example, we are seeking proposals for resolving the following bottleneck issues but will also accept other innovative proposals:

- Development of new efficient, energy-saving materials capable of separating and capturing greenhouse gases
- Development of chemical processes with improved efficiency for the capture and separation of greenhouse gases
- Development of new technologies for synthesizing high-value-added compounds from carbon dioxide

b. Research on new synthesis technologies for producing high-performance, highly functional materials from biomass with high efficiency and low environmental impact

The importance of utilizing biomass (woody and herbaceous materials) for absorbing, fixing, and recycling carbon dioxide is commonly recognized throughout the world, and research on such utilization has been conducted in a wide range of fields. While Japan has abundant forest and marine resources, in some aspects the country has fallen behind other countries in research on biomass utilization. In particular, we must develop technologies that account for Japan's unique weather, environment, and geographical conditions. We are looking to develop challenging new methods of chemical synthesis for efficiently converting non-food biomass into high-performance or highly functional chemical products and polymer materials required by society, and technologies for enabling the low-cost production of commodity chemicals, such as organic acids and alcohols, as well as fuels and other products from non-food biomass.

For example, we are seeking proposals for resolving the following bottleneck issues but will also accept other innovative proposals:

- Chemical synthesis technologies for converting raw materials into high-performance or highly functional chemical products and polymer materials utilizing their skeletal structures
- Synthesis technologies for efficiently producing commodity chemicals and polymer materials at low cost using biomass-derived raw materials

Biological uses for biomass are addressed in the Green Biotechnology area. For more information, please refer to "6.4 Green Biotechnology Area" in Chapter 6 of the Application Guidelines.

c. Research on the development of recycling processes using degradable and easily dismantled materials for contributing to a reduction in greenhouse gases

To attain carbon neutrality, using our limited resources efficiently with low energy consumption will likely be important from the perspective of sustainability. In particular, we anticipate the implementation of "carbon recycling," which will treat greenhouse gases as resources, as well as the recycling of storage batteries and solar cells, which are experiencing increasing demand for the realization of carbon neutrality. The development of energy-saving and efficient methods of decomposing and dismantling materials will be vital for such resource recycling. In this category, we are seeking the development of chemical synthesis methods for degradable materials that can contribute greatly to the reduction of greenhouse gas emissions, the development of easily dismantled materials that contribute to improved energy-saving and efficiency in resource recycling, and the development of material utilization processes that enable greenhouse gases to be recycled and reused as resources.

For example, we are seeking proposals for resolving the following bottleneck issues but will also accept other innovative proposals:

- Development of recyclable polymer materials that can be decomposed and reused as raw

materials in the environment
- Development of synthesis methods and utilization processes for efficient adhesive and bonding materials that achieve both good bonding strength and ease of dismantling for dissimilar materials such as metals and resins

d. Research on new chemical concepts for resource circulation aimed at realizing carbon neutrality

We welcome any R&D proposals related to the recycling of organic or inorganic resources that do not fall into the above categories if they are based on novel chemical concepts and will contribute greatly to the realization of carbon neutrality.

6.4 "Green Biotechnology" Area

Program Officer
EZURA Hiroshi
(Professor, Institute of Life and Environmental Sciences, University of Tsukuba)

I. Overview of the Technology Area

Biomanufacturing and the food, farming, fishing, and forestry industries have been highlighted as key areas in the Green Growth Strategy to help Japan achieve carbon neutrality, and there is an increasing focus on technology development using biotechnology. In particular, there is growing interest in the use of plants and microorganisms to fix carbon dioxide and recycle as a resource for forestry or the lumber, agricultural, and marine industries. This is expected to make significant contributions to reducing greenhouse gas (GHG) emissions. In this technology area therefore, we aim to maximize the use of functions found in microorganisms and plants to develop innovative and game-changing emerging technologies that will contribute to reduced GHG emissions.

A lot of research has already been done to elucidate and improve microorganism and plant functions, but over the past few years, attention has turned to include the symbiotic relationships between the microbiota and plants and also with other organisms in the surrounding environment. We now know that in the complex biological systems where this diverse range of organisms interacts, there is communication mediated by the metabolism or secretion of signal transducers in minute quantities. We hope to be able to elucidate, control, and utilize the interactive mechanisms involved in complex biological systems to be able to maximize biological functionality.

In this technology area, researchers mostly in academia will conduct innovative and challenging research in domains where there are many unknowns, such as the elucidation and utilization of interactive mechanisms in complex biological systems in the natural environment, and will develop new technologies that apply biotechnological methods to help achieve carbon neutrality. Through this R&D, we have strong expectations for reduced GHG emissions as well as carbon dioxide fixation and use as a resource.

