NESTI 2050

National Energy and Environment Strategy for Technological Innovation towards 2050

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Council for Science, Technology and Innovation

Contents

1. Background ······························ 1

2. Creating the National Energy and Environment Strategy for Technological Innovation towards 2050 (NESTI 2050) ······························ 2

(1) Details behind the Formulation of NESTI 2050 ······························ 2

(2) Positioning of NESTI 2050 ······························ 3

3. The Ideal Future Direction of Energy and Environmental Systems under this Strategy ····· 4

4. Identifying Target Technology Fields ······························ 5

(1) The Evaluation Axis for Identifying Innovative Technology Fields ············ 5

(2) Innovative Technology Fields Targeted under this Strategy ·················· 6

5. Research and Development Implementation Structure ······················ 33

(1) Forming Research and Development Structures as Unified Government Agencies 33

(2) Creation of Innovation Technology Seeds and Flexible Positioning ············ 34

(3) Mechanisms to Encourage Industry Investment in Research and Development ········· 35

(4) Promotion of International Coordination and Joint Development ·············· 36

6. Summary ······························ 37

Reference 1

National Energy and Environment Strategy for Technological Innovation towards 2050 Draft Working Group Member List ······························ 38

Reference 2

National Energy and Environment Strategy for Technological Innovation towards 2050 Draft Working Group Discussion History ······························ 39

1. Background

The 2015 United Nations Climate Change Conference (COP 21) held at the end of 2015 adopted the Paris Agreement. This agreement sets a new international framework for the year 2020 and beyond, aiming for significant reductions in anthropogenic greenhouse gas emissions*, a main cause of global warming. The agreement addressed holding the increase in the global average temperature to well below 2 ºC above pre-industrial levels, further pursuing efforts to limit the temperatures increase to 1.5 ºC, aiming to reach global peaking of greenhouse gas emissions as soon as possible, and achieving a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century.

According to the synthesis report on the aggregate effect of the Intended Nationally Determined Contributions (INDCs) released by the Secretariat of the United Nations Framework Convention on Climate Change in October 2015, the total global emissions for the year 2030 is estimated to be approximately 57 billion tons. This figure is based on the total of the global greenhouse gas emission reduction targets according to INDCs submitted by each party prior to COP 21. Meanwhile, the planet must reduce emissions to the level of approximately 24 billion tons of greenhouse gas by the year 2050 towards achieving the 2 ºC scenarios. This suggests the need to find more than 30 billion tons of additional greenhouse gas emissions reduction targets.

These circumstances demand a need for new innovations to drastically reduce emissions on a global scale. These innovations should include disruptive, innovative technologies compared to current reduction methods as well as the extension of current reduction efforts.

During the era of high economic growth in the 1970s, Japan was beset by the oil crisis, during which oil prices soared 400 percent, shocking the Japanese economy. In response, Japan formulated the Sunshine Project in 1974 and the Moon Light Project in 1978. Each of these initiatives represented national strategic programs designed to promote the long-term research and development of solar cells, heat pumps, fuel cells, and other advanced technologies under the auspices of the Japanese government. The research and development stemming from this long-term strategy resulted in Japan leading the world in breakthrough innovations such as high-efficiency solar power generation, the wide-scale adoption of heat pumps, and the introduction of residential-use fuel cells and fuel cell vehicles to the world markets. These initiatives were responsible for helping Japan overcome the oil crisis by achieving 35 percent energy consumption efficiency over the 20 years following the oil crisis. At the same time, the continued technological development in the energy and environment fields resulted in Japan becoming the foremost among advanced nations in public investment in energy and environment sector research and development as a percentage of GDP.

Expectations are high that Japan will produce innovative technologies that will contribute to large-scale reductions of greenhouse gases—particularly CO_2—to solve global warming, which represents one of the most significant issues facing our world today. Japan is expected to accomplish a role on the global forefront of the energy and environmental fields by leveraging industry-academic-government intelligence in research and development to produce innovations to reduce CO_2 emissions over the medium and long term, introducing these results to the world at large.

*According to the Fifth Assessment Report published by the Intergovernmental Panel on Climate Change, the likelihood is extremely high that the emissions of anthropogenic greenhouse gases is a predominant cause of global warming observed during the mid-20th century. Information made possiblethrough Japanese climate change forecasting technology was used in this assessment report.

2. Creating the National Energy and Environment Strategy for Technological Innovation towards 2050 (NESTI 2050)

(1) Details behind the Formulation of NESTI 2050

Based on the background discussed above, Japanese Prime Minister Abe made an announcement at the Global Warming Prevention Headquarters (November 26, 2015) and at COP 21 (November 30, 2015) regarding Japan's outlining of a National Energy and Environment Innovation Strategy by spring 2016. Prime Minister Abe also specified the promising innovative technologies for which our nation will focus on and strengthen its research and development efforts. Based on the prime minister's instructions, the National Energy and Environment Strategy for Technological Innovation towards 2050 Draft Working Group was created within the Cabinet Office Council for Science, Technology and Innovation (CSTI) in December 2015. The members of this working group met four times to engage in focused discussions and considerations, outlining the National Energy and Environment Strategy for Technological Innovation towards

2050 (NESTI 2050).

(2) Positioning of NESTI 2050

The Council for Science and Technology (currently the Council for Science, Technology and Innovation)) created the Low Carbon Technology Plan in April 2008, which they revised as the New Low Carbon Technology Plan in September 2013. This plan identifies a total of 37* technological fields, including those expected to be put into practical application over the short to medium term (prior to 2030) and those expected to be put into practical application and widespread adoption over the long term (after 2030). The plan also provides a roadmap for each of the technologies, as well as the measures required for the widespread adoption of them in Japan and around the world.

*The 37 technologies identified under the New Low Carbon Technology Plan:

High-efficiency coal-fired power, high-efficiency natural gas power, wind-power generation, solar energy utilization (photo voltaic), solar energy utilization (solar heat), ocean energy (wave power, tidal power, ocean current power), geothermal power generation, biomass utilization, nuclear power generation, carbon dioxide capture and storage (CCS), artificial photosynthesis, next-generation vehicles (HV, PHV, EV, clean diesel, etc.), next-generation vehicles (fuel cell vehicles), aircraft/ships/rail (aircraft), aircraft/ships/rail (ships), aircraft/ships/rail (rail), intelligent transportation system, innovative devices (information devices, lighting, displays), innovative devices (power electronics), innovative devices (telework), innovative structural materials, energy management systems, energy-saving residences/buildings, industrial usage of high-efficiency energy, high-efficiency heat pumps, environmentally friendly steel production processes, innovative manufacturing processes, hydrogen production/transport/storage (production), hydrogen production/transport/storage (transport and storage), fuel cells, high-performance electricity storage, thermal storage/thermal insulation technologies, superconducting power transmission, stabilization via vegetation, other (methane, etc.) greenhouse gases reduction technologies, global warming adaptation technologies, earth observation/climate change forecasting

Among these technologies, several technologies such as telework, energy-saving residences/buildings, wind-power generation, high-efficiency thermal power generation, nuclear power generation, biomass utilization, are either already the subject of implementation structures, in the verification stage/practical application stage, or are in development toward practical application in the near or mid term. Note that not all the technologies may be targets under this strategy, which identifies those technologies that require an extended period for practical application and stronger research and can be developed into high-risk, high-reward innovative technologies. Even so, our nation regards these as important technologies in which we will continue to invest, looking for required results.

Meanwhile, the strategy recently created looks toward 2050 from a long-term perspective, targeting the creation of innovations that will dramatically reduce greenhouse gases in a global basis. The role of this strategy is to identify technologies that should be targeted for more focused, intensive research and development activities, to discuss the technological issues to be overcome, and to outline the systems under which research and development activities should be pursued. At the same time, this strategy is designed to describe the measures by which Japan will contribute to the world.

