Korea Green Climate Technology Outlook

2020

GREEN TECHNOLOGY CENTER Korea

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GREETINGS

The adoption of the Paris Agreement in 2015 established a strong foundation to facilitate prompt and joint actions by all the countries in response to the daunting challenges associated with climate change. Among many such joint actions, the United Nations Framework Convention on Climate Change presented the development and transfer of climate technologies as key measures for tackling climate change. Along with the financial mechanism, the technology mechanism will be an essential element of the new climate regime, fostering diverse sets of partnerships on both regional and global scales.

The Green Technology Center was established in 2013 with the recognition of climate technologies based on the increasing demand for policy research for Korea's green, innovative, and inclusive growth. One of our main duties is to develop national strategies in accordance with the technology policies of UNFCCC. We intend to advance Korea's leadership in climate change cooperation by providing cutting-edge information platforms for analysis and research. One of our greatest accomplishments was the publication of the *White Paper 2017 on Green Climate Technology*, which introduced ten major green climate technologies with respect to our classification system as well as their domestic and international trends and implications for the industry and policy-making processes. The next edition, the *White Paper 2018 on Green Climate Technology*, classified and discussed a broader range of technologies from fourteen different sectors. Therefore, we wish to improve the understanding of the general public about green climate technologies and their evolving trends.

The *Korea Green Climate Technology Outlook2020* is the latest edition of the publication and contains additional discussions about the rationales associated with the global climate change regimes when ensuring that the objectives of the UNFCCC are achieved. Thus, this edition intends to present the increasing importance of green climate technologies in the new climate regime.

I sincerely hope that this edition will serve as an excellent reference for various readers, including students, researchers, entrepreneurs, and policy-makers. I also believe that it can raise public awareness about the application of green climate technologies as effective solutions for climate change because all of us are in search for collective wisdom to achieve sustainable growth.

Green Technology Center will continue to share its expertise and knowledge about green climate technologies through subsequent editions of the *Korea Green Climate Technology Outlook2020* in the coming years. I would like to request your consistent support and encouragement.

Thank you.

* "Green Climate Technology" refers to a set of terminologies coined by Green Technology Center, combining 'green technology' and 'climate technology'.

President of Green Technology Center

Byung-ki Cheong

Part

1

Climate Technology Classification in Korea

Background/Objectives/Methodology

Climate Technology Classification in Korea

Background

The Fourth Report (2007) presented by Working Group 3 of the Intergovernmental Panel on Climate Change (IPCC) provides policy directions for greenhouse gas (GHG) mitigation and adaptation measures with respect to climate change. The Glossary of Terms of IPCC (2012) provides the following definition for "mitigation and adaptation." "Mitigation" is defined as "human intervention to reduce the sources or enhance the sinks of greenhouse gases," and "adaptation" is defined as "the process of adjustment to actual or expected effects of climate change in human and natural systems to moderately harm or take advantage of the beneficial opportunities owning to climate change."

Thus, mitigation can be defined as the process of reducing the total amount of GHGs or controlling emissions, whereas adaptation can be defined as the process of responding to the effects of climate change (Richard B. Rood, 2007).

GHG mitigation may be understood as the process of reducing GHG emissions owing to socio–economic activities. Adaptation may be defined as the prevention of human and natural systems, including resources, such as food and water, ecological systems, residential environments, and health as well as the related communication in environmental systems, from being damaged owing to climate change. The climate change response technologies should be roughly classified to achieve GHG mitigation and adaptation. Therefore, this study classifies the climate change response technologies into (1) GHG mitigation and (2) adaptation in accordance with the international standards to establish a comprehensive range of such technologies.

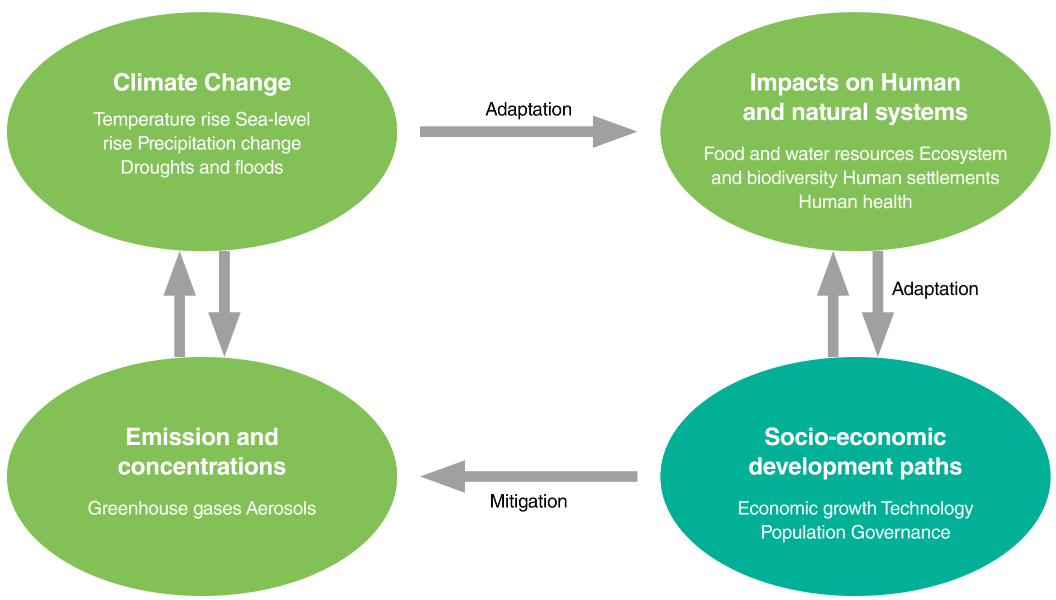

Figure 1 | Mitigation and adaptation framework for climate change response by Richard B. Rood

Objectives

The objective of this study is to classify the types of climate change response technology (hereafter climate technology) that have not yet been defined in terms of category and level and create a classification system to present policy directions for the development and application of climate technologies.

A classification system provides an important policy direction, which allows the discussion of priorities with respect to the development of technologies that can reduce GHGs at the government level and also provides a blueprint that can be transferred to developing countries for ensuring a comprehensive understanding of these technologies.

Methodology

The scope and types of technology have been delimited by conducting a documentary survey with respect to the current status of domestic and overseas climate technologies and via consultation, review, and evaluation of the policies and opinions of the climate change response technology experts.

Documentary surveys are used to compare the climate technology classification standards used by the IPCC and other climate change-related international organizations.

A list of climate technology classification systems, which are used by international organizations responsible for combating climate change (e.g., IPCC, WIPO Green, Climate Tech Wiki, and Open EI), has been developed, and the scope and type of climate technologies applicable to South Korea have been determined.

The technical definitions, scope, verification, and classification of climate technologies have been discussed via technical consultation, expert advisory meetings, and surveys.

Climate Technology Classification in Korea

Literature review is the first step to establish a climate technology classification system. Data related to the classification of climate technologies have been examined in prior domestic and international research. Based on these data, the notion of climate technology was summarized and organized into two categories, i.e., mitigation and adaptation. Subsequently, the GTC gathered the opinions of experts and added the field of "mitigation/adaptation convergence." Previous studies may be divided into five categories. Their contents are as follows:

1. Technological Scope of the IPCC Working Group 3: With respect to the climate change responses, the IPCC (2007) Working Group 3 classified the options for GHG mitigation and adaptation in case of climate change into two categories, i.e., mitigation options and adaptation options, and presented technology and policies as implementation measures. The IPCC's Fourth Assessment Report (2007) divided the GHG mitigation sector into seven sections.
2. Technological Scope of the United Nations Framework Convention on Climate Change (UNFCCC): Even though the UNFCCC does not specify the scope of the climate technology, it provides information on climate technology through "TT: Clear."

   - The UNFCCC's TT: Clear is an information platform that provides information about the climate technology of each country as reference. This includes information provided by institutions, including IRENA REsource, IRENA Inspire, Climate Tech Wiki, WIPO Green, OpenEI, Reegle, the Energy and Resources Institute, and the Climate-Smart Planning Platform.
3. Technology Scope Classification by the Cabinet Office of Japan: The Cabinet Office of Japan's Energy and Environment Innovation Strategy intends to realize a low-carbon society internationally and contribute to the energy security, environment, and economies of the developing countries. Their classification system, which was presented at the 114th General Science and Technology Conference on September 13, 2013, specified short-term and mid-to-long-term plans for technology development, enhanced the measures to promote the development of technology, and evaluated the environmental energy technology with respect to the revised plan for overseas technology transfer and distribution.
4. Climate Technology Network Classification (CTCN): CTCN is a climate technology network comprising 213 institutions as of 2016, among which 74 institutions (34.7%) belong to the Asia–Pacific region, whereas 72 institutions (33.8%) belong to Europe. These 213 CTCN affiliates have an average of four specialized research areas per institution in the field of climate technology. Technology Needs Assessment (TNA) for developing countries is a core project under UNFCCC Articles 4 and 5, which is funded by GEF's Technology Transfer Program and conducted by the UNEP. TNA classifies the climate technology field in accordance with the action type and sector based on the technical demand analysis reports submitted by each country. The action type is explained in terms of adaptation and mitigation and can be classified into 17 sectors.
5. Examples of Scope Classification of Domestic Climate Technologies: Korea established and announced climate change response strategies and green growth strategies for ensuring low-carbon green growth. The Ministry of Education, Science, and Technology established a basic framework for technology development fields and sectors by proposing the "Mid-to-Long-Term Master Plan for National R&D in Response to Climate Change" in 2008. The technology classification of the "Mid-to-Long-term Master Plan for National R&D" significantly contributed to the establishment of national green R&D support policies based on the green growth policy trends from 2009 to 2013. The Framework Act on Low Carbon, Green Growth enacted in 2010 stipulates that clean energy and green technologies should be developed to mitigate climate change and reduce environmental damage. Additionally, green technology intends to achieve strategic technology development for GHG mitigation, and discussions have focused on establishing support measures for R&D investments. In July 2014, the government announced six core technology development strategies in response to climate change. In April 2015, the government implemented a plan for new energy industry revitalization and core technology development strategies. In June 2016, the government announced the Climate Technology Roadmap to manage the progress of the 13 ministries related to climate change.

The second step to establish a climate technology classification system was to comparatively analyze the established climate technology scopes. In previous domestic and overseas studies, the electric power sector is the field that is most frequently defined as an intermediate category during the classification of climate technology; this sector is followed by bioenergy, solar energy, transportation, construction, waste management, and energy. 286 types of technologies are frequently mentioned in previous studies; among them, policy alternatives or solutions for climate change issues have been suggested for only 86 types of technologies. They have 3 fields, 14 categories, and 45 technology scopes.

The following technology subfields have been organized based on the opinions of technology experts.

Table 1 | Climate technology classification in Korea

Field	Category	Technology scope	Description
Mitigation	(1) Non-renewable energy	1. Nuclear power generation	A technology to design, construct, and operate nuclear power plants exhibiting stability, economic efficiency, and environmental friendliness by upgrading nuclear power plants that can generate electricity using nuclear fission
		2. Nuclear fusion power generation	A technology to produce electric power or hydrogen by safely and effectively recovering the energy of neutrons in the form of heat energy based on the control of the fusion reaction occurring in the high-temperature plasma state of deuterium–tritium and using high-energy neutrons
		3. Clean thermal generation and efficiency	A high-efficiency clean fossil fuel technology that can achieve CO_2 reduction through fuel diversification via biomass co-firing and that exhibits higher efficiency when compared with those exhibited by conventional thermal power generation, fossil fuel purification, CO_2 recirculation, etc.
	(2) Re-newable energy	4. Photovoltaic energy	A technology to directly convert solar light energy into electric energy via photovoltaic generation systems (comprising solar cells, modules, storage batteries, power regulators, and AC/DC converters)
		5. Solar thermal energy	Various technologies related to the conversion, storage, and utilization of solar radiation into useful thermal energy
		6. Bioenergy	An alternative energy source technology that can replace fossil fuel energy via thermochemical or biological conversion techniques from animals, plants, derived resources (biomass), or marine biomass
		7. Waste energy	Waste energy is obtained using flammable wastes with a high calorific value obtained from daily and business activities; waste energy technology (WTE) is used to convert combustible waste with high energy content into energy
		8. Geothermal energy	A technology to generate electricity or heat using water, underground water, and underground heat or temperature differences
		9. Ocean energy	A technology related to the practical application of marine clean energy that does not emit carbon dioxide such as algae, tidal force, wave power, seawater temperature difference, seawater salinity difference, and ocean currents
		10. Wind power	A power generation technology that generates electricity by absorbing the kinetic energy of wind using rotor blades and converting it into mechanical energy
		11. Hydro power	Various technologies to convert energy by utilizing the potential energy of the water in dams, rivers, and watersheds
Mitigation	(3) New energy	12. Hydrogen production	A technology to manufacture hydrogen by converting fossil fuels or decomposing water by thermochemical, photochemical–thermochemical, photochemical, electrochemical, biological, or chemical methods
		13. Fuel cell	A technology to simultaneously produce electricity and heat with a high degree of efficiency and low emissions by directly converting the chemical energy of fuel (hydrogen, methanol, coal, natural gas, petroleum, biomass gas, landfill gas, etc.) into electric energy through an electrochemical reaction
	(4) Energy storage	14. Power storage	An energy storage technology in which peripheral devices are used, which can reduce greenhouse gas emissions by improving the quality of electric power and maximizing energy efficiency via high-efficiency storage and usage of electric energy.
		15. Hydrogen storage	A technology to safely and efficiently store hydrogen in the form of hydrogen compounds or through compression, liquefaction, or adsorption
	(5) Trans-mission and distri-bution and electric power IT	16. Transmission and distribution systems	A technology to develop digital and intelligent power systems and heavy electric machinery that can add value to electric power services by introducing information and communication technology and automation systems into power technology, such as power generation, transmission, and distribution, including part and system technology development, and intelligent power monitoring/control technologies
		17. Intelligent electronic devices	Products, technologies, systems, and linkage technologies to reduce energy loss and maximize the energy-saving effects
	(6) Energy demand	18. Efficient transport	A technology that contributes to reduce the greenhouse gas emissions from the transport sector by improving the energy efficiency of the land, sea, and air transportation means and optimizing the transportation and logistics systems
		19. Industrial efficiency	An infrastructure technology suitable for conversion to the industrial structure in which integrated high-efficiency new processing and low-carbon type raw material substitution are linked by considering the whole process from raw material collection to post-production waste disposal/recycling to fundamentally reduce the energy injected and distributed in various forms into the industrial sector, where petroleum and other resources are mainly processed
		20. Building efficiency	A technology to optimize the energy efficiency of the existing buildings and core parts of the buildings to increase the number of zero-energy buildings, which is a major agenda item for new buildings to reduce greenhouse gases

Field	Category	Technology Scope	Description
Mitigation	(7) Green-house gas fixation	21. Carbon Capture, Utilization, and Storage (CCUS)	A technology that can capture CO_2 from large-scale sources, compress it, transport it for safely storage in a land or marine environment, directly use it, or convert it into useful materials
		22. Non-CO_2 reduction	Technologies to monitor non-CO_2 greenhouse gases, build a corresponding database, develop alternative materials and processes that can reduce emissions at the source, and collect, refine, utilize, and decompose those gases to reduce their presence
Adapta-tion	(8) Agricul-ture and Livestock	23. Genetic resources, genetic improvement	A technology to understand the impacts of climate change on crops and livestock production and minimize adverse impacts, including reduced agricultural and livestock productivity due to climate change
		24. Crop cultivation and production	
		25. Livestock disease management	
		26. Processing, storage, and distribution	
	(9) Water	27. Water system and aquatic ecosystem management	Technologies related to the improvement of water quality, water resources, water storage and supply, etc. to address regional and seasonal water quality degradation and imbalances, excesses, and shortages of water resources owing to climate change
		28. Securing and supplying water resources	
		29. Water treatment	
		30. Water disaster management	
	(10) Climate change prediction and moni-toring	31. Climate prediction and modeling	Technologies to track, diagnose, and predict the past, present, and future climate patterns, respectively, by observing, monitoring and analyzing the natural and anthropogenic factors that contribute to climate change and the numerical modeling of the factors that change the global climate systems
		32. Climate information warning systems	
	(11) Oceans, fisheries, The coast	33. Marine ecosystem	Technologies, including R&D and policy projects, necessary for strengthening scientific capacity and establishing adaptation strategies in response to climate change in the fields of marine, fishery, and coastal management
		34. Fishery resources	
		35. Coastal disaster management	
Adapta-tion	(12) Health	36. Infectious disease management	Technologies that can be used to prevent a wide range of diseases caused by the environmental impacts of climate change
		37. Food safety and preventive healthcare	
	(13) Forest and land	38. Promotion of forest production	Technologies to maintain and promote forest health and diversity in the long run by conserving biodiversity, promoting the absorption and storage of CO_2 in the atmosphere, and reducing the damage caused by disasters and pests due to the complexity of the forest system, where carbon is absorbed and stored. Forests act as a source of emission because of human impacts, such as damage, or disaster, or maladjustment to climate change
		39. Reduction of forest damages	
		40. Ecology, monitoring, and restoration	
Mitiga-tion/ adapta-tion conver-gence	(14) Multidis-ciplinary conver-gence	41. New and renewable energy hybrid systems	Technologies related to power, heat, and gas supply and management systems (renewable energy hybrid systems) that combine energy storage systems with two or more energy production systems, including renewable energy; technologies related to low-power consumption equipment and energy harvesting technologies
		42. Low-power-consumption equipment	
		43. Energy harvesting	
		44. Artificial photosynthesis	
		45. Other climate-change-related technologies	

Part

2

Mitigation Technology

Non-Renewable Energy

Renewable Energy

New Energy

Energy Storage

Transmission and Distribution and Electric Power IT

Energy Demand

Greenhouse Gas Fixation

NON-RENEWABLE ENERGY

Overview

Definition and Scope of Technology

Non-renewable energy mainly refers to fossil fuels, the production of which is considerably less than their consumption. The most common examples of non-renewable energy are thermal and nuclear energy because their sources, such as coal and uranium, respectively, are consumed faster than they are produced and become increasingly depleted with usage. Although non-renewable energy has played a pivotal role in industrial development, it has been the main cause of environmental pollution and global warming. Recently, ecofriendly new and renewable energy sources have been developed as an alternative; however, the advances in this field are still limited in terms of their efficiency. Next-generation nuclear power plants (NPPs), ecofriendly emission systems, and clean thermal power are being actively researched to overcome environmental challenges and make non-renewable energy technology more environmentally friendly. Nuclear fusion power, which generates clean energy and has a large-scale production capacity, is expected to be a promising energy source in the future and has witnessed rapid technological progress.

Clean thermal power generation is a hybrid power generation system based on the synthesis gas (CO and H_2) produced via the reaction of light hydrocarbon fuels, such as coal and vacuum residue, with oxygen and steam at high temperatures of greater than 1000°C and high pressures of 10–30 atm. It involves ecofriendly and clean coal generation with higher efficiency and less pollutants when compared with a conventional power plant that uses pulverized coal.

Table 2 | Subtechnology classification

	Subtechnology	Technology description
Nuclear power generation	1. Next-generation light-water reactor	A system technology with improved stability and economic feasibility
	2. GEN-IV system	A future power generation system that overcomes issues related to nuclear nonproliferation and waste
	3. Nuclear fuel cycle system	Reduces the volume and toxicity of spent nuclear fuel from the reactor
	4. Nuclear decommissioning technology	Enables the dismantling of nuclear facilities in a safe and ecofriendly manner
Nuclear fusion power generation	1. Technology for generating and maintaining high-performance burning plasma	Reliably control high-temperature plasma and maintain nuclear fusion
	2. Nuclear fusion reactor material development	Develops materials that can withstand high temperatures exceeding 100 million degrees and radioactivation by neutrons
	3. Technology for conversion of nuclear fusion energy	Delivers energy from a reactor to a power generation system (e.g., a turbine generator)
Clean thermal power generation & efficiency	1. Air Separation Units (ASUs)	Separates oxygen and nitrogen in the air and provides it as an oxidant
	2. Gasifier	Converts coal into synthesis gas ($CO + H_2$)
	3. Synthesis gas purification	Uses purification devices to eliminate H_2S and COS
	4. Combined generation	Utilizes both the steam turbine and gas turbine
	5. System operation technology	Realizes the reliable and efficient operation of an Integrated coal Gasification Combined Cycle (IGCC) plant

In nuclear fusion power generation, power is produced by the release of nuclear fusion energy from the nuclear fusion of hydrogen and tritium via a similar process to that occurring in stars such as the Sun. However, unlike the Sun, the Earth does not have an environment suitable for performing continuous nuclear fusion; hence, such an environment should be artificially created using magnetic fields or lasers in a nuclear fusion reactor. Therefore, the fusion reactor is also known as the artificial Sun. An almost infinite supply of deuterium and tritium, which are the primary sources for nuclear fusion power generation, is possible because of their abundance in seawater. This type of power generation produces ecofriendly energy and emits no nuclear waste or byproducts that pollute the environment.

Nuclear power generation utilizes the converted energy (nuclear mass defect energy) during the process of nuclear fission along with the reduced mass of the nucleus. A nuclear power generation system typically contains a nuclear reactor that controls nuclear fission, a system that delivers the energy generated during nuclear fission, and a turbine that converts the delivered energy into electricity. The energy generated in the nuclear reactor is transferred to the primary coolant system, and the coolant generates steam through the steam generator in the secondary system. This steam drives the turbine to produce electricity. Currently, the NPPs in South Korea are operated through light and heavy water reactors of the second and third generation of nuclear reactors.

Technology Trends and Industry Outlook

Integrated coal Gasification Combined Cycle (IGCC) for clean thermal power generation is an ecofriendly next-generation power generation technology. The feasibility of its commercial use has been established through the design, construction, and operation of demonstration plants with government support in many countries, including the USA, Germany, the Netherlands, Japan, and China. This technology is currently in the early stage of commercialization. Major advanced countries are working on the construction and operation of the IGCC demonstration plants via public–private partnership to nurture the industry as a strategic export market for the next-generation power generation technology.

Research on the nuclear fusion power generation technology is ongoing in many countries, including South Korea, the USA, Russia, the EU, Japan, China, and India. We are approaching the commercialization of nuclear fusion energy with the demonstration of large-scale power production using the International Thermonuclear Experimental Reactor (ITER), which is a part of an international nuclear fusion research and engineering megaproject undertaken by seven countries.

With respect to nuclear power generation, large-scale NPPs are expected to be continuously operated in countries aiming for economic growth to meet the target of the 2015 Paris Agreement. New markets led by small-scale power plants are likely to be created, and continuous growth is expected in the market for decommissioning old NPPs.

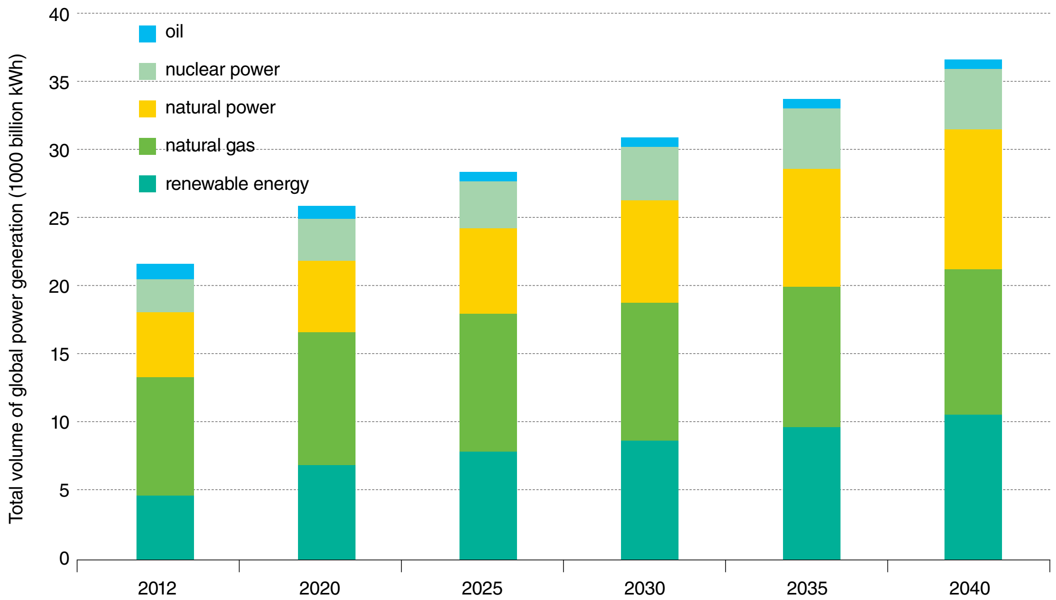

Figure 2 | Total volume of global power generation by energy source

© International Energy Outlook, 2016, EIA

In Korea, the domestic coal gasification technology for clean thermal power generation has been funded through the G7 project and the new & renewable energy technology development project, with a total budget of KRW 28.2 billion in 1988–2002 (KRW 171 billion was provided by the government for performing 37 tasks), primarily focusing on developing technologies for infrastructure and bench-scale equipment design, construction, and operation rather than on large-scale demonstration projects. The synthesis gas plant market is at the budding stage, with Korea Electric Power Corp. establishing a joint venture with Germany's Uhde through a technology partnership to compete with the existing advanced processing firms. Korea Western Power Co. can perform the commercial operations of the IGCC plants that generate power from the synthesis gas plants. POSCO will begin commercializing a complex plant connecting a gasification plant and the Synthesis Natural Gas (SNG) production plant by adopting overseas technologies. In the sector of nuclear fusion energy, Korea's Korea Superconducting Tokamak Advanced Research (KSTAR) recently achieved a world record by maintaining nuclear fusion for 70 s (2016). Among other outstanding studies in this field, KSTAR proposed a groundbreaking physical theory in 2016 that plasma may be prevented from decaying by measuring the turbulence on the surface of plasma for the first time in the world.

Korea has attained technological self-reliance in large-scale next-generation nuclear power generation with a well-established industrial supply system. As the world leader in the area of small-scale next-generation light water reactor and advanced reactor system, Korea has secured world-leading technological prowess with regard to the nuclear fuel cycle system. Korea is currently engaged in joint international research projects. However, there is a lack of experience in decommissioning large-scale NPPs and related infrastructure; the technology for nuclear plant decommissioning should be developed, especially for domestic NPPs nearing the ends of their lifecycles. Currently, the spent nuclear fuel in Korea can be processed only with the consent of the USA.

An energy policy should be established based on the Paris Agreement because a policy for drastically phasing out nuclear power could undermine Korea's plan to reduce GHG emissions. As the next-generation NPP and advanced reactor system will overcome the challenges associated with stability and waste, the policy for their development should be reviewed.

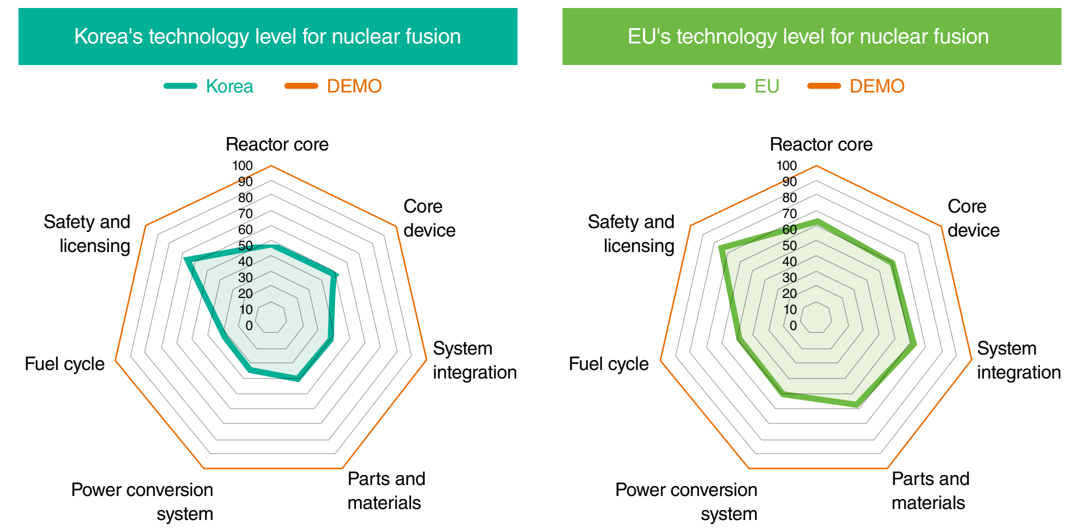

Figure 3 | Comparison of the nuclear fusion technology levels of Korea and the EU

© 2014 Technology Level Evaluation, KISTEP (2015)

Waste energy from non-renewables excluded from renewable energy

In January 2019, the Korean government announced a partial amendment of the Act on the Promotion of the Development, Use, and Diffusion of New and Renewable Energy and decided to exclude the waste energy generated from non-renewable sources, such as solid waste (plastics), from the category of renewable energy from October 2019. This amendment, wherein the criteria for waste energy are updated, prevents reckless incineration and reduces pollution owing to Solid Refuse Fuel (SRF) plants. Although the construction of new SRF plants is banned, measures to handle the existing SRF plants and process wastes, such as plastics, need to be adopted.

Shale gas industry outlook

The International Energy Agency anticipates that the proportion of oil with respect to the global energy consumption would reduce from 31.5% in 2018 to 27% in 2035; this signifies that the use of renewable energy is increasing because of the concerns associated with the increasing environmental pollution owing to the usage of fossil fuels. This change began with rapid progress in shale gas development technologies, including fracturing. In particular, the production of oil and gas is significantly increasing in the USA; the production cost of shale gas, which is being developed since the early 2000s, is now economically efficient. Further, the world will be able to use shale gas for more than three centuries. Mass production of natural gas, which is relatively clean and economically efficient, makes it possible to replace oil from the transportation and energy industry. According to the USA Energy Information Administration, the USA produced 8.9 million barrels of oil per day (bpd) in 2016, 9.4 million bpd in 2017, and 1090 bpd in 2018. It is expected that more than 12 million bpd will be produced in 2019. Shale gas can be attributed to this increase in oil production, and this revolution of shale gas has caused the replacement of oil in the USA. Oil dependency is decreasing because of other factors, including the increasing cost of oil development, environmental improvement contributions and maintenance costs, development, pollution abatement cost, etc.

Nuclear Decommissioning Industry

In April 2019, the Korean government held the 13th contingency meeting to revitalize the economy and announced strategies to foster the nuclear decommissioning industry, including plans to establish nuclear decommissioning research centers. The announcement noted that the global nuclear decommissioning market will expand from the mid 2020's and will become worth KRW 546,000 billion. However, the domestic nuclear industry has been focusing on construction and management activities and has not yet decommissioned any NPP. Post-management processes, such as decommissioning, are in their initial state as Korea lacks a related industrial base, work force, and technologies when compared with countries such as the USA, the UK, and France. The government intends to cultivate nuclear decommissioning as a new axis of the nuclear industry and occupy 10% of the global market share by 2035.