The Japan Science and Technology Agency's (JST) Green Technologies for Excellence (GteX) Program also invites research and development proposals under the team-based research domain Biomanufacturing, which will connect next-generation platforms for biomanufacturing systems using microorganisms/plants in order to apply them to biomanufacturing technologies in a wide range of industries. In terms of the research scope, the GteX program is also actively calling for applications on innovative research into underlying component technologies, so please review the GteX application guidelines and consider how your application fits with the purpose of this program. Please refer to "1.4 Points of Attention when applying to ALCA-Next" in the ALCA-Next Application Guidelines for more information on the connections with the GteX program.

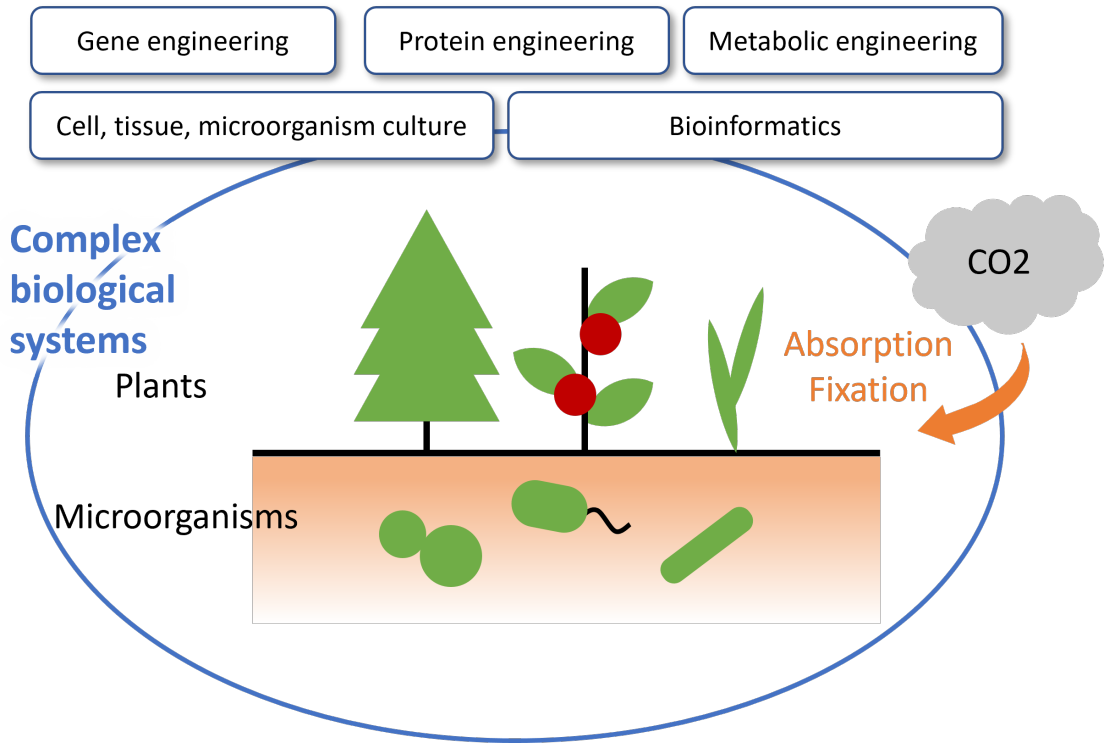

Fig. 4: Technologies targeted in the Green Biotechnology area

II. Technical Elements Expected to Be Proposed

In the Green Biotechnology domain, we expect to receive research and development proposals in the following categories:

a. Innovative technologies to analyze the structures and functions of complex systems of microorganisms
b. Methods to control complex biological systems to maximize plant functions, such as improved carbon dioxide fixing capabilities or ability to withstand environmental change
c. Next-generation breeding technologies for various plants aimed at biomass production that produces high yields with less environmental impact
d. Novel technologies that utilize microorganisms or plants for food production while also reducing GHG emissions
e. New concepts utilizing biotechnology to achieve carbon neutrality

a. Innovative technologies to analyze the structures and functions of complex systems of microorganisms

Microorganisms play a major role in the Earth's carbon and nitrogen cycles. It is believed that the function control of microorganisms in the environment is vital towards GHG emissions reductions. In the natural environment, not only do many types of microorganisms make up the microbiota but also exist as entities forming part of a complex biological system together with plants and other organisms. The literature suggests that the microorganisms, plants, and other organisms in these complex biological systems influence each other via various interactive factors (signal transducers), but there are numerous unknowns at this stage, such as how these interactions change under different climate and geographical conditions. Progress has been made with microbiota metagenome analysis, but many

fungi or bacteria in the environment are difficult to culture and we lack the technologies to analyze such microorganisms. Therefore, it is still extremely difficult to analyze in a systematic fashion the structures and functions of complex biological systems in the environment.