3. The Ideal Future Direction of Energy and Environmental Systems under this Strategy

As described in the 5th Science and Technology Basic Plan adopted by the Cabinet Office in January 2016, major trends propelling social and industrial structural revolution over the medium and long term towards the year 2050 include short-term developments such as the Internet of Things (IoT), artificial intelligence (AI), Big Data analysis technologies, information and communication technology (ICT), and other rapidly expanding technologies that are being embraced in societal applications. As individual products, technologies, and multiple systems become more easily networked, the resulting value chain serves as a new type of value added to society, leading to the creation of Society 5.0 (a Super-Smart Society), which is expected to bring about a more fulfilling lifestyle to the people across the world.

Developments in the energy and environmental fields also call for networking energy-related devices and facilities, rather than the development and adoption of individual emission reduction technologies. By the same token, individual devices and facilities must be seen as integrated energy systems, controlled as a whole to optimize the entire system, rather than controlled individually at the local level. As technology is developed and adopted to integrate energy—whether electrical or thermal—across different regions, enterprises, and systems, supply can more appropriately match demand, providing energy when, where, and to which extent required. In this way, we will realize complete energy efficiency, minimizing energy consumption and CO_2 output across the world.

Looking at global CO_2 emissions on a secoral basis shows that the main sources of emissions can be attributed to the energy conversion sector, the industrial sector, and the transportation sector. Accordingly, any strategy to dramatically reduce emissions must first focus on these three sectors. In the energy conversion sector, activities are already underway in developing, testing, and adopting power generation systems for high-efficiency thermal power, solar power, wind power, biomass power, and nuclear power. In parallel, the innovative technologies targeted by this strategy that require medium- to long-term development will also progress along the path toward practical application, with maximum focus on conversion toward non-fossil energy. Development is underway for storage, transport, and utilization technologies for high-efficiency of non-fossil energy. This development is designed to cope with increased output fluctuations due to the development and adoption of solar power generation and other naturally variable energy sources serving as renewable energies.

On the energy consumption side, Japan is developing and adopting ultra-efficient/energy-saving components, including next-generation power electronics for use in each field. In the industrial sector—particularly the materials industry—our nation is developing manufacturing processes completely different from the traditional energy-intensive model. This development will lead to significant reductions of CO_2 emissions during the manufacturing process. In the transportation sector, we are seeing the widespread adoption of electric, fuel cell, and other next-generation vehicles around the world.

4. Identifying Target Technology Fields

(1) The Evaluation Axis for Identifying Innovative Technology Fields

① Technologies that are discontinuous and high-impact

Innovative technologies that are discontinuous and high impact. Technologies that are not already in existence. Technologies that are not already at the development and testing stages (or an extension thereof) for short-term practical adoption. Technologies that apply completely new materials, structures, or systems to enable significant advancements in efficiencies and/or performance.

② Technologies with the potential for widespread adoption and significant emission reductions

Technologies which, if successful in overcoming technological issues and developed to the level of practical implementation, offer economies and the potential large-scale adoption in future in the fields of energy and systems. Technologies with applications both in Japan and overseas. Technologies believed to have the potential to sufficiently reduce large amount of global greenhouse gas emissions.

③ Technologies that require combined forces among industry, academia and government due to the mid- to long-term period before practical adoption and high development risks

At present, many technologies are in the basic research or initial development stages, some of which entail major technological hurdles and significant development risks before testing or practical implementation. These are technologies that could not come to fruition without and support of the combined forces of industry, academia, andgovernment.

④ Technologies in which Japan can take the lead or demonstrate our superiority

Technologies in the research stage for which Japan can be the global leader, or technologies which are already in the full development stage, but in which Japan can still take the lead in the world. Also, technologies that Japan may not currently have technological superiority, but may be able to demonstrate superiority due to Japan’s geographical characteristics or natural conditions andcan reduce the significant amount of CO_2 emissions, if introduced in Japan.

(2) Innovative Technology Fields Targeted under this Strategy

Based on the evaluation axis discussed in (1) above, the Japanese government has identified the following particular innovative technology fields for focused development. These innovative technology fields are expected to reduce significant amounts of CO_2 if they are successfully adopted around the world. The ETP 2012 published by the IEA provides an estimated calculation of CO_2 reductions for each technology field for CO_2 reduction targets that are consistent with the 2 ºC scenario achieved in the most economic way. The total CO_2 reduction made by the technology fields selected under this strategy amounts to more than 5 billion tons. Were these technologies successfully developed and adopted throughout the world in combination with technologies already in development and testing stages, we could expect a potential positive impact of almost the same level (between several billion tons and 10 billion tons) on global CO_2 by the year 2050.

[1] Energy Systems Integration Technologies

Developments in ICT over recent years have resulted in technologies that optimize the balance among energy systems demand. These technologies connect transmission networks and information communications networks in both directions between power generation entities and residential/office consumers. Further, many nations are moving forward in the development of smart grid and smart community technologies, as well as HEMS, BEMS, FEMS, CEMS, and other energy management systems (EMS). These technologies, which provide more visibility in energy consumption, incorporate mechanisms that promote the efficient use of energy and are presently in the development and testing stages—or practical adoption stages—in Japan and other countries around the world.

Demand-response (DR) systems are under development to forecast daily energy demand based on the weather and other indicators of the day previous, allowing for the adjustment of energy prices according to the time of day. In so doing, we can influence energy consumption volume by encouraging conservation and shifting the timing of power consumption.

At the same time, demand will emerge for innovations in energy systems optimization technologies, as well as for next-generation storage battery, various power storage/transport systems via hydrogen and other energy carriers, and regulation with respect to variable frequency and voltage. Further, needs will arise for demand-side energy services that range beyond the adoption of high-efficiency/energy saving devices and facilities. These services must provide flexible options for a variety of consumers, tailored to national, regional, and age differences, among other factors. Energy consumption is a function of a number of factors, including climate, lifestyles, personal preferences, and more. Making use of Big Data analysis and energy consumption forecast technologies can help all consumers enjoy optimal services, allowing for both high-quality lifestyles and the minimization of energy consumption.

Under this strategy, current smart grid and other technologies under development, testing, and practical adoption serve as the basis for utilizing IoT, AI, Big Data analysis technologies, and ICT to the greatest extent possible, leading to maximum energy consumption efficiency through the integrated control of the system as a whole. This calls for the concurrent development of systems integration technologies and other core technologies capable of minimizing CO_2 emissions. This strategy also addresses measures for optimizing the balance between supply forecast and demand, as well as securing technologies that allow for the best selection from among energy storage options across a wider range of energy schemes beyond the simple integrated control of multiple EMS facilities and assets. If the development of these types of technologies results in system-wide integration, then we can expect a dramatic change in consumer lifestyles as related to transportation choices and family living conditions.

The following provides more specific examples of integrated systems technologies, CO_2 minimization technologies, and related core technologies that maximize energy consumption efficiencies.

① Integrated Systems Technologies and CO_2 Minimization Simulation Technologies

(Technological Impact)

- Societies that adopt the innovative technologies targeted within this strategy, including solar and other renewable energy subject to natural output fluctuations, storage batteries, and other technology that utilizes hydrogen and other energy carriers, can expect to maximize energy supply efficiencies while minimizing CO_2 emissions.

(Technology Overview)

As nations strengthen the adoption of renewable energy, the ratio of renewable energy as a primary energy source over the medium and long term could rise as high as 20 to 30 percent or more (Japan is currently at eight percent). As the adoption ratio of solar power and other variable energy sources rises, so too will the level of output variability, resulting in the need for more complex means of control and demand/supply balance. Energy storage and transport formats are also expected to experience a significant increase in options—or internal system variables—not only for pumped-storage hydroelectric power, but also for electricity storage or conversion to hydrogen.

Given the current stage of progress, we forecast future energy systems that disperse a variety of energy sources to a variety of wide-ranging areas. If the innovative technologies targeted by this strategy are ultimately realized, we will be able to develop technologies that will optimize energy systems as a whole.