01

Nuclear Power Generation

Definition and Scope of Technology

Nuclear energy can generate electricity by converting nuclear fission energy, equivalent to the amount of mass lost from the nucleus based on Einstein's general theory of relativity. A nuclear power generation system comprises a nuclear reactor in which nuclear fission occurs, generating heat, a transfer system that delivers the heat generated in the nuclear reactor to a turbine, and a turbine that converts the delivered heat energy into electricity.

The nuclear reactor, which provides a reliable supply of energy, contains nuclear fuel and is equipped with the moderator, coolant, and containment as well as structural materials. The energy generated in the nuclear reactor is transferred to the primary coolant system, and the coolant generates steam through the steam generator in the secondary system. This steam drives the turbine, which produces electricity. The fuels used for nuclear power generation, such as uranium, plutonium, and thorium, are heavy elements that can trigger nuclear fission reactions. Currently, uranium is the only commercialized nuclear fuel. Natural uranium, which contains 0.7% of U-235, a uranium isotope causing nuclear fission, and enriched uranium, which contains 2%–5% of U-235 are the two types of fuel mainly used. The most common forms of nuclear fuel are UO_2 or PuO_2 (mixed oxide).

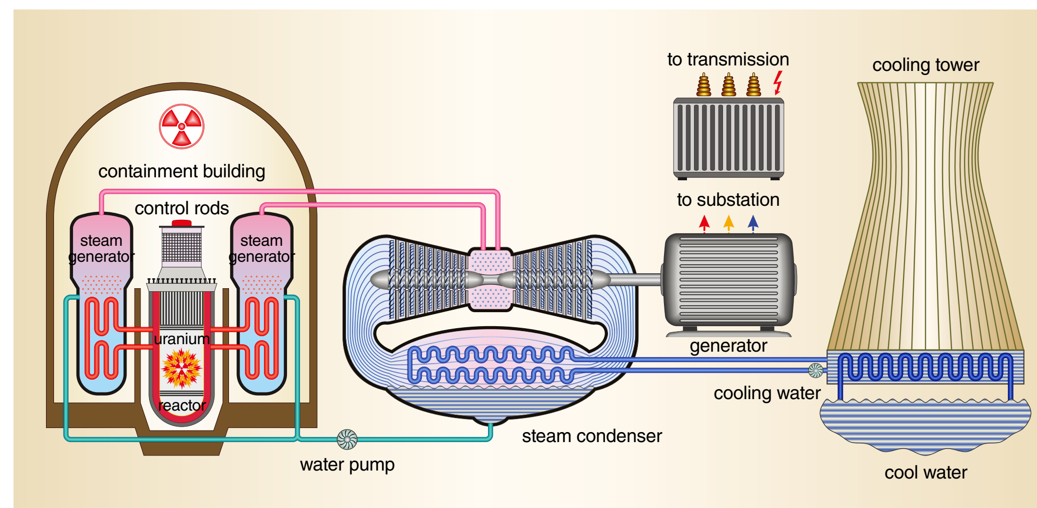

Figure 4 l The operating mechanism of nuclear power generation © shutterstock.com

Next-generation nuclear power technologies will improve the stability and economic feasibility compared with the conventional nuclear reactors using light-water reactor technologies. A nuclear reactor system for the future (GEN-IV) that addresses the requirements of peaceful use and an ecofriendly energy system exhibit the advantages of nonproliferation and low waste generation. In addition, we will explain a nuclear fuel cycle system, which reduces the volume and toxicity of the spent fuels used in light-water reactors and a decommissioning technology that ensures safe and ecofriendly dismantlement of the nuclear facilities.

Key Technology and Research Trends

The USA has been committed to develop small-scale NPPs with strong support from the government. In 2012, the USA launched a program to develop small modular NPPs with an investment of USD 904 million (USD 452 million from the government and USD 452 million from the private sector) to obtain approval for one or two USA light-water reactor designs and begin commercial operation in the 2020s.

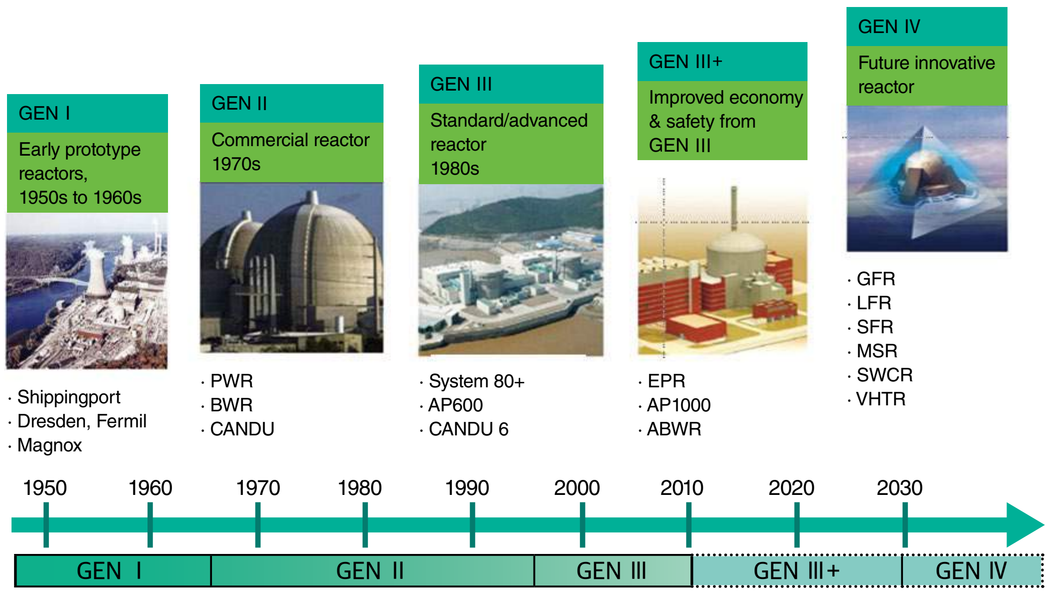

Figure 5 | Evolution of the nuclear power reactors

In the EU, France is the leader in developing futuristic nuclear reactor systems. The French have gained considerable experience with sodium-cooled fast reactors from the development of their experimental reactors Rapsodie (40 MWt) in 1967, Phénix in 1973, and Superphénix in 1985. With the enactment of the Bataille Act in 1991 by the French Parliament, technology development for the past 15 years has been under the review of the Parliament. Under the Planning Act of 2006 regarding the management of spent nuclear fuel, the French have planned to assess the feasibility of commercializing the transmutation processing technology via a sodium-cooled fast reactor (SFR) by 2012, construct a demonstration SFR (ASTRID) by 2025, and begin its commercial deployment in the 2040s.

Table 3 | Major overseas research groups

Group	Nation/Institution	Research description
Complex research group for nuclear power	USA/Idaho National Laboratory (INL)	Development of nuclear energy and sustainable energy systems • Advanced nuclear front-end and back-end fuel cycle technology, reactor systems, safety and risk assessment, space power systems
	France/French Alternative Energies and Atomic Energy Commission (CEA)	Research on energy in France • Research radioactive waste, development of the fourth-generation nuclear reactor system
	Japan/Japan Atomic Energy Agency (JAEA)	Comprehensive research on nuclear energy systems and radioactive isotope use • Decommissioning of the Fukushima reactor and environmental protections; basic and advanced research on nuclear power, high-temperature reactors, and hydrogen production; fuel cycle R&D of fast reactors; R&D on the geologic disposal of high-level wastes
Small modular nuclear reactor development	USA/BWXT	Development of a small modular pressurized light water reactor (mPower) with a module output of 180 MWe since 2009 by establishing Generation mPower through a joint venture with Bechtel, a balance of plant (BOP) design company
	USA/Westinghouse	Design and development of integral reactors with 800 MWt of thermal output and 225 MWe of electrical output
	USA/NuScale Power	Development of an integral pressurized light-water reactor (NuScale) with 60 MWe of output and a full-scale 12-module plant (720 MWe)
	Russia	Development of transportable reactors capable of small-scale power generation and heat supply
	Argentina	Development of an integral pressurized light-water reactor CAREM25 (27 MWe/100 MWt)

In Japan, the Fast Reactor Cycle Technology (FaCT) has been under development since the construction of an experimental reactor (JOYO) and a prototype reactor (Monju) in the 1970s and mid-1980s, respectively. However, the Japanese government decided to decommission Monju and develop a Fast Breeder Reactor (FBR) R&D at Oarai in the Ibaraki Prefecture near Tokai-mura.

In China, an experimental reactor (CEFR) was completed, and full power operations were successfully realized in December 2014. China aims to establish a demonstration reactor (CFR600) by 2023 and a commercial reactor (CFR1000) in the 2030s. China is currently in the phase of light-water reactor construction and has been establishing Sodium-cooled Fast Reactors (SFRs) for breeding purposes. The aim is to use SFRs to improve power generation and resource utilization instead of focusing on issues related to the spent nuclear fuel.

Korea has applied for Design Certification from the USA Nuclear Regulatory Commission for the Advanced Power Reactor (APR) 1400, coordinated by Korea Hydro & Nuclear Power Co. (KHNP) and the Korea Electric Power Corporation (KEPCO), to enhance the export competitiveness of the indigenous NPPs in the global market. Additionally, KHNP aims to meet the European Utility Requirements (EUR) to enter the European market as well as other markets and subsequently satisfy the EUR standards in 2019. In Korea, the SFR research began in the 1980s with small- scale research on basic technology at the Korea Atomic Energy Research Institute. This research was supported by mid-to-long-term planning projects on national nuclear power R&D since the 1997. In 2001, the design concept of KALIMER-150 (150 MWe), a small-scale SFR, was finalized through technical cooperation with General Electric. From 2002 to 2006, the conceptual design of KALIMER-600 (600 MWe), a mid-scale SFR, was developed, and the Generation IV International Forum selected KALIMER-600 as a reference design for future GEN-IV SFR systems. Based on the conceptual design of KALIMER-600, the inherent characteristics of GEN-IV SFR were investigated in 2007–2009. Construction and operation approval is scheduled to be obtained based on the preliminary safety analysis report by 2020 and based on the final safety analysis report by 2026, respectively. The construction of the prototype reactor is intended to be completed by 2028. It is necessary to demonstrate the combustion in the prototype reactor using transuranic waste (TRU) nuclear fuel via pyroprocessing because the objective of the prototype SFR is to address the issue of spent nuclear fuel management.

Table 4 | Major research groups in Korea

Group	Institution	Research description
	Korea Atomic Energy Research Institute	Development of the small integral reactor, future reactor systems, nuclear fuel cycle systems, and core technology for decommissioning
	Korea Hydro & Nuclear Power Central Research Institute	Development of the next-generation light-water reactor and practical technology for decommissioning

Kori-1 Reactor, the commercial operation of which commenced in 1978 in Korea, was permanently shut down on June 18, 2017. The decommissioning process will be accelerated with the approval for decommissioning being expected from the Nuclear Safety and Security Commission by June 2022. The government has increased its efforts to be ready for decommissioning the reactors since 2012 because the country's reactors need to be decommissioned one by one as their lifecycles expire after the closure of Kori-1. The government-led development of core decommissioning facilities is planned to be completed by 2021, and technologies for the commercialization of decommissioning are currently under development.

02

Nuclear Fusion Power Generation

Definition and Scope of Technology

Nuclear fusion is a reaction in which nuclei of lightweight atoms, such as hydrogen, are combined. Nuclear fusion occurs when electrons and atomic nuclei are separated and are in the plasma state. Plasma, the fourth state of matter distinct from the solid, liquid, and gaseous states, is a state in which gas molecules are separated into ions and electrons at a high temperature under the macroscopic neutrality condition. In such a state, light atomic nuclei, such as hydrogen, combine and transform into heavier atomic nuclei, such as helium, resulting in nuclear fusion.

The reduction in mass during nuclear fusion is released as a huge amount of energy called "nuclear fusion energy." The fusion reactor achieves nuclear fusion using deuterium and tritium, the fusion of which can be more easily initiated when compared with the reaction between hydrogen in the Sun. Its primary fuel source, i.e., deuterium, exists almost infinitely because it accounts for approximately 0.015% of the ocean water. Nuclear fusion does not release carbon dioxide during energy generation, and the only byproduct is helium, which is the most stable and harmless element in nature.

Nuclear fusion power generation requires the following three subcategories of technologies.

The first category contains the technology required to maintain high-performance plasma for an extended period of time for obtaining an increased energy output. Conventional nuclear fusion devices cannot sustain high-performance plasma for a considerable amount of time owing to magnetic heating; in this regard, the operations of the ITER and KSTAR, which study nuclear fusion using a superconducting magnet, are expected to demonstrate the engineering feasibility.

The second category includes the technology used to develop materials that can withstand the nuclear fusion conditions. Because nuclear fusion occurs on the Earth at extremely high temperatures exceeding 100 million °C, a reactor that can maintain the high-temperature plasma state should be developed.

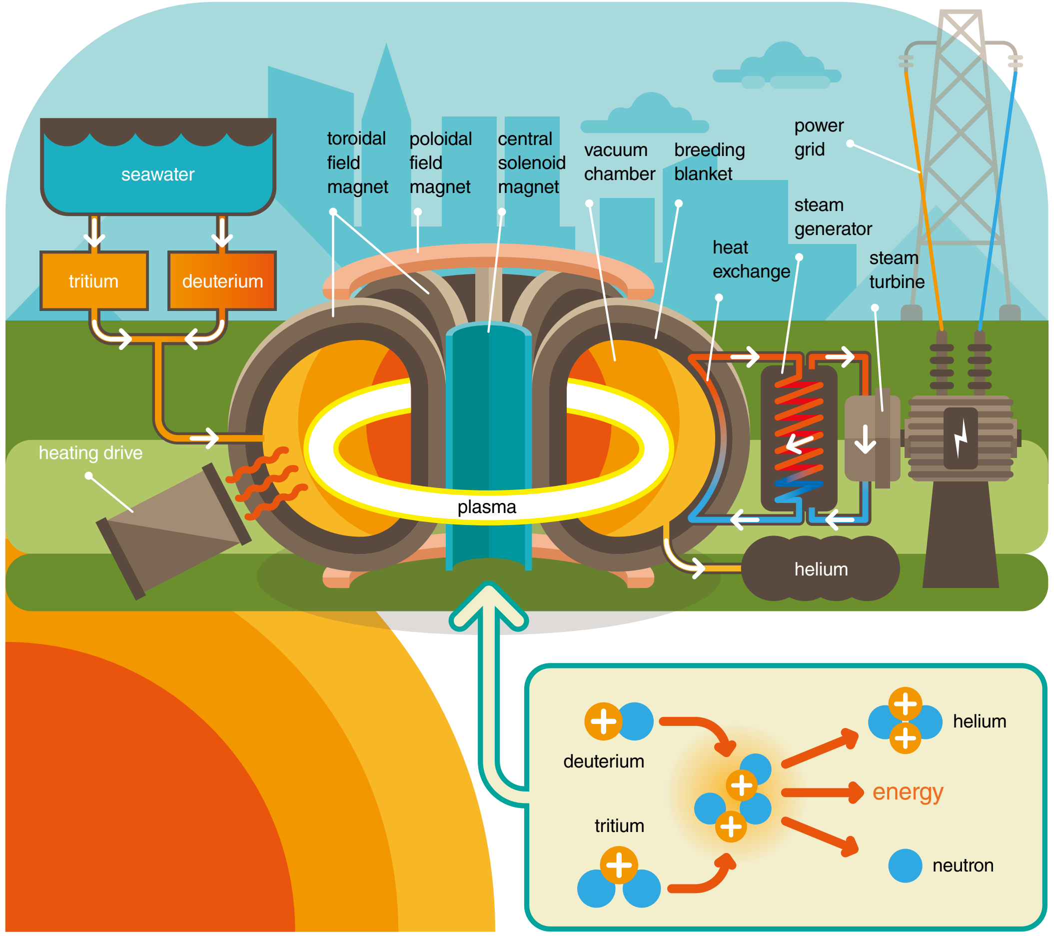

Figure 6 | How nuclear fusion works © shutterstock.com

The third category includes the power conversion technology used to convert nuclear fusion energy into electricity. A fusion reactor will be meaningless if the energy from nuclear fusion cannot be converted into electricity. Because electricity has not yet been generated via nuclear fusion, technologies should be initially developed for achieving efficient conversion and transportation to handle the production of 500 MW of thermal power from the ITER, which is to be operated after 2015 with 10% and higher energy amplification. Particularly, in the ITER, a technology called a "blanket" is applied for the first time, which converts the kinetic energy of the neutrons released via nuclear fusion into thermal energy to generate electricity. The blanket is expected to be the key technology to commercialize the nuclear fusion reactors.

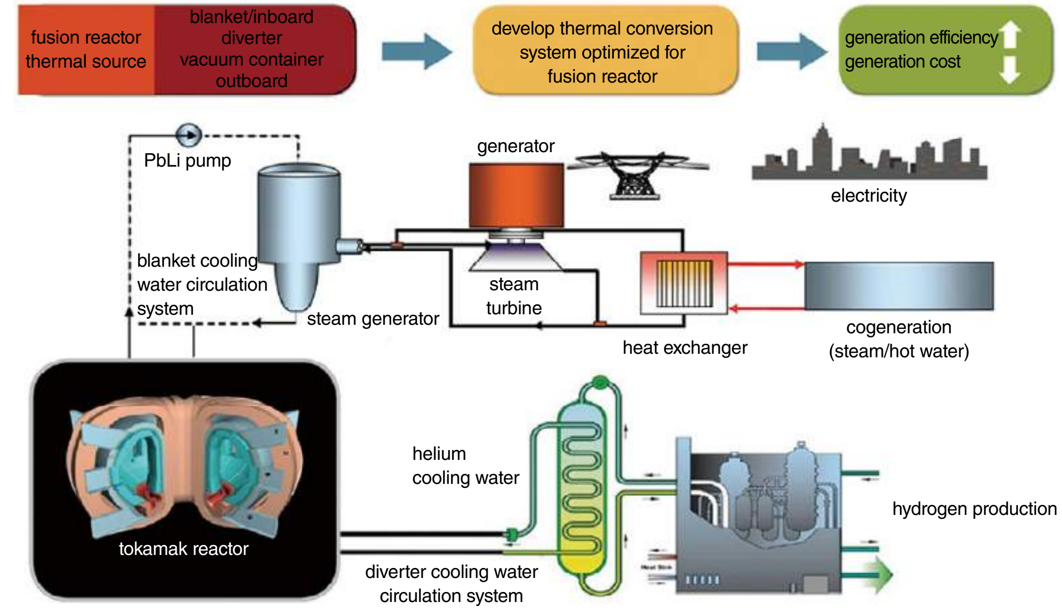

Figure 7 | Nuclear fusion generation

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Key Technology and Research Trends

The USA, along with the EU, has been the largest investor in the R&D of nuclear fusion technology for the previous five decades (contributing USD 950 million, as of 2016). With the increasing corporate interest and investment in nuclear fusion energy from Lockheed Martin (magnetic mirror type, commercialization by 2024) and Tri Alpha (linear reverse magnetic field type, commercialization by 2025), etc., DIII-D (General Atomics) and NSTX-U (Princeton Plasma Physics Lab) are currently in operation as the major nuclear fusion research devices. C-MOD (MIT) device was closed in 2016 for the efficiency of experimental research. NSTX-U was upgraded using an investment of USD 100 million (2012–2015); DIII-D aimed to ensure a heating power of 31.5 MW by 2018 to lead research in the ITER and DEMO (a demonstration power plant).

Meanwhile, the EU, by adopting aggressive policies, modified its roadmap to achieve fusion electricity in 2016 in the background of changes in external factors, such as the extension of ITER; further, the EU has promoted the mission of developing eight fundamental technologies for DEMO construction, which was initiated by the EUROfusion (a consortium of European nations). Under the Horizon 2020 program, EUR 3.07 billion (EUR 2.36 billion for ITER and EUR 710 million for EUROfusion) was planned to be invested in 2014–2018. The D–T (deuterium–tritium) experiment conducted based on the globalization strategy of JET (Joint European Torus), which is the major research device for magnetic field nuclear fusion (tokamak-type), and the technology development for longer plasma operation by W7-X (Stellarator, Germany) have been accelerated.

In 2015, Japan reorganized the Technical Working Group of the Advisory Committee on Nuclear Fusion under the Nuclear Science and Technology Committee and established the Nuclear Fusion Science and Technology Committee and the Task Force to obtain a comprehensive strategy for a prototype reactor. Japan also invested JPY 276 billion (direct costs) in ITER, the Broader Approach (BA) project, and large helical devices in 2016 to strengthen their support for nuclear fusion.

Status of nuclear fusion energy development in Korea

1980s	1990s	2000s	2010s
construction of basic infrastructure	construction of large-scale devices	participation in international joint research	full-scale R&D
SNUT 79 KT-1	KSTAR	ITER	KSTAR operating technology ITER core technology

In South Korea, research on small-scale nuclear fusion devices was initiated in the 1970s. In the 2000s, Korea developed KSTAR (construction period: 1997–2007), which has been operating successfully since 2008. The country has also participated in the joint development project of ITER since 2003 and has established a legal and institutional foundation by implementing the Fusion Energy Development Promotion Act and Master Plans to promote the development of fusion energy (2006–), thereby leading in international fusion energy development. Research on the commercialization of fusion energy and technology development for a Korean-type reactor is currently underway; this research is led by NFRI, which is the only national institute dedicated to fusion energy development, with three other hub centers, i.e., Ulsan Institute of Science and Technology (UNIST), Korea Advanced Institute of Science and Technology (KAIST), and POSTECH. Korea has obtained outstanding research achievements in this field using KSTAR. In 2016, the operation of high-performance plasma (H-mode) was successfully maintained for 70 s, and a groundbreaking physical theory regarding turbulent flow on plasma surface was presented; this flow was confirmed and measured for the first time in the world and can be used to suppress plasma decay. Under the 3rd Master Plan to promote development of fusion energy (2017–2021), research and development were conducted to meet the goals to accelerate core technology development for K-DEMO, strengthen the research foundation and human resources system, and expand the support basis for fusion energy development.

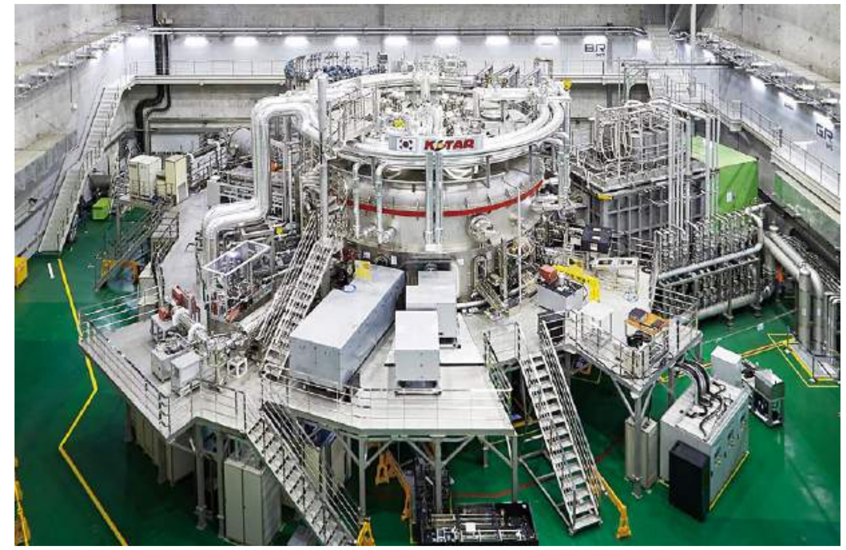

Figure 8 | Research equipment at KSTAR © National Fusion Research Institute

ITER Project

Korea and other ITER members (the EU, Japan, the USA, Russia, China, and India) are collaborating to develop the ITER (a demonstration fusion power plant that will produce 500 MW of thermal power and demonstrate the possibility of generating electricity via nuclear fusion) to achieve core technologies for developing nuclear fusion plants by building an experimental nuclear fusion reactor. The ITER project is a great joint project designed to prove the feasibility of the engineering aspect of nuclear fusion as a large-scale energy source on Earth. The ITER is based on research results obtained from the past half century and aims to secure energy sources for the future, which is a global issue.

The ITER is a tokamak developed to maintain nuclear fusion for a long time via deuterium–tritium (D–T) nuclear fusion with 500 MW of thermal power and 10% and higher energy amplification (Q).

The ITER members signed the ITER Agreement in November 2006; the ITER project has been undergoing since the ITER organization was officially established in October 2007. Korea, as a follower country, joined the project in June 2003 to reach and ensure the level of nuclear fusion technology accumulated by developed countries. The project aims to build the facility in 2007–2025 and begin nuclear fusion energy demonstration experiments in 2025.

The ITER members jointly invest in equipment manufacturing, organization management, and joint R&D. Tokamak building construction is underway in Cadarache located toward the south of France: Each member manufactures its own allotted portion and supplies it, and the delivered parts are assembled on site. Specialists from among the ITER members are sent to the ITER organization for construction.

03

Clean Thermal Power Generation and Efficiency

Definition and Scope of the Technology

Clean thermal power generation is considered to be a hybrid power generation system in which power can be generated from the synthesis gas [CO + H_2], produced by the reaction of coal with oxygen and steam under high temperature and pressure. It is an ecofriendly and clean coal power generation technology with higher efficiency and lower pollutant generation when compared with those of a conventional pulverized coal power plant. This technology exhibits high efficiency (currently 39%–43% or 46% in case of high-performance green technology with higher heating values at the sending end), is environmentally friendly (with a desulfurization rate of 99.9% and nitrogen oxide (NOx) concentration of 22 ppm), and reduces CO_2 emissions by 15% when compared with conventional thermal power generation (>90% in case of Carbon Capture Storage (CCS)). Gasification technology, which forms the basis for IGCC, is a core technology that can be linked to the hydrogen production technology developed by FutureGen, coal-to-liquid fuel technology, Synthesis of Natural Gas (SNG), production of chemical materials, and combined generation technology for Integrated Gasification Fuel Cells (IGFCs).

IGCC is an integrated process technology that requires several subordinate technologies. First, IGCC involves the gasification process technology for gasifying coal using oxygen under high temperature and pressure, obtaining a synthesis gas mainly comprising CO and H_2. Thus, this process incorporates technologies from related fields, including high-temperature and high-pressure gasification, coal preprocessing and transfer, oxygen supply, oxygen separation, coal gas cooling, and processing of slag emissions.

Second, IGCC involves the technology used to purify and generate the synthesis gas. The purification technology allows the appropriate and economic elimination of impurities, such as sulfur and ash, which contaminate the synthesis gas produced by gasification. The generation technology for synthesis gas is used for primary power generation by burning the synthesis gas in a gas turbine and for secondary generation by operating a steam turbine using the steam produced from the high-temperature emissions of the gas turbine.

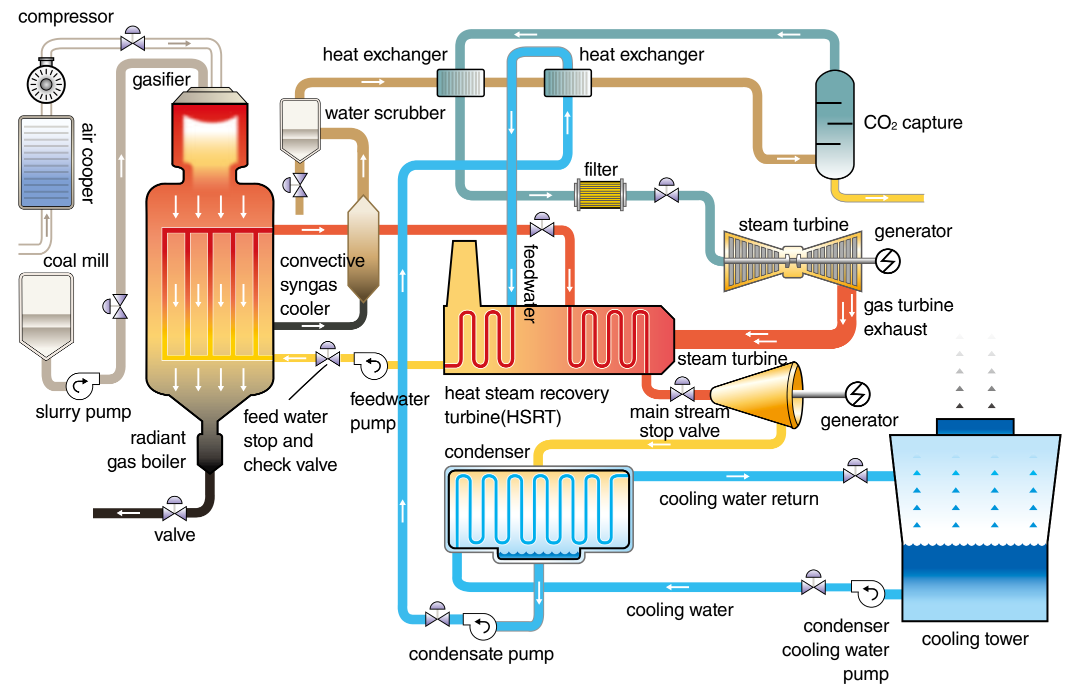

Figure 9 | IGCC process diagram © shutterstock.com

Other necessary technologies include those required for cooling the high-temperature synthesis gas, high-temperature filtration, high-efficiency desulfurization, sulfur recovery equipment, gas turbine optimization, and integrated technology for the steam turbine equipment.

Third, IGCC incorporates a technology related to the integrated equipment for the measurement, observation, and control of each process during the operation of an IGCC plant, realizing the stable and efficient operation of the plant.

Technology Trends and Industry Outlook

The USA DOE has listed gasification technology as a core technology under the Vision 21 program and has promoted technology development by focusing on innovation and CCS application. In 2012, USD 16.3 billion (USD 5.9 billion from the DOE) was dedicated to more than 400 projects as a part of the clean coal research program.

In Europe, technology development has been led by Shell (Netherlands), Siemens (Germany), and Uhde (Germany), and technology using mixed fuels (coal + biomass) is currently under investigation. The Nuon Buggenum IGCC plant in the Netherlands, constructed by Shell (operated from 1994 to 2013; closed in June 2013), and the Puertollano IGCC plant in Spain, built by Uhde, represent major advances in this field. Currently, the HypoGen project of the EU is under development; this project explores clean thermal power plants with no CO_2 emissions by integrating technologies for gasification and capturing CO_2, and such plants are expected to be operational by 2020.