We invite proposals on innovative, high-throughput analytical technologies to derive information on complex systems of microorganisms in order to elucidate the structures and functions of complex microorganism systems that are mostly unknown to science today and to uncover new findings that will help to maintain the Earth's matter cycles.

For example, we are seeking proposals for resolving the following bottleneck issues, but will also accept other innovative proposals:

- Development of innovative, high-throughput analytical technologies relating to environmental change for the microbiota, in order to protect the soil and maintain the carbon and nitrogen cycles
- Development of microbiota analytical technologies to reduce GHG emissions in the hydrosphere, including control of biofilm activity during wastewater treatment

b. Methods to control complex biological systems to maximize plant functions, such as improved carbon dioxide fixing capabilities or ability to withstand environmental change

Plants are thought to exhibit adaptability to various environments through symbiotic relationships with various other organisms. For example, investigations are ongoing into how plants interact with the microbiota, identifying microorganisms that contribute to plant growth and exploring interactive factors (signal transducers), but researchers also need to identify the receptors and factors that exist in the plants themselves and analyze how they change dynamically in order to establish more efficient and effective interactions.

Moreover, by utilizing the actions complex biological systems exert on plants, we may be able to develop plants that are more able to withstand various environments, are more resistant to pests, or can maintain production volume/growth in different environments. However, it is still difficult to get a full understanding of the mechanisms of interaction between the various different elements involved in complex biological systems.

We invite proposals on the analysis of plant genes that contribute to interactions in complex biological systems; the elucidation of interactive factors and other substances produced by plants; and the development of methods for the genetic transformation, breeding, and cultivation of novel plants based on these mechanisms of action, in order to utilize the actions of complex biological systems and to raise plants capable of superior growth or carbon dioxide fixation and able to withstand environmental change.

For example, we are seeking proposals for resolving the following bottleneck issues:

- Analysis of plant genes that are affected by symbiotic microbiota or plants and development of plants using these genes
- Development of new plant cultivation technologies that use complex biological system design and control to promote development or improve ability to withstand environmental change or pest resistance

c. Next-generation breeding technologies for various plants aimed at biomass production that produces high yields with less environmental impact

The fixation of carbon dioxide through plant photosynthesis is expected to contribute to carbon neutrality through negative emissions. We need to increase land for plant growth, increase/improve productivity, and through this accelerate the use cycle if we are to mass-produce plant biomass that has the potential to make a significant contribution to reduced GHG emissions. For example, for herbaceous plant biomass, we expect the development of technologies to allow food production with less environmental impact and selective breeding for more efficient crops. For woody plant biomass,

we look for the production of elite trees (selected from the next generation of tree specimens obtained through artificial cross-breeding of elite trees with good traits such as growth or timber quality, to produce elite trees with superior traits for growth etc.) to expand timber use and ensure/improve medium- and long-term forest absorption of GHG through appropriate forest management. To achieve this, we need to be able to efficiently develop elite trees through more rapid forest tree breeding and to expand production of such saplings.

Therefore, in this category, we invite proposals for the development of next-generation platform technologies to increase the efficiency and speed of breeding of a wide range of plants, including trees.

For example, we are seeking proposals for resolving the following bottleneck issues, but will also other innovative proposals:

- Development of technologies for plant genomic data analysis, gene selection, or genome editing, based on new breakthroughs, to allow biomass mass-production that produces high yields and less environmental impact
- New breeding technologies to develop plants that require fewer resources or fertilizer for the same yields

d. Technologies applying novel microorganisms or plants to food production while also reducing GHG emissions

It is hoped that in the future, microorganisms and plants will have a large role to play in providing solutions to the protein and energy crises, and a lot of work has already been done to develop food production technologies using microorganism and plant functions. From the perspective of helping us achieve carbon neutrality as well, we need to improve food production efficiency while also reducing GHG emissions. For example, to reduce GHG emissions in the agriculture sector, the use of microorganism resources to improve the efficiency of soil improvement or fertilization or in the livestock industry would also reduce energy inputs. There are also expectations for the development of technologies to use precision fermentation in the production of alternative proteins or fatty acids.

Under this category, we invite proposals on technologies that maximize the use of microorganism or plant functions to enable food production that uses less energy and fewer resources, or the development of novel microorganisms or plants that contribute to food production.