Our strategy also considers those developing nations that have poor power infrastructure, as well as ways to provide power to isolated island locations. By adopting geographically distributed power generation systems on a wide scale, we can develop the necessary integration technologies to facilitate the adoption of geographically contained systems that use renewable energy as the main energy source, rather than that of existing power systems.

(Technological Issues)

- In the future, small-scale power supply systems will be dispersed among many regions, supported by advanced energy generation, saving, and storage technologies. In this future, we expect to see the maximum utilization of technologies that forecast renewable energy output with extremely high precision, not to mention DR, energy storage, multi-region supply and demand operations, centralized power (thermal and hydroelectric) regulation, dispersed power sources, and other energy system modeling and simulations for optimal power allocation. Further, we expect to see the maximum utilization of IoT, AI, Big Data analysis, ICT, and other software technologies that offer optimal system-wide solutions in the near future. The implementation of system-wide integration and control will lead to maximized energy consumption efficiency, but will require the development of system integration technologies to minimize CO_2 emissions. In parallel, we must develop normally-off computing, and innovative quantum information processing technologies that allow for large-scale processing to facilitate energy saving and sophistication in the system integration technologies themselves.
- Development is required for system stabilization-compatible gas turbine power generation technologies capable of handling the variable output of renewable energy. These technologies must prioritize power load follow-up, while providing superior transient response and the ability to withstand repeated load cycles. As well, development must address frequency and voltage regulation technologies capable of handling the variable output of renewable energy while providing stable supply from energy systems.

② Core Technologies for Systems

＜Next-Generation Power Electronics＞

(Technological Impact)

- Develop next-generation power electronics vital to the advancement and energy efficiency of system components. Creating ultra-compact, high-power density/integrated power electronics will result in halving the power loss of power converters and reducing the footprint of devices to one-fourth or even smaller compared to current sizes. The development of high-performance devices that offer new value in control and communications functions will lead to the creation of unprecedented systems. In turn, power electronics devices may be adopted in a variety of components within system networks.

(Technology Overview)

Today, power electronics is used in each stage of power generation, transmission, distribution, and consumption for transforming to optimal voltage, current, and frequency. To limit power loss as much as possible during transformation, power electronics devices must be designed with compactness, integration, and high efficiency.

The Next-Generation Power Electronics project is already underway within the Cross-ministerial Strategic Innovation Promotion Program (SIP). Research and development activities are focused on replacing Si material in power devices sometime between 2020 and 2030 with SiC, GaN, or other materials that demonstrate much higher performance. The strategy in this report looks further into the future toward the year 2050, developing technologies for control functions, communications functions, other value-added integration technologies, high-performance power modules that significantly reduce power loss through the simplification of cooling mechanisms, and the development of peripheral materials that take advantage of the characteristics of these power modules. Development targets also include packaging technologies, circuit design technologies, control technologies, and related systemization technologies. Research and develop is also underway on power devices incorporation next next-generation semiconductor materials such as diamonds. Recently, these materials have shown promise for both impressively high thermal conductivity and dielectric strength.

This field is experiencing intense research and development competition in Japan, the United States and Europe today. While Japan’s processes, devices, and packaging technologies for semiconductors are among the best in the world, to secure international competitive advantage in power electronics requires both superior technologies and efficient consortium-type investment capital in research and development in devices and peripheral equipment. Competitive ability also requires the promotion of networked research and development systems among related parties.

(Technological Issues)

- The development of heat-resistant peripheral components and packaging technologies for high heat/speed/voltage/current density device modules is still in the nascent stages. The field must not only make gains in materials and device development, but also in establishing devices and systems for power electronics.
- Establishing economies requires the development of production technologies for large-format, high-quality semiconductor wafers used in power devices.
- Researchers must develop new value-added integration technologies for power devices, including control and communications functions.

＜Sensing Technologies for Energy and Systems＞

(Technological Impact)

- Develop highly environmentally resistant MEMS sensor technologies that offer the low cost, ultra-compact, mass-produced features required in the era of IoT. Create highly sensitive sensors that detect minute changes in the environment and that can operate maintenance-free for at least several years.
- Incorporate new energy conversion theories in the development of ultra-low powered passive sensors that generate operating power with extremely minute vibrations, breezes, heat, etc. occurring in the natural environment. These advancements will eliminate the constraints of wiring and battery life in sensors, allowing for the placement of sensors in any location.
- Develop environmentally resistant sensors that can operate reliably over the long term, even in strongly acidic environments or high-temperature environments in excess of 300 ºC to 400 ºC or more.

(Technology Overview)

By 2014, global sensor shipments had already exceeded 25 billion units. With the advancement of IoT, these shipments may soon exceed several hundreds of billions of units. Multiple numbers of sensors will be incorporated into energy systems in a variety of ways. From the standpoint of energy saving, sensors will need to operate passively at ultra-low power. Further, sensors will be required to perform not only in the general societal environment, but also in high-temperature, high-pressure situations such as with power generation turbines. The advent of wireless sensors that can also operate maintenance-free over an extended period could provide constant information related to turbine operations, facilitating optimal performance and providing improved energy efficiency. Depending on usage, sensors may be required to be heat-resistant, corrosion-resistant, resistant to dramatic changes in temperature, pressure resistant, acceleration-resistant, vibration-resistant, wear-resistant, and/or resistant to magnetic fields. Accordingly, we must develop sensors that accommodate a wide range of extreme environments, while providing high reliability in a compact, lightweight, and low cost package.

(Technological Issues)

- Passive semiconductor sensors that operate at ultra-low power are in the basic research stage at universities and other research institutes. However, basic analysis and design technologies must still be structured to create high-efficiency energy conversion technologies, and research and development for miniaturization and mass production have yet to be initiated.
- Sensors that capture the behavior of power plant turbines or sensors used to measure that status of geothermal reservoirs for geothermal power generation must be able to withstand temperatures of up to 300 ºC to 400 ºC or more, wear, dramatic temperature changes, pressure, and other influences. However, materials that meet these conditions have yet to be developed. Future assessment and development may include work on ceramics and other non-metal materials.

＜Superconductivity Applications＞

(Technological Impact)

- High efficiency, high function, low cost, improved reliability, and miniaturization of cooling medium pump cooling systems (less that one-tenth of current size).

- Overwhelming miniaturization and footprint minimization for devices in order to accelerate the application and adoption of coils (magnets) in power transmission, motors, power generators, and other devices.
- Achieve production yield for coil wires of 90 percent or greater.

(Technology Overview)

Superconductivity is a phenomenon in which electrical resistance falls to zero. At this point, transmission loss is suppressed by a significant amount, resulting in the passage of large amounts of electricity at low voltage, as well as the generation of extremely strong magnetic fields demonstrating a high current density. Given these characteristics, development is ongoing for superconducting power transmission systems, superconductivity motors, power storage systems, transformers, high magnetic field coils, and more. Several technologies in these fields are already in the performance testing phase.

The power transmission and motor fields in particular offer a promise of significant energy savings through the application of superconductivity. However, generating superconductivity to obtain the necessary performance requires ultra-low temperatures below the temperature of liquid helium (or temperatures lower than liquid nitrogen for high-temperature superconductivity). In any case, superconductivity requires large-scale refrigeration systems, which represent a serious barrier to practical implementation both physically and economically.

Meanwhile, the transition temperature of superconducting materials to reach superconductivity is -70 °C when applying ultra-high pressure (1.5 million atmospheres) to hydrogen sulphide, as recently discovered at the Max Planck Institute for Chemistry in Germany.

As more research and production technology development goes into new superconductive materials, research and development is moving forward vigorously in reducing the cost of wire, as well as in innovations to reduce the size, weight, and cost of cooling systems. At the same time, establishing technologies that facilitate application in power transmission lines, industrial-use motors, and power generators may lead to radical improvements in energy consumption efficiencies and the creation of new integrated energy systems.