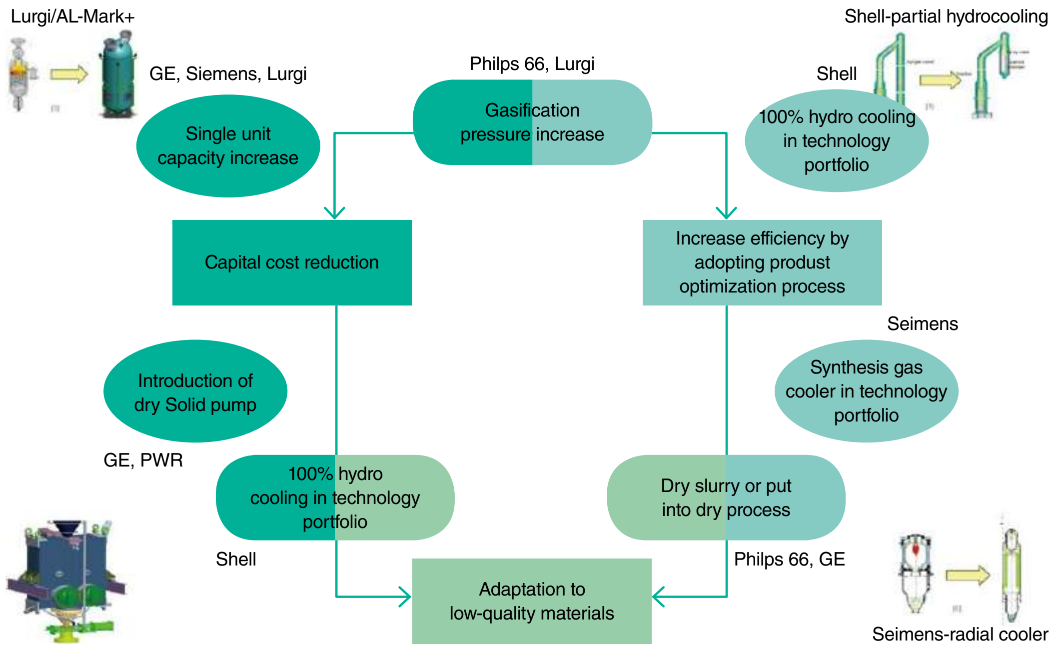

Figure 10 | Technology development process of a synthesis gas plant

Japan has been focusing on the development of a high-efficiency CO_2 capture technology to minimize the CO_2 emissions since the 1970s. Currently, Japan is targeting overseas markets with its own gasification technology. With the launch of its New Sunshine Project by the New Energy and Industrial Technology Development Organization (NEDO), the promotion of R&D on clean coal technology has increased. NEDO's action plans for high-efficiency coal generation have accelerated the advances in IGCC, IGFCs, and the Ultra-SuperCritical (USC) technology, which has a generation efficiency of 41% (net for Higher Heating Value (HHV)).

China has also developed its own gasification technology and is in the early demonstration stages for gaining a foothold in the overseas market. Since the early 1990s, a 250,000 ton/day gasification plant that uses coal has been in operation in China with its own gasification technology. Commercial gasification technologies, including the Opposite Multi Burner developed by the East China University of Science and Technology, technologies by Tsinghua and the Thermal Power Research Institute (TPRI), HT-L technology, Multi-Component Slurry Gasifier technology, and ICC technology, are currently under development.

In South Korea, the construction of a 300 MW scale IGCC plant (Taean), primarily led by the Korea Western Power Co., commenced in 2011. Since its completion on August 19, 2016, the plant has been operated for demonstration and has achieved approximately 800 h of maximum continuous operation (March–April 2017). The equipment optimization will begin after construction for capacity improvement. The field research was terminated by the end of October 2017 following field operation.

Figure 11 | A 300 MW IGCC plant in Taean, Korea Western Power Co., Ltd Korea

The Korea Institute of Energy Research (KIER) is currently conducting R&D on gasification technology for various types of coal by focusing on slurry-feed-type entrained-flow coal gasification. The Institute of Advanced Engineering is also developing a gasification technology for various types of coal by focusing on entrained bed coal gasification technology. They have also developed technology for multiple purposes, such as for refining synthesis gas, producing DME/SNG, and adopting fuel cells for power generation.

The Research Institute of Industrial Science & Technology (RIST) and POSCO are currently conducting joint R&D projects on process optimization, production cost reduction, and equipment improvement to reliably produce 500,000 tons of SNG annually at the Gwangyang SNG plant, which is based on slurry-feed-type entrained-flow coal gasification. Since 2011, RIST has operated laboratory- and bench-scale (1 ton/day) slurry-feed type entrained-flow coal gasifiers, resulting in technology development for material optimization and cost reduction for the commercial gasifiers used in the SNG plants. POSCO adopted the slurry-feed-type entrained-flow coal gasification technology of CB&I and established its SNG plant; this plant is currently undergoing test operation.

RENEWABLE ENERGY

Overview

Definition and Scope of Technology

Renewable energy is the energy obtained using sustainably renewable resources, including sunlight, water, geothermal heat, precipitation, and biological organisms. This term includes solar energy, wind power, hydropower, ocean energy, and geothermal energy and also refers to the energy (including waste energy) that falls within the criteria and scope prescribed by the presidential decree.

The various renewable energy sources are described in brief here. Photovoltaic technology is a power generation technology that converts sunlight into electricity using the photovoltaic effect of solar cells. Biomass refers to the biological organisms produced via the photosynthesis of plants and microorganisms and by the animals feeding on them. Bioenergy is produced when biomass is converted into liquid, solid, or gaseous fuels or electrical or heat energy, either directly or through biochemical and physical conversion processes. Waste energy is obtained when waste is properly processed into fuel and energy resources. Geothermal energy utilizes the thermal energy of soil, bedrock, and groundwater. Ocean energy is obtained by converting the effects of the gravitational interactions of the Sun, Moon, and Earth into electricity; this term also includes the solar energy radiated from the Sun into the ocean. Wind power is obtained by converting the wind-driven mechanical movement of wind turbines into electricity. Similarly, hydropower refers to the electricity generated from the mechanical energy of hydraulic turbines operated by the energy of the falling water.

Table 5 | Subtechnology classification

Subcategory	Technology description
Photovoltaic Energy	Solar cells convert light energy into electric energy via a photovoltaic effect, which is the primary factor that determines the performance and price of the photovoltaic generation system
Solar Thermal Energy	A technology to absorb solar radiation (sunlight) from the Sun and convert it into thermal energy and generate electricity by concentrating solar radiation with high density using thermal generators
Bioenergy	A technology that converts biomass into liquid, solid, or gaseous fuels to obtain electricity or thermal energy, directly or through the biochemical, physicochemical, or thermochemical conversion processes
Waste Energy	Solid, liquid, or gaseous fuels obtained by processing the flammable waste obtained from businesses and households and the energy obtained in the form of heat, hot water, steam, or electricity via the combustion or conversion of these fuels
Geothermal Energy	The thermal energy contained within the soil, bedrock, and groundwater that comprise the underground structure Employed for power generation using hot water with high or medium-to-low temperature, district heating and industrial applications using medium-to-low temperature, and cooling/heating technology using shallow ground heat
Ocean Energy	A technology that converts the energy generated by tides, arising from the gravitational interactions of the Sun, Moon, and Earth, and solar radiation from the Sun into electricity
Wind Power	Wind power generator converts the kinetic energy of wind into electric energy through mechanical movements The generator is equipped with blades, a drivetrain shaft, and a power electronic converter
Hydropower	Various technologies to convert the energy of flowing water into electricity Hydropower generation facilities have hydraulic turbines that convert the energy of falling water into mechanical energy and generators that convert this mechanical energy into electricity

Technology Trends and Industry Outlook

As of 2015, 19.3% of the global energy consumption was derived from renewable energy, i.e., 10.2% from modern renewables and 9.1% from traditional biomass. The thermal energy sources, such as biomass, geothermal heat, and solar heat, account for the greatest share of modern renewables (4.2%), followed by hydropower (3.6%), wind power and photovoltaic (1.6%), and biofuels for transportation (0.8%). In 2016, the renewable energy generation capacity increased to 161 GW, which is a 9% increase from 2015, owing to the fact that the newly established facilities achieved a total cumulative renewable energy capacity of 2017 GW. As of 2016, renewable energy accounted for 62% of the capacity of the newly built generation facilities and 24.5% of the global electricity demand.

The International Energy Agency's report, Renewables 2017, forecasts that the total generation capacity of renewable energy is likely to reach 920 GW by 2022, with contributions of 321 and 438 GW from wind power and photovoltaics, respectively. If the total generation capacity exceeds 8,000 TWh, renewable energy will satisfy 30% of the global energy demand.

Table 6 | Renewable energy generation target portions of major countries

Source: Technology Development and Current Status of New and Renewable Energy, by the Climate Technology Strategy Center, Korea Institute of Energy Research

Country	Renewable energy generation targets (Percentage of the country's energy demand)
USA	28% (by 2030)
China	15% (by 2020)
Japan	20% (by 2030)
Europe	27% (by 2030)

The share of renewable energy in the total power generation of Korea was approximately 7% as of 2016. The Korean government introduced energy transition policies to phase out nuclear power and coal and increase the share of renewable energy, as specified in the "Renewable Energy 3020 Implementation Plan." The essence of this plan is to increase the share of renewable energy to 20% by 2030. Therefore, 95% of the new generating capacity can be attributed to clean energy sources, including solar photovoltaics (30.8 GW) and wind power (16.5 GW). Specifically, the objectives for solar photovoltaic energy will be satisfied by initiating large-scale projects and public engagement programs with respect to private solar photovoltaic systems for homes and buildings as well as small-scale businesses, such as cooperative businesses (co-ops). The government has established specific targets, including the expansion of photovoltaics for urban and rural areas, promotion of co-ops and social enterprises, and the initiation of large-scale projects under public–private partnerships. The government also plans to focus on introducing a Korean-style Feed-In-Tariff (FIT) model, improving the electricity trading system, establishing the foundation for a planned estate system, easing regulations, and promoting public relations.

The issues of gaining local acceptance and selecting installation sites need to be addressed to foster new industries in the energy sector and ensure the stable supply of renewable energy; therefore, various measures have been outlined. The short-term focus for solar photovoltaics will be on R&D projects to reduce unit costs to secure price competitiveness against China as the mid- and long-term goals will involve the promotion of R&D projects to develop next-generation technologies. Therefore, technologies to commercialize thin-film solar cells and processes to ensure flexibility, permeability, and low weight will be developed. With respect to wind power, efforts will be made to reduce the system costs by localizing the core parts in accordance with the development of the high-capacity offshore wind power systems. In addition, there are plans to develop floating offshore wind power systems with the advances in next-generation technology. It is also expected that the establishment of infrastructure for various distributed power sources and service industries will lead to the growth of energy demand and energy management service industries by utilizing the Internet of Energy (IoE).

01

Photovoltaic Energy

Definition and Scope of Technology

The Photovoltaic (PV) power generation technology converts light energy into electricity using semiconductors. The stable operation of a PV system requires various power processing systems, including solar cells (modules). The solar cell, which is the basic unit of solar power generation, is a semiconductor photoelectric conversion device that converts sunlight into electricity.

A PV power generation system generally refers to the integration of solar modules, peripheral devices for storage and control, and related technologies. There are three types of solar power systems: a grid-connected PV system connected to the commercial electric power system, a stand-alone (off-grid) PV system used independently from the commercial power system, and a hybrid PV system. A grid-connected PV system, which is usually employed in buildings and homes and for commercial generation in urban areas, provides electricity directly by feeding the solar power to grid lines, and additional electricity, if necessary, is supplied from the commercial electric power system. A stand-alone system is used in areas where access to the public power grid is difficult or where an independent power system is needed; in such a system, storage batteries are used along with the solar modules to supply electrical power at night or in bad weather and supplement unstable power generation. A hybrid PV system is a stand-alone system that is used in combination with other energy sources, such as diesel and wind power, and processes, such as cogeneration.

Subtechnologies of PV power generation include technologies related to crystalline silicon solar cells, Copper Indium Gallium Selenide (CIGS) solar cells, dye-sensitized and organic solar cells, perovskite solar cells, microinverters that optimize energy production by preventing system power loss because of various causes (shadows of clouds/buildings, contamination, and cell degradation), and monitoring systems that facilitate the checking, maintenance, and control of power generation status for long-term use.

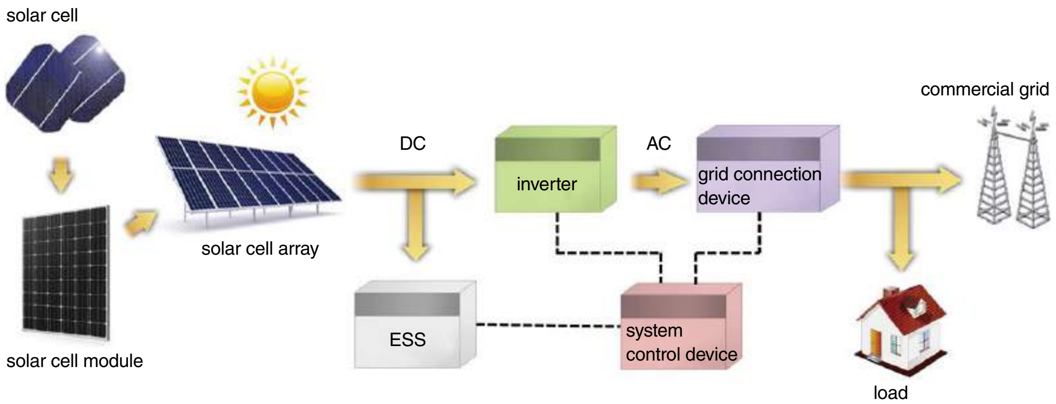

Figure 12 | Components of a photovoltaic power generation system

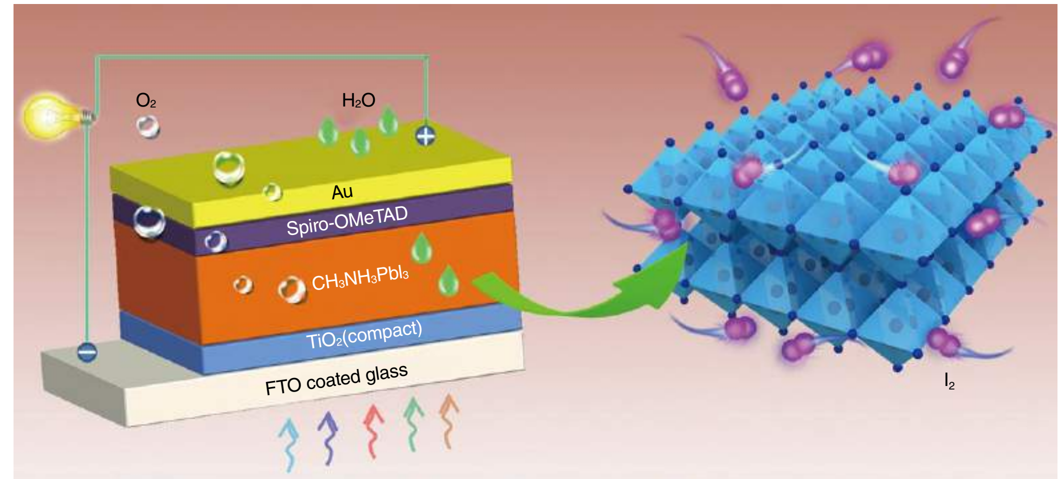

Figure 13 | Structure of a perovskite solar cell
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Key Technology and Research Trends

In the USA, various studies on solar cell technology have been conducted by the National Renewable Energy Laboratory (NREL) and other research institutes and universities. The USA has focused on high-efficiency CIGS thin-film and silicon solar cells since the 1980s. In 2008, NREL claimed the record for CIGS efficiency of 19.9% and realized an efficiency of 20.7% in its recent research on the band edge of light-absorbing materials. NREL also studied organic quantum dots and perovskite. By developing fundamental technologies, impressive results can be obtained with respect to organic quantum dot solar cells, resulting in an efficiency of 13%. Along with studies on the improvement of efficiency, the institute has been expanding its focus to include research on long-term reliability.

In the EU, Germany leads in R&D on silicon, high-efficiency compound semiconductors, and next-generation solar cells. Fraunhofer ISE of Germany, which is the largest solar cell research institute in Europe, has recently become the leading group in the field of crystalline silicon (single crystalline and polycrystalline) technologies, realizing efficiencies of 25.6% and 21.9% for single crystalline and polycrystalline devices, respectively. The institute has also reported the structure of the Tunnel Oxide Passivated contact (TOPcon) and is attempting to enhance the efficiency, scale, and reliability of small-area devices.

In Japan, extensive work has been conducted in the field of heterojunction silicon and CIGS thin-film solar cells. The Hetero Junction-Interdigitated Back Contact (HJ–IBC) solar cells developed by Kaneka Corporation have the highest conversion efficiency of 26.33% in case of silicon solar cells. This was reported in Nature Energy in 2017. Further, many Japanese companies are leaders in the high-efficiency silicon solar cell sector. Panasonic reported a conversion efficiency of 25.6% and Sharp reported a conversion efficiency of 25.1% for the same solar cell structure. With respect to the CIGS solar cells, Solar Frontier set a new world-record efficiency of 23.35% using Cd-free CIGS technology.

As of 2015, Korea's level of technology for silicon-based solar cells was 89.0% that of the USA, the world leader, and Korea ranked fourth among the five major developers (South Korea, USA, Japan, China, and EU). When compared with the technology levels of the USA, the remaining developers are ranked in the following order: Japan (99.6%), the EU (98.5%), South Korea (89.0%), and China (82.7%). In the field of non-silicon solar cells, Korea was ranked fourth at 87.0%. The technology levels for the remaining major developers were 97.3% for the EU, 95.7% for Japan, and 75.2% for China. In the field of perovskite solar cells, a Korean research group holds the world's highest efficiency record of more than 24% based on a research conducted at the Korean Research Institute of Chemical Technology. This research group is conducting research to ensure high efficiency, reliability, and large-area fabrication. Progress in perovskite solar cell research is also being made by other institutes, including the Seoul National University, the Sungkyunkwan University, the Korea University, the Konkuk University, and KIER. With the goal of future commercialization, various studies are focusing on developing new materials to replace lead (Pb), which is the primary element in the perovskite absorber layer, securing long-term stability against moisture and lighting; attempts are being made to integrate the perovskite solar cell with the existing silicon solar cell to obtain multijunction solar cells with considerably high efficiency.

Solar Thermal Energy

Definition and Scope of Technology

Solar thermal energy can be used by directly supplying the thermal energy converted from solar radiation or storing it for future use or generating electricity using heat transfer devices and a power generation system that concentrates solar radiation to achieve high density. In majority of the cases, solar thermal is converted into heat energy.

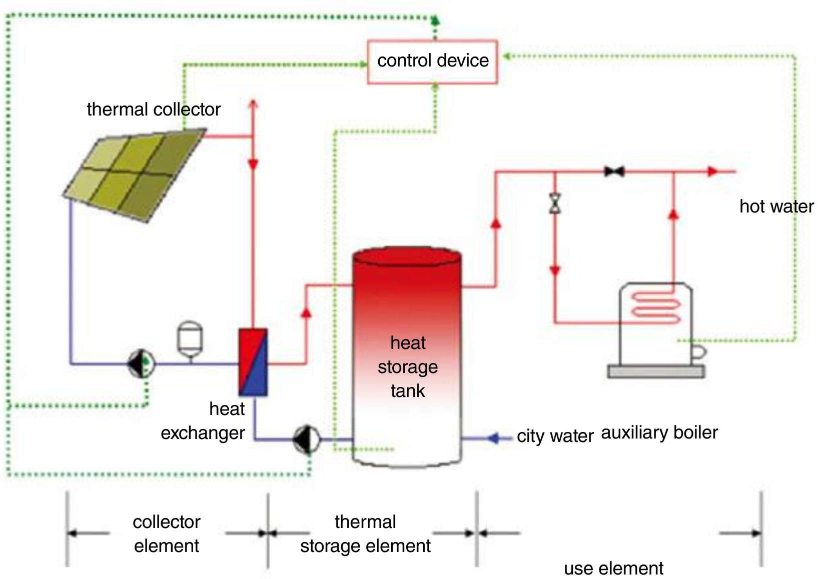

Figure 14 | Active solar thermal system (for hot water and heating)

Solar thermal technology is used for heating water and heating and cooling buildings by connecting the system to an auxiliary boiler and/or electric heating system. This technology is also used for electric power generation, similar to conventional steam generation. It can also collect and use solar radiation instead of fossil fuels to supply thermal energy for heavy industry, engineering, and construction purposes.

Solar thermal systems are usually active solar systems that transfer the thermal energy obtained from solar radiation to a thermal storage tank or another point of utilization using transport devices such as pumps or fans. Subtechnologies for solar thermal energy include technologies to collect solar radiation for hot-water supply and for heating and cooling, produce and store thermal energy, and control devices for operating solar thermal systems.

Key Technology and Research Trends

The USA has been pushing for the development of a solar thermal electric generation system instead of focusing the hot-water supply technology. It aims to secure an economically feasible solar energy electric generation system within a decade without government support. The specific target is to achieve a Levelized Cost Of Electricity (LCOE) of less than 6 cents/kWh by 2020. Further, the objective for absorbers is to achieve 90% efficiency, 10,000 times of lifecycle, and an LCOE of USD 150/kW. With respect to solar fields, the objectives are to secure an accuracy of no more than 3 mrad (1 rad = 1000 mrad), more than 30 years of life cycle, and an LCOE of USD 75 / m. The objectives for power blocks are an efficiency of greater than 50%, an air cooling function, and a unit price of less than USD 1,200/kW. The objectives for heat storage systems are an efficiency of greater than 95% and a unit price of USD 15/kWh. The USA has dedicated USD 127 million to 42 projects to meet these goals.

Figure 15 | Gemasolar solar thermal power plant, one of Spain's solar power plants
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Table 7 | Major research groups in Korea

Group	Institution	Research description
Solar Thermal Convergence Laboratory	Korea Institute of Energy Research	• Establishment of ecofriendly energy towns and research on seasonal thermal energy storage • Thermal energy network based on a solar thermal system and seasonal thermal energy system • Research on solar thermal desalination systems • R&D on Plus Energy Solar House Low-priced heliostats for solar power generation, thermochemical hydrogen research
Professor Hi-ki Hong	Kyung Hee University	• Research on solar thermal systems • Research on thermal energy storage
Professor Hyun-jin Lee	Kookmin University	• Research on solar photovoltaics/thermal hybrid
Professor Tae-Bum Seo	Inha University	• Research on collecting mid- and high-temperature solar thermal energy • Research on solar thermal energy for industrial process

In Europe, the use of low-temperature solar thermal energy has been more pervasive for developing solar thermal technology. Considerable research effort in Europe has been dedicated to reduce costs and realize mass production and high efficiency by developing new materials. In 2014, the International Energy Agency Task-39 completed its study on the development of a solar collector and its system using polymers, which was launched in 2006. The objective of this study was to stabilize the rising costs of copper and aluminum and utilize highly workable polymers; in this regard, some products have already been developed.

China's installed capacity of solar collectors accounts for approximately 60% of the global market, and it has shown the fastest growth rate in this sector. Further, China aims to expand the use of solar thermal energy by employing it for industrial processes and not confining it to hot-water supply and heating for residential buildings. In particular, the reduced unit cost associated with collector production in China is expected to increase the competitiveness of the country in the field of solar thermal facilities for industrial processes. Projects are also underway to develop a Compound Parabolic Collector (CPC) for mid-temperature applications and heat pumps that do not require an additional heat supply system. The Institute of Electrical Engineering/Chinese Academy and Science and Shanghai Jiao Tong University are leading the "solar thermal electric generation project" for the western provinces with high insolation to provide related technologies relevant to the domestic Chinese market.

In Korea, an eco-energy town project by the Ministry of Science and ICT was completed in Jincheon County in the North Chungcheong Province. One of the objectives of the eco-energy town project led by KIER was to develop a heat supply system, including solar thermal systems and seasonal thermal energy storages, and conduct empirical operation of this technology. In addition, zero-energy solar houses that employ renewable energy systems, including a solar heating and hot water system, a geothermal heat pump system, and a photovoltaic system, have been developed. Other studies were designed and conducted with respect to solar thermal desalination, operation of a solar thermal system connected to fourth-generation district heating, and the application of solar heat for industrial processes. With regard to mid- and high-temperature solar thermal systems, a solar thermal electric power pilot system with a 200 kW scale was developed using domestic technologies. However, it is difficult to secure the domestic market and it cannot be activated because of the low solar insolation in Korea. Additional research is currently underway to support Korea's entry into the overseas market.

03

Bioenergy

Definition and Scope of Technology

Bioenergy production technology deals with the conversion of biomass into liquid, solid, or gaseous fuels; electricity; or heat via biochemical, physicochemical, and thermochemical conversion processes. Biomass refers to biological organisms, including plants and microorganisms, which have been produced during the process of photosynthesis and because of animals feeding on them. Biomass also includes various animals, plants, agricultural byproducts, wood byproducts, food waste, and energy crops that have been cultivated to produce bioenergy.

Because various biomass resources can be converted into different types of bioenergy, the bioenergy production technology can be divided into three subcategories: technologies to utilize organic wastes, such as livestock manure, sewage sludge, and food waste, technologies to produce transportation biofuels from oilseed crop, starch crop, trees, and straw, and technologies to utilize lignocellulosic biomass, such as the materials originating from crops, wood, wood waste and its byproducts, as well as urban waste

Table 8 | Criteria and definition of bioenergy

Energy source	Candidates for renewable energy generation	
Bioenergy	Criteria	1) Gaseous, liquid, or solid fuels converted from biological organisms 2) Energy generated by combusting or converting fuels from 1) * When energy from 1) or 2) is mixed with that generated from petroleum products apart from new and renewable energy sources, only the energy from biological organisms is included in the term
	Scope	1) Biogas, bioethanol, bio-crude, and bio-syngas converted from biological organisms 2) Landfill gases converted from organic waste of landfills 3) Biodiesel converted from plant and animal fats and oils 4) Solid fuels, such as converted firewood, wood chips, wood pellets, and charcoal, obtained from biological organisms

Biomass can be categorized into liquid fuels, such as bioethanol and biodiesel, solid fuels, such as wood pellets and wood chips, and gaseous fuels, such as methane. In another classification scheme, the bioenergy technology includes biofuel production for energy generation (producing heat and electricity), biofuel production for transportation (using biodiesel and bioethanol), and bio-refinery (producing heat and electricity from byproducts).

Figure 16 | A bioethanol plant in Rotterdam, Netherlands © shutterstock.com

Key Technology and Research Trends

In the USA, efforts are being made under the Renewable Fuel Standard 2 (RFS2) to extend the supply of the transportation biofuels based on nonfood feedstocks, including lignocellulosic biomass. The Energy Independence and Security Act mandates that the country's fuel supply should include 36 billion gallons of renewable energy by 2020 and that the oil imports should be reduced by a third by 2025. The USA is the largest bioethanol producer in the world, producing approximately 5 billion gallons of ethanol annually, mainly from corn starch.

In Europe, the Renewable Energy Directive mandated in 2009 that 10% of energy in terms of the transportation fuels should be produced from renewable sources by 2020, increasing the share of bioenergy from 5.75% in 2010. The target is that the share of biofuels should be 90% of the renewable fuels. Incentives for blended diesel and government subsidies for energy crops have been introduced in Germany, France, and Italy to promote the use of biofuels. Thus, the production of biodiesel and biogas from rapeseed, used frying oil, and lignocellulosic biomass has increased. Europe currently produces 41% of the world's biodiesel supply.

Meanwhile, since 2002, Japan has actively implemented policies on biofuel development and supply based on its comprehensive biomass strategy.

Table 9 | Major research groups in Korea

Group	Institution	Research description
Bioethanol production	Changhae Ethanol	Developed the nation's largest bioethanol distillation facility and conducts an ongoing research on bioethanol
	SK Innovation	Developed the bioethanol production technology
	Rural Development Administration	Developed the biofuel production technology using agricultural biomass
Biobutanol production	GS Caltex	Developed a technology for the commercial production of biobutanol using lignocellulosic biomass
Biodiesel production	SK Chemical	Produced biodiesel using high-acid-value oils and fats
	Dansuk Industrial	Produced biodiesel using low-grade oils and fats
	Aekyung	Produced biodiesel and established glycerin-refining facilities
	M Energy	Developed a biodiesel production technology by employing a heterogeneous complex catalyst
Bio heavy oil production	SK Chemicals	Developed a technology for bio heavy oil production using the oleic acid derived from animal and plant sources
Pyrolysis oil production	KIST	Research on the deoxygenation-upgrading catalyst reaction of the biomass pyrolysis oil
	Seoul National University	Research on the pyrolysis process of various biomass resources
	KIER	Developed a technology for pilot-scale pyrolysis reactor operation and supercritical upgrading of the pyrolysis oil
	University of Seoul	Research on the biomass and catalytic pyrolysis processes
	KIMM	Developed a technology for pilot-scale pyrolysis reactor operation and pyrolysis oil stabilization

The biofuel technology innovation plan that was jointly established by the Ministry of Economy, Trade, and Industry and the Ministry of Agriculture, Forestry, and Fisheries in 2008 aimed to reduce the bioethanol production costs for lignocellulosic biomass to JPY 100/liter by 2015. In 2009, a fundamental law on promoting the use of biomass to comprehensively implement the biomass policies was enacted. Japan has been moving toward a distributed power generation system that utilizes biomass to reduce its dependence on nuclear power after the Fukushima nuclear disaster in 2011. Technological development for the commercial production of lignocellulosic fuel is in progress since the Comprehensive Strategy on Science, Technology, and Innovation was launched in 2014. This strategy proposed the objective of achieving a clean and economic energy system. Japan has also conducted pilot projects on the production and utilization of 3% bioethanol blended in gasoline (E3), produced at seven locations across the country. Japan also imports bioethanol from Brazil for the commercialization of the ethanol production processes using lignocellulosic biomass.

Brazil is the world's second-largest producer of bioethanol. Following the oil crisis of 1975, Brazil adopted ProAlcool, which was the government policy to boost ethanol production as an alternative to fossil fuels. This policy considerably boosted the adoption of bioethanol. Bioethanol is produced in Brazil mainly from sugarcane, and Brazil accounts for approximately 80% of the global bioethanol production along with the USA. Since 2010, 72% of the domestic cars in Brazil are powered by the flex-fuel engines fueled using ethanol, whereas regular vehicles are powered by blending gasoline with 25% ethanol. Brazil plans to increase the share of biodiesel (20%) in diesel blending by 2020, with its current mandatory use of 5% of biodiesel in diesel (BD5) being enforced since 2013. Incentives are also provided for the usage of blended fuels.

In Korea, as of 2017, biodiesel is the only commercially used transportation biofuel. The objective was to supply 5 billion kL of biodiesel at a blend rate of 2.5%, and the blend rate was expected to become 3.0% by 2018. The pilot tests for bioethanol distribution have been completed, and the process is under review for actual distribution. Research on pilot-scale lignocellulosic-based bioethanol production is underway and is being led by SK Innovation, the Rural Development Administration (RDA), and Changhae Ethanol. GS Caltex developed technology for producing biobutanol from agricultural and forest waste and built a commercial biobutanol plant in Yeosu. Following the production of biodiesel, SK Chemicals began the commercial production of bio heavy oil for power generation. A heavy-oil-fired power plant in Jeju produces all of its electricity from bio heavy oil, and the plants located in Pyeongtaek, Daegu, and Ulsan use blends of bio heavy fuel (10%–20%) and heavy oil for power generation.

Research on several aspects is being conducted to develop a technology for operating pyrolysis reactors using lignocellulosic biomass and for upgrading pyrolysis oil for power generation or transportation. Since 2015, 82,000 tons of wood pellets have been produced by 23 production facilities, including those in Yeoju, and wood pellet boilers have been distributed by the Korea Forest Service for household and industrial use to ensure a production capacity of 10 billion tons by 2020. Under the Renewable Portfolio Standard (RPS) scheme, the weighting factors are considered to be 1.0 for typical bioenergy and 1.5 for full-firing lignocellulosic biomass.