For example, we are seeking proposals for resolving the following bottleneck issues, but will also accept other innovative proposals:

- Development of technologies that utilize microorganisms to enable the production of food and animal feed with reduced energy inputs
- Development of new food production technologies using novel microorganisms, plants, etc.

e. New concepts utilizing biotechnology to achieve carbon neutrality

We are looking for research and development proposals that are based on new concepts, using microorganisms or plants and contributing to carbon neutrality, and that do not fit into the categories described above.

The development of technologies for chemical product synthesis using biomass raw materials is categorized under Resource Circulation. For more details, see “6.3. Resource Circulation Area” in the Application Guidelines.

6.5 "Semiconductor" Area

Program Officer
KURODA Tadahiro
(Professor, Graduate School of Engineering, The University of Tokyo)

I. Overview of the Technology Area

Power consumption in the information and communication infrastructure has increased exponentially as we progress toward a full-fledged advanced information society integrating 5G and 6G networks, IoT, self-driving technology, robotics, and digital transformation (DX). Consequently, achieving drastic power-savings with semiconductors and circuitry on which this infrastructure is founded will be essential to realizing carbon neutrality. With regard to power transmission, reducing energy consumption and improving reliability in large-scale, complex power grids connected to renewable energy hydrogen generators and storage batteries will also be vitally important to attaining carbon neutrality.

Our goal in this technology area is to radically reduce power consumption in semiconductors designed for information and communication infrastructure. Specifically, we intend to develop semiconductor devices and process technologies to realize ultra-low-power logic and memory, innovative transmission hardware technologies for reducing power consumption per bit by several orders of magnitude, and materials and packaging methods for realizing efficient thermal management. We will also develop efficient and reliable power conversion and control circuits and inverter/converter stabilization technologies for improving energy savings and reliability in large-scale, complex power grids.

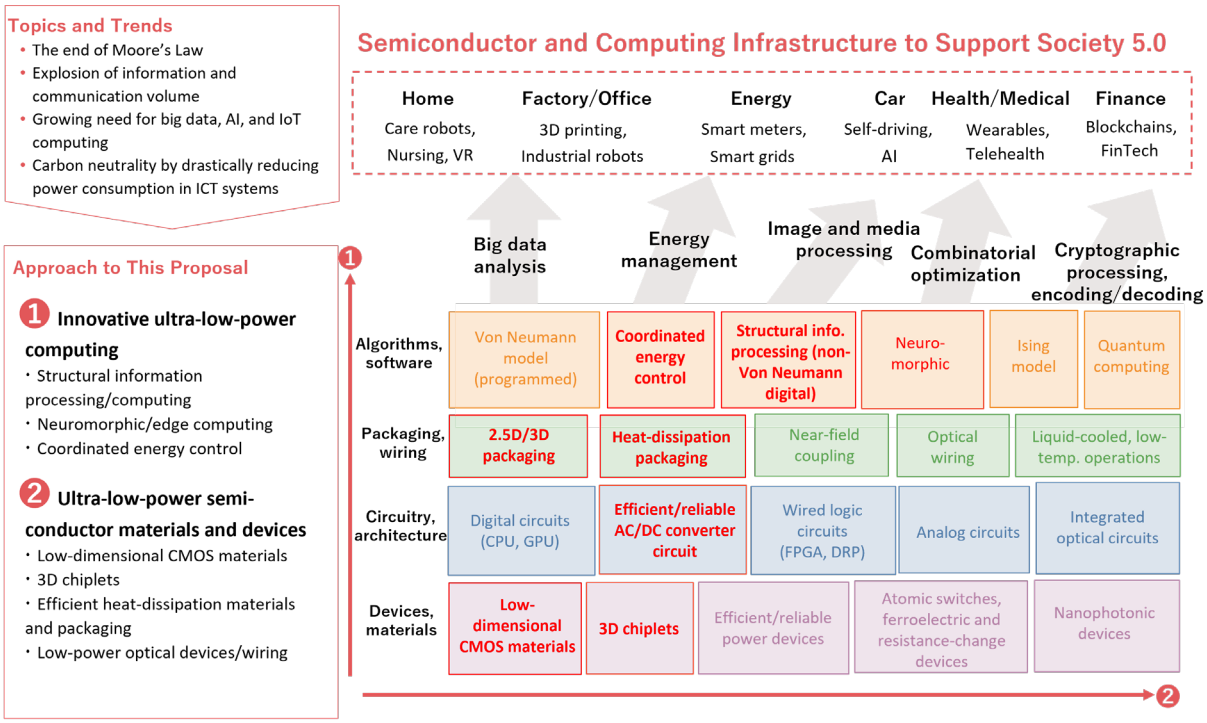

Fig. 5：Technologies targeted in the Semiconductor area
(modified from JST/CRDS Strategic Proposal CRDS-FY2017-SP-02)