Over the past 30 years, Japan has led the world in the development of superconductive wire, particularly bismuth-based high-temperature superconductive wire and superconductive cable. Our nation maintains world-class technological capabilities in refrigeration equipment, cabling, and other foundational technologies. In particular, only Japanese corporations to date have established cooling systems designed for long-distance cooling. In the future, Japan will continue to demonstrate leadership in the field of superconductivity.

(Technological Issues)

- Extend long-distance cooling from current one kilometer limit to several kilometers; develop technologies for highly efficient, long-lived, and low-maintenance long-distance cooling systems.
- Incorporate both miniaturization and high efficiency into cooling systems.
- Create superconductive motors and power generations by reducing wire costs and cooling costs.
- Research practically applicable superconductive wires and related production technologies at liquid nitrogen cooling ranges (around 77 K) and higher; develop superconductive magnetism and power transmission technologies that operate normally without degradation of superconductive properties.

[2] Energy Saving Fields

Develop energy saving technologies for energy created through energy generation technologies to reduce energy loss occurring during various phases of societal use.

① Innovative Production Processes

Separation and purification processes to produce basic chemicals that serve as raw materials for a variety of products rely on the distillation process. These processes use differences in boiling points for separation, benefitting from the merits of continuous processing. However, an enormous amount of energy is consumed as the heating and cooling process is repeated dozens of times or more. As such, energy costs account for 50 percent of the production costs of basic chemicals. To realize a low-carbon society, we must utilize leading-edge technologies in chemical production processes. These technologies must move away from traditional energy consumption models, incorporating membrane separation processes, catalyst technologies, plasma reactions, bioprocesses, or other techniques to create new types of production processes and innovations. These new technologies could result in large-scale energy saving, CO_2 emission reductions, and improved process economies.

Japan is a world leader in membrane separation materials development and application, catalyst technologies, and plasma technologies. The advancement of nanotechnologies leads us to expect much in the way of innovation in catalyst technologies, which are key to reaction processes.

The following are specific examples of innovative production processes.

＜Membrane Separation Technologies＞

(Technological Impact)

- Realize 50 percent or greater improvement in energy consumption efficiency compared to distillation column processes, while maintaining the same purity and yield as current production processes that use distillation columns.

(Technology Overview)

Technologies that separate chemical substances through the control of minute pores in membrane materials may facilitate significant energy saving if they are capable of non-equilibrium separation. This is mainly due to the ability to process enormous volumes of substrate on a continuous basis. In recent years, inorganic membrane, support, and other technologies have developed to a point allowing for liquid-liquid, liquid-gas, and gas-gas separation processes, raising expectations for more future innovation in this field.

(Technological Issues)

- The membrane separation process is affected by a number of factors, including the quality of the material and form of the separation membrane, as well as the size of the substance targeted for separation. Accordingly, one cannot predict separation performance in the same manner as one can in the distillation process, where there is known boiling points, vapor pressure, and other physical property values for target substances. Sufficient data and information have yet to be compiled for systems without a wealth of historical records, forcing scientists to estimate separation performance based on basic data and similar experiments.

- Transport and membrane permeability must be elucidated for each target substance. At the same time, researchers must develop membrane materials offering long-term reliability and long-lived usage, as well as membrane-reaction field systems that provide both outside-system transport for products and suppression of byproduct reactions.

＜Innovative Catalysts used in Production Process Technologies＞

(Technological Impact)

- Target the development of new catalysts that use common metals while demonstrating high response selectivity and low activation energy.
- Target highly efficient synthetic yield of lower olefins and aromatic compounds of 20 percent or greater, derived via synthesis of oxygenated compounds and dehydrogenative coupling of methane through the direct oxidation of methane.

(Technology Overview)

Engage in research and development related to technological processes using new catalysts for processes used to develop high-value-added chemicals. For example, develop a new process to selective separate and recover products in parallel with the development of catalysts to selectively synthesize basic chemical products. This is important, since cheap methane can turn to CO_2 simply via oxidation in air.

The performance of new catalysts is hoped to improve response selectivity, improve reaction activity, and extend useful life. Lowering activation energy by 10 kJ/mol would improve productivity by a factor of six for reactions at 400 ºC. Lowering by 30 kJ/mol would allow the 400 ºC reaction to take place at 200 ºC (waste heat utilization temperature range). Lowering the reaction temperature suppresses gas phase autoxidation and improves product selectivity for oxidation reactions. The development of new catalysts is hoped to significantly increase the activity, selectivity, and stability of production processes for any number of chemicals.

Catalyst development and the hybridization of membrane separation and catalyst could lead to process changes and considerable reductions in consumption rates, which in turn could lead to significant energy saving in the reaction process. This scenario would result in a major reduction in CO_2 and a significant impact on industry; however, the technological difficulties involved will require long-term development to overcome.

Traditional catalyst development involves catalyst preparation and analysis via methods incorporating surface science. New catalyst research and development, on the other hand, combine kinetic or molecular dynamic simulations and computer science/informatics methods that incorporate AI and Big Data analysis. This results in a considerable savings in time and effort compared to the trial and error method.

(Technological Issues)

- Lack of actual catalyst development using computer science/informatics; limited to improvements of existing catalysts at this point in time.
- Many unresolved technological issues at present, including ultra-efficient catalyst design methods, highly difficult catalyst reactions, etc.
- Researchers must conduct basic foundational research into life extension and side reaction control via catalytic site protection technology through catalyst surface modification. Other necessary basic research includes side reaction suppression technologies combining catalysts and separation membranes, technologies for more efficient multi-step reactions by compositing heterogeneous catalyst active sites, etc.

② Ultralight and Super Heat-Resistant Structural Materials

(Technological Impact)

- The development of innovative structural materials (for example, medium- and high-carbon steel with tensile strength of 1.5 GPa and elongation of 20 percent) and bonding technologies (for example, differential materials adhesive technology with joint interface having a tensile shear strength of 10 MPa or higher) could result in reducing the weight of vehicles by 50 percent or more, bringing dramatic weight savings to transport equipment.

・ Develop heat-resistant materials for use in gas turbines and other applications that demonstrate stability at 1800 ºC and higher with 60 percent or greater efficiency.

(Technology Overview)

Lightweight, heat-resistant materials have a significant impact on improving energy consumption efficiency. For example, turbines are more efficient at higher combustion temperatures, while transport equipment is more fuel efficient as weight is reduced. Presently, the SIP is conducting the Structural Materials for Innovation project, which is pursuing research and development toward the year 2020 in lightweight materials offering superior heat/environment-resistant properties, as well as work to reduce materials development times by structuring systems that integrate databases of strength/destruction/lifetimes with computer science/informatics. Under the strategy in this report, our nation is advancing forward-looking research and development for the utilization of new materials incorporating ceramic matrix composite materials (CMC), carbon fiber reinforced plastics (CFRP), graphene and other materials with superior lightness and specific strength, and heat-resistance in structural materials over the medium and long term.

Using new materials in structural materials results in a higher safety factor due to the lack of sufficient usage experience, reflecting the fact that materials—even materials demonstrating superior characteristics—may not be completely reliable, preventing researchers from fully eliciting the true performance inherent in the material. By attaching sensors in various locations to monitor the status of the material in real-time, researchers can use AI and other analysis techniques to capture information related to distortion and damage prior to destruction or deformation from the material component material itself, providing data to predict the timing of destruction/deformation. In doing so, we may be able to utilize the characteristics of structural materials to a much greater degree than before. For example, researchers could begin research and development on lightweight, heat-resistant materials to be used in innovative medium- and high-carbon steel, highly heat-resistant moldable ceramics, CMC, and graphene structural materials.

Japanese manufacturers currently enjoy an overwhelming share of the global market for light, strong carbon fiber. In the same vein, Japanese corporations possess advanced technologies for light, strong innovative steel plate; however, competition is expected to intensify in the future as manufacturers work to lower costs, increase strength, and improve malleability. Furthermore, development is moving forward for non-combustible magnesium alloys, raising expectations for full practical adoption of these metals.