04

Waste Energy

Definition and Scope of Technology

Waste energy refers to the energy generated (in the form of heat, hot water, steam, or electricity) by burning or converting the solid, liquid, or gaseous fuels obtained by processing combustible waste from business sites and households.

The waste energy technology is divided into four sub-categories: solid fuel technology, pyrolysis liquefaction technology, gasification technology, and incineration heat recovery technology. The solid fuel technology refers to the technologies used to produce and utilize the Solid Refuse Fuel (SRF), and the pyrolysis liquefaction technology is used to produce and utilize the pyrolysis oils obtained from polymer wastes. The gasification technology is used for the pyrolysis gasification or anaerobic gasification of organic wastes, and the incineration heat recovery technology is employed for the high-efficiency low-pollution incineration of waste and subsequent heat recovery and the usage of this recovered heat.

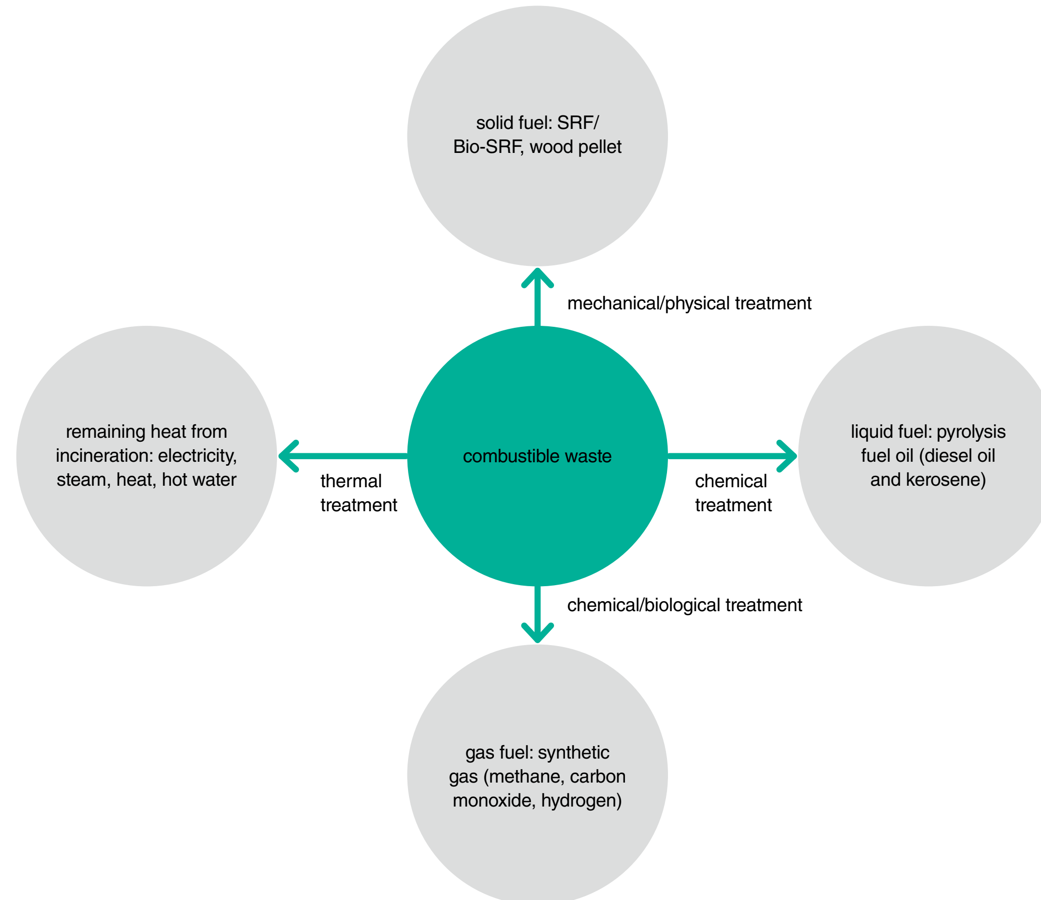

Figure 17 l Scope of waste energy

Key Technology and Research Trends

The USA produces the largest volume of waste energy in the world. It has promoted waste-to-energy technology since the early 1970s. The USA has a maximum capacity of 2000 ton/day for SRF facilities and 7000 ton/year for pyrolysis liquefaction on a commercial scale. With respect to gasification, Texaco has developed a technology for utilizing entrained bed gasifiers with respect to the coal and heavy residual oil obtained from waste plastics.

In the EU, the Directive on the Landfill of Waste (99/31/EC) issued in 1999 prohibits landfilling of waste that can be converted into energy. Hence, the mechanical biological treatment is facilitated (Trienekens Group, Biodegma, Ecodeco, New Earth, RosRoca, Rumen, etc.); further, the EU has established that the treatment of organic waste and the SRF production process can be combined. Research on improving the efficiency of the fluff-type SRF combustion boilers was conducted by Metzo, ANE, and VTT by focusing on the circulating fluidized bed combustors.

In Japan, joint development projects for SRF technologies were conducted since the late 1980s by more than 20 companies, such as Japan Recycle Management, Kawasaki Heavy Industries, IHI, Ebara, NKK, Kubota, Kobe Steel, Sumimoto Chemical, and J-Catrel, as an alternative to small- and medium-sized waste incinerators. Currently, more than 50 SRF production and combustion plants are in operation. Japan has also implemented waste-to-energy policies and R&D projects to establish a wide-area waste-to-energy processing system. Currently, the five large-scale power plants exclusively used for SRF are operated by Kawasaki Heavy Industries, Hitachi Zosen Corporation, and JFE Engineering.

In Korea, the technological development for SRF production and utilization began in the late 1990s, and the commercial-scale SRF production facilities commenced operation in 2006. Additionally, a technology for SRF combustion boilers and power generation systems that can be exclusively used in the 10–20 MWe SRF plants is being developed.

Figure 18 | Layout of a waste power plant built by POSCO E&C in Poland © POSCO E&C

The SRF demonstration technology is being developed via government-led projects, and the scale of SRF power generation is estimated to reach 50% of the technical level of advanced countries. The technologies under development include high-efficiency low-cost SRF production plants (with heating values of more than 5500 kcal/kg and moisture content of less than 10 wt%), organic waste fuel systems (high-temperature and -pressure hydrolysis reactors are under development), and dry fuel from high-moisture-content waste with ultralow energy consumption (process capacity of 50 kg/h for organic waste and moisture content of less than 8 wt%).

The development of the pyrolysis liquefaction technology was initiated by small- and medium-sized companies in the mid-1990s. Currently, application technologies for rotary kilns, tubular reactors, Continuous Stirred-Tank Reactors (CSTRs), and fluidized bed reactors are under development.

The process capability of waste pyrolysis liquefaction has reached 60% of the leading countries, and a demonstration technology has been obtained for the pyrolysis liquefaction process with an annual capacity of 1,000 tons. The aim of the follow-up commercialization project is to increase the annual capacity to 6,000 tons.

With regard to pyrolysis gasification, pilot studies were conducted on gasification melting furnaces, synthetic gas purification, and utilization technologies. A design technology has been developed for achieving a capacity of 30–50 ton/day. However, the lack of related technology for recovering high-value fuels from synthetic gas poses a challenge to the widespread adoption of gasification plants.

Various types of incinerators, including stokers, fluidized beds, and rotary kilns, have been developed and distributed along with the technology for waste heat recovery. Research on using waste heat from medium-scale incinerators for power generation began in the early 2010s.

Figure 19 | Process of generating energy from waste © shutterstock.com

Geothermal Energy

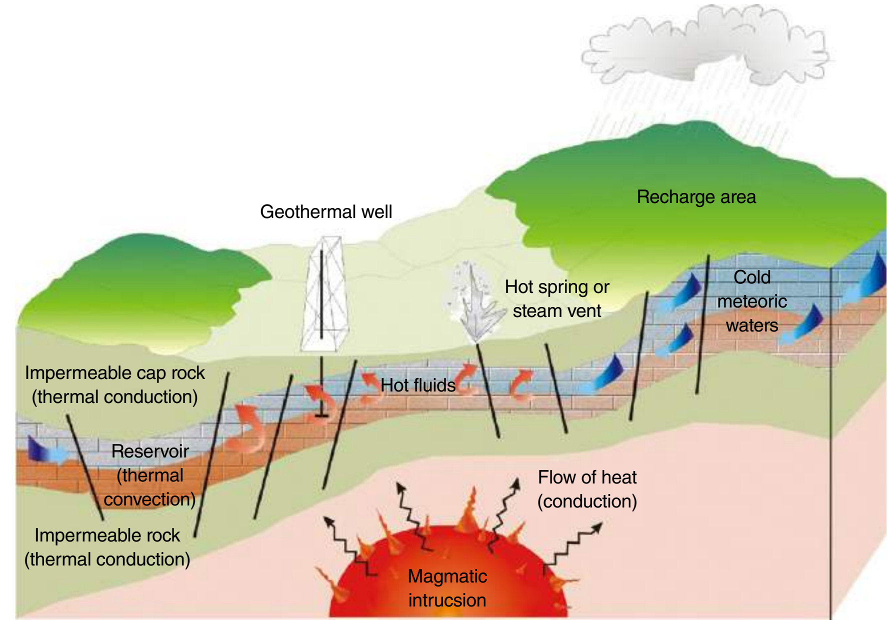

Figure 20 | A schematic of deep geothermal water circulation (modified from Dickson and Fanelli (2004)). When the rainwater that permeates into the ground is heated by a deep thermal source, its density decreases and the water rises along the fracture zones in the bedrock

Definition and Scope of Technology

Geothermal energy refers to the thermal energy contained in soil, rock, and groundwater, i.e., the elements of subsurface formations. This energy is usually in the form of high-temperature heat because the temperature increases with increasing depth; however, it can be used as an energy source if the temperature of this heat is different from the ambient temperature. Furthermore, geothermal energy is barely influenced by the weather conditions and can be consistently accessed.

The geothermal energy technology involves all technologies that explore underground geothermal resources and deal with drilling boreholes or wells to generate electricity and/or supply heat using pipeline networks. Based on the properties of the energy source, the energy sources may be classified as deep geothermal resources having high temperature and shallow ground heat. Furthermore, depending on the form of utilization, the technology may be classified as geothermal generation of electricity (indirect use) and direct use of thermal energy (including a geothermal heat pump).

Subtechnologies include those for exploring and evaluating the geothermal resources, the drilling technology for deep boreholes, the geothermal reservoir engineering technology for the commercial production of deep geothermal resources, the plant technology to generate electricity from the geothermal fluids (water, steam, or water + steam) produced from a geothermal reservoir, and the technology for geothermal heating/cooling systems.

Key Technology and Research Trends

The Frontier Observatory for Research in Geothermal Energy (FORGE) of the USA Department Of Energy (DOE) facilitates the development and testing of the Enhanced Geothermal System (EGS) technologies and techniques, enabling rapid development in this field. FORGE deals with cutting-edge research, drilling, and technology testing and helps scientists to identify the replicable commercial pathways for EGS. In addition, it aids robust instrumentation, data collection, and data dissemination to capture and share data and activities with respect to the FORGE in real time. Its funding opportunity announcement was made in 2014; subsequently, intensive assessments were performed to select the University of Utah as the FORGE site in June 2018 (www.energy.gov/eere/forge/forge-home).

The EU invested in the technological development and R&D of geothermal power generation to ensure market competitiveness with EGS technology. Some European countries led the project to develop supercritical geothermal water by drilling into magma. Other projects implemented by the EU member states are currently underway in the form of international joint research projects, called “Horizon 2020.”

Japan maintained a geothermal capacity of 520 MW over the past two decades. However, since the Fukushima nuclear disaster in 2011, Japan has aggressively introduced renewable energy policies that have resulted in active geothermal projects.

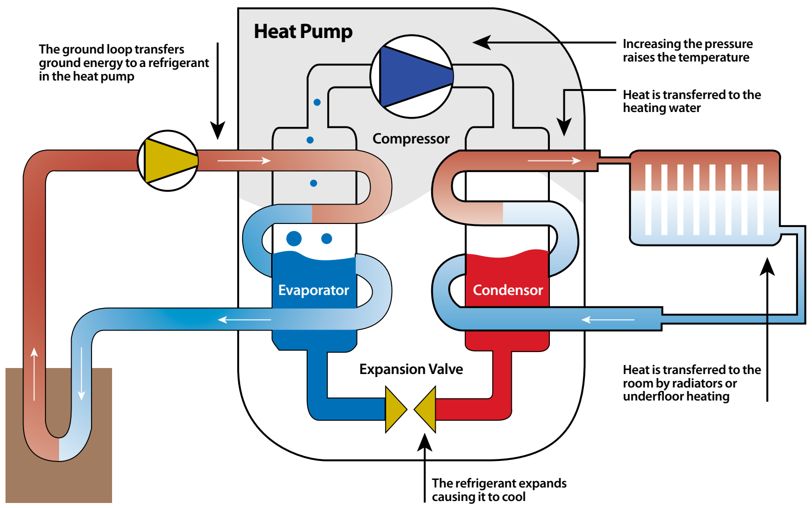

Figure 21 | Operation principles of a geothermal cooling and heating system

One of these policies involves the small-scale binary generation projects that have been established using hot spring water throughout Japan, induced by the newly adopted policies such as the establishment of a strong FIT and the easing of environmental regulations since 2012. As of 2016, 26 new projects were in progress in Japan, with the aim of increasing the share of geothermal power generation from 0.3% of the total power generation to 1%–1.1% by 2030.

Table 10 | Major overseas research groups

Research group	Country/ Institution	Research description
International Center for Geothermal Research	Germany/ GFZ Potsdam	EGS technology development and demonstration - EU Horizon 2020 International joint research projects
Geothermics & Information Systems	Germany/ LIAG	GeotIS development and information services
Geomechanics & Drilling Lab	USA/Sandia National Lab	Deep drilling technology, investigation of the fracture zones in deep bedrock and thermomechanical behavior
Energy & Geoscience Institute (EGI)	USA/ University of Utah	Leading USA DOE FORGE project at Milford, Utah
Energy Geosciences Division	USA/LBNL	Investigation of the thermo–hydro behavior in deep bedrock, survey and interpretation of the microseismicity

The R&D projects on geothermal technology in Korea are supported by research funding for new and renewable energy development projects through the Korea Institute of Energy Technology Evaluation and Planning. Geothermal R&D began in 2001 and has been promoted by companies or joint ventures of companies. The focus was mainly to improve the performance of the geothermal heat pump system and empirical studies. The Korea Institute of Geoscience and Mineral Resources has conducted basic and applied research for utilizing geothermal energy since 2003. These projects include studies on the development and practical use of the deep geothermal water resources in Pohang in the North Gyeongsang Province and the Seokmodo Island in the Incheon Metropolitan City. Other projects include studies on the characteristics of geothermal resources in Korea, for example, the assessment of the potential of geothermal power generation.

Geothermal or ground-Source Heat Pump (GSHP) is another promising area wherein the shallow ground heat of the geothermal resources is used for heating and cooling buildings, residential homes, and greenhouses. GSHP amplifies the difference between the ambient temperature and the temperature of the shallow underground or ground water based on an external electricity input, saving more than one-third of the electric energy needed for heating or cooling. Since its first installation in Korea in 2001, GSHP deployment has considerably increased, with a thermal capacity of more than 1,000 MW in 2016. Further, owing to government subsidy programs and renewable energy deployment policy, Korea has witnessed a rapid increase in GSHP deployment with several new installations having capacities of more than 100 MW each year.

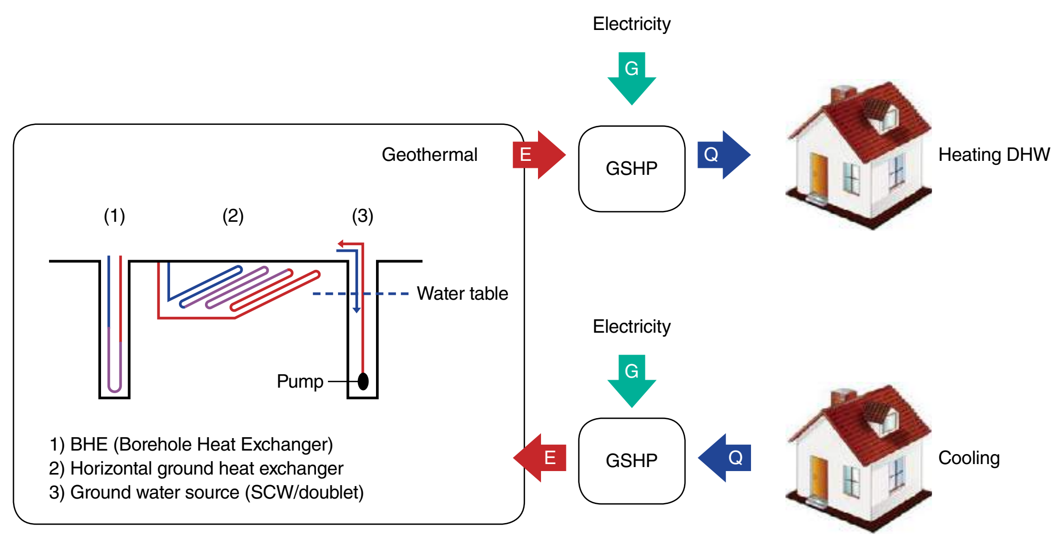

Figure 22 | A schematic showing the energy flow for heating and cooling a residential building using a geothermal heat pump system
© Korea Institute of Geoscience and Mineral Resources

06

Ocean Energy

Definition and Scope of Technology

Various forms of energy can be obtained from the oceans. Tides, which can be attributed to the interactions between celestial bodies, are the most regular form of dynamic motion in the ocean and are the only renewable energy source with accurate long-term predictability. Hence, the systems, such as the tidal barrage and tidal-current-based systems, present a predictable generation capacity regardless of the weather.

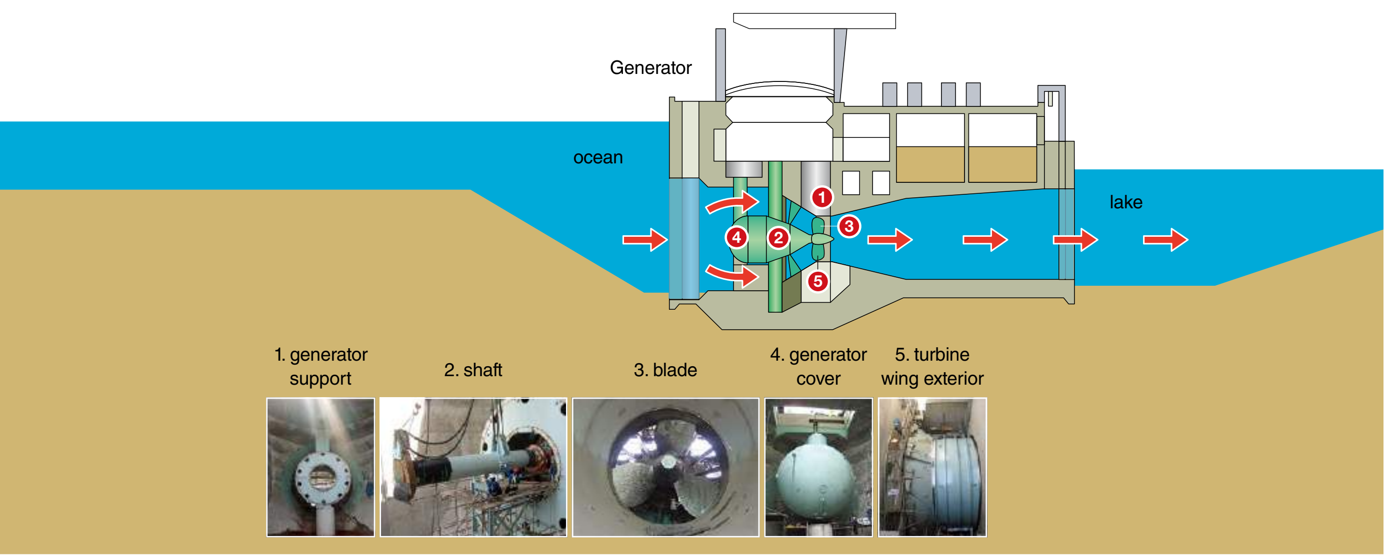

Figure 23 | Principles of tidal barrage power generation
When the level of water outside the tide embankment increases during a high tide, the potential energy of water increases. As the water passes through the installed generator, it turns the blades and induces electricity in the generator coil connected to the shaft. The turbine generator is the core facility that produces electricity in the tidal barrage power plant. The numbers in the schematic correspond to the numbers in the photographs.
© Science Dong-A

The various forms of ocean energy include tidal current, wave energy, and ocean thermal energy. Tidal current power harnesses the kinetic energy of the tides created from tidal movements and geographical influences. This power is used to operate turbines without establishing a large-scale dam for storing volumes of seawater. In tidal barrages, large dams and sluice gates are built along the coast. The barrage system utilizes the difference in water levels between high and low tides to convert the rotational energy of turbines into electricity.
Wave energy converts the kinetic and potential energy of waves into electricity by turbines, mechanical equipment, or hydraulic systems. Ocean thermal energy directly harnesses thermal energy for a cooling/heating system or produces electricity by utilizing the temperature gradients using turbines in a heat engine system.

The ocean energy sources should be developed in accordance with the local environment conditions because each energy source has its own characteristics and resources are unequally distributed over different regions. Korea has large resources for tidal current and tidal barrage power along the west and south coasts. The southern coast and Jeju Island also have potential for exploring wave power, whereas the ocean thermal energy can be harnessed along the east coast.

Key Technology and Research Trends

As a leader in renewable energy development, Europe is expected to achieve commercialization and feasible commercial development of ocean energy after 2020. The UK, which has considerable expertise in this sector, established the European Marine Energy Centre (EMEC) and National Renewable Energy Centre (NAREC) to verify the technical feasibility of the ocean energy technologies while taking a leading role in setting the standards for the renewable energy industry in the areas of industrial health, safety guidelines, certification, design criteria, reliability, maintenance, and lifecycle of the ocean energy technologies.

Since the oil crisis of 1973, the USA has developed ocean energy technology, focusing on turbine technologies and ocean thermal power generation. A 50 kW closed Mini-Ocean Thermal Energy Conversion (OTEC) was developed on a test scale in 1979. Thereafter, various pilot and laboratory-scale researches were conducted on ocean thermal power generation. Lockheed Martin and Makai Ocean Engineering conducted a performance test on the 10 MW OTEC facilities using the ocean thermal power generation resources in Hawaii, which is located close to the equator.

Table 11 | Technology level of ocean energy

Nation	Basic research level & gap			Applied and development research level & gap			Technology level & gap		
	Group	Level (%)	Gap (year)	Group	Level (%)	Gap (year)	Group	Level (%)	Gap (year)
Korea	Catch -up	74.3	5.7	Catch -up	75.7	5.5	Catch -up	75.0	5.6
China	Catch -up	65.2	7.0	Catch -up	65.2	6.2	Catch -up	65.2	6.6
Japan	Lead -up	87.8	2.3	Lead -up	90.3	3.2	Lead -up	89.1	2.7
EU	First mover	100.0	0.0	First mover	100.0	0.0	First mover	100.0	0.0
USA	Lead -up	94.8	1.5	Lead -up	95.8	1.6	Lead -up	95.3	1.6

Extensive R&D and demonstration tests on ocean energy were conducted in Japan after the oil crisis in the 1970s. Japan is a world leader in technologies related to ocean thermal, wave, and tidal current power generation. Research on the Darrieus hydro turbine, a vertical turbine for tidal current and ocean wind power generation, has advanced through the flow simulation technology and various experimental studies. Further, the wave power generation device Mighty Whale, an oscillating water column wave power system, has been deployed in the sea by the Japan Agency for Marine-Earth Science and Technology.

Korea is currently closing the technology gap with leading nations, including the USA and European countries. The technologies in tidal current and tidal barrage power generation are nearing commercialization and demonstration phases. Research on system verification with respect to wave and ocean thermal power generation is underway.

After a small-scale helical turbine was tested by the Korea Institute of Ocean Science and Technology in 2003, a 1 MW helical tidal current device was installed in Uldolmok. The testing of a 250 kW tidal current device with an active yaw control system was planned in 2018. The tidal current generation R&D was initiated and led by the Inha University with its research on the feasibility of the tidal current generation and technology development projects. After Ocean Space Inc. and Inha University successfully installed a 25 kW tidal current generation device at the Samcheonpo power plant; a 100 kW high-efficiency floating tidal current generation system was developed and verified in field in Myodo in 2009. An overall feasibility study on tidal barrage power generation on the west coast was conducted in the 1980s in Garolim Bay. The 254 MW Sihwa Lake Power Station, which is the largest tidal barrage in the world, is currently in operation.

07

Wind Power

Definition and Scope of Technology

The wind power system converts the kinetic energy of wind into mechanical energy and then into electric energy. This system comprises a blade that transforms wind into rotational movements, a drivetrain shaft that converts the rotational movements of the blades into electricity, and a power electronic converter that converts the rotational movements into electric energy.

Contrary to the general misunderstanding that wind power generation is only related to wind turbines, it is a combination of various technologies, including wind farm design via the examination of wind resources, system and component development of land and offshore wind power, system transport, installation and construction, operation and management of wind farms, grid connection technology, and certification technology for systems and projects

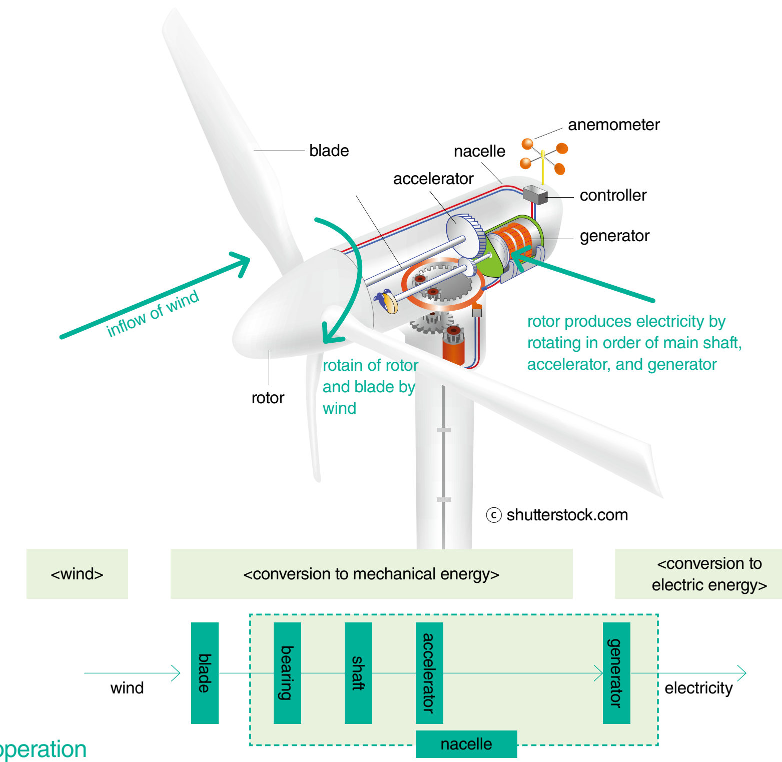

Figure 24
Wind power generator operation

The wind power systems are generally classified into onshore and offshore systems depending on their locations; offshore wind power systems may be either fixed, i.e., installed in shallow sea, or floating, i.e., installed in deep sea, at depths of at least 50 m.

The onshore and offshore wind turbines are similar in design except for their corrosion resistance. However, they differ in technologies for support structures, installation, construction, and maintenance operation. Also, compared with onshore wind farms, the cost of offshore wind farm development is considerably higher because their foundation and Bottom of Plants (BoP) costs are extremely high.

Because wind farms require high developmental costs, the resource evaluation and wind farm design technologies, which improve the annual energy production and assess the feasibility of wind farms, and the technologies to transport, install, construct, operate, and manage wind farms are equally as important as wind power systems and their components.

Key Technology and Research Trends

The LCOE should be reduced to expand wind power generation, and this reduction is significantly influenced by the turbine technology. Various strategies are being explored to increase the efficiency of turbines, including the usage of longer blades to enlarge their surface space, the installation of higher wind towers for faster wind, and the increment of their size to increase the capacity.

The wind power market is mainly centered in Europe and the USA, where relevant research is also in progress. Recently, China too has become a major market. 37% (19.6 GW) of the 52 new GW installations in 2017 were established in China, and active research is being conducted.

Europe is the world leader in the wind power market and technology. Vestas (Denmark) ranks first in turbine production in the world, and five of the top 10 companies in this sector are European. The EU is attempting to increase its wind power generation capacity because the generation costs can be reduced via the usage of large wind turbines. The current technology has an approximate capacity of 10 MW (Vestas 9.5 MW, Siemens 8 MW); further, the EU has announced the launch of next-generation extra-large wind turbine development having capacities of 12–13 MW.

GE Renewable Energy is the only American company (ranked 4th) among the top 10 companies in this sector. Its technology development strategies are similar to the companies in Europe. GE is investing to develop Haliade-X (a 12 MW turbine), which is to be commercialized in 2021; its prototype was installed in the Netherlands in the summer of 2019. In the USA, the extended tax credit for new and renewable energy in 2015 was expected to draw more investment in this sector. An additional investment of USD 25 billion is expected between 2016 and 2021, expanding the wind power market with a capacity of 44 GW. However, because some projects planned in 2016 were delayed until 2017 due to the extended tax credit, a decrease was expected with respect to the newly built capacity.

China too has entered this sector with the National Development and Reform Commission setting a goal of meeting 15% of the total power demand using new and renewable energy sources by 2020. This goal has created a huge domestic market with focused support in China. Currently, three companies in China (Goldwind, Envison, and Mingyang) are among the world's top 10 original equipment manufacturers. Their strategy to reduce the LCOE focuses on increasing the diameter of rotors rather than the turbine capacity. Because the wind resources along majority of the coasts in China are normal, the diameter of the 6 MW turbine rotor (Goldwind) was increased from 155 to 184 m rather than increasing the capacity of the turbine to 10 MW.

Meanwhile, in Japan, the share of new and renewable energy in total power generation is to be increased from 3% to 15% by 2020. Japan has maintained its policy to expand wind power generation by freezing the cost of electricity purchased from large wind farms. Eurus Energy Holdings and J-Power, which are the leading companies in wind power generation in Japan, announced plans to invest JPY 60 billion (approximately KRW 650 billion) each by 2020, and Pattern Energy, a US-based wind power company, announced its plan to build a 1000 MW wind power generation facility via joint venture projects with Japanese companies.