II. Technical Elements Expected to Be Proposed

In the area of semiconductors, we seek R&D proposals in the following categories.

a. Semiconductor devices and process technologies for drastic power savings in logic/memory circuits
b. Innovative transmission hardware technologies for radically reducing power consumption per bit in communications
c. New materials, devices, and thermal management technologies for attaining efficient heat conductivity and heat dissipation in chips and boards
d. Power conversion elements, circuits, and control technologies for improving the efficiency and reliability of large-scale, complex power grids
e. New ideas related to semiconductors toward realizing carbon neutrality

a. Semiconductor devices and process technologies for drastic power savings in logic/memory circuits

Semiconductor devices fabricated from existing silicon semiconductor materials for use in information processing are up against the limits of miniaturization, but there is heightened expectation for using new two-dimensional layered materials unlike conventional silicon, such as graphene and transition metal dichalcogenides (MX2), as channel materials for a sub-nm generation of CMOS that will achieve even greater performance with lower power consumption. However, we have yet to establish elemental technologies to satisfy the requirements of sub-nm generation CMOS in film deposition and contact formation processes, not to mention practical performance, integration, and reliability, which are major barriers to further progress.

Moreover, since memory and logic are separated in current information processing, a challenge for

AI and other applications whose use is rapidly expanding will be to reduce the large amount of power consumption and latency that occurs when transferring high volumes of data between logic and memory. Therefore, there is much anticipation for three-dimensional integrated devices that integrate memory with logic to drastically shorten the distance of data transfers, resulting in higher transfer rates and lower power consumption. Oxide semiconductors such as IGZO, which have been applied to display driver circuits, are attracting attention as a promising technology for three-dimensional integrated devices because of their ability to form high-quality transistors at low temperatures in the multilayer wiring of semiconductor integrated circuits. However, one difficulty in achieving nanoscale integration is the high technological level required to ensure high mobility and reliability with low variation. Further, for the three-dimensional integration of logic and memory to be useful as a system, we will need to improve the performance of high-frequency data transmission and to optimize power delivery.

In this category, we invite R&D proposals on innovative channel materials possessing high mobility in ultra-thin films, such as two-dimensional layered materials designed for practical sub-nm generation CMOS, as well as formation processes, integration, reliability, and other elemental technologies; and R&D proposals on the materials exploration, process development, and integrated device applications of oxide semiconductors designed for three-dimensional integration of logic and memory.

For example, we are seeking proposals for resolving the following bottleneck issues but will also accept other innovative proposals:

- Development of processes to form defect-free, ultra-thin materials for high-mobility channels
- Development of an ultra-thin, high-mobility channel material on the order of several nanometers for sub-nm generation CMOS and techniques for large-area or active-area selective deposition of the channel material
- Development of defect mitigation and repair techniques for large-area, uniform, high-quality crystalline thin films
- Development of elemental and integration technologies for gate stacks, sources/drains of transistors having channels formed of ultra-thin layered materials
- Searches and deposition processes for materials having excellent mobility, reliability, and processability for three-dimensional transistors
- Development of high-density technologies for 3D-structured memory devices
- Development of integration technologies using hybrid structures of silicon CMOS and oxide semiconductors
- Development of technologies for high-frequency data transmission, such as enhanced decoupling properties in three-dimensional integrated systems and power delivery technologies aimed at suppressing IR drop

b. Innovative transmission hardware technologies for radically reducing power consumption per bit in communications

Developments of an advanced digital society (Society 5.0) will require us to handle data of an enormous amount exceeding conventional expectations, with the amount of information in the world reaching more than 30 times the 2018 amount in 2030 and 4,000 times in 2050. If the current situation were to continue in this manner, the annual power consumption for the information sector alone is expected to reach 42 PWh in 2030 and 5,000 PWh in 2050, far surpassing the current global power consumption of approximately 24 PWh. The development of innovative hardware technologies that can reduce power consumption per bit in communications by several orders of magnitude is urgently needed to meet the ever-growing demand for communications and to realize a low-carbon society. It will be particularly important to reduce energy consumption for communications in data centers, where large amounts of data are processed. For example, we must eliminate obstacles to information processing and communication paths using a variety of technologies for achieving power-saving in high-speed routers, ultralow-power optoelectronic interfaces containing co-packaged optics (CPO),

power-saving in communications between information processing boards, power-saving in chip-to-chip communications required for large-scale SoCs having a multi-chiplet packaging design, and power-saving in communications between chiplets.