Japan also possesses advanced technologies in world-leading Ni single crystal super alloy and Ni-Co forged alloy heat-resistant materials. In addition to these alloys, Japan also leads the world in heat-resistant ceramics and other non-metals. More development is needed for advanced crystal control technologies related to heat-resistant materials. The fundamental knowledge obtained through this work will form the foundation of development for extreme environment materials even beyond applications in supercritical geothermal power generation and gas turbines.

(Technological Issues)

- Technologies are still under development related to bonding two materials with significantly differing characteristics, assessing performance of joint interfaces, and bonding technologies for different materials. Technologies still do not exist allowing for the free combination of materials.
- Materials for 1800 ºC gas turbines do not offer sufficient high-temperature strength in solid solution phases for securing ductility and toughness in the case of metal materials. At the same time, researchers are struggling with technological development for improving heat resistance, trying to answer the demands for advanced crystal control technologies.
- While the potential for ceramics and other non-metal materials should be pursued, ceramic itself is extremely brittle. CMC holds promise as a means to add metal-like levels of toughness and malleability; however, durability in extreme environments (high temperature, highly acidic atmosphere) is still in the basic research stage.

[3] Energy Storage Fields

Solar power and wind power, two technologies expected to gain wide adoption in the future, are subject to wide output variability due to weather and other conditions. During periods of low demand, energy output outpaces energy demand, potentially leading to the generation of surplus power. Accordingly, researchers must conduct research and development into technologies for the efficient storage of energy. These technologies must facilitate the store of energy in batteries and/or the large-scale, efficient storage of hydrogen or other energy carriers for transport and use.

Japan has secured a major share of the global market based on our nation's advanced technological capabilities in storage battery field related to our work in areas such as lithium ion secondary batteries for use in electric vehicles. Furthermore, Japan leads the world in research and development of the hydrogen supply chain. Continuing to lead the world in both fields, our nation can accommodate both global warming countermeasures and economic growth.

The storage of power in storage batteries is already well underway throughout the world. Meanwhile, the loss of energy when converting to hydrogen or other energy carriers is quite significant compared to the direct use of energy or storing energy in batteries. However, where storage batteries are suited to energy storage on the order of several hours to several days, conversion to an energy carrier offers the benefit of being suitable for storing energy in much greater volume and over longer cycles spanning months or seasons. Research and development into technologies in each of these fields is expected to lead to the maximum effective utilization of renewable energy.

① Next-Generation Storage Batteries

(Technological Impact)

- Develop storage batteries offering energy density 700 percent greater at one-tenth the cost of current technologies, providing driving distance of more than 700 km on a single charge for most passenger cars of average size and weight.
- Realize low-cost, highly safe storage batteries for stationary installations to promote the spread of renewable energy adoption. Development work forecasts the use of batteries that involve heavy loads, including frequent rapid charging and discharging. Researchers are also looking into the potential applications of technologies developed for in-vehicle batteries, which will be limited in terms of space and weight.

(Technology Overview)

Develop next-generation technologies that exceed the limits of current mainstay lithium ion batteries. For example, batteries used as a main energy source in electric vehicles must perform in environments that are exceptionally more severe than those used in general consumer applications. More specifically, these types of batteries must accommodate high-level performance in output, safety, and durability, which are tradeoffs to energy density.

Researchers must also incorporate the advancement of power storage systems as a whole, considering means to dramatically shorten charging time to allow for long-distance driving.

Researchers are also looking into using the potential of high-performance vehicle storage batteries in the development of batteries used in stationary installations.

Research and development for next-generation storage batteries will incorporate computer science/informatics methods—including AI, Big Data analysis, and simulations—as opposed to traditional methods that rely on individual research and development related to positive electrodes, negative electrodes, and electrolytes based on prior experience and trial-and-error. This new approach to research and development will lead to optimized storage battery systems.

The following are specific examples of next-generation storage batteries.

＜Metal-Air Batteries＞

Storage batteries that use various metals as the active material in the negative electrode (aluminum, magnesium, lithium, etc.) and air as active material in the positive electrode. Theoretically, using oxygen in the air used as the active material in the positive electrode allows for high energy density.

＜All-Solid-State Batteries＞

A storage battery that uses solid electrolytes instead of liquid electrolytes, resulting in all-solid structural materials. While the exact benefits vary according to battery systems, all-solid-state batteries generally offer both safety and long life.

(Technological Issues)

- Issues remain to be resolved in terms of materials development, new design, and life in order to extract the most potential out of the battery.

② Manufacturing, Transport, Storage, and Use of Hydrogen and Other Energy Carriers

(Technological Impact)

- The full-scale adoption of a major supply chain for and power generation through hydrogen and other energy carriers could significantly expand the use of hydrogen energy. The result could lead to improvement in flexibility for energy supply systems, energy security, and considerable reductions in CO_2.

(Technology Overview)

The use of hydrogen for energy does not result in CO_2 emissions, leading to great expectations for hydrogen as a clean-energy replacement for fossil fuels. Many projects are already underway to test the full-scale adoption of this energy source as a means to create a hydrogen society of the future, and hydrogen stations—vital for the adoption of fuel cell vehicles—are being planned in many locations. The April 2014 Basic Energy Plan decision by the Japanese cabinet also included a commitment by the government to “move forward now with strategic initiatives in hydrogen usage, including technological development.”

The SIP Energy Carriers project includes research and development into hydrogen, as well as other highly efficient, low-cost energy carrier technologies (including liquid hydrogen) such as ammonia and organic hydride, which offer promise due to their energy densities, ease of handling, and ability to utilize existing facilities and equipment. More recently, Japanese universities and other research institutes have been conducting research and development into the potential for magnesium as an alternative energy carrier.

To position these candidates for energy carriers as serious contenders to replace fossil fuels, researchers must come up with transport and storage technologies, as well as production technologies that can supply these carriers in major volumes while limiting the impact of said production on the environment. For example, research is moving forward in developing technologies to produce hydrogen from lignite; however, this process results in CO_2 emissions. To produce hydrogen via CO_2-free methods requires the parallel use of CCS and other technologies. The Haber-Bosch process is responsible for the commercialization of ammonia production manufactures hydrogen (used as a raw material) using fossil fuels. This process entails both the significant consumption of energy and CO_2 emissions. The strategy in this report calls for research and development into technologies that facilitate the economic mass production of these energy carriers via radically different means that use renewable energy while eliminating CO_2 emissions. Basic research into some aspects of these technologies is already moving forward at universities and public research institutes. For example, significant interest exists for innovative technologies that synthesize ammonia directly from UV rays, water, and air using plasma technology. Next, researchers must begin full-scale research and development into the practical adoption of this technology, as soon as it has been determined that there is a potential for economic mass production. Experts also have high expectations for technologies that produce hydrogen via high-temperature thermal decomposition of water.

Furthermore, researchers are faced with the imperative to develop technologies that efficiently extract hydrogen from organic hydride, ammonia, and other energy carriers, while refining hydrogen to a highly pure state. Once the hydrogen extraction process becomes more efficient, economical, and compact in size, this progress can be applied to hydrogen stations, commercial buildings, and other small- and medium-sized facilities.

Development will also turn to technologies that extract energy from the direct combustion of hydrogen and other energy carriers, as well as the development of innovative next-generation fuel cells that incorporate completely new electrolytes and electrodes.

(Technological Issues)

・ New technologies are required to manufacture, transport, and store hydrogen and other energy carriers at current or lower costs when compared to traditional fuels. These hydrogen manufacturing methods include the use of renewable energy to electrolyze water, high-temperature thermal decomposition of water, or fossil fuel used in combination with carbon dioxide-suppression technologies.