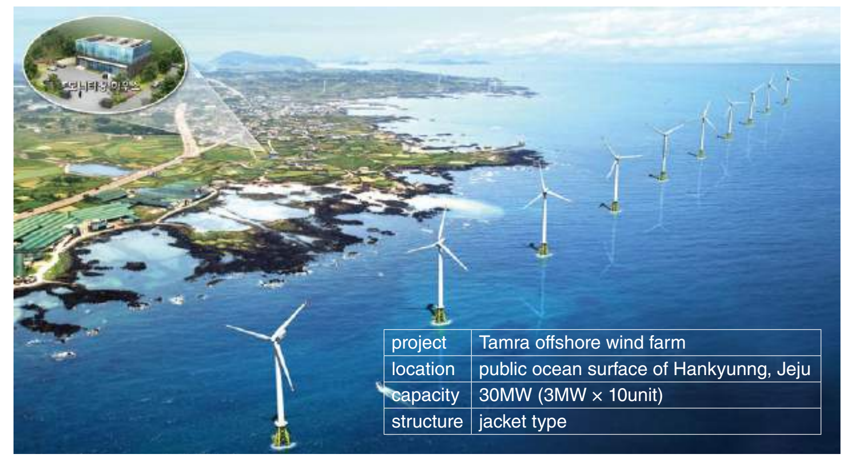

Figure 25 | Layout of the Tamra offshore wind farm © Jeju Special Self-Governing Province

The Korean government published the Renewable Energy 3020 Implementation Plan in December 2017. According to this plan, 20% of the total electricity is to be generated from renewable energy sources by 2030. Accordingly, the 8th Basic Plan for Electricity Supply and Demand expects that the installed capacity of wind power would increase to 177 GW, among which 16.5 GW of facilities should be newly established. Korean companies are putting in efforts for technology development, licensing and M&S to ensure competitiveness to occupy the growing domestic market and enter international markets.

In Korea, 2 MW (6 companies, including Hyosung), 2.3 MW (Unison), and 3 MW (Doosan) onshore wind turbines have been completed and certified. However, sufficient track records have not yet been established. Because large offshore wind turbines increase the cost effectiveness of wind energy, Korean companies have been accelerating their efforts for technology development. The offshore wind turbines of Doosan (3 MW and 5.5 MW) and Hyosung (5 MW) have been certified and are currently in the demonstration stage. Unison has completed the design of 4.2 MW on and offshore wind turbines.

However, international markets require track records to meet the general requirements (annual operation and production volume of more than 100 MW) of international biddings. In the domestic market, it is still difficult to acquire orders because of the competition from foreign turbines with respect to price based on scale economy.

With regard to offshore wind power, the construction costs of fixed support structures, including offshore substations tend to increase with the depth of the water levels; it is estimated that the floating wind farms have a higher economic efficiency than the ones fixed at depths of 50 m and more. The competitiveness of the offshore wind power can be attributed to the development of various support structures, including hybrid and floating wind power systems. In particular, a floating wind power system employs various support structures, among which the forms that have been most researched recently include the semi-submersible type, spar type, and Tension Leg Platforms (TLPs).

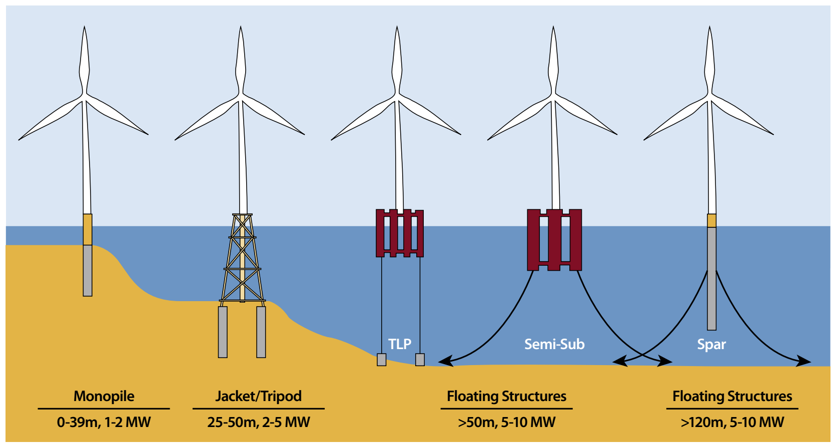

Figure 26 | The offshore wind power foundation structure © EWEA 2013

The demonstration projects are underway in Europe (France, the UK, Portugal, Norway, Germany, and Spain), Japan, the USA, etc. to manifest the notion of floating wind power plants, and commercialization projects are also being planned. Globally, 21 of the 26 projects are demonstration projects; of these, five, such as those in Hawaii, California, and France, are in the commercialization stage. The demonstrated floating offshore turbines have capacities of 2–8 MW. The biggest model is Senvion 8.4 MW from the Kincardine project, which is planned to be installed in Scotland in 2020.

Currently, Korea is trying to secure core technologies for floating wind power projects. A semisubmersible pilot plant with a capacity of 750 kW will be installed in the waters off Seosaeng-my-eon, Ulsan, in October 2019. A spar-type wind power system with a capacity of 5 MW is being designed. The Korean government plans to develop and demonstrate a floating wind power system with a capacity of 5 MW in the future. Further, feasibility studies are being conducted to examine the coexistence of the marine industry (floating offshore wind farms + aquaculture) and wind–hydro hybrid power generation systems, which are expected to result in future-oriented hybrid technologies.

08

Hydropower

Definition and Scope of Technology

Hydropower refers to the electricity generated using the energy of flowing water. Hydropower technologies include the technologies for design, fabrication, and installation of hydropower equipment to convert hydraulic energy into electricity as well as the technologies for testing the performance of equipment and developing hydropower resources.

When establishing hydropower plants, the first technology to be applied is the technology for optimizing the hydraulic design. Once the conditions, including the flow rate and pressure at the installation sites, are determined, the optimal turbine type (Francis, Pelton, propeller, etc.) and turbine characteristics (size and RPM) are determined accordingly.

Once the hydraulic design is completed and applied, the generator in the plant converts the rotational energy of the turbine into electric energy. The main components of the generators are a rotor, stator, shaft, and bearing (for supporting the load and rotating the shaft). The design of the generator requires technologies for conducting electromagnetic field analysis, rotating the machinery design, and realizing unit insulation.

Various factors affect the economic feasibility of the hydropower plants. Their remote location makes it difficult to manage facilities with a local workforce, especially in case of small-scale facilities. Further, the grid connection cost is enormous. Hence, the grid connection protection devices and remote automatic operation technology are essential to secure the stability and economic feasibility of the hydropower generation facilities.

Because it is difficult to alter the large-scale turbines after their construction, it is necessary to possess a technology to conduct performance evaluation based on an identical model turbine. Although the performance evaluation technology is currently specified in the international standards, the technology for performing model performance tests has not yet been completely secured. Therefore, the development of this technology is an urgent task.

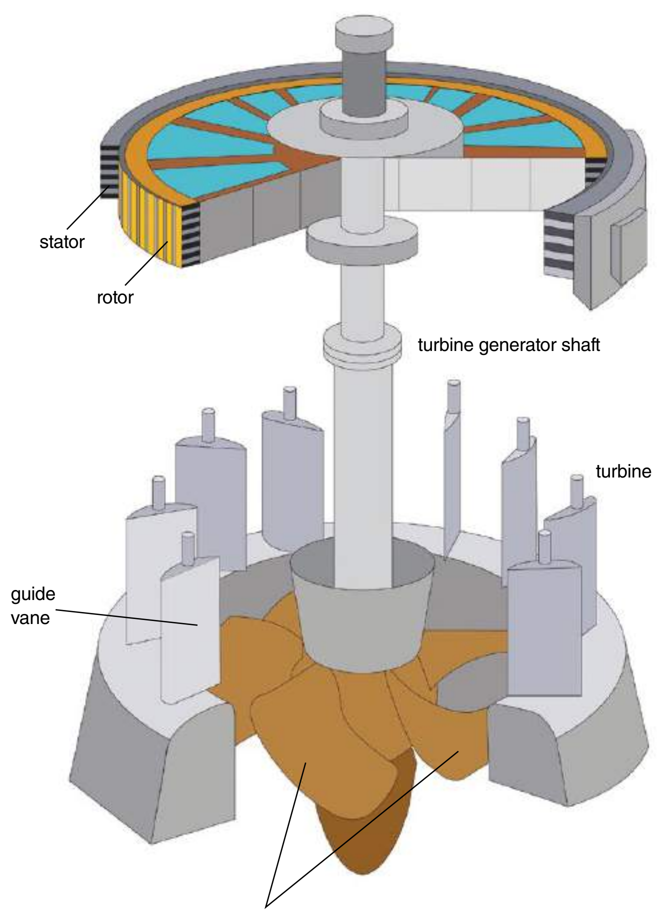

Figure 27 | Overview of a hydroelectric power plant

Figure 28 | The performance test facility for a model turbine

Key Technology and Research Trends

Hydropower has been the primary power source in European countries for a considerably long time. The European countries have a much higher level of technology when compared with other countries. Major global manufacturers, such as Andritz Hydro, GE, Alstom, and Voith Hydro, are European companies. The Federal Institute of Technology Lausanne (EPFL) in Switzerland is recognized globally for its expertise with respect to the design and performance testing of turbines; the EPFL conducts performance tests, which should be performed by a third party, in case of large international projects. Active research is also being conducted with respect to cavitation and water hammer owing to the sudden changes in flow rate.

Japan has adopted an FIT system, which provides JPY 34 for plants having a capacity of less than 200 kW and JPY 29 for those having a capacity of 200–1000 kW. The government support has significantly increased the demands for hydroelectric power. The Japanese government has subsidized large-scale hydropower projects since 2016. In particular, it has spent JPY 1.05 billion annually for its project to promote the commercialization of hydropower generation. To encourage new R&D projects, subsidies of JPY 2.25 billion were invested for the on-site application of newly developed hydroelectric technologies.

Meanwhile, China has a massive domestic market for hydroelectric generation; hence, the government supports local manufacturers. Chinese companies and major manufacturers, such as Dongfang and Harbin, tend to focus on the domestic market rather than the international market. Chinese manufacturers have the advantage of a relatively lower price (40%) than their western counterparts; they also have made advances in terms of new technologies in collaboration with the China Institute of Water Resources and Hydropower Research (IWHR), a state-run research institute, Tsinghua University, and others.

Table 12 | Major overseas research groups

Group	Country/ Institution	Research description
Prof. Avellan	Switzerland/ EPFL	• Performance testing technology for model turbines • Cavitation of the hydropower generation facilities • Flow analysis and testing using computational fluid dynamics
Division of Hydropower	Austria/ Andritz Hydro	• Optimal design, fabrication, and performance testing technology for hydraulic turbines • 26,000 installation cases (245 GW) • Development of optimal operation technology in a limited environment, such as minimizing the effects of silt
Prof. Miyagawa	Japan/Waseda University	• Flow analysis and testing using computational fluid dynamics • Internal and abnormal flow analysis within fluid equipment
Department of Hydraulic Machinery	China/IWHR	• Model hydraulic turbine performance test technology • Cavitation of hydropower generation • On-site performance testing technology for actual turbines

Table 13 | Major research groups in Korea

Group	Institution	Research description
K-water Institute Performance Test Center	K-Water	• Model hydraulic turbine performance test technology based on international standards • On-site performance testing technology for actual turbines • Optimal operation technology for generation facilities • R&D projects for the localization of the hydropower generation facilities
Central Research Institute Hydro Technology group	Korea Hydro & Nuclear Power	• R&D projects for the localization of the hydropower generation facilities • Integration technology for hydropower design and shaft systems
	Daeyang Hydro Shinhan Precision Kumsung E&C	• Hydro turbine design and production technology
Energy Systems Research Center **Green Energy System Technology Center**	Korea Institute of Machinery & Materials Korea Institute of Industrial Technology	• Fluid equipment (turbine, pump) design, performance test technology • Design technology development for new hydro turbines

In the early stages of renewable energy development in Korea (1991–2006), the government investment in the small-scale hydropower sector was mainly with respect to hydraulic turbines. Subsequently, approximately KRW 4.5 billion has been invested, and the government has increased its investment budget as it pushed ahead with empirical research projects that focused on small- and medium-sized hydropower plants. Recently, empirical projects on all processes, including design, fabrication, performance testing, and on-site installation, have been undertaken for medium- and large-sized hydropower generation facilities having capacities of 15–50 MW.

The biggest challenge associated with the installation of a hydropower plant is to secure adequate water resources. With respect to building medium-to-large-scale hydropower plants, it is almost impossible to obtain a site, where there is no complaint from residents or there is minor environmental impact. Hence, constructing large-scale energy production facilities has become a challenge. For each selected target site, hydraulic design has to be completed before the generator design. Such challenges make it difficult for local latecomers to ensure market competitiveness. To solve these challenges, hydropower technologies have been developed by the concerted efforts of state-run companies, such as K-water and the Korea Hydro & Nuclear Power Corporation, universities, such as the Korea Ocean University, Mokpo University, and Yonsei University, and other small and medium-scale enterprises, such as Daeyang Hydro, Kumsung E&C, and Shinhan Precision.

NEW ENERGY

Overview

Definition and Scope of Technology

New energy is defined as the energy sources that have been newly developed to address various problems related to fossil fuels, including pollution and depletion. The common forms of new energy include hydrogen energy, fuel cells, and liquefied/gasified coal. New energy technologies encompass new methodologies of producing energy without being dependent on coal, oil, nuclear power, and natural gas.

Hydrogen can be easily converted into other energy forms and exhibits high potential as an energy storage medium. In addition, water electrolysis powered by the electricity generated using renewable energy, such as wind power and photovoltaics, has been widely used over the previous decade. This process offers the benefits of supplementing the discontinuous nature of renewable energy sources and can achieve high-efficiency production of fuels having wide applicability, including hydrogen.

Hydrogen can also be produced via the photochemical splitting of water with a photocatalyst in water or organic materials, the thermochemical splitting of water using solar or waste heat, and other methods of splitting water using microorganisms.

From the perspective of new energy, hydrogen energy is closely related to fuel cells because they have the highest efficiency among all the energy conversion technologies that use hydrogen. A fuel cell converts the chemical energy of fuel into electrical energy and generates electricity via redox reactions. Because water is the sole byproduct when hydrogen is used as a fuel, pollution-free energy can be generated by substituting other forms of energy, such as conventional fossil fuels, nuclear power, and fuels for internal combustion engine vehicles, with hydrogen.

Table 14 | Subtechnology classification

Subtechnology	Technology description
Hydrogen Production	• Technology development for high-efficiency water electrolysis processes, such as alkaline electrolysis and proton exchange membrane electrolysis, securing the reliability of high-temperature water electrolysis, performance improvement and cost reduction technology • Production and purification technology for hydrogen byproducts • Photochemical water splitting with photocatalyst in water or organic materials, thermochemical water splitting with solar or waste heat, technology for splitting water or organic materials using microorganisms • Hydrogen production from hydrocarbons, such as fossil fuels, technology for system integration and compactification of pretreatment, reformer, heat exchange, and hydrogen purification
Fuel Cell	• Polymer Electrolyte Membrane Fuel Cells (PEMFCs) for portable devices, passenger vehicles, residential buildings, and small-scale distributed generation • Molten Carbonate Fuel Cells (MCFCs) for large-scale distributed generation • Phosphoric Acid Fuel Cells (PAFCs) for large-scale distributed generation • Solid Oxide Fuel Cells (SOFCs) for residential buildings and small-scale distributed generation

Technology Trends and Industry Outlook

The hydrogen energy technology can be applied in various energy consumption sectors and to fuel cell vehicles, domestic fuel cell systems, and small- and large-scale generation systems. The annual global production of hydrogen is estimated to be 65 million tons; it is mainly produced from natural gas, followed by coal and oil. Hydrogen production from hydrocarbons, such as natural gas, generates CO_2, which is the primary source of GHG emissions. The water electrolysis technology produces ecofriendly and carbon-free hydrogen; therefore, this method has been developed as an alternative.

Germany is the world leader in developing new and renewable energy technologies and has strived to ensure the economic feasibility of hydrogen as a primary energy source for the future. Therefore, it has established a long-term roadmap and an appropriate budget. Germany plans to construct more than 10 hydrogen fueling stations in large cities and at least one station after every 90 km on the highways connecting these cities. Thus, it aims to establish 400 stations by 2023.

In the USA, the California Fuel Cell Partnership (CaFCP) has been operated to demonstrate hydrogen fuel cell electric vehicles and establish hydrogen infrastructure. In addition, DOE promotes the demonstration of fuel cell vehicles and its infrastructure through various projects, including the National Hydrogen Light Duty Program.

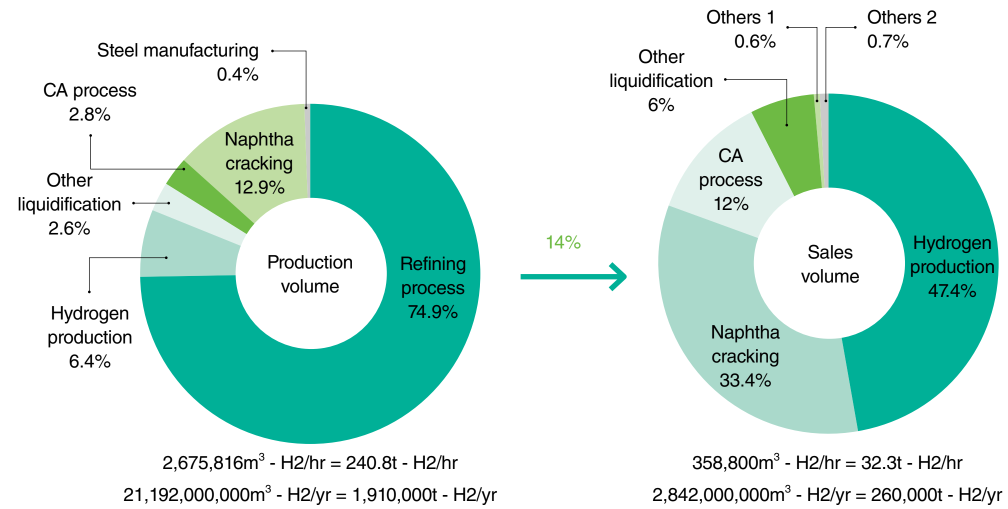

Figure 29 | Production and sales volume of hydrogen in Korea

The automotive industry has been actively engaged in the development of transport fuel cells, and the R&D for stationary fuel cells and the fuel cells for power generation has been mainly led by companies involved in power generation. Beginning with 17,700 units in 2010, the global shipment of fuel cells has reached 71,500 units in 2015, which is an annual growth of 32.2%.

South Korea currently produces approximately 1.9 million tons of hydrogen per year, among which 14% is sold in the market. With respect to the hydrogen that is actually sold, the hydrogen produced and sold by gas companies or generated as a byproduct accounts for 47% of the total sales volume. The sales volume of the hydrogen byproduct is 14 billion tons, and the share available for hydrogen vehicles is 100,000 tons. If each hydrogen vehicle travels 15,000 km per year, each vehicle will consume approximately 200 kg of hydrogen annually, indicating that 100,000 tons of hydrogen can fuel 500,000 units of vehicles annually. In August 2016, the Korean government launched the Hydrogen Fusion Alliance, which is a public–private partnership involving 42 members, including the central government, local governments, hydrogen vehicle part manufacturers, manufacturers and distributors of hydrogen, and companies involved in the building of hydrogen fueling stations. This partnership aims to expand the distribution of the Fuel Cell Electric Vehicles (FCEVs) and charging infrastructure, and the government is gearing up for the establishment of a special purpose company to support the project

Korea has achieved notable advancements in the field of fuel cells, with the success of the world's first mass production of hydrogen fuel cell vehicles and the establishment of the world's largest fuel cell power plants and hydrogen-powered towns. Based on the RPS, Korea has emerged as a testbed for the global fuel cell industry with the rapid growth of the market with respect to fuel cells for power generation; therefore, domestic and overseas companies are vying for market dominance in Korea.

As of September 2017, 160 units of hydrogen fuel vehicles and 11 hydrogen stations are being operated in Korea. Technologies for air compressors, radiators, recirculation pumps, membrane humidifiers, gas diffusion layers, separators, inverters, and hydrogen storage tanks have been localized. The fuel-cell power generation capacity is 262 MW, spread over 36 locations (191 MW for Molten Carbonate Fuel Cells (MCFC) and 70 MW for Phosphoric Acid Fuel Cell (PAFC)). Further, with respect to the usage of fuel cells for distributed generation, Korean-type fuel cells are being developed by incorporating global advanced technologies into domestic technologies.

01

Hydrogen Production

Definition and Scope of Technology

Hydrogen production is an ecofriendly energy conversion technology used to obtain hydrogen through water electrolysis by utilizing renewable energy, including wind power and photovoltaics. The hydrogen production technology is closely related to fuel cells because majority of the fuel cells are powered by hydrogen. Hydrogen is generally obtained by the reaction of fossil fuels, including natural gas or coal, with high-temperature water vapor or via water electrolysis.

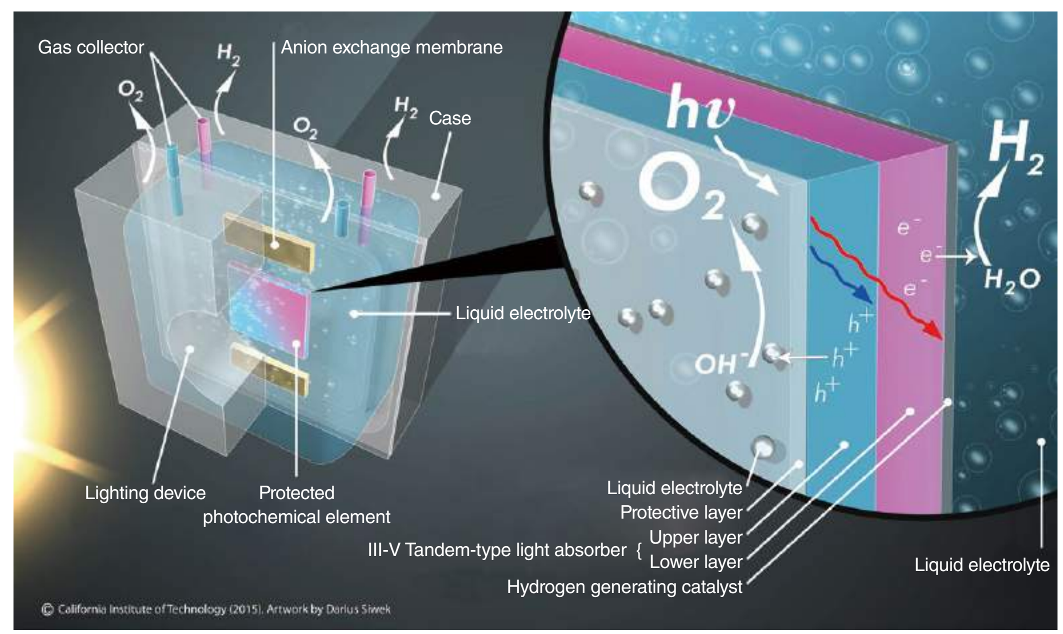

Figure 30 | An artificial photosynthesis device developed by the California Institute of Technology (water electrolysis using sunlight)

Water electrolysis is the decomposition of water into oxygen and hydrogen owing to the passage of an electric current. It is one of the easiest and reliable methods to produce high-purity hydrogen and is suitable for mass production. High-purity hydrogen improves the durability of fuel cells without any pollutant emissions. However, hydrogen production from water electrolysis cannot be categorized as new energy because it consumes electricity generated using conventional sources. Thus, the electricity generated from renewable energy is the most suitable power source for performing water electrolysis, which is considered to be the best method to achieve steady production of electricity and manufacture hydrogen for various purposes because it overcomes the disproportionate and discontinuous nature of renewable energy.

Water electrolysis can be categorized into alkaline electrolysis based on alkaline electrolytic cells, proton exchange membrane electrolysis based on proton transfer polymers, and high-temperature electrolysis using solid oxides as the electrolyte. KOH or NaOH is used as an electrolytic solution in alkaline electrolysis, which is the most common commercially used method. In this method, oxygen is produced at the anode, whereas hydrogen is produced at the cathode. The generated oxygen and hydrogen are separated by a membrane. The setup for proton exchange membrane electrolysis comprises a solid electrolyte membrane that transfers protons, anode and cathode with a metal-containing catalyst, a diffusion layer that transmits water and gas, and a separator. The setup for high-temperature electrolysis comprises a solid oxide electrolyte, ceramic cathode, metal-ceramic anode, separator, and sealer.

Key Technology and Research Trends

In the USA, a system built by AC Transit in 2012 in Emeryville supplies hydrogen to 20 cars and buses each day. Further, a facility built by Proton in Wallington can generate 100 kg of hydrogen daily; this facility is also being operated to fuel the hydrogen fuel cell vehicles.

From the early-2000s to mid-2000s, the alkaline electrolysis technology was jointly developed by GE and Teledyne. Since 2003, research on the integration of wind power and water electrolysis has been conducted by the NREL. Recently, the research on advanced alkaline electrolysis was supported by the DOE's Hydrogen and Fuel Cells Program and the Advanced Research Projects Agency for Energy (ARPA-E).

Table 15 | Major overseas research groups

Group	Country/Institution	Research description
Institute of Engineering Thermodynamics, Solar Research Division	Germany/DLR	• Technology development for alkaline and PEM water electrolysis • Technology for manufacturing steam (VPS) electrode
Global Environment Protecting Technology & Business Promotion Department	Japan/Hitachi Zosen	• Technology for composite catalyst (Ni, Fe, and Co) electrodes • Development of high electric current density, large capacity/size alkaline water electrolysis systems
Fraunhofer IFAM, Hydrogen Technology Department	Germany/Fraunhofer	• Ni- and Fe-based nanoelectrode material • Porous three-dimensional electrode technology • Water electrolysis research on material and electrode test
Nuclear Science and Engineering Department	USA/Idaho National Laboratory	• Large-size planar (electrolyte supporting) • Basic stack unit of 60 cells × 4 modules • Usage of external heat sources and heat waste
Fuel Cell and Solid State Chemistry Division	Denmark/Risoe National Laboratory	• Planar (anode supporting), 16 cm^2 cells • Pressurized operation of the co-electrolysis of carbon dioxide and steam

Table 16 | Major research groups in Korea

Group	Institution	Research description
Hydrogen Research Team	Korea Institute of Energy Research	• Development of high-efficiency alkaline water electrolysis electrodes • Development of alkaline water electrolysis membranes for separation • Development of alkaline water electrolysis stack
Fuel Cell Research Center	Korea Institute of Science and Technology	• Technology development for polymer electrolyte membranes • Technology for metal reduction and electrodes • Technology for membrane electrode assembly • Technology for reversible fuel cells
High-Temperature Fuel Cell Research Team	Korea Institute of Science and Technology	• Technology for preventing electrode delamination • Technology for nanocatalyst impregnation • Technology for improving the stability of bidirectional switch operation
Sang-Bong Moon, CEO	Elchemtech	• Core technology for polymer electrolyte-type water electrolysis • Stack manufacturing technology for polymer electrolyte-type water electrolysis • Hydrogen compression technology

In the EU, a collaboration of companies, including Linde, Siemens, and Stadtwerke Maiz, has studied the establishment of ENERGIEPARK MAINZ in Mainz, Germany (period of study: 2014–2017). Their research intended to develop a 10 MW class wind power generation system, an 8 MW class proton exchange membrane electrolysis system, and a 1000 kg hydrogen storage facility. According to the plans, ENERGIEPARK MAINZ was expected to produce approximately 200 tons of hydrogen annually for nationwide supply after 2018.

Japan has made strategic efforts to increase the distribution of fuel cell vehicles and the related infrastructure with its plan to build 320 hydrogen fuel stations by 2025 and reduce their overall construction costs. From 2014 to 2018, the R&D project on hydrogen production via alkaline electrolysis for the joint operation of wind power generation was undertaken by Asahi Kasei and Hitachi Zosen, which is powered by the leading R&D projects of the New Energy and Industrial Technology Development Organization (NEDO).

Korea possesses technical expertise in the area of water electrolysis. The setup for water electrolysis and its R&D approaches are similar to those applicable for fuel cells. This expertise allows the use of hydrogen energy for various purposes other than for transport. However, technical and industrial infrastructure are still lacking in areas, including renewable-energy-based hydrogen production by water electrolysis, chemical hydrogen storage, and safety/standardization.

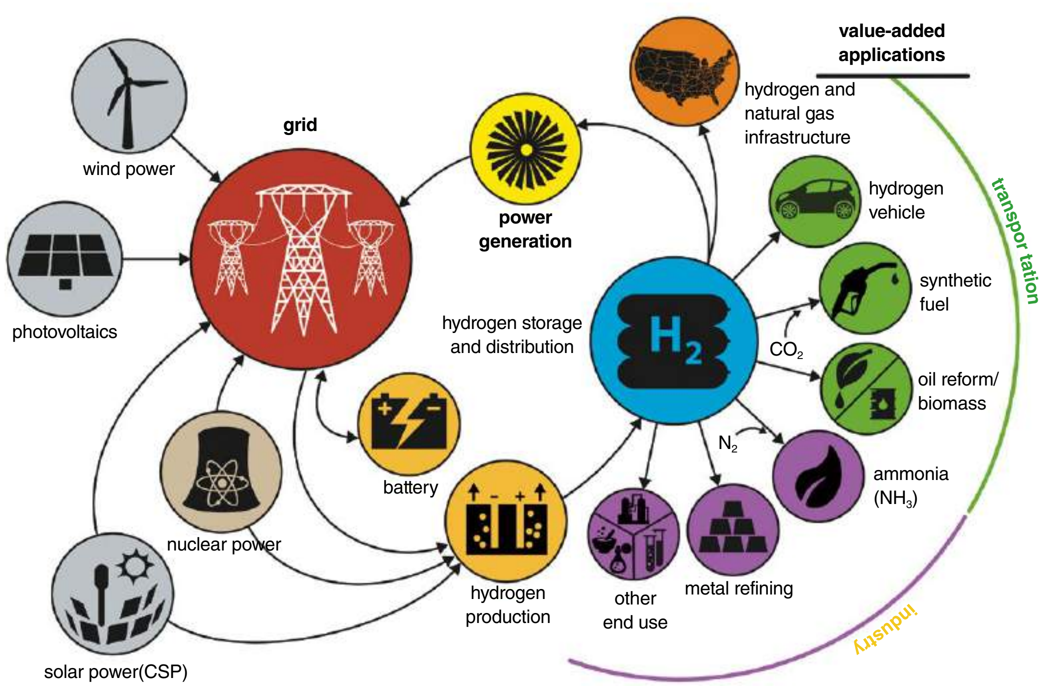

Figure 31 | Concept map of hydrogen economy and society encompassing electric power, transportation, and industry

02

Fuel Cell

Definition and Scope of Technology

MCFCs generate heat and power via the chemical reaction of hydrogen and oxygen (reverse reaction of water electrolysis). Fuel cells minimize pollutant emissions and are an ecofriendly energy source that can sufficiently function as a type of distributed generation system along with photovoltaics and wind power because the efficiency of the hydrogen fuel cells is twice or thrice that of the typical internal combustion engines and water is the only byproduct.

The Polymer Electrolyte Membrane Fuel Cell (PEMFC) contains a polymer electrolyte membrane that separates the anode and cathode sides. It generates electricity through the oxidation of hydrogen at the anode and reduction of oxygen at the cathode.