For example, we are seeking proposals for resolving the following bottleneck issues but will also accept other innovative proposals:

- Optoelectronic interface technologies for improving transmission/reception speeds and saving power in optical communications
- Ultra-low-power chip-to-chip information transmission technologies using optical or wireless communication
- Ultra-low-power, low-latency, and high-bandwidth communication technologies for connecting chiplets in packages
- Innovative memory and FPGA technologies for achieving power-savings in high-speed routers

c. New materials, devices, and thermal management technologies for attaining efficient heat dissipation in chips and boards

As semiconductor integrated circuits continue to increase in capacity, heat dissipation from chips with integrated circuits has become a major impediment to improving information processing speeds and reducing power consumption. As progress in semiconductor miniaturization slows, greater expectation has shifted to three-dimensional integrated circuits (3D ICs) formed of vertically stacked semiconductor chips as a means of improving integration density and reducing power consumption, but there is concern that the increased power density and high junction temperatures of the devices inherent in their three-dimensionality may lead to poor reliability. We must develop innovative heat dissipation technologies at various levels, including the system, device structure, material, and physical levels, but the lack of an academic system has become an obstacle. In this category, we invite R&D proposals on theoretical studies of heat dissipation models, exploration and development of materials and material processing, and investigation and proposals of system and device structures.

For example, we are seeking proposals for resolving the following bottleneck issues but will also accept other innovative proposals:

- Construction and validation of heat transfer models for nanoscale heat transfer and interfaces and their incorporation into simulations
- Proposals and demonstrations of advanced heat dissipation technologies utilizing phonon engineering, etc.
- Development of new high-thermal conductive materials applicable to the packaging process and their manufacturing technologies
- Development of low thermal budget, BEOL-compatible technologies for fabricating insulating materials with excellent heat dissipation properties
- Research on new high heat dissipation materials that incorporates materials informatics (MI) methods

d. Power conversion elements, circuits, and control technologies for improving the efficiency and reliability of large-scale, complex power grids

To attain carbon neutrality, we must not only achieve the difficult goal of reducing power consumption in information infrastructure but must also reduce electrical energy consumption throughout the entire large, complex supply chain from “generation” and “transportation” to “supply” and “utilization” of electrical energy resources. To this end, we must improve efficiency in interface devices and circuits, which are present in large numbers in complex power systems consisting of renewable energy hydrogen generators and storage batteries connected to a main power grid. Additionally, numerous inverters must be installed to connect various distributed energy sources to consumer systems and to

coordinate operations from the power grid to equipment in homes and buildings. Since large voltage conversions frequently occur to and from the grid, functions for stabilization and noise suppression of grid-connected inverters have shown to be a bottleneck. Basic research on future-generation semiconductor devices that can far exceed the performance of conventional devices in terms of drive voltage and current will be important for future high-voltage power conversion.

For example, we are seeking proposals for resolving the following bottleneck issues but will also accept other innovative proposals:

- Inverter/converter circuit technologies adaptable to the instability and noise in power grids
- AC/DC circuit technologies with high-efficiency and reliability
- High-performance gate driver technologies for high-precision power control

e. New ideas related to semiconductors toward realizing carbon neutrality

We welcome R&D proposals on semiconductors that do not fall into the above categories if they are based on new concepts aimed at achieving carbon neutrality.

6.6 "Green Computing and DX" Area

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I. Overview of the Technology Area

The communication volume and power consumption in information and communication systems have increased exponentially as we progress toward a full-fledged advanced information society integrating 5G and 6G networks, IoT, self-driving technology, robotics, and digital transformation (DX). Consequently, there is an urgent need to introduce innovative computing architectures that can drastically reduce power consumption in information and communication systems in order to achieve carbon neutrality. We must also not overlook the fact that a series of developments in intellectual information processing technologies such as AI (prediction, recognition, generation, and optimization), which were expected to eliminate waste and improve efficiency in human society, are already causing significant social problems instead, including a massive increase in communication volume and power consumption. With regard to power transmission, there is a strong need to develop a coordinated control architecture that, in addition to reducing power consumption in power infrastructure hardware, can help conserve power throughout the entire complex supply chain from “generation” and “transportation” to “supply” and “utilization” of energy resources.

Our goal in this technology area is to radically reduce power consumption in information and communication systems. Specifically, we hope to effect a paradigm shift from general-purpose computing with high power consumption to low-power computing confined to a specific domain. That is, we will conduct R&D on innovative domain-specific non-von Neumann computing architectures and edge chips that incorporate these architectures, and efficient data control technologies for addressing the explosive increase in data communications between the edge and cloud. We will also conduct R&D on innovative architectures capable of estimating and predicting the conditions of power system components, as well as human behavior and intentions, through an analysis of data collected by IoT sensors with the aim of conserving energy throughout the entire power system.