- Compared to fossil fuels, hydrogen combustion offers a higher combustion speed and takes place at higher temperatures. Accordingly, the development of hydrogen-based gas turbine power generation necessitates combustion control technologies that incorporate cycle systems capable of handling the properties of hydrogen. At the same time, researchers must come up with super heat-resistant, lightweight materials for use in turbine blades that can both tolerate and operate reliably in temperatures in excess of 1700 ºC.
- Ammonia is an energy carrier that does not produce CO_2 emissions when used as fuel in power generation and industrial settings. However, ammonia is much more difficult to ignite compared to fossil fuels. As well, ammonia combustion speed is slower than traditional fossil fuel and emits undesirable fuel NOx. Accordingly, researchers must invent combustion control technologies that suppress these emissions while provide stable combustion, all at efficiency levels on par with hydrocarbon combustion. Research is also needed into technologies that facilitate the safe use of ammonia.
- Researchers must incorporation these and other new concepts into research and develop methods and underlying foundational technologies for next-generation fuel cells that incorporate completely new electrolytes and electrodes.

[4] Energy Generation Fields

Develop technologies that accelerate and expand the use of renewable energy and technologies that produce revolutionary efficiency improvements at lower costs.

① Next-Generation Solar Power Generation

(Technological Impact)

- Realize a two-fold or greater increase in efficiencies compared to currently adopted solar power generation methods.
- Achieve reductions in manufacturing and installation costs, while delivering significant improvements in power generation efficiencies to lower power generation costs below current main power sources (¥7/kWh).

(Technology Overview)

Presently, crystal silicon solar cells are predominant form of adoption throughout the world. After nearly 60 years since the invention of crystal silicon solar cells, this technology remains a more expensive alternative power source than thermal power or other main energy sources. To achieve wider adoption, we must introduce innovations that dramatically lower the cost of creating energy through solar power. Accordingly, researchers are faced with the task of developing next-generation solar cells that use completely new and different structures and materials (quantum dot, perovskite, etc.) compared to current solar cells. In Japan, universities and national research and development institutes are engaged in solar power-related research, while universities in Europe, the United States, and Korea are also helping to accelerate progress in this field. Japan has long led the world in the field of solar cell module development, and our nation possesses superior technology in the independent development of perovskite and other technologies for use in next-generation solar power generation.

Since solar energy offers low energy density, the technology requires an immense area for solar cells to produce the same amount of output as thermal power generation, even at significantly improved conversion efficiencies. While solar power generation at night is obviously impossible, solar power also entails a considerable range of output variability during the day. Given these conditions, researchers must develop efficient solar power storage technologies if we are to see wide-scale adoption. Researchers are considering methods to store and transport energy from solar cells installed in areas of high sunlight exposure to areas of energy demand. Development must be conducted in parallel for storage battery technologies and technologies for conversion to hydrogen or other energy carriers. At the same time, researchers must assess the practicality of these technologies, balancing transportation costs and energy loss in the equation.

The following are specific examples of next-generation solar power generation.

＜Perovskite Solar Cells＞

These are products of organic thin film and dye-sensitized solar cell development. Raw materials having a special crystalline structure (perovskite structure) are used in developing organic-inorganic with hybrid solar cells and other new high-efficiency solar cell structures. Researchers are faced with the task of developing low-cost materials and process technologies to derive power generation costs lower than the current widely adopted main power sources. If researchers are able to develop manufacturing technology to produce lighter, more flexible solar cells, the industry will be able to realize additional cost savings in terms of installment costs.

＜Quantum Dot Solar Cells＞

Quantum dots and other nano structures are extremely minute structures (1/1 billionth of a meter) created artificially within semiconductors. Encapsulating electrons within a semiconductor results in the generation of a phenomenon called quantization, which allows for the absorption of light emitted from a variety of energy sources. Further, the direction of the movement of electrons can be restricted to more efficiently extract them. To make leaps forward in this field, researchers must develop high-efficiency solar cells that utilize this technology.

For example, intermediate-band solar cells that use the energy level (intermediate band) formed inside semiconductors by compound semiconductor quantum dots are expected to absorb a solar energy spectrum in one solar cell across a much wider spectrum than currently possible. This suggests a theoretical conversion efficiency of 60 percent or greater under concentration—an innovative technological development that could break out of the conventional wisdom for current solar cells. By changing the size of semiconductor quantum dots, researchers can control the light wavelength (band gap) absorbed by the base material. Capitalizing on this phenomenon, researchers may be able to produce high-efficiency solar cells in the form of quantum dot multi-junction solar cells that combine solar cells made with quantum dots of differing sizes.

(Technological Issues)

- Current reports indicate that researchers have achieved comparatively high efficiencies for organic-inorganic hybrid solar cells using perovskite. However, these materials contain lead, on top of which material degradation progresses relatively rapidly, calling for further materials development that produced materials that are both non-damaging and highly durable.
- More development of encapsulation technologies is required to achieve greater

perovskite solar cell durability.

- Solar cells that utilize quantum effects increase power generation efficiency. Accordingly, more development is required for crystal growth technologies capable of lining up high-density, uniform quantum structures as designed in three dimensions. This also requires more development of pattern formation technologies.
- To achieve the ¥7/kWh cost target and a 30-40 percent efficiency will require the development of high-efficiency technologies (full-spectrum solar cell technology) that effectively uses the full spectrum of solar energy. This includes, for example, the development of high-performance multi-joint solar cell technology.

② Next-Generation Geothermal Power Generation

Geothermal resources exist in abundance in volcanic countries where magma is located in comparatively shallow strata. Being the third-most active volcanic nation in the world in terms of active volcanoes, Japan possesses one of the greatest potential source of geothermal resources on the planet. Geothermal power output is stable, not affected by weather or time. As with hydroelectric power, geothermal power is one of the few renewable energy sources regarded as a base load power source, and expectations are high for the future effective use of this resource.

However, geothermal power generation as it stands today presents difficulty in accurately identifying geothermal reservoirs that exist at one to three kilometers below ground. As well, building geothermal power plants requires time to perform geological surveys and geophysical exploration, entailing significant economic risk. As such, geothermal power generation today accounts for less than one percent of total energy production worldwide.

Given these circumstances, researchers are faced with the task of developing new-era geothermal power generation systems that overcome these issues, while making use of geothermal resources, a resource which has been historically difficult to utilize with existing power generation methods. Japan is at an advantage among nations of the world, having potential sources of high-temperature geothermal resources located in comparatively shallow strata (four to five kilometers) compared to other countries.

The following are specific examples of next-generation geothermal power generation.

＜Hot Dry Rock Power Generation＞

(Technological Impact)

- Historically, geothermal power generation has been limited to locations of natural reservoirs; however, hot dry rock power generation is technologically applicable to a wider area (locations without natural reservoirs). This dramatically increases the possibilities for the adoption of geothermal power generation. According to a resource survey conducted by the New Energy and Industrial Technology Development Organization (NEDO), this technology more than doubles the potential adoption for geothermal power generation within the borders of Japan.

(Technology Overview)

Under existing geothermal power generation, no technologies have been available to forecast the scale of reservoirs or sustainable power output thereof. This results in issues of steam/hot water volume attenuation. In contrast, hot dry rock power generation artificially fractures high-temperature rock underground (using hydraulic fracturing, etc.), accumulating large volumes of water in the cracks created inside the rock, creating an artificial geothermal reservoir. Injected water from the surface generates a stable volume of steam, which is used to generate power on the surface. By regulating the amount of water injected, engineers can create a stable source of usable energy.

Japan, the United States, France, Germany, Switzerland, Australia, Korea, and other nations have been engaged in research and development related to the potential of hot dry rock power generation. In connection with this technology, Japan has a successful history of developing water injection simulators for underground reservoirs and reservoir sensing systems. Based on these foundational technologies, researchers will coordinate and share underground reservoir data with the United States and other nations, while at the same time continuing mutually supported technological development.

(Technological Issues)

- Numerous development risks are associated with the inability to accurately understand conditions underground. Most development is required for technologies that accurately understand the behavior of underground cracks and underground water via simulation.

- Current technologies suffer barriers to practical implementation due to poor economies and the low volume of power generation from an individual site.
- More development is required for technologies that dig rapidly and at low cost.
- More development is required for technologies to control water flow inside artificial geothermal reservoirs.