The MCFC uses molten carbonate as the electrolyte. Oxygen and carbon dioxide are combined at the cathode with electrons from an external circuit, resulting in the creation of a carbonate ion. This carbonate ion is transferred to the anode through the electrolyte comprising molten carbonate. At the anode, the carbonate ion produces water and carbon dioxide as it combines with hydrogen, and the isolated electrons travel through the external circuit, generating electricity.

The Solid Oxide Fuel Cell (SOFC) is a clean energy-converting device with almost no pollutant emissions. It converts chemical energy from air and fuel gas directly into electric and thermal energy through electrochemical reactions at high temperatures of approximately 800°C.

Figure 32 | Nexo, hydrogen fuel cell vehicle manufactured by Hyundai Motors © Hyundai Motors

PAFC uses liquefied phosphoric acid as an electrolyte and works on the same principle as the PEMFC. Because this type of fuel cell can be operated at temperatures of approximately 200°C, it has a higher resistance to carbon monoxide poisoning than PEMFC, and carbon monoxide can be relatively easily removed when connected to a reformer that decomposes fossil fuels. PAFC is mainly used as a type of distributed generation because it uses liquefied electrolyte.

Key Technology and Research Trends

CaFCP. The market for hydrogen fuel cell vehicles is forecasted to increase from 139 units in 2015 to 21,957 units by 2020, with an annual growth rate of 175.2%. Currently, more than 1,000 fuel cell vehicles are in operation in California. Automakers, such as Hyundai and Toyota, whose hydrogen fuel cell vehicles have already been launched in the market have been selling or leasing fuel cell cars in California. The findings from the demonstration projects will be applied to the manufacturing of materials and construction of systems to improve the reliability and long-term stability of the fuel cell vehicles.

Table 17 | Major research groups in Korea

Group	Institution	Research description
Fuel Cell Research Center/ High-Temperature Fuel Cell Research Team	Korea Institute of Science and Technology	• Development of the PEMFC core parts • Technology for the long-term stability of MCFC • Technology for improving the performance and stability of SOFC
Fuel Cell Research Team	Korea Institute of Energy Research	• Development of the PEMFC core parts • Development of the fuel cell stacks and system • Development of the SOFC materials
-	Hyundai Motors	• Production of the hydrogen fuel cell vehicles • Development of the transport fuel cell stacks, BOP, and system
-	Doosan	• Production of PAFC • Development of large-capacity fuel cells for power generation

In Europe, Germany has secured its position as a leader in applied technologies for hydrogen and fuel cells. The German government supported the construction of 50 new hydrogen fueling stations by the end of 2016, half of which are already completed, and promoted the establishment of infrastructure for future commercialization. Germany planned to build an additional 100 stations by the end of 2019.

In Japan, Toyota and Honda launched fuel cell vehicles under the brand names of Mirai in 2015 and Clarity in 2016, respectively. These vehicles are equipped with considerably small and light PEMFA stacks and systems having a generating capacity of more than 3 kW/L. The improved membrane electrode assemblies and newly structured separators mainly contribute to the reduction in size and weight, and further research on cost reduction is expected to continue. The Japan-based research institute Fuji–Keizai Group forecasts that the total shipment volume of the fuel cell vehicles will become approximately 40,000 units by 2020. In 2013, Hyundai became the first automaker in the world to begin the mass production of fuel cell vehicles, followed by Toyota and Honda in 2016 and Nissan in 2017. Daimler, BMW, Audi, and other automakers in Japan, Europe, and North America have announced their plans for mass production after 2020.

Unlike other countries, Japan has long maintained the sales of residential fuel cells, which have a power range of 500 W–2 kW, using the fuel cell stacks produced by utilizing PEMFC and SOFC. Although the fees for users (including installation costs) in case of residential fuel cells vary depending on the conditions, they are usually sold at a price of JPY 1.4 million for PEMFC and JPY 1.75 million for SOFC.

South Korea has accumulated technological knowledge through long-term research on fuel cells and has industrial competitiveness in the fields of machinery, electricity, and electronics, which are related to the development of fuel cell systems.

ENERGY STORAGE

Overview

Definition and Scope of Technology

Energy storage technology refers to a technology that converts external electric energy into other forms of energy (e.g., chemical energy and potential energy), stores it, and discharges it when needed. An Energy Storage System (ESS) is a device that performs this process repeatedly and efficiently. As a core technology for the future smart grid, ESS reduces the consumption of fossil fuels and utilizes more renewable energy.

Based on the storage type, power storage can be categorized into storage for electrochemical energy, mechanical energy, thermal energy, potential energy, and chemical energy. Currently, the most common type of power storage is potential energy storage, which includes pumped hydropower; however, additional deployment is not feasible owing to its low efficiency, potential environmental issues, and so on. Thus, electrochemical energy storage, which has high efficiency and density, is currently the most widely studied and installed type.

Additionally, the development of an efficient hydrogen storage technology, which converts surplus renewable energy into hydrogen and converts hydrogen into electrical energy when necessary, is also underway. The hydrogen storage technology is expected to establish new energy infrastructure for the upcoming hydrogen energy era, replacing the conventional fossil-fuel-based energy infrastructure for the transportation and power generation industries.

The scope of energy storage technology based on secondary battery includes lithium-ion batteries, redox flow batteries, room-temperature sodium-ion batteries, mid-to-high-temperature sodium-based batteries, and ultrahigh-capacity capacitors. A secondary battery contains four core materials (anode, cathode, separator, and electrolyte), and their configuration considerably influences the characteristics and performance of a secondary battery. Therefore, the development of these key materials is assigned high priority to improve the performance and characteristics of secondary batteries, and the cell manufacturing technology using these core materials must follow accordingly.

Table 18 | Subtechnology classification

Subtechnology	Technology description
Power storage (Battery based)	• A technology that stores electric energy as another form of energy, converts it into electric energy, and repeats this process • Lithium-ion battery: ultrahigh-capacity anode material technology, metal cathode technology, fire retardant & non-combustible electrolyte, and separator technology • Redox flow battery: electrode, redox couple, and ion exchange membrane technology for ion reactions involving oxidation–reduction • Room-temperature sodium-ion battery: anode, cathode, separator, electrolyte technology with sodium ion as the reaction species • Mid-to-high-temperature sodium-based battery: separator and electrode technology with molten sodium ion for its reaction species • Ultrahigh-capacity capacitor: electrode material, electrolyte material, electricity technology design
Hydrogen storage	• A technology that converts the surplus electricity generated from renewable energy into hydrogen • High-pressure compressed hydrogen storage technology (over 700 bar) • Low-temperature liquefied hydrogen storage technology: hydrogen liquefaction, reliquefaction of the released hydrogen, cryogenic insulation container manufacturing • Solid hydrogen storage technology: high-capacity hydrogen storage materials, highly efficient metal-hydride-based system production • Chemical hydrogen storage technology: high-capacity chemical hydrogen storage materials, hydrogenation and dehydrogenation catalysts, hydrogen purification, highly efficient system production

The scope of the hydrogen-based energy storage technology encompasses technologies to compress and liquefy hydrogen and store hydrogen by converting it into chemical hydrides, metal hydrides, and/or complex hydrides in the gas, liquid, or solid forms. It also includes a storage container technology for molecular hydrogen or hydrides that exist in the form of a gas, liquid, or solid, thermal management technology to integrate the heat released or supplied during the hydrogen storage and/or release processes, system manufacturing technology, and control technology to monitor temperature and pressure as well as detect hydrogen leakage.

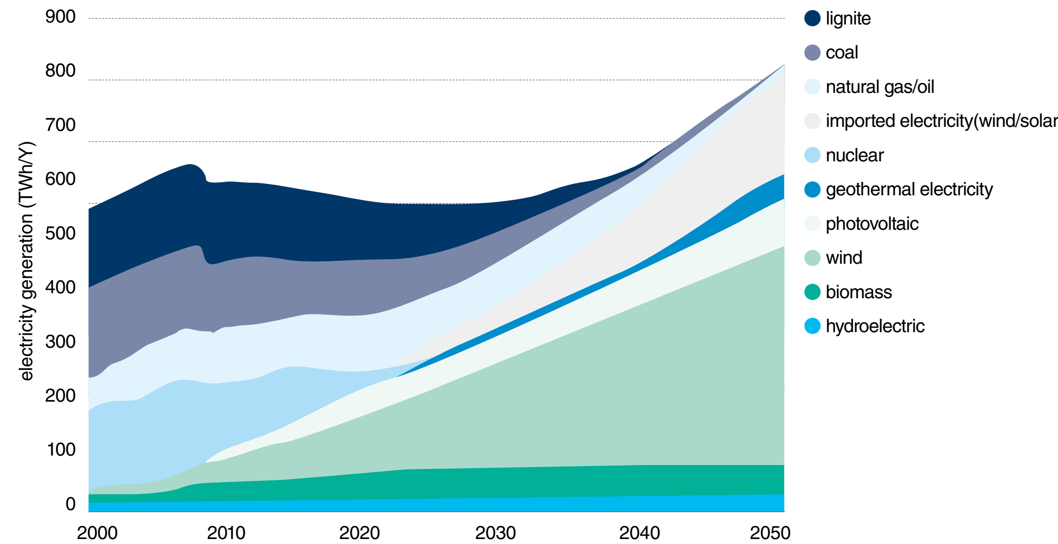

Figure 33 | Expected penetration of renewable energy in Germany

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Technology Trends and Industry Outlook

Germany is the world leader in terms of renewable energy penetration. It has set a goal of increasing the share of renewable energies by up to 60% by 2050. The USA, the EU, and many other countries are expanding the deployment of renewable energies as a strategy to achieve the objectives established at the climate change agreements. For example, the USA, Australia, India, and China aim to integrate 20%, 23.5%, 40%, and 15% of new and renewable energies by 2030, 2020, 2030, and 2020, respectively.

To efficiently integrate renewable energies into energy grids, a large-scale ESS will likely be needed to meet the fluctuating short- and long-term maximum power needs. For instance, secondary batteries can be applied to cater to the power-quality control and load-leveling demands, which are relevant for hours or weeks of storage, whereas the hydrogen-based energy storage technology is applicable to high-capacity demands for seasonal storage extending for weeks or years.

The smart grid technology that uses small-scale secondary batteries for distribution is also likely to be adopted. In addition, technology demands for long-term energy storage methods based on hydrogen and/or hydrogen storage materials are likely to increase.

It is necessary to develop various technologies and integrate them systematically for efficient energy storage because different energy storage technologies are suitable for different storage times/capacities. The market for ESS is expected to grow rapidly in the future in accordance with the growth of new industries, including self-driving electric vehicles and hydrogen electric vehicles (hydrogen fuel cell vehicles), increased use of new and renewable energies, and changes in the energy sector.

Similar to those in other advanced countries, the Ministry of Trade, Industry, and Energy of Korea has recently announced "Renewable Energy 3020 Implementation Plan" aiming to install an additional 53 GW of renewable energy by 2030 and expand the share of new and renewable power generation by up to 20%. Thus, the market for ESS is expected to grow significantly in accordance with this policy.

Korea stands out in the lithium-ion secondary battery industry owing to the strong support from the government. However, the investment in ESS has been quite small because majority of the investment has been made to improve the energy density of the small-sized lithium-ion secondary batteries and vehicles. Along with lithium-ion secondary batteries, a wide range of next-generation secondary cells are showing potential in the ESS industry, and various systems and new markets are expected to be created.

Although relevant technology has not been developed significantly in the field of hydrogen-based ESS in Korea, large-capacity energy storage technology is likely to be realized in conjunction with the hydrogen storage technology currently under R&D. Further, the market for ESS based on liquid hydrogen storage materials using renewable energy surpluses is expected to increase by utilizing the extant storage and supply infrastructure.

Hydrogen storage has gained attention recently as a new method to store energy with advances in terms of the storage technology. It has potential for application in the fuel cell industry. High-density large-capacity hydrogen storage may replace the primary power network by expanding the distributed generation of renewable energy and may be applied to medium and large microgrids.

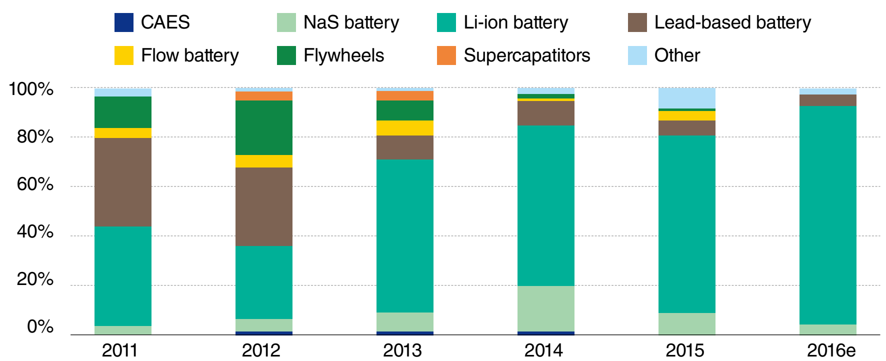


Figure 34 | Shares in annual non-pumped hydro storage technology addition
© Tracking Clean Energy Progress (2017), International Energy Agency (2017)

01

Power Storage

Definition and Scope of Technology

Power storage refers to a technology that converts external electric energy into other forms of energy, stores it, converts it to electric energy when necessary, and repeatedly performs this conversion process. Power storage can be categorized based on the type of energy stored, i.e., electrochemical energy, mechanical energy, thermal energy, and potential energy.

Currently, the most common type of power storage is potential energy storage, commonly referred to as pumped storage hydropower; however, additional deployment is not feasible because of its low efficiency and environmental issues. Thus, electrochemical energy storage with high efficiency and energy storage density is currently the most widely studied and installed type of power storage.

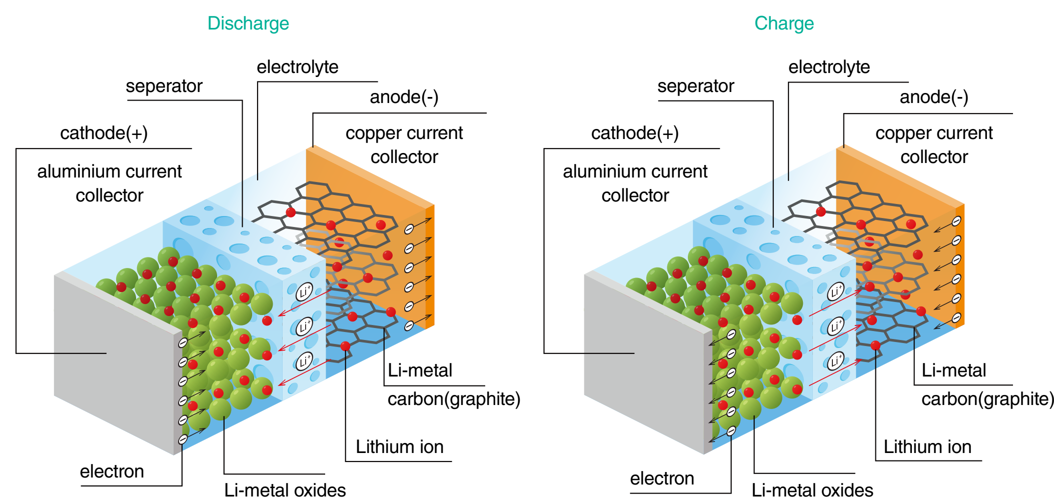


Figure 35 | Lithium-ion secondary battery © shutterstock.com

A battery converts chemical energy into electric energy. Primary batteries perform this conversion process only once and are discarded after use; secondary batteries can be used repeatedly by restoring external electric energy in the form of chemical energy. Although both primary and secondary batteries are widely used for various purposes, secondary batteries have been at the center of attention as mid- to large-size batteries for power storage and electric vehicles.

Secondary batteries have four major components (anodes, cathodes, separators, and electrolytes) and store and generate electricity based on the voltage differences between the anodes and cathodes. The subtechnologies of secondary batteries include the technologies for lithium-ion batteries, redox flow batteries, room-temperature sodium-ion batteries, separators with molten sodium ion as the reaction species, high- and medium-temperature sodium-based batteries, electrode materials overcoming the current energy density limitations, electrolyte materials, and ultrahigh-capacity capacitors.

Key Technology and Research Trends

The USA conducts R&D of secondary batteries for electricity storage and electric vehicles under the initiative of the DOE. The Energy Efficiency & Renewable Energy program is one of the primary R&D projects of the DOE to support R&D for power storage and electric vehicle technologies. The R&D on secondary batteries for energy storage is led by the Vehicle Technologies Program.

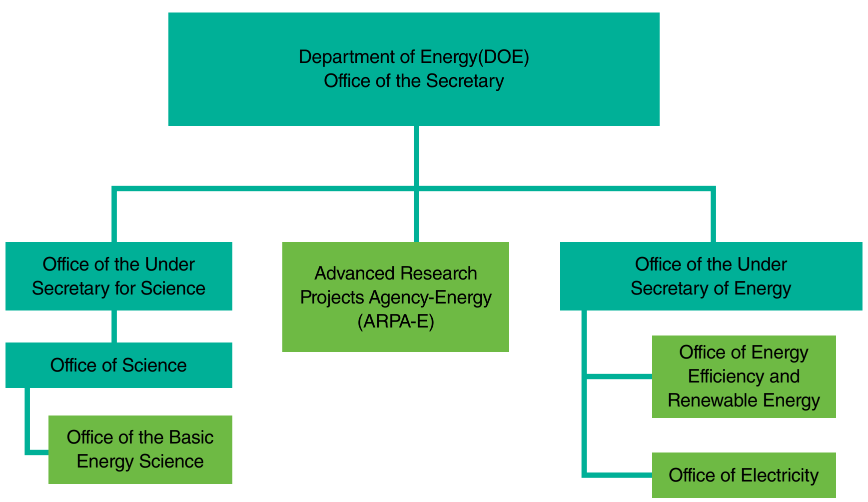


Figure 36 l Secondary battery-related institutions under the DOE, USA

European countries have been vigorously establishing R&D support programs for next-generation secondary batteries to overcome the limitations associated with lithium-ion batteries. The German Federal Ministry of Education and Research is conducting R&D on secondary batteries through the LISA (EUR 1.7 million), REALIBATT (EUR 2.1 million), and LI-HEBE (EUR 2.2 million) programs. LIB2015 was established as a part of a strategy for developing advanced technologies to address climate change since 2008. It has a total investment volume of EUR 60 million, among which EUR 35 billion has been funded by the Ministry of Economy and Technology from 2009 to 2012.

Table 19 l Technology level of secondary batteries

Source: 2012 & 2014 Technology Level Research Report (KISTEP)

Year	Korea		USA		Japan		EU		China	
	Relative level	Gap (year)	Relative level	Gap (year)	Relative level	Gap (year)	Relative level	Gap (year)	Relative level	Gap (year)
2012	82.2%	3.3	94.6%	1.3	100%	-	85.2%	3.1	68.3%	5.4
2014	86.2%	2.9	96.6%	0.8	100%	-	90.7%	1.9	69.8%	4.6
Relative difference	4%p	△0.4	2%p	△0.5	-	-	5.5%p	△1.2	1.5%p	△0.8

Table 20 l Technology level of secondary battery industry

Source: 2013 & 2015 Industrial Technology Level Research Report (KEIT)

Year	Korea		USA		Japan		EU		China	
	Relative level	Gap (year)	Relative level	Gap (year)	Relative level	Gap (year)	Relative level	Gap (year)	Relative level	Gap (year)
2013	85.6%	1.1	98.2%	0.1	100%	-	89.6%	0.8	76.9%	1.9
2015	87.2%	1.4	98.5%	0.6	100%	-	89.8%	1.4	80.1%	2.2
Relative difference	1.6%p	0.3	3%p	0.5	-	-	0.2%p	0.6	3.2%p	0.3

In Japan, the New Energy and Industrial Technology Development Organization (NEDO) announced their Secondary Battery Technology Development Roadmap 2013 based on the 2010 roadmap. The new roadmap modifies the categorization of secondary batteries, renews the development map for materials and batteries, and adds a technology map for innovative batteries.

In China, secondary batteries are being actively researched; however, there is little information available with respect to the progress of this research. With respect to the power storage system, research institutes and universities are researching a technological development for the materials and parts of a redox flow battery.

China's Prudent Energy, a world-renowned vanadium redox flow secondary battery supplier, has been conducting demonstration projects around the world.

Meanwhile, in South Korea, the R&D investment of the government has remained at only 1/14th of that of the USA and half of that of Japan and Germany, which are some of the advanced countries in the field of secondary batteries. When compared with these countries, South Korea's capacity for technological innovation is low. Because the R&D on materials and parts are supported mainly with respect to short-term performances, these works remain unconnected with the R&D for secondary batteries, resulting in a low performance with regard to commercial business.

In the secondary battery sector, investment has mainly been provided for the development of the lithium-ion battery. A survey conducted by the Korea Institute of Science & Technology Evaluation and Planning (KISTEP) in 2015 indicated that next-generation technology development has stalled or has been declining since 2013. However, Japan is considered to have the world's highest level of technology for secondary batteries. With its growing investment in technological development for next-generation secondary batteries, NEDO has expanded the support for advancing high-capacity ESSs based on its roadmap for secondary battery technology development.

Although Korea holds the largest share of the global market for lithium-ion secondary batteries, the focus is mainly on small batteries. Even though government-level support is required to ensure market competitiveness for medium- to large-sized secondary batteries, research efforts by individual researchers for secondary battery development have been fragmented and disjointed, and various projects led by ministries (including projects within ministries) split up the investment with possible overlapping. All the players in this sector can work in synergy by sharing responsibilities.

An analysis of Korea's research capacity shows that the level of technology in basic and applied technologies has improved by 4% compared with the first-ranked country (Japan) and that the technology gap has narrowed by 0.4 years; however, compared to other countries, Korea is relatively slow in reducing the technology disparity. The level of applied technologies has decreased by 0.2%p from 2012. The relative industrial technology level compared to the first- ranked country (Japan) has increased by 1.6%p, whereas the technology gap has widened by 0.3%.

02

Hydrogen Storage

Definition and Scope of Technology

Hydrogen storage refers to a technology that can store the surplus electricity generated from renewable energy sources in the form of hydrogen and supply the stored hydrogen when required. This technology can be used for small- and large-scale (> GWh) energy storage for long periods. Further, this technology can be categorized into compressed or liquefied storage, which stores hydrogen by compressing or liquefying it, and chemical/metal hydrogen storage (solid hydrogen storage), which stores atomic hydrogen in the form of chemical hydrides (gas, liquid, or solid) or metal hydrides (solid) as hydrogen storage media. Thus, this technology involves high-pressure compression, low-temperature liquefaction, and use of metal and chemical hydrides.

In case of the high-pressure compressed hydrogen storage technology, compressed hydrogen is stored in the gaseous state in a high-pressure container (700 bar) designed for the hydrogen fuel cell vehicles that are prevalent in commercial use. Low-temperature liquefied hydrogen storage technology allows storage of hydrogen in liquid state by cooling the gas to its liquefaction temperature. In this case, the core technologies include liquefaction, reliquefaction of the boil-off hydrogen, and manufacturing of the cryogenic insulation containers.

The solid hydrogen storage technology is applied for storing the atomic hydrogen in solid-state metal hydrides or in a molecular state on the surface of porous materials via physical absorption.

The chemical hydrogen storage technology employs various gases, liquids, and solid compounds that can control the hydrogen storage and release reactions. The core technologies involve the development of the hydrogenation and dehydrogenation catalysts, hydrogen purification, and high-efficiency system production.

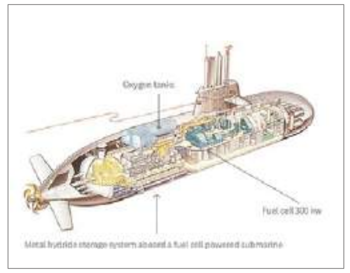
Hydrogen fuel cell vehicle(Hyundai Motors)

Stationary hydrogen storage system(Hydrexia)

Hydrogen storage module(McPhy Energy)

Hydrogen internal combustion engine vehicle(BMW)

Fuel cell fork lift(Siemens)



Alloy for submarine fuel cell(Gfe)

Figure 37 | Applications of hydrogen storage technology

Key Technology and Research Trends

The USA DOE supports various research institutes, including Sandia National Laboratories, Savannah River National Laboratory, Lawrence Livermore National Laboratory (LNLL), Pacific Northwest National Laboratory, and Oak Ridge National Laboratory. The DOE has studied hydrogen storage using metal and chemical hydrides in a consortium with universities and research labs. In particular, hydrogen storage materials applicable to hydrogen storage tanks for hydrogen fuel cell vehicles are being actively researched.

In the EU, the EU Framework Program (FP) 6 and 7, joined by Germany, France, Switzerland, Norway, the UK, the Netherlands, Denmark, Italy, and Greece, has led research on hydrogen storage using complex metal hydrides and porous metal organic materials (Metal Organic Framework). A system for large-capacity energy storage using liquid chemical hydrides (e.g., dibenzyltoluene) is also under development.

In Japan, under the NEDO Program of the Ministry of Economy, Trade and Industry, the National Institute of Advanced Industrial Science and Technology (AIST), Tohoku University, Hiroshima University, and Kyushu University conducted R&D on hydrogen storage using room-temperature hydrogen storage alloys and metal hydrides since the 1990s. Further, Toyota has worked on hydrogen storage materials for hydrogen fuel cell vehicles using various solid hydrogen storage materials, including BCC-type alloys.

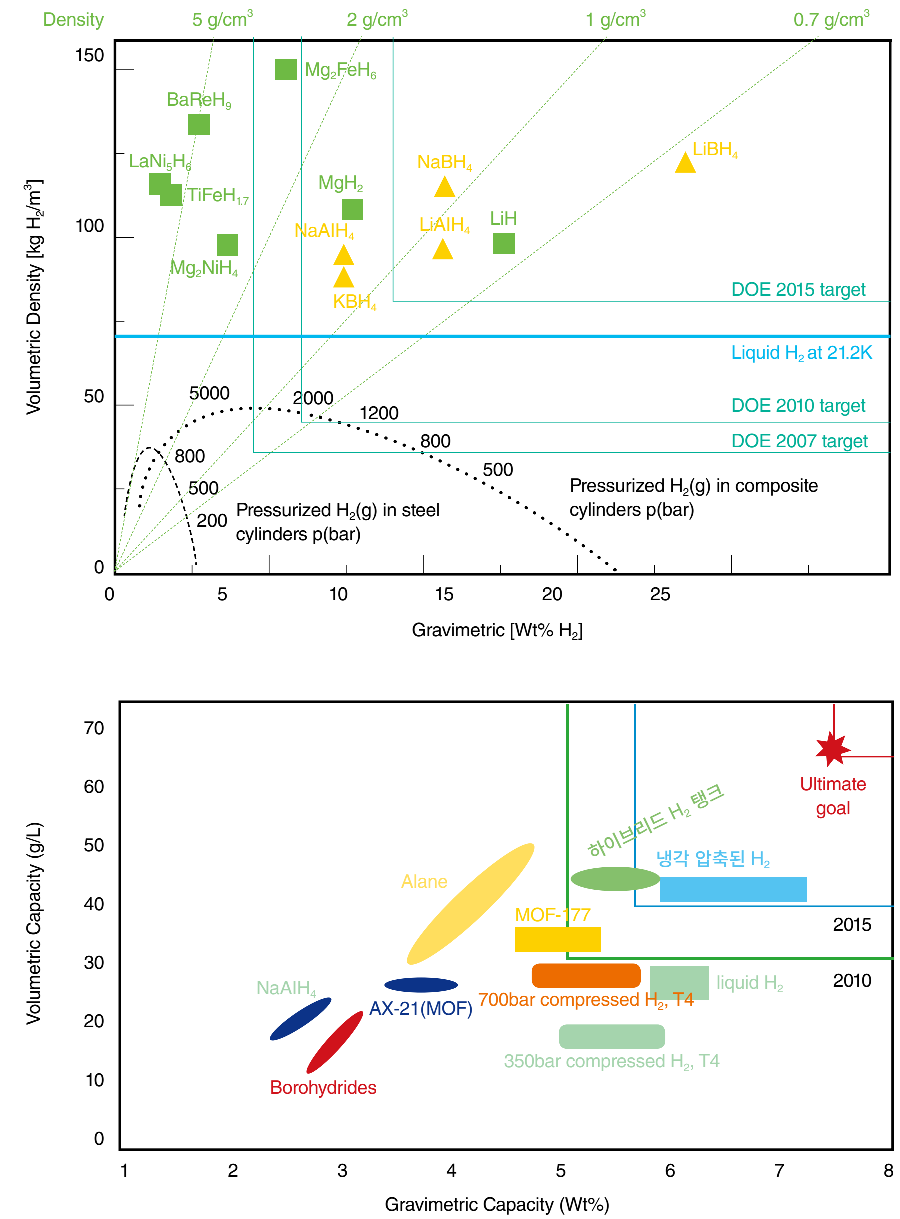


Figure 38 | Current status of the hydrogen storage research conducted by the Department of Energy in the USA © DOE

Little information is publicly available about the level of hydrogen storage technology in China in the past. Hence, it is difficult to evaluate China's technological capability in this sector. China is lagging in terms of technological development in this sector compared to the USA, Japan, and the EU. However, it has achieved steady progress in the technological development and commercialization of the AB5 alloy for the Ni–MH battery, the share of which is significant in the secondary battery market. China has focused on state-led mid- and long-term hydrogen storage technology development projects since the mid-2000s, and active R&D on metal hydrides is underway in the Dalian University, Zhejiang University, Fudan University, and Peking University.

Figure 39 | Achievements in the development of domestic hydrogen storage technology
© High-Efficiency Hydrogen Energy Project Group, KIST, Hyundai Motors, Iljin Composites

In Korea, as part of the 21st-century Frontier Project from 2003 to 2013, the High Efficiency Hydrogen Energy Program has contributed to technology development for physical adsorption using porous materials, room-temperature hydrogen storage alloy, and storage of solid and chemical hydrogen with the help of mid- and high-temperature metal hydrides. The convergence research group of the Korea Institute of Science and Technology (KIST) worked on small-scale hydrogen liquefaction technology for self-cooling liquefied materials for five years since 2011.

A technology for small-scale hydrogen liquefiers and small-scale liquid hydrogen storage containers is being developed with the support of Hylium Industries. Projects have been promoted for developing core technologies in the field of next-generation hydrogen energy since 2015, and R&D on metal- and chemical-hydride-based stationary hydrogen storage is underway. Hyundai Motors developed high-pressure hydrogen storage tanks for the existing hydrogen fuel cell vehicles. These tanks are currently installed in commercial Hyundai vehicles. Iljin Composites also developed high-pressure-compressed hydrogen storage tanks.

TRANSMISSION AND DISTRIBUTION AND ELECTRIC POWER IT

Overview

Definition and Scope of Technology

The electricity generated at a power plant is transferred to remote factories or homes. After transmission from power plants to substations (transmission), the voltage or current is then converted at a substation (transformer) and distributed to customers (distribution). Although power grids and power industries mostly use analog devices, the Information and Communication Technology (ICT) has been recently incorporated into this sector. This has led to the emergence of the technology for transmission and distribution and the electric power Information Technology (IT), which has improved the efficiency and reliability of power grid operation. This IT technology is classified mainly into two groups, i.e., transmission and distribution systems and intelligent electronic devices. The former refers to a comprehensive power supply system, including transmission lines, transformers, and distribution equipment, whereas the latter refers to products, technologies, systems, and related technologies for consumers to actively reduce power loss and maximize the effectiveness of energy saving.