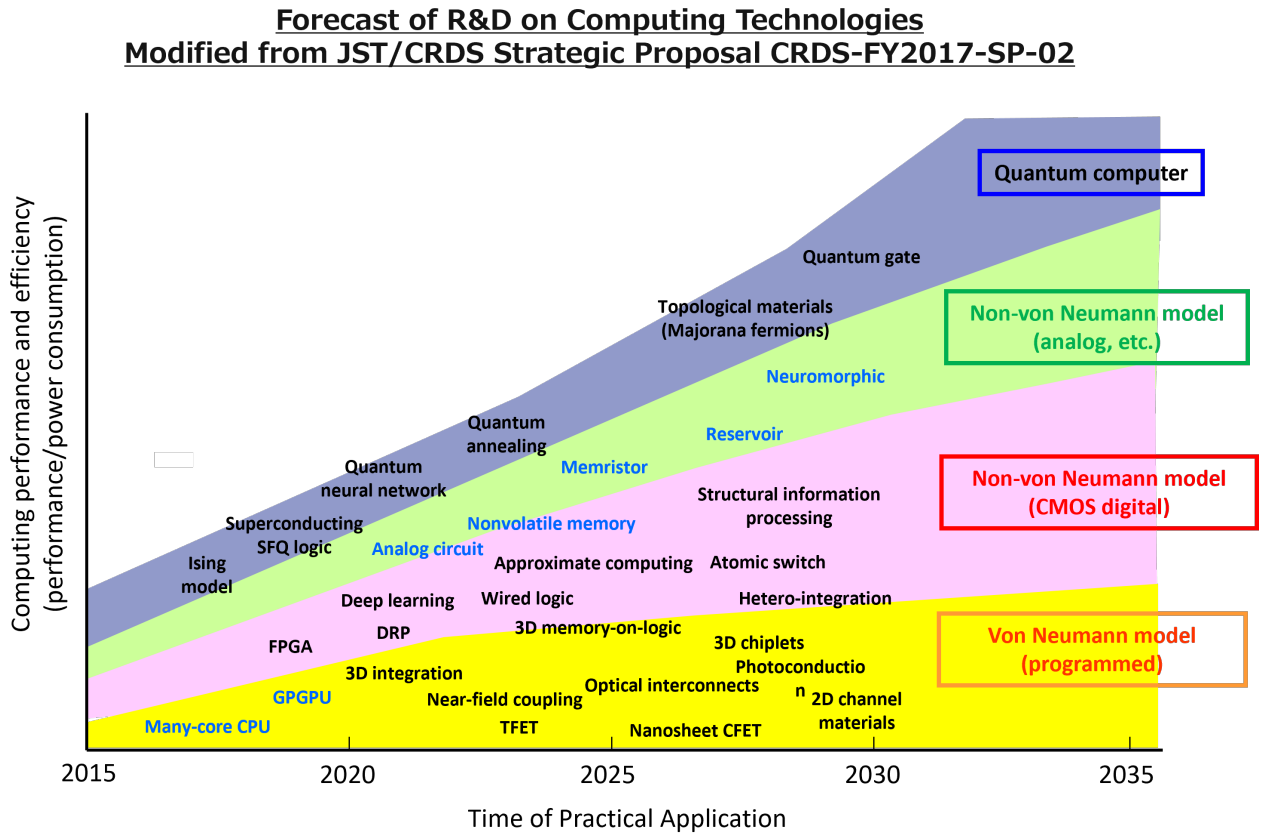

Fig. 6：Technologies targeted in the Green Computing and DX area
(modified from JST/CRDS Strategic Proposal CRDS-FY2017-SP-02)

II. Technical Elements Expected to Be Proposed

In the area of digital computing and DX, we seek R&D proposals in the following categories.

a. Innovative non-von Neumann computing architectures
b. Computing systems for saving power in AI processing
c. Innovative architectures for improving data processing efficiency throughout an entire communication system or energy management system
d. New ideas related to green computing and DX toward realizing carbon neutrality

a. Innovative non-von Neumann computing architectures

Dramatic developments in and utilization of AI processing has led to an increase in demand for advanced chips, such as GPUs, and an explosive increase in power consumption at data centers where GPUs are installed. A substantial future increase in power consumption is also predicted in mobile applications due to a growing trend to expand AI processing not only in conventional PCs and smartphones, but also in edge devices, such as robots and self-driving cars, that require advanced intelligent decision-making. However, current AI processing using common von Neumann architectures uses a large amount of energy to transfer data between the processors and memory. This AI processing is expected to be revolutionized with the development of AI and other data processing technologies through the introduction of new domain-specific, non-von Neumann, next-generation computing technologies. In this category, we invite R&D proposals on game-changing, non-von Neumann, next-generation computing architectures, AI processing technologies using such computing architectures, and chips for realizing these technologies.