＜Supercritical Geothermal Power Generation＞

(Technological Impact)

Compared to traditional geothermal power generation techniques, this technology utilizes high-temperature/high-pressure geothermal resources. Accordingly, researchers project an increase in power generation volume per each individual power generation plant. According to the calculations of the National Institute of Advanced Industrial Science and Technology, geothermal wells have a production capacity of more than 500 percent compared to current technologies. This has the potential to increase Japan’s geothermal power generation volume by an order of 10 (between 10 GW and several hundred GW) or even greater.

(Technology Overview)

This is a new form of geothermal power generation that utilizes a reservoir of high-temperature, high-pressure water (supercritical water) that reaches a supercritical condition deep underground as a result of sea water that has been pulled underground due to the sinking of ocean floor plates.

To date, there are no direct confirmed cases anywhere in the world of the detection of underground supercritical water. However, interpretations of the results of seismic wave analysis suggest the existence of magma-based volcanic rock that contains about one percent supercritical water per unit volume among the 50 or more ancient volcanoes/ancient caldera understructures (four to five kilometers) in Japan’s northeastern region. Successful development in this field will lead to a completely new geothermal resources offering major volumes of power, while at the same time significantly reducing greenhouse gas emissions and contributing to better energy self-sufficiency rates in our nation.

(Technological Issues)

- No cases in the world to date of successful supercritical water confirmation or testing as a power generation source.
- Technologies have yet to be developed to accurately detect and predict the location, scale, condition, etc. of underground supercritical water.
- Indications suggest that researchers will discover during development that the phenomenon occurring within supercritical rock formations is significantly different than current geothermal power generation. Researchers will need to continue to use controlled-environment testing incorporating simulators and test excavations to gain a scientific understanding of the phenomena involved, as well as to be able to predict and model this phenomena.
- Supercritical water believed to exist around magma is derived from sea water, and therefore contains a significant amount of chlorine, which leads researchers to believe that there is a high likelihood that supercritical water is strongly acidic. Accordingly, materials and equipment must be developed that can withstand severely high-temperature, high-pressure, and highly corrosive conditions over an extended period (at least 20 to 30 years).
- Technologies must be developed for crack design, creation, and control to efficiently extract heat from geothermal reservoirs over an extended period.

＜Extreme Environment-Compatible Sensors＞

(Technology Overview)

Power generation utilizing high-temperature geothermal resources requires the use of sensors to capture the behavior of water and steam. These sensors must be able to endure heat of 300 to 400 ºC or greater, corrosion due to salt and melting sulfur, sudden temperature changes, and tremendous pressure. Sensors must be developed that are capable of handling a variety of extreme environments while providing high reliability in a compact, light, low-cost package.

(Technological Issues)

- Almost no electronic circuits existing today can operate at temperatures between 300 and 400 ºC. Improved heat-resistance is also needed for optical fibers, most of which are not suited to maintain long-term performance at high temperatures.

- Development is required for corrosion-resistant sealing compounds used under high temperatures to protect sensors and electronic circuits from the external environment. Sensors that come into direct contact with geothermal fluid must be highly corrosion- and scale-resistant. However, almost no materials in existence today meet such requirements. Further development is needed for non-metallic materials to be used in these applications.

[5] Capture and Effective Usage of Carbon Dioxide

By effectively separating, capturing, and using anthropogenic carbon dioxide—a cause of global warming—we will be able to mitigate climate change as well as realize the cyclical utilization of carbon.

Several technologies exist to separate and recover CO_2 from exhaust gas (a major source of CO_2), working as a means of effective carbon dioxide capture and utilization (CCU). Specific examples of these technologies include artificial photosynthesis (converts CO_2 into raw materials and produces carbon compounds which become chemical raw materials) and technologies that convert biomass to hydrocarbon fuel, chemical raw materials, and other valuable resources for use in manufacturing environmentally friendly concrete. However, room for improvement remains in terms of reducing CO_2 separation and recovery costs, as well as in increasing the effectiveness and volume of capture and utilization.

Several methods for CO_2 separation exist, including chemical absorption, physical absorption, solid absorption, and membrane separation. Chemical absorption is the main technology for this application, being used in practical applications today. Physical absorption is also being used in part in practical applications for certain commercial purposes. Among the technologies used for CO_2 separation and recovery, chemical absorption, solid absorption, and membrane separation are the targets of research and development work being conducted in cooperation with industry. This work is investigating more efficient, more economical CO_2 separation and recovery. Projects addressed by the strategy in this report are accelerating the pace of research and development toward reducing the costs of CO_2 separation and recovery. These projects are pursuing the most efficient techniques for separation and recovery, including the combination of multiple separation methods. This particular technology will make a significant contribution to reducing the cost of carbon dioxide capture and storage (CCS), allowing for the mass processing of CO_2.

As to the question of how to reduce CO_2 moving ahead, more technological development will be conducted to make a major leap forward from current levels in CO_2 reduction and efficiency through CCU.

The following are specific examples of carbon dioxide capture and effective utilization.

＜Innovative CO_2 Separation and Recovery Technologies＞

(Technological Impact)

・ Cut the energy used in separation and recovery by half (1.5 Gj/t- CO_2).

(Technology Overview)

Researchers are developing a high-performance chemical absorption liquid capable of recovering CO_2 from absorption liquid at low temperatures at lower levels of energy for separation and recovery. When separating CO_2 from high-pressure gas resulting from steel production and similar processes, high-pressure energy within the processing gas can be used effectively in the separation/recovery and compression process. This potential calls for more development of high-pressure regenerative chemical absorption liquids, which will allow for significant energy reductions in the CO_2 separation and recovery process.

Applying the knowledge accumulated in chemical absorption research to solid absorption, scientists will be able to support chemical absorption liquids in porous bodies, realizing a significant reduction in energy consumed in sensible heat and latent vaporization heat during the regeneration process, while at the same time achieving CO_2 absorption capacity on par with chemical absorption liquids.

Membrane separation uses gas press to separate and recover CO_2. Developing practically adoptable technologies for this method could result in energy and cost savings compared to other absorption methods.

(Technological Issues)

・ Current recovery temperature under chemical absorption is approximately 120 ºC. However, researchers are tasked with finding absorption liquid that allows for long-term stable recovery at temperatures of 100 ºC or less.
・ Future solid absorption technology must introduce innovative solid absorption materials that offer high withdrawal performance at low temperatures.

＜Effective CO_2 Utilization Technologies＞

(Technological Impact)

・ Compared to current technologies, CCU technologies may provide considerably improved CO_2 reduction volume and efficiency.

(Technology Overview)

As one example, Japan is developing artificial photosynthesis technologies that produce chemical raw materials that use separated and recovered CO_2, taking advantage of existing catalyst technologies for which our nation has demonstrated international superiority. Japanese researchers are also moving forward with research and development that may lead to innovative breakthroughs in the conversion and use of biomass (captured CO_2) as hydrocarbon fuel, chemical raw materials, and other valuable resources. At the same time, we will continue with research and development into innovative CCU technologies which may introduce dramatic improvements in CO_2 reduction and efficiency compared to current technologies.

(Technological Issues)

・ More development is needed to secure mass production and high-efficiency production technologies that produce current chemicals at the same manufacturing costs.
・ From the standpoint of dramatically reducing CO_2 emission volume, researchers must come up with innovative technologies that can efficiently synthesize valuable resources in mass quantities, in addition to the current use of olefin and other basic chemicals.