Technology Trends and Industry Outlook

Transmission and distribution systems

China has aggressively pursued the establishment and R&D of the High-Voltage Direct Current (HVDC) facilities. Several demonstration facilities have been built in China, and continuous efforts are being made to develop new technologies. The commercial operation of HVDC, with the highest transmission voltage of 1100 kW in the world, is expected soon.

Table 21 | Subtechnology classification

Subtechnology	Technology description
Transmission and distribution system	• High-Voltage Direct Current (HVDC) facilities, which utilize stable DC for the existing AC system • Flexible AC Transmission System (FACTS) • Wide-Area Monitoring and Control (WAMAC) system • Digital substations (flawless power supply systems that employ power grid intelligence)
Intelligent electronic devices	• Advanced Metering Infrastructure (AMI), which is a power service infrastructure based on two-way communication and information exchange between end users and power companies • Demand Response (DR), which reduces electricity usage by motivating end users with incentives • Energy Storage System (ESS) & Energy Management System (EMS), which reduce energy consumption and improve energy efficiency

In this sector, the global market is dominated by European companies. For example, ABB possesses the HVDC core technologies. Meanwhile, EIPP America has focused on the research and application of the data visualization of power systems and improvements in EMS data accuracy. CEORU of China has utilized various techniques for monitoring and analyzing technologies for generator operation, real-time low-frequency fluctuation, and power system stability. In Canada, Hydro Quebec applied fault analysis, parameter tuning of the dynamic analysis model, and real-time control of the static VAR compensator technology. Terna, Italy, applied substation voltage, phase difference, frequency analysis, power system stability analysis technology, and early warning systems.

However, in Korea, there is lack of a comprehensive national roadmap on HVDC research. Hence, R&D investment has excessively focused on the smart grid sector. The HVDC research is categorized mainly under the transmission and conversion fields. Generally, heavy electric machinery manufacturers lead the development of the power conversion field, whereas the transmission field is led by electric power companies. KEPCO decided to introduce advanced technologies from overseas rather than conducting local development. Therefore, it established KAPES, a joint venture with Alstom, which is one of the world's top three power converter manufacturers (sold to General Electric in 2016). LSIS signed a contract with KAPES to transfer technology and is undertaking efforts to introduce current-fed technology.

The Korea Electric Power Research Institute (KEPRI) has taken a leading role in transmission research and maintenance. The Conversion Research Team of the Korea Electrotechnology Research Institute has accumulated large amounts of experience in localized basic research on HVDC, including research on semiconductor devices for the conversion process. Realizing the importance of HVDC research five years ago, KEPRI has established an HVDC research center and striven to promote the research on HVDC conversion

Intelligent Electronic Devices

The deployment of smart meters in North America has been underway since 2008. As of early 2016, the total number of smart gas and power meters installed in the USA and Canada was approximately 70 million. However, because the supply of smart meters has been delayed since 2015, the investment in intelligent electronic devices has decreased; currently, the smart meter investment has not increased any further.

At the end of November 2015, three power companies in California declared their first demand response auction mechanism to be successful. As the demand resource resulting from the auction reached 40 MW, which considerably exceeded the minimum requirement of 22 MW, the operational requirements of the Demand Response (DR) market were estimated to have been sufficiently established. In all, nine demand resource providers participated in the contract, including residential buildings and commercial and industrial setups, and it also included smart charging for electric vehicles and storage capacity utilization for Demand Response (DR).

Figure 40 | HVDC transmission lines connecting large-scale power grids © UPV/EHU

The EU has established 5 research areas and 19 tasks for intelligent electronic device strategies. The aim is to establish a smart distribution network, efficient long-distance energy supply, capital management for transmission and distribution, sustainable operations, and technology foresight for power supply. The EU developed the European Smart Grids

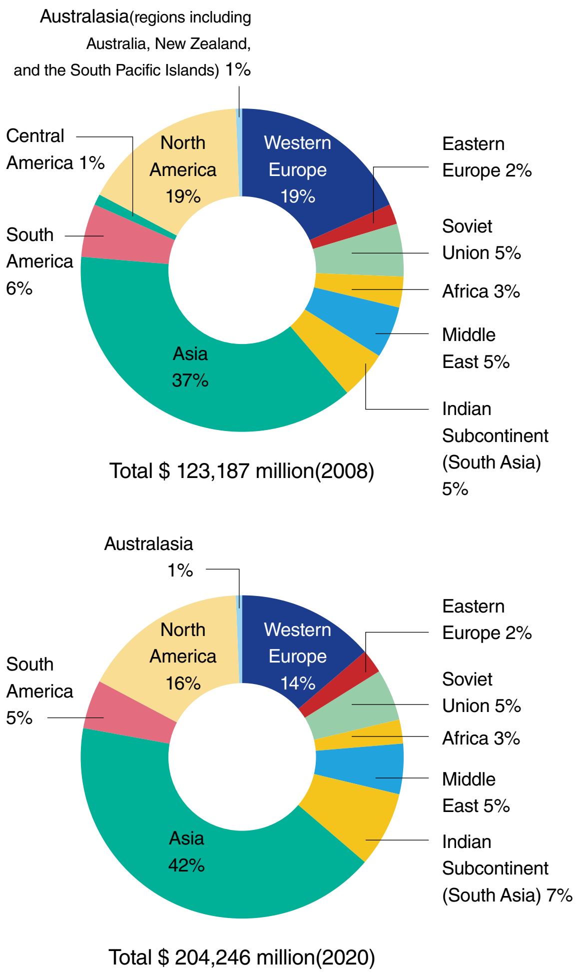


Figure 41
Global T&D device market share and forecast

Technology Platform in 2006 to effectively streamline the transmission and distribution systems across Europe, facilitate international electricity trading, and integrate new and renewable energy into the existing power grids by 2020.

Japan has actively utilized intelligent electronic device technology via its Triple I power systems: Intelligent, Interactive, Integrated (TIPS) system. This technology is used to monitor the newly established power networks and evaluate the reliability of all the networks. Japan recently surpassed China to become the world's largest smart metering market.

In Korea, the Korea Energy Master Plan was established and implemented based on Article 41 of the Framework Act on Low Carbon, Green Growth, and Article 10, Clause 1 of the Energy Act. The Second Korea Energy Master Plan, established in 2014, provided a basic direction for energy policies based on six major tasks with issues directly or indirectly related to smart grids, including the expansion of critical peak pricing, creation of an ICT-based demand and Energy Management System (EMS), and development of a future energy technology portfolio.

The Jeju Smart Grid Demonstration project represents a wide range of intelligent electronic device technologies and business models. A total budget of KRW 239.5 billion was provided for 6,000 homes located in Gujwa-eup of Jeju from December 2009 to May 2013 to commercialize and export the smart grid technology by establishing the world's largest test bed with the most sophisticated technology. Twelve consortiums comprising intelligent electronic device-related companies involved in electric power, telecommunications, and automotive industries and the development of electric home appliances from five sectors, i.e., smart power grids, smart electricity services, smart consumers, smart transportation, and smart renewables, participated in this project by establishing test beds and implementing pilot projects.

01

Transmission and Distribution System

Definition and Scope of Technology

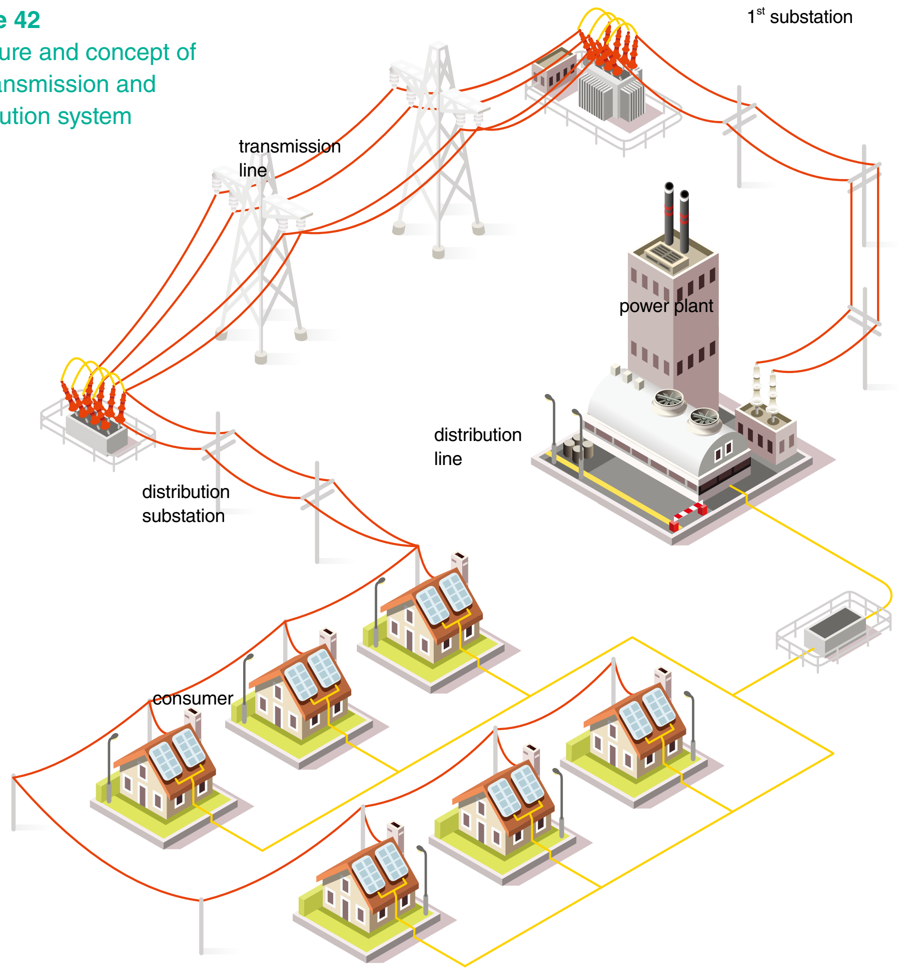
The transmission and distribution system transports the electricity generated in the power plants to the demand areas and involves a series of processes and setups, including the boosting-stage transformers in power plants, transmission lines, substations to compensate for the voltage drop in the intermediate stage for long-distance transmission lines, change voltage when necessary, reduce the voltage near the demand sites, and supply voltage to a distribution system.

The emerging technologies include HVDC, smart grids, Flexible AC Transmission System (FACTS), WAMAC systems, and digital substation technology.

The HVDC system comprises a rectification system (rectifier, Alternating Current (AC)–Direct Current (DC), which converts the AC generated in power plants into Direct Current (DC), and the rectified DC is reconverted in demand sections. Smart grids are next-generation power infrastructure systems that integrate ICT into the existing power grids, enabling intelligent demand management, the integration of new and renewable energy, and electric vehicle charging by exchanging real-time power information between suppliers and consumers.

FACTS introduces powered electronic component-based voltage-converting devices into AC power systems to minimize the power loss in the transmission lines and increase the transmission volume. The WAMAC system can predict the instability in power systems, evaluate the operational capacity, and adopt necessary measures by incorporating Internet of Things (IoT), big data, and machine learning based on synchronization devices and high-speed communication networks. This system is designed to overcome the limitations of supervisory control and data acquisition, which is the existing grid network operation system. In the digital substation system, copper wiring is replaced by optical fibers, and the physical contact units of the auxiliary relay are provided for various controls using software systems. This technology addresses the challenges related to the upgrading of reliability and compaction of the conventional analog substations by digitalization.

Figure 42
Structure and concept of the transmission and distribution system



Key Technology and Research Trends

China is the most active country with respect to the establishment and R&D of the HVDC facilities. China has built several demonstration facilities and made continuous efforts to develop new technologies; the commercial operation of HVDC with the highest transmission voltage (1100 kV) in the world is anticipated. To localize HVDC, the Chinese government has been preparing to facilitate field research over the past two decades, with mid- and long-term roadmaps aiming to develop new products. The government has also conducted prototype demonstration tests with the participation of power companies, manufacturers, research institutes, and universities under the leadership of the China Electric Power Research Institute (China-EPRI).

The EU is the global power industry leader. Its smart grid technology connects the UK, Scandinavia, and mainland Europe via HVDC submarine cables. However, Europe is currently moving in a new direction to overcome the limitation associated with smart grids owing to the low return on investment.

Further, the EU has accelerated its efforts to establish HVDC submarine cable systems with massive investment in the super grid using international and intercontinental HVDC technologies. The conversion technology in Europe has been steered by companies such as ABB, Siemens, and Alstom. ABB is the world leader in research on current- and voltage-source converters, and it has research facilities in the High Voltage Valley in Sweden. Power transmission is primarily studied in the Sweden Transmission Research Institute (STRI), ABB's affiliate research lab, following its commitment to play a leading role in development of the HVDC technology. Siemens in Germany and Alstom in the UK have stimulated R&D and commercialization of HVDC, increasing their shares in the global HVDC market.

In the USA, EIPP America focuses on research and application of the technology for power system data visualization and for improving the accuracy of EMS data. CEORU of China has also been conducting research on technologies to monitor generator operation, monitor and analyze real-time low-frequency fluctuation, and analyze the power system stability.

In Korea, the lack of a comprehensive national roadmap on HVDC research has led to disproportionate R&D investment, which is centered on the smart grid sector. With regard to HVDC conversion research, KEPCO established KAPES, a joint venture with Alstom, which is one of the world's top three converter manufacturers, and introduced the line-communicated converter technology under the technology transfer contract from KAPES to LSIS. KEPRI has taken a leading role in transmission research and maintenance management. Recognizing the importance of HVDC research five years ago, KERI has established a HVDC research center and striven to promote the research on HVDC conversion. However, KERI was unable to pursue further research on converters because KEPCO is more focused on introducing foreign technologies rather than developing them domestically, and its research is centered on HVDC circuit breakers. Furthermore, the Conversion Research Team of KERI has made considerable achievements in the field of localizing basic devices in HVDC, including the localization of semiconductor devices for the conversion process.

The research in the field of transmission has drawn attention from the world's transmission community after the development of a double bipole +/– 500 kV HVDC test transmission line with the world's first ecofriendly transmission and capacity of 8 G at the Gochang Power Testing Center, where successful research on AC 765 kV was conducted. In the HVDC conversion field, the Institute has accumulated remarkable research experience regarding the introduction and installation of the Alstom conversion facilities and technologies for accident recovery, operation, and maintenance as it operates two submarine cables in Jeju for 20 years.

Because LS Cable & System Ltd. has established production facilities for submarine cables after its success in localization, various achievements have been obtained with respect to submarine cable research, for example, the development of ±180 kV MI in 2006 and ±250 kV MI in 2008.

In 2011, LS Cable & System Ltd. succeeded in developing ±80 kV current-source cross-linked polyethylene (XLPE) cables for the first time in Korea and finished its completion test for the demonstration test lines in 2012. Successful operation was achieved in the Jeju test

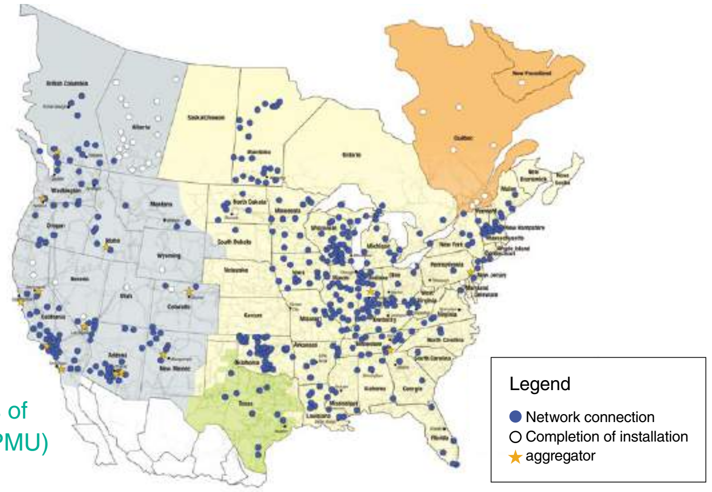


Figure 43
Installation and operation status of the Phase Measurement Unit (PMU) in the USA Power Network

bed. After the development of the current-source HVDC XLPE compounds in 2008–2011, the company developed ±250 kV HVDC XLPE cables in 2013 and secured a technology for cable system evaluation. The ±250 kV MI cable, developed for the first time in Korea, is being commercially used since 2012 (±250 kV Jindo–Jeju Cable). LS Cable & System Ltd. also developed the first 285 kV MI cable in Korea and successfully commercialized it in 2014 (285 kV Den Konti-Skan project). The company also succeeded in developing ±500 kV MI–PPLP cables for the second time in the world in 2014 and has been applying them to the ±500 kV North Dangjin–Godeok construction project since 2015.

With regard to WAMAC in Korea, the infrastructure for synchronization data acquisition has been designed and established, with the support of 27 substations and 40 PMUs. Real-time big data processing technology can obtain 60 samples per second and process tens of terabytes each month. Technologies for system analysis and system status indexing based on PMU data and those for fault event alarm and recognition have been under development, and these technologies have contributed to the development of a technology for multiple-step load shedding and intelligent generator tripping in case of a 765 kV transmission line fault.

The digital substation research was completed in 2011 with the support of the KEPRI; this research focused on the development of an Intelligent Electronic Device (IED). The achievements in this research include the development of an IED for protecting and controlling the station level of a 154 kV digital substation; a bay controller and 7 IEDs, among which an IED is used for transmission line protection, 2 IEDs are used for distribution line protection, 2 IEDs are used for main transformer protection, and 2 IEDs are used for phase-modifying equipment protection; a power-quality IED; a high-precision integrated unit at the process level; agent software for reliability verification; text-based IED integration engineering tool; and a comprehensive operating system for digital substation, gateway, and HMI.

02

Intelligent Electronic Devices

Definition and Scope of Technology

IEDs establish bidirectional communication networks by integrating IT into the existing grid networks. They enable the exchange of real-time power information to improve the efficiency of energy usage and encourage customers to save energy, optimizing energy efficiency. Thus, improving the energy efficiency and encouraging the voluntary engagement of consumers for the efficient use of energy form the essence of the IED technology.

The field of IEDs is transforming from the current one-way closed energy supply into a two-way EMS based on Advanced Metering Infrastructure (AMI). The objective of IEDs is to rationalize energy consumption and improve load management using smart meters or ESSs to achieve the ultimate target of maximum power reduction. The subtechnologies in this field include those related to AMI, DR, and ESS and EMS.

AMI is significant because it secures interoperability between systems and supports two-way communication via smart meters. AMI is the core infrastructure that is essential for realizing smart grids because it is the power service infrastructure that connects end users and power companies. The DR service between supply and demand sides by two-way information exchange can motivate consumers to actively save energy. DR is defined by the Federal Energy Regulatory Commission of the USA as changes in electricity usage by the demand-side resources with respect to their normal consumption patterns in response to the changes in the price of electricity over time or incentive payments designed to induce low electricity use at times of high wholesale market prices or when system reliability is jeopardized.

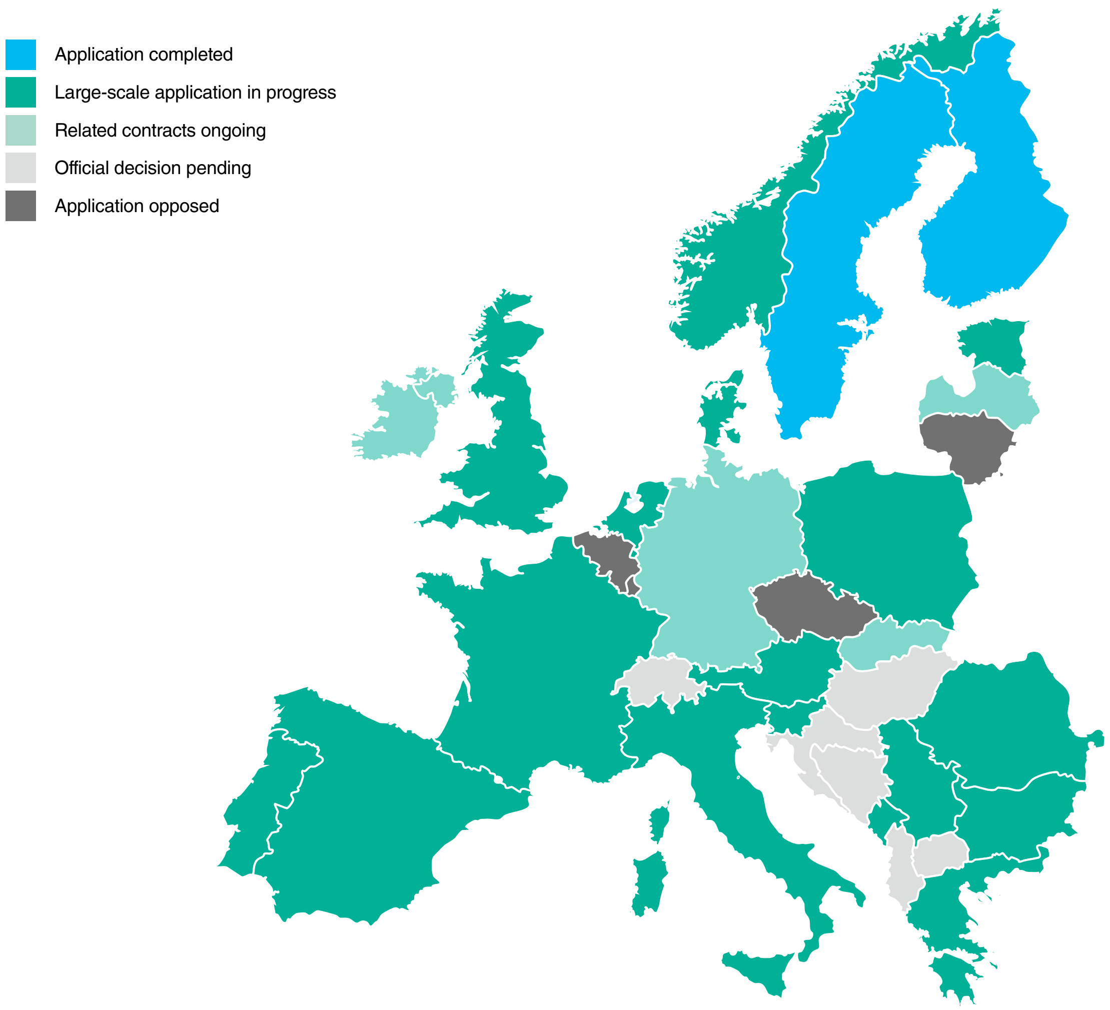


Figure 44 | Status of smart metering in Europe

© Bloomberg New Energy Finance (2016.2.25.)

Power storage technology, which is one of the technologies related to ESS and EMS, stores the generated electricity for future use. This technology can be applied to various fields because it improves the load factors, reduces the peak load, levels the load, supports the stable outputs of new and renewable energy, and improves the power quality. It can also be used for emergency power generation and high-quality power supply. The smart grid station project led by the KEPCO is an example of the application of EMS to buildings. The smart grid station, a regional smart grid control center, was implemented in the buildings owned by KEPCO to integrate ICT into the cooling and heating operation facilities, new and renewable energy sources (fuel cells and wind power generators), ESS, AMI, electric vehicle chargers, smart devices, and power automation systems.

Key Technology and Research Trends

The USA government provided legal and institutional support via Grid 2030 (2003), the Energy Independence and Security Act (2007), the Smart Grid Stimulus Package (2009), etc. This support has stimulated research and demonstrations for IEDs. The utility companies of USA have also been actively engaged in related businesses.

The EU established five research areas and 19 tasks for IED strategies to realize smart distribution networks, efficient long-distance energy supply, capital management for transmission and distribution, sustainable operation, technology foresight for power supply, innovation and standardization of customer interface technology, and regulatory reforms. The EU launched the European Smart Grids Technology Platform in 2006 with the 20-20-20 target for 2020. The targets are to reduce CO_2 emissions by 20% when compared with the 1990 levels, increase the share of energy production from renewables to 20%, and increase the energy efficiency by 20%. The EU aims to streamline the transmission and distribution systems across Europe and facilitate international electricity trading to meet the objective of integrating new and renewable energy into the existing power grids by 2020.

With its TIPS project, Japan has actively utilized technology for IEDs to monitor the newly established power networks and evaluate the reliability of the overall network. The TIPS project plans for sophisticated asset management to meet the future social needs using advanced power equipment, stable system operation, and self-healing systems.

Japan recently surpassed China to become the world's largest smart metering market. As of 2015, 10 integrated operators installed more than 6 million smart meters, forming a single market generating more than USD 2 billion. In April 2016, Japan published guidelines to deliver the smart meter information to retail suppliers in preparation for complete liberalization of the retail market.

China has been determined to shift its vertically integrated coal power generation system into a flexible and clean power source with significant investment in the IED technology. Further, China is cultivating this sector at the policy level to achieve sustainable economic growth against long-term economic downturn.

According to the annual meeting of State Grid Corporation of China in December 2015, 312 million units (cumulative) were installed in China for residential purposes, and an additional 100 million units were needed. The aim was to complete the installation of smart meters for residential users by the end of 2017.

In January 2010, the Korean government released the National Smart Grid Roadmap to build a smart grid based on IEDs, identifying three phases to complete the nationwide roadmap. The first phase aimed to verify new technologies by establishing and operating smart grid test beds (2010–2012), the second phase dealt with the expansion of smart grids into the metropolitan areas and the completion of smart grid intelligence on the consumer side (2013–2020), and the third phase aimed to deploy national-level smart grid networks (2021–2030).

In Korea, the Energy Master Plan is established and implemented every 5 years for a planning period of 20 years based on Article 41 of the Framework Act on Low Carbon, Green Growth and Clause 1 of Article 10 of the Energy Act. The first plan was established in 2008, whereas the second was unveiled in 2014. Under the second master plan, the basic direction of energy policies was presented based on six major tasks for issues directly or indirectly related to smart grids, including the expansion of demand management pricing and opt-in rate, the creation of a demand management market based on ICT, the reformation of the energy information management systems, and securing the competitiveness of the future energy technologies.

The Jeju Smart Grid Test Bed project was launched for the early construction of the world's largest test bed for smart grids having the most sophisticated technology, commercialization of the related technologies, and expansion of the export opportunities. From December 2009 to May 2013, a total budget of KRW 239.5 billion (KRW 68.5 billion by the government and KRW 171 billion from the private sector) was invested in 6,000 homes located in Gujwa-eup in Jeju. Twelve consortiums comprising the 171 companies involved in the field of IEDs, including the electric power, telecommunications, automotive, and electric home appliance companies from five sectors, i.e., smart power grids, smart electricity service, smart consumers, smart transportation, and smart renewables, participated in this project by establishing test beds and implementing pilot businesses for a wide range of IED technologies and business models.

ENERGY DEMAND

Overview

Definition and Scope of Technology

Energy is an essential part of every aspect of human life. The demand for energy is increasing with the need to achieve increasingly comfortable and convenient lifestyles. Increased energy consumption results in considerable pollution and resource depletion. With the evolution of technologies for the efficient production and consumption of existing energies, technologies to discover new energy resources are also evolving.

The transportation efficiency technology intends to improve the efficiency of energy consumption associated with means of land, sea, and air transportation that carry passengers and cargo. It also intends to reduce the GHG emissions from the transportation sector by optimizing the transportation and logistics systems. This technology includes electric vehicles, high-efficiency railways, and ecofriendly vessels.

The technologies for ensuring industrial efficiency improve energy efficiency via the means that are commonly applied to major industries, including power, cement, petrochemical, steel, general consumer goods, paper, and oil refining. An example is the management system applied to optimize the energy performance in production facilities.

The building efficiency technology includes passive technologies that minimize the required amount of energy, active technologies that minimize energy usage, and technologies for efficient use of energy and deploying new and renewable energy systems in buildings, including power stations.

Table 22 I Subtechnology classification

Subtechnology	Technology description
Transportation efficiency	• A technology to improve the efficiency of energy consumption in case of passenger and cargo transportation by land, sea, and air and reduce greenhouse gas emissions from transportation by optimizing the transportation and logistics systems; subtechnologies include ITS and ecofriendly vehicles, railways, and aviation systems • This category includes road capacity management systems, the deployment of next-generation ecofriendly vehicles, and the establishment of infrastructure, such as railway systems, based on ultralight and large-scale capacity fuel cell technology, establishment of low-carbon ecofriendly green ships and ports, and management of aviation operations to minimize the carbon emissions
Industry efficiency	• A technology to improve the energy efficiency in case of major industries, including electricity, cement, petrochemicals, steel, general consumer goods, paper, and oil refining; subtechnologies include FEMS and smart factories • This category includes management systems for optimizing energy performance in production facilities such as in manufacturing industries; equipment in factories as an evolved form of factory automation; and smart factories with interconnected and compatible components
Building efficiency	• A technology for improving the efficiency of energy consumption for heating/cooling, hot water supply, cooking, lighting, and ventilation and household appliances in buildings; subtechnologies include passive technology (reducing the energy load of buildings), active technology (improving the energy efficiency of building facilities), technology for adopting new and renewable energies (energy production), and energy management technologies • This category includes building technologies to reduce heating and cooling loads of buildings, building facility technologies, such as heat source facilities and HVAC (heating, ventilation, and air conditioning) facilities, a technology for the control and management of operation energy, a technology for applying new and renewable energy sources such as solar heat, photovoltaics, and geothermal heat

Technology Trends and Industry Outlook

Transportation Efficiency

The technology trends in transportation efficiency include a transition from Intelligent Transport Systems (ITSs) based on road infrastructure to the next-generation Cooperative Intelligent Transport System (C-ITS) based on V2X (Vehicle to Everything, the vehicle communication technology that exchanges information with vehicles and objects via networks). These trends also include the expansion of ecofriendly vehicles such as electric and hydrogen vehicles, the deployment of railway systems with light rail transit systems and large-scale capacity fuel cells, and the application of naval and aviation technologies that reduce carbon emissions. Various C-ITS projects have been rolled out in the USA and Europe, and connected and automated vehicle technologies are rapidly developing. Additionally, mobility services based on big data technologies have emerged, which focus on deploying electric vehicles as a policy to reduce carbon emissions.

The Korean government is working to cultivate a market for ecofriendly vehicles and build nationwide infrastructure for ecofriendly vehicles to respond to stringent environmental regulations. The government is adopting policies to reduce traffic accidents and GHG emissions using cooperative driving systems that permit communication between autonomous vehicles and road infrastructure. Various ministries are collaborating on a vehicle policy that can help to commercialize level-3 autonomous vehicles connected with vehicle–road–ICT infrastructure coordination. The government and private sector are actively engaged in the development of automobile technologies based on the convergence of an array of technologies suitable for electric and autonomous vehicles. R&D investments have been made in roadways, aviation, and railways to reduce energy consumption in transportation. Various policies have been implemented to develop new technologies and services related to the fourth industrial revolution and reduce energy consumption in transportation based on a sharing economy.