For example, we are seeking proposals for resolving the following bottleneck issues but will also

accept other innovative proposals:

- Innovative domain-specific non-von Neumann computer and other architectures for self-driving, robotics, etc.
- New computing architectures that perform computations such as structural information processing by switching arithmetic units without the use of memory
- New edge computing architectures that perform computations such as intermittent computing using power only when necessary
- Computing, such as probabilistic computing, that incorporates uncertainties
- In-memory and Ultra-low-power near-memory computing architectures that reduce power consumption by processing information in or near memory
- Domain-specific computing architectures that can efficiently handle the sparsity, irregularity, and graph-like structures that are ubiquitous in big data, which is a subject of AI processing

b. Computing systems for saving power in AI processing

The computational processing required to train transformers will become massive with the explosive growth in generative AI, possibly leading to an explosive increase in power consumption in the cloud. Preventing this will require new computing architectures capable of achieving the performance required for the applications, even with lightweight learning. Together with power savings in learning processes in the cloud, power-saving models, architectures, and implementation techniques for independent learning at the edge will be important.

In this category, we invite R&D proposals on game-changing, next-generation computing architectures whose primary objective is saving power, AI processing technologies using these architectures, and chips for realizing the architectures.

For example, we are seeking proposals for resolving the following bottleneck issues but will also accept other innovative proposals:

- Innovative computing architectures for drastically reducing power consumption in generative AI
- Development of ultra-low-power circuits based on an innovative AI architecture, such as a brain-inspired AI architecture, and chips applying these circuits
- Development of on-device and on-site learning technologies that do not require large-scale learning in the cloud, and edge chips based on these technologies
- Development of new models, algorithms, and computer architectures for information processing based on knowledge of biological information processing
- Development of implantable information processing technologies and their compatible architectures and edge chips
- Development of domain-specific, power-saving AI accelerators for robots, etc.

c. Innovative architectures for improving data processing efficiency throughout an entire communication system or energy management system

Society 5.0, which is aimed at achieving safe and comfortable lifestyles and a vibrant society by enhancing human capabilities and supporting human activity, is expected to be realized through cyber-physical systems (CPS) that highly integrate physical space, including the smart robots, self-driving, IoT, and other technologies in the physical world, with cyberspace, comprising various data and information on computers and networks. However, transferring vast amounts of data collected by sensor devices to the cloud to undergo information processing not only requires an enormous amount of communication energy, but also results in significant latency, and CPS/IoT has not shown to be sufficiently effective in areas requiring real-time performance. In energy management systems as well, there is a strong need to reduce power consumption throughout the entire complex supply chain from “generation” and “transportation” to “supply” and “utilization” of energy resources. In order to achieve

significant energy savings across the entire energy system, we must collect and analyze data at the edge in real-time, including not only sensor information and information on equipment operations and the surrounding environment, but also data related to human activity within the system, and must optimize the supply of energy throughout the system.

In this category, we invite R&D proposals on new architectures for suitably controlling the massive amount of information collected by edge devices such as IoT sensors and transferred between the edge and the cloud and for drastically reducing power consumption in the entire communication system. We also call for R&D proposals on methods of concealing data collected by IoT sensors, ascertaining the status of systems and components through data analysis, estimating and predicting human behavior, intentions, etc., and secure and efficient data sharing and distribution algorithms.

For example, we are seeking proposals for resolving the following bottleneck issues but will also accept other innovative proposals:

- Ultra-low-power edge-cloud information transferring and processing architectures using multi-access edge computing
- Domain-specific edge-cloud information processing architectures for smart robotics, self-driving, etc.
- Secure methods of data collection, management, and sharing for hierarchical IoT devices and innovative algorithms for ensuring efficient data distribution across the entire power network
- Integrated algorithms for minimizing power consumption by estimating and predicting consumer behavior and intentions from power data
- Development of technologies for generating and distributing synthetic data on power usage and movements of humans and objects
- Development of technologies for forecasting energy demand on a spatial/temporal multiscale

d. New ideas related to green computing and DX toward realizing carbon neutrality

We welcome R&D proposals on green computing and DX that do not fall into the above categories if they are based on new concepts aimed at achieving carbon neutrality.