5. Research and Development Implementation Structure

(1) Forming Research and Development Structures as Unified Government Agencies

- Innovative technologies requiring an extended period before showing concrete results generally entail significant benefits for society, as well as equally significant development risks. Accordingly, the government of Japan has taken the lead in establishing implementation structures for products to be conducted over the medium and long term. More specifically, the CSTI has taken on a headquarters role, gaining the cooperation of related ministries and agencies to strengthen the promotion of the strategy in this report as a unified group.
- Under the overall management of the CSTI, related ministries and agencies accomplish their individually assigned roles, establishing a research and development implementation structure that shares information and provides mutual feedback of results. Under the leadership of related ministries, agencies, and other research institutes, form and strengthen the functions/coordination of organizations that conceive and propose promising next-generation technology fields identified in the strategy, after detailed studies and research and development have been performed.
- The CSTI utilizes the headquarters function of the SIP and Comprehensive Strategy on Science, Technology, and Innovation, taking on the role of leadership. In so doing, it has placed three existing SIP projects (Next-Generation Power Electronics, Structural Materials for Innovation, and Energy Carriers) in important roles under the strategy in this report.
- To establish a practicable research and development implementation structure based on the strategy in this report, Japan is creating a projection of future related to research and development for promising technology fields, as well as a vision of the future looking forward to the year 2050. At the same time, we are creating a roadmap, engaging in constant revisions according to the progress of research and development.
- Further, as we advance projects over the medium and long term, we will continue to secure, support, and train researchers and in-the-loop management personnel. Training will include skills in individual elemental technologies, systematization, and implementation.

(2) Creation of Innovation Technology Seeds and Flexible Positioning

- To create sustainable discontinuous greenhouse gas-reduction technologies based on new concepts, including technologies not imagined under the strategy in this report, we must establish greater activity in basic and applied research at universities and national research institutes. Further, we must uncover technologies under development at overseas universities, research institutes, mature companies, and venture companies.

- The Japanese government will work as one group to uncover promising technology seeds, sharing information related to leading research in energy and environment fields at the Cabinet Office and related ministries and basic research being conducted at universities and research institutes. Additionally, with the cooperation of researchers and industry professionals, we will investigate potential exit strategies and societal adoption for other technologies, actively pursuing strategies for those technologies viewed as having high potential for emission reduction.
- While we will maintain a flexible approach to reviewing the positioning of technology seeds, as we advance the concepts under the strategy in this report, we will establish appropriate stage gates for each field, moving forward strategically while optimizing research and development projects through appropriate schedules (in terms of several years) according to R&D progress and societal circumstances.
- Beyond the year 2050 targeted in the strategy in this report, we plan to also promote the advancement of nuclear fusion and space solar power, which are technologies likely to be in development over a much longer term.

(3) Mechanisms to Encourage Industry Investment in Research and Development

- In recent years, industry investment in research and development has shifted toward short-term projects. The time frame for research and development in technology fields discussed in the strategy in this report covers the long term between research and development and practical implementation. To encourage industry investment in research and development, we must share our technological outlook and future vision toward the year 2050 among government, academy, and industry, demonstrating the government’s long-term commitment and framework for focused development.
- Projects will be designed to promote the active participation of industry. Rather than a public appeal, we will look to establish a framework for creating the most appropriate research and development implementation structure, including taking the lead in approaching domestic and international universities, corporations, and research institutes that have the wherewithal to execute the project in question.

- Japan will support industry in commercializing technologies, taking research and development results obtained by the nation or participating companies and applying to business ventures, even in cases where overall development is at an interim stage of completion.
- Technologies to reduce greenhouse gas emissions is an important technology to spread around the world. From the beginning stages of research and development, we will engage in industry-academy-government cooperation related to international standards, timing, and the handling of intellectual property. We will create proposals for international standards under the direction of the government and research and development institutes, leading the world in proposing standards to international federations. In so doing, we will be able to clearly understand the path to international markets, encouraging private investment.
- International standards and certification are inseparable. Here, for the initial stages of each project, we plan to engage industry-academy-government cooperation in investigating standards and certifications in parallel with research and development activities. We will improve and strengthen structures to assess and certify the performance and safety of target technologies.

(4) Promotion of International Coordination and Joint Development

- Reducing greenhouse gas emissions is a common issue for all nations across the world. Already, the governments, research institutes, and industries of each country are tackling the problem in their own projects. Promoting international coordination and joint development is significant from the standpoint of gathering the world's knowledge and applying it to resolving global-scale issues.
- Here, Japan intends to introduce the contents of this strategy, making an appeal for joint development in the fields related to the strategy. This will be part of the process to specify fields targeted for international cooperation and competition and to proactively advance international joint development in the fields targeted for the international cooperation. The upcoming G7 Summit and related minister-level meetings, the Innovation for Cool Earth Forum (an upcoming international conference in which leaders across the globe from industry, academia, and governments gather and hold discussions), and other such gatherings are good candidates for promoting this strategy. In so doing, we intend to take

advantage of international workshops and opportunities to share information with experts in a variety of technological fields, exchanging information related to research and development, technology deployment, and other initiatives between and among countries.

- Stakeholders will come together to discuss fields targeted for international cooperation and competition, after which we will coordinate with other relevant nations. However, we must be aware of and careful not to impose excessively constraining conditions on patenting results of international joint research.
- Some technologies overseas are expected to show greater promise for reduction effects than that of Japan (solar heat usage, biomass, stabilization via vegetation, for example). If Japanese technology can make a contribution in these cases, we understand the importance of proactively participating in the international joint development in such research and development projects.
- Energy systems demonstrating expanding adoption of renewable energy sources may be more easily introduced to developing or emerging nations with weak energy infrastructure, rather than to advanced nations which have mature fossil-fuel based energy systems in place. Our nation will look into ways to jointly advance international standards and others related to technology and systems performance assessment methods. In so doing, we must include approaches to construct energy system reflecting each country's situation and international contributions, including building capacity.

6. Summary

Strengthening innovative technology development in the energy and environment fields is an activity that does not end with the resolution of the global warming issue. This process also includes economic and diplomatic strategies overlooking the long term. Looking forward to the year 2050, Japan intends to strengthen our research and development based on this strategy as quickly as possible. We will accomplish our role in leading the world in next-generation innovation that addresses both climate change and economic growth.

Reference 1

National Energy and Environment Strategy for Technological Innovation towards 2050 Draft Working Group Member List

	Shuichiro Hirai	Professor, Graduate School of Science and Engineering, Tokyo Institute of Technology
Chair	Takao Kashiwagi	Institute Professor, Tokyo Institute of Technology
	Tetsuhiko Kobayashi	Vice-President, Natl. Inst. Adv. Ind. Sci. Technol. Director-General, Department of Energy and Environment, AIST
	Yuichi Moriguchi	Professor, Graduate School of Engineering, The University of Tokyo
	Hiroshi Okajima	Project General Manager, R&D Management Division, Toyota Motor Corporation
	Akira Sudo	Executive Committee Chair, Council on Competitiveness-Nippon (COCN) Senior Adviser, TOSHIBA CORPORATION
	Akimasa Sumi	President, National Institute for Environmental Studies
	Kanako Tanaka	Japan Science and Technology Agency (JST) Senior Researcher, Center for Low Carbon Society Strategy (LCS)
	Akira Yabe	Director, Technology Strategy Center, New Energy and Industrial Technology Development Organization
	Kenji Yamaji	Director-General, Research Institute of Innovative Technology for the Earth

(Listed in alphabetical order)

Reference 2

National Energy and Environment Strategy for Technological Innovation towards 2050 Draft Working Group Discussion History

Session 1 December 15, 2015

- Discussions regarding the establishment of the National Energy and Environment Strategy for Technological Innovation towards 2050 Draft Working Group
- Discussions regarding the identification of target emission reduction fields and considerations when forming specific strategies

Session 2 January 26, 2016

- Discussions regarding new technologies likely to produce dramatic reductions in greenhouse gases
- Discussions regarding specific energy and environment innovation strategies

Session 3 February 16, 2016

- Measures for compiling promising technological fields and for advancing related development
- Outline of the National Energy and Environment Strategy for Technological Innovation towards 2050 (Draft)

Session 4 March 24, 2016

- Summary draft of the National Energy and Environment Strategy for Technological Innovation towards 2050