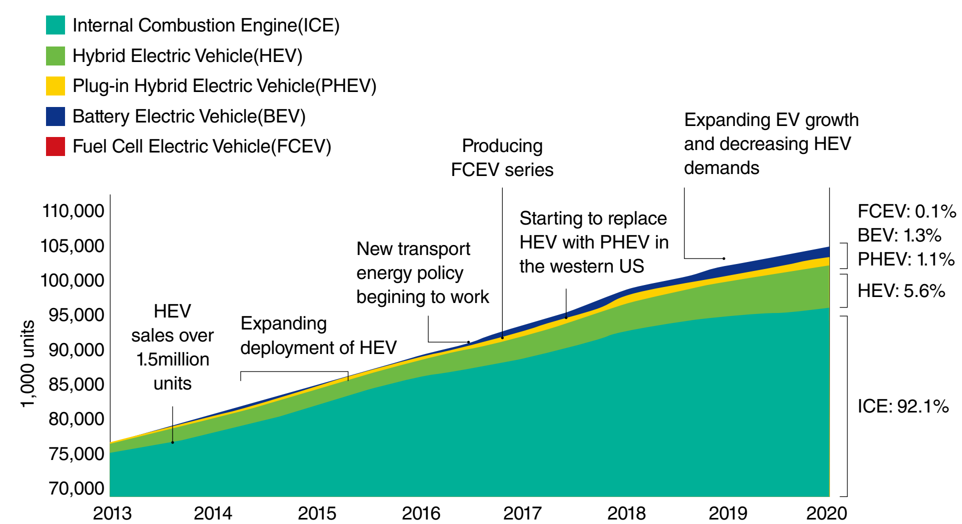


Figure 45 I Global automotive sales forecast based on the vehicle types

Industry Efficiency

Industry efficiency has been evolving with the usage of various technologies to add certain functions of smart systems, such as demand prediction, optimal control, and risk management, to energy management functions, which mainly focus on visualization and monitoring. The energy supply and management technologies have been widely adopted to conserve energy, minimize consumption, and visualize and optimally control photovoltaic energy, thermal energy, and distributed generation facilities, including ESS. In the USA, energy policies have focused on stimulating the economy and creating jobs through energy independence and improvement of the aging power grids. Japan adopted technologies and policies to reduce energy consumption, introduced a subsidy program for installing EMS, and established a policy to support investment for smart factories for the first time in the world. In Germany, every process is monitored to minimize unnecessary energy consumption and technologies to boost industrial productivity by applying the IoT.

In Korea, governmental support to achieve industry efficiency has led to the growing adoption of EMS; however, Korea still lags behind advanced countries, including Germany. Considering the need of technology and policy support to completely utilize the system, the policy trend has been shifting toward developing technology to consume less energy and reduce the GHG emissions, reducing the national energy consumption and improving the energy efficiency. The demand for Factory Energy Management System (FEMS) is increasing in the industrial sector, and the domestic FEMS market is expected to induce tremendous growth.

Building Efficiency

With respect to building efficiency, technologies have been adopted for design, construction, and operation management based on energy efficiency. Europe has proposed energy efficiency policies and zero-energy buildings and set the standard to implement these policies. In the USA, the target for building efficiency and GHG reduction was established using mid-to-long-term policies for minimizing the energy consumption in federal buildings. Meanwhile, Japan strived to reduce its energy consumption in buildings by high-performance energy conservation and by deploying new and renewable energy systems.

In Korea, building efficiency was investigated from the viewpoint of element technology development for zero-energy construction and remodeling of low-energy constructions. Projects for constructing zero-energy detached houses, zero-carbon and zero-energy multiunit houses, and zero-energy houses are underway. The government has established a center for zero-energy buildings and green remodeling innovations to deploy technologies to reduce the building energy consumption and GHG emissions.

Figure 46
Heidelberg Village, a low-energy residential complex that is under construction in Heidelberg, Germany © Frey Architekten

01

Transportation Efficiency

Definition and Scope of Technology

The transportation efficiency technology is applicable for land, sea, and air transportation of passengers and cargo and facilitates the optimization of traffic and logistics systems, reducing the GHG emissions in the transportation sector. With respect to domestic transportation in Korea, GHGs are generated via all the means of transportation, including roads, railways, aviation, marine, pedestrian, and bicycles and transportation of passengers and cargo.

The subtechnologies include intelligent transportation systems, next-generation automobiles, high-efficiency railways, ecofriendly vessels, and low-carbon aeroplanes. ITS is an environment-friendly transportation system for the future. It combines advanced technologies, such as electronic controls and communication with transportation, and transportation facilities to maximize the efficiency of the existing transportation facilities and improve safety.

The next-generation vehicles include zero-emission vehicles, such as Electric Vehicles (EVs) and FCEVs, designed to reduce GHG emissions and address environmental pollution and energy issues. Other next-generation vehicles are intelligent vehicles that improve the convenience and safety of the drivers and automated vehicles that can drive and autonomously make decisions using various electronic systems without a driver. High-efficiency railways refer to the railway technologies that are suitable for environment-friendly and complex urban environments; these technologies maximize the economic and operational efficiency. The technology for high-efficiency railways considers the connectivity and accessibility with respect to other modes of transportation as well as the convenience of passengers. Ecoships, also known as green ships, refer to ships that use clean or alternative energies instead of fossil fuels and ships with high fuel efficiency. The technology development in this sector has focused on aviation transportation with low carbon emissions because the increasing demand for aviation transportation is likely to increase the GHG emissions.

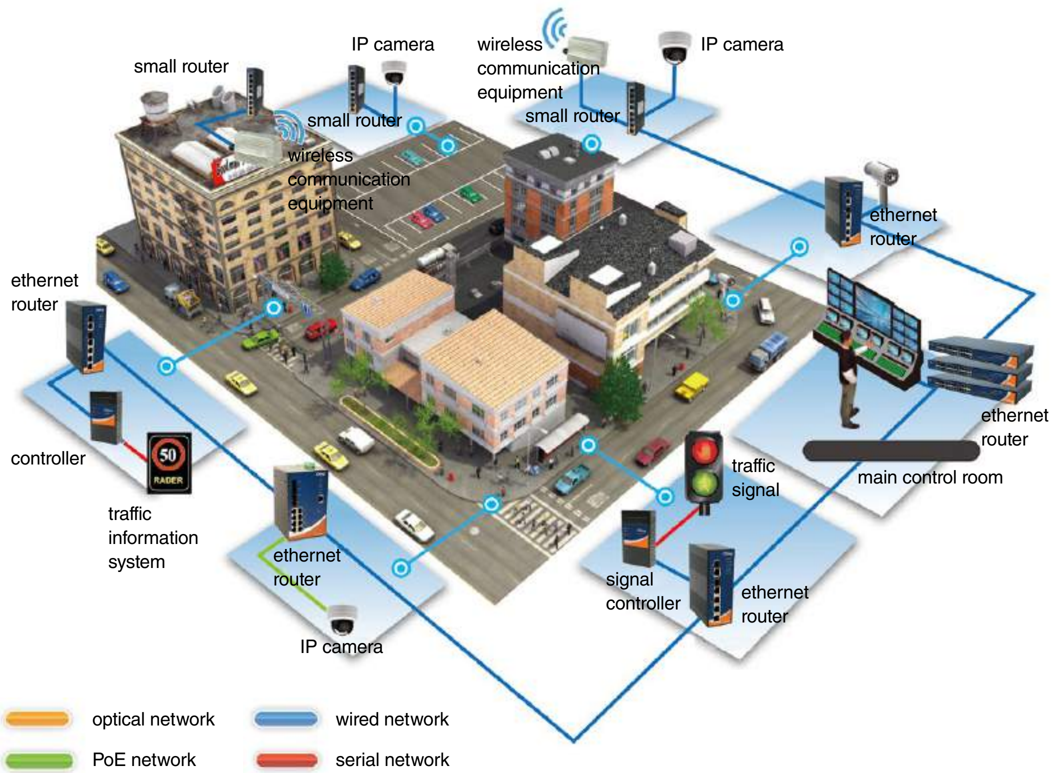


Figure 47 I The schematic of an ITS system © Lunar Technology Ltd

Key Technology and Research Trends

Currently, the USA is the largest market for next-generation vehicles. It has the largest electric vehicle fleet in the world, with approximately 210,000 EVs (193,000 hybrid cars) being registered as of December 2015. The DOE, the Department of Transportation, and the Environmental Protection Agency (EPA) are jointly pushing the deployment and technology development of EVs. A subsidy of USD 2.4 billion is planned for the development, production, and deployment of batteries for next-generation vehicles and EVs. The DOE offered USD 500 million to EV part manufacturers, USD 1.5 billion to battery manufacturers, and USD 400 million to EVs and EV-supporting infrastructural projects.

In the EU, efforts to develop high-efficiency railway technologies have resulted in the establishment of the Trans-European Transport Core Network and integrated technology development, ensuring energy efficiency. To create inter-network and inter-country connections, the EU has supported numerous projects for building railway infrastructure. Additionally, the EU has spurred technological development by investing EUR 160 million for technical assistance to secure the efficiency and reliability of the energy supply systems, such as electricity, hydrogen, bioenergy, and alternative energies as well as railway transportation energy.

Japan has been pushing for the development, production, and deployment of EVs to upgrade its automobile sector and become the hub of the next-generation global automobile industry. Japan has revised its targets for electric vehicle deployment to 1 million vehicles by 2020. With its Next-Generation Vehicle Strategy 2020, the country aims to achieve EV sales of 15%–30% among the total vehicle sales by 2020 and has selected six strategic projects for accomplishing this goal.

With regard to China, during 2014–2016, at least 30% of the new vehicles purchased by the government should be new energy vehicles, and new energy cars were provided with a discount of 10% on their taxes. Therefore, China's next-generation car sales in 2014 exceeded 50,000 units, when considering the 30,000 units purchased by the government. China plans to build 1,200 additional mid-sized charging stations and 4.8 million charging facilities to expand its charging infrastructure.

In Korea, the ecofriendly vehicle industry has become essential to meet international regulations regarding GHG emissions from vehicles because it seems impossible to meet the strict emission regulations when using internal combustion engine vehicles. The survival of the automobile industry is believed to depend on securing technological competitiveness in the transportation sector.

The Korean government plans to foster the autonomous vehicle sector as one of the nine national strategy projects for future growth engines. In the 2nd Science Technology Strategy Meeting, nine state strategy projects were selected. These projects included self-driving vehicles. Vigorous plans have been made by the Ministry of Trade, Industry, and Energy for their implementation. The focus of government support will be the internationalization of key components, including sensors and system semiconductors, which form an essential part of the autonomous vehicles that are currently dependent on foreign technology. Among the eight key components, cameras for sensing the surrounding environment and a common platform for autonomous vehicles designed using a standardized interface are planned to be developed by 2019 and 2021, respectively. The Smart Vehicle Promotion Group led by the private sector was organized in coordination with the Ministry of Trade, Industry and Energy, the Ministry of Science and ICT, and the Ministry of Land, Infrastructure and Transport to meet the objective of developing automated vehicles based on the interconnected vehicle–road–ICT infrastructure. With these ministries sharing responsibility, the implementation of the plan is expected to meet the targets.

Additionally, the government plans to strategically expand the deployment of fuel cell vehicles by utilizing policies and fiscal measures to encourage the automobile industry, improve the air quality, and reduce the GHG emissions. In December 2015, the Ministry of Trade, Industry, and Energy and the Ministry of Environment jointly announced a policy plan on fuel cell vehicles and market activation to gradually expand the purchase subsidies for fuel cell vehicles and the number of vehicles eligible for subsidies. Further, a phased reduction plan was established with respect to the purchase price of the fuel cell vehicles with a target of approximately KRW 40 million by 2018 and approximately KRW 30 million by 2020.

Industry Efficiency

Definition and Scope of Technology

The industrial sector is the largest energy consumer and is responsible for 62.5% of the total energy use, more than 54% of the total electricity use, and more than 50% of the GHG emissions in Korea. The latest technologies to improve energy efficiency that can be applied throughout the industrial sector include the FEMS and smart factories, which involve the factory automation, supply chain management, and big data analysis technology.

FEMS is a management system that can optimize energy performance with respect to production facilities, similar to those used in the manufacturing industry. It is an IT-based energy-saving technology for efficient energy usage via the monitoring, analysis, and remote control of the energy used in production activities and facility maintenance.

A smart factory is a step up from Factory Automation (FA) and may be defined as an interactive production system that connects the equipment and components in factories through IoT, big data, cloud computing, and cyber physical systems by combining ICT and the manufacturing technologies. The smart factory is expected to improve the productivity of factories and the stability of the production environment, reduce energy consumption, create a human-oriented work environment and personalized production systems, and integrate manufacturing with the service sectors.

FEMS is a key component of the smart factory, the other subcomponents of which include product development, Supply Chain Management (SCM), Enterprise Resource Management (ERP), and process automation and FA based on the automation of logistics and facilities. Thus, a smart factory can be broadly categorized as an energy-efficient technology.

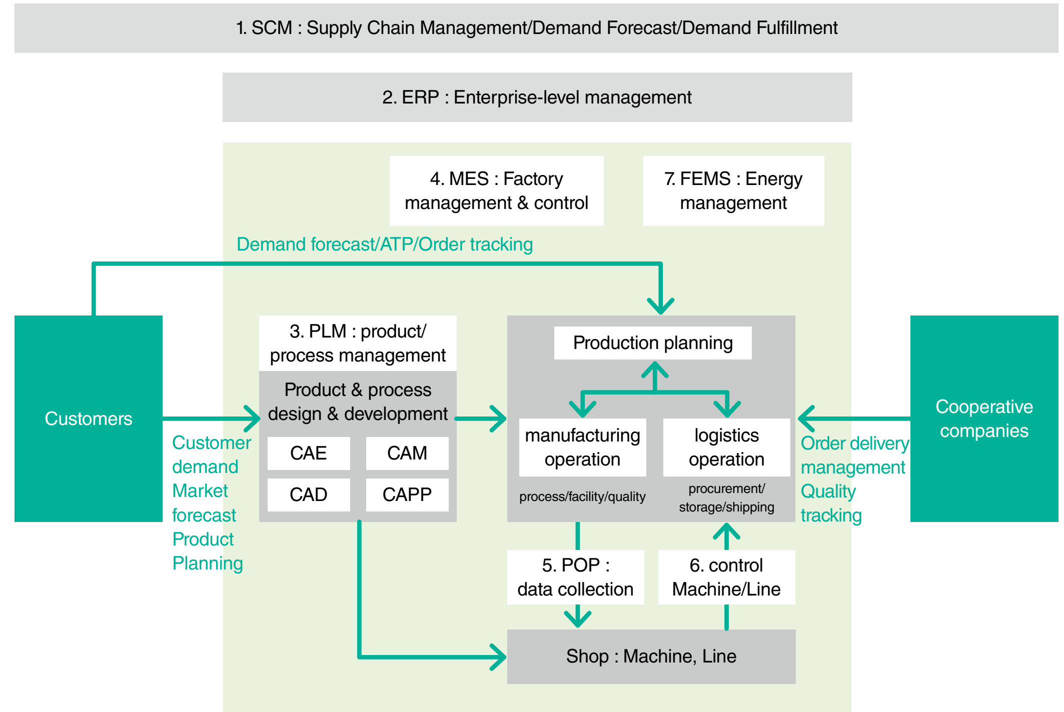


Figure 48 l A smart factory system and FEMS © Smart Factory Promotion Group

Technology Trends and Industry Outlook

Since the early 2000s, USA IT companies, including IBM, GE, and Honeywell, have been aggressively entering the FEMS market. In 2013, IBM unveiled the "GIView FEMS," a solution for optimizing energy use based on the energy status in a factory every minute and by managing supply and demand. The GIView FEMS is a combination of the FEMS and the "IBM Global Integrated View (GIView)," which is a production management solution that can be used to optimize the supply network inside and outside a factory. The visualization of the detailed energy use in the factory allows energy monitoring to conserve energy in the factory, ensure energy efficiency in accordance with the production schedules and performance, and minimize the impact of power failure on production.

In Japan, the experience of unstable power supply resulting from the Fukushima nuclear disaster has led to rising demand for energy conservation and facility improvement in factories. The government has promoted projects on cloud EMS and smart grids, and companies such as Fujitsu, Hitachi, and Fuji Electric have entered the FEMS market. Japan is also stepping up its efforts to upgrade EMS particularly for architecture specification technology such as home servers and service providers with the goal of creating a community energy management system by 2020, integrated with local EMS, including HEMS, BEMS, and FEMS for homes, buildings, and factories, respectively.

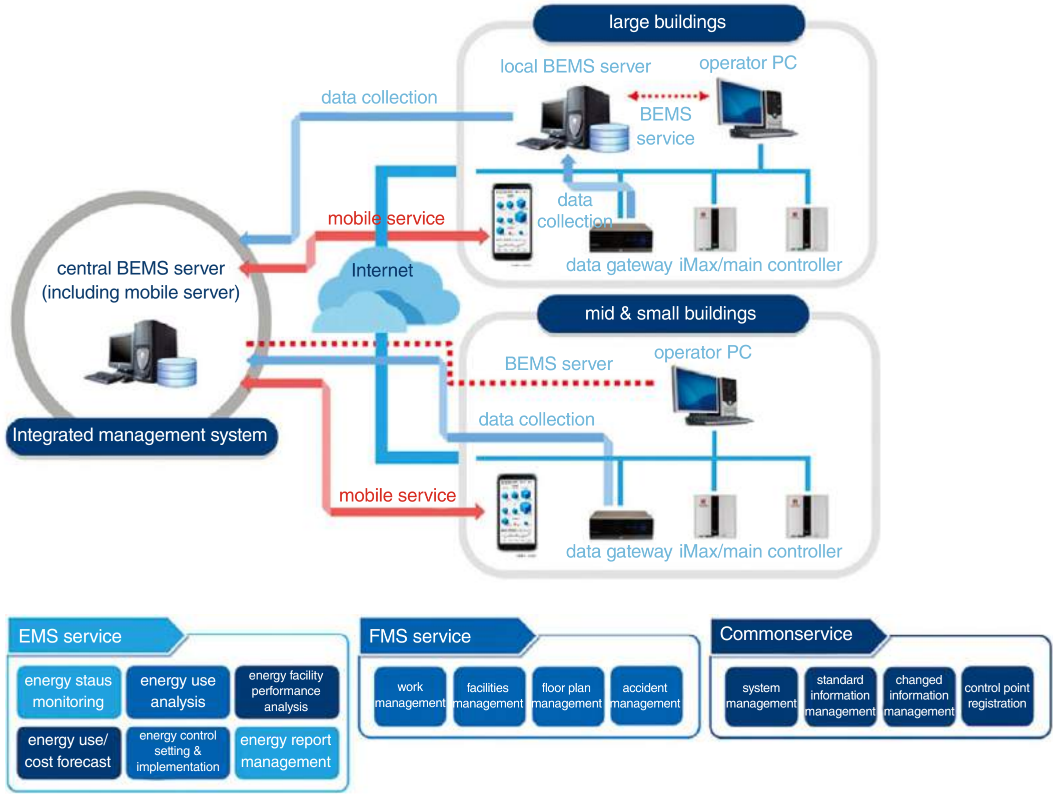


Figure 49 | A schematic of BEMS © Mobiletalk

In Germany, the EWA (Electronic Works Amberg), Siemens' Amberg system, is one of the most successful cases of smart factories. The system is operated by collecting 50 million pieces of information every day and automatically issuing work instructions for each manufacturing process. As this system enables observation of the lifecycles of every product production process, the energy efficiency is significantly improved and the energy consumption is less than that of conventional factories by 30%.

Since 2015, China has launched projects such as China Manufacturing 2025 and Internet Plus' with detailed plans and strategies aimed at strengthening the competitiveness of the manufacturing industry. Based on the major targets of Germany's Industrie 4.0, China has also set four targets that include smart manufacturing, smart factories, smart logistics, and smart services. To promote the adoption of smart factories, China plans to designate leading companies in each industry to provide subsidies and tax benefits to support technological development.

In Korea, the Energy Management System (EMS) has been widely adopted and utilized and is backed by government support; however, the system is still in its initial phase, with a relatively low deployment rate compared to advanced countries such as Germany. Projects to identify and support commercialization models for BEMS and FEMS are underway through K-MEG, the Korean-type EMS technology development and demonstration project, as well as the IT-based ESCO project. The ESCO demonstration project verifies the field applicability, productivity, and marketability of IT-based EMSs (BEMS and FEMS) and supports businesses with a fast return on investment (3–5 years). This project supports an integrated management system that can monitor and control real-time energy status by connecting wired and wireless communication networks with sensors, measuring equipment, and analysis software for specific buildings and factories. ESCO is participating in the pilot project to improve the efficiency of energy-saving efforts and to promote IT-based energy-saving businesses.

The number of domestic EMS suppliers is estimated as 100, with 80 of them being small and medium-sized companies. Because of the technology gap with foreign companies, domestic suppliers focus on only a few areas: In the hardware market, communication devices and electricity meters are supplied by domestic companies, while foreign companies lead sectors such as flow meters and valves, which require advanced technologies. In the software market, the basic software is developed and supplied by Korean companies, while foreign firms provide analysis and control algorithms for the collected data on seasons, temperature, and output. In the system construction and management segment, ESCO and System Integration (SI) enterprises offer an integrated construction and management service in collaboration with software and hardware providers.

Korea lags behind major advanced countries in terms of the competitiveness of domestic suppliers in the field of EMS components. Technological capabilities in sectors such as special sensors, flow meters, and controllers are particularly low. Despite the outstanding products (90% of GS-certified products are produced by SMEs), small and medium-sized enterprises are not properly evaluated because of the market dominance of huge companies. System establishment is also hindered by the lack of standards for required functional specifications for technology and equipment and the lack of a definition of EMS.

Building Efficiency

Definition and Scope of Technology

Operation and maintenance of buildings require a large amount of energy for heating, cooling, hot water supply, cooking, lighting, ventilation, and household appliances. Energy-efficient technologies for buildings can be categorized by passive technology (reducing the energy load of buildings), active technology (improving energy efficiency of building facilities), and technology adopting new and renewable energy (energy production).

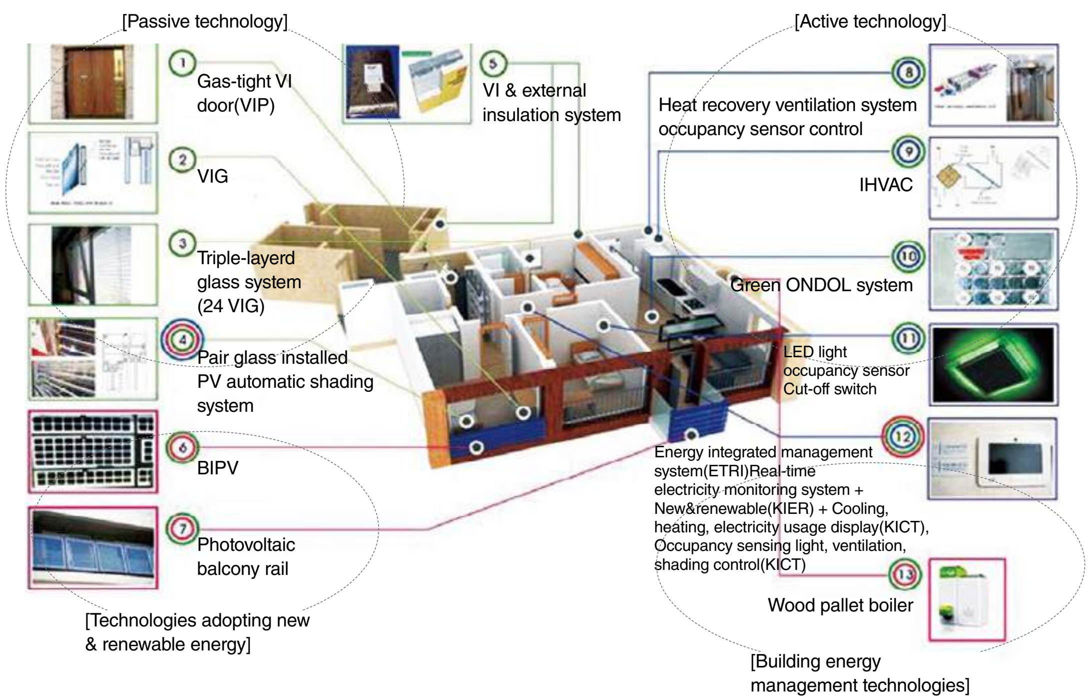


Figure 50 | Illustration of building an energy-efficient technology
© Korea Institute of Civil Engineering and Building Technology

Passive technologies for buildings include high-performance insulation for building envelopes in the form of walls and windows, exterior insulation technology, high-performance window system and air-tight insulation technology, thermal bridge barriers, solar shading devices and thermal shield technology, and sustainable building design. Active technologies include high-efficiency equipment and facilities to provide energy necessary for buildings for purposes such as lighting; boiler, refrigerator, pump, and HVAC equipment operation; air transfer, and operation of electricity facilities. It also includes high-efficiency refrigerators, high-efficiency boilers, ice thermal storage systems, high-efficiency HVAC technology, pumps, blowers, and high-efficiency lighting devices such as LEDs.

A BEMS (Building Energy Management System), includes technologies for building energy monitoring, building energy simulation and analysis, and energy control and management. The technology for adopting new and renewable energy for buildings includes technologies for solar thermal and photovoltaic systems that apply the existing new and renewable energy for buildings, geothermal systems using heat pumps, and heat source facilities using fuel cells.

Technology Trends and Industry Outlook

The EU decided to mandate building energy efficiency and zero energy buildings since 2020 based on the specific policy directions of the Energy Performance of Buildings Directive (EPBD), upon recognizing that buildings are the greatest contributor to energy savings and GHG reductions. Since January 2006, the standards for building energy shifted from the minimal performance for each element of buildings and facilities to the total performance managing the overall energy efficiency for buildings as a whole.

The UK government, in particular, announced that from 2016 all new homes are mandated to be zero-energy houses with no CO_2 emissions. In Germany, a policy plan was established to mandate passive housing standards, and the country is trying to promote further adoption and awareness of energy-saving housing.

Figure 51
Solar House, a demonstration building for zero energy houses,
built by the Korea Institute of Energy Research © Korea Institute of Energy Research

With the AIA Architecture 2030 Action Plan, the USA set goals for energy efficiency and GHG reduction in the building sector and set policy directions to transform federal buildings into net-zero energy buildings by 2030. Further, the policy for development and commercialization of building energy-efficient technology was pushed forward with the goals of shifting 50% of the existing commercial buildings to net-zero buildings by 2040, to finally shift all 100% by 2050. Technology information of low-energy buildings is provided through Internet-based information sites with the support of the DOE.

Japan has been vigorously reviewing its plans for residential buildings to expand energy-saving housing design, high-efficiency water heaters, solar thermal water heaters, and application of new and renewable energy. For general buildings, plans for energy-saving building design, high-efficiency lighting, office equipment, deployment of BEMS, and new and renewable energy have been promoted.

Korea is currently still at the stage of development of elemental technology and pilot demonstrations of zero-energy buildings by major construction companies and the public sector. Some pilot buildings are the EZ house, Seoul energy dream center, Green Tomorrow House, Generheim, and 3L house. KIER has conducted technology demonstration research on a zero-energy detached house, and the Korea Institute of Civil Engineering and Building Technology has built a multiunit house to demonstrate zero-carbon energy. Myongji University's research group for energy-zero housing projects has promoted the construction of zero-energy multiunit houses as a national R&D project and established Energy-Zero houses (EZ houses) in Nowon-gu in Seoul. The major technologies applied in this sector are those for high-efficiency exterior insulation walls, thermal bridge barriers, high-performance windows, external shading, photovoltaic generation, high-efficiency lighting, LED lighting, high-efficiency boilers, and high-efficiency heating facilities.

The Korean government also established the Center for Zero Energy Building and the Green Remodeling Innovation Center to step up its efforts to provide and promote technology for building energy efficiency. This technology is meant to reduce building energy consumption and GHG emissions. Technologies in the fields of wall insulation, air-tight insulation, high-efficiency facilities, renewable energy systems, interior finishing materials for indoor environment improvement, building vegetation system, waste recycling, and BEMS have been applied to this sector with government support and policy implementation.

GREENHOUSE GAS FIXATION

Overview

Definition and Scope of Technology

The term “greenhouse gas” refers any gas that contributes to a temperature rise on the surface of the Earth by absorbing or reflecting radiant infrared heat from the Earth’s surface into space. Seven types of gases are currently recognized as GHGs—one is CO_2, the other six non-CO_2 GHGs are CH_4, N_2O, SF_6, HFCs, PFCs, and NF_3. CO_2 is the GHG produced in almost every human activity. The use of energy of fossil fuels such as coal and oil is a major contributor to carbon dioxide emissions. Methane mainly originates from livestock and food waste; SF_6, HFCs, and PFCs are generated by air-conditioner refrigerants, aerosol sprays, semiconductor cleaners, and insulators. N_2O is emitted upon waste incineration and by chemical fertilizers.

A technology should be developed to reduce the GHG emissions to decelerate global warming. GHGs can be reduced by eliminating the GHGs already released into the atmosphere and before their release into the atmosphere. It is extremely difficult to eliminate the GHGs that are already present in the atmosphere. This can be achieved using only specific plants. However, GHGs can be eliminated before their release using the capture, storage, and utilization technologies. Some of these technologies are currently in the commercialization phase.

Table 23 | Subtechnology classification

Subtechnology	Technology description
Carbon Capture, Utilization, and Storage (CCUS)	• CO_2 capture technology • CO_2 utilization technology • CO_2 storage technology
Non-CO_2 reduction	• Methane (CH_4) separation & purification technology • Nitrous oxide (N_2O) emission reduction technology • Sulfur hexafluoride (SF_6) separation, purification, recovery, destruction, and reuse technology

Different approaches are applied to the GHG mitigation technology in case of CO_2 and non-CO_2 gases. The Carbon Capture, Utilization, and Storage (CCUS) technology is generally referred to as the CO_2 mitigation technology. The CO_2 originating via the combustion of fossil fuels in thermal power plants and steel, cement, and petrochemical factories and from the CO_2 sources created via specific processes is captured. The captured CO_2 is stored in a safe underground layer and isolated from the atmosphere. The CCUS technology recently includes an isolation technology with CO_2 recycling; in this method, the captured CO_2 is used to recover oil or natural gas or converted into useful materials, including polymers or liquid fuel. The technology for non-CO_2 fixation replaces non-CO_2 GHGs with other materials having less or no impact on global warming, minimizes the use of non-CO_2GHGs, and recovers, recycles, and destroys the generated non-CO_2 materials in an ecofriendly and highly efficient manner.

Technology Trends and Industry Outlook

As of 2016, 38 large-scale integrated CCS projects are being conducted around the world, primarily in the USA and China. The USA has 12 large-scale capture facilities, which is the largest number in the world, in the operation, construction, and planning stages; eight, five, and five projects are currently underway in China, Europe, and Canada, respectively. Among the 38 large-scale capture plants, 12 target power generation facilities, whereas the remaining 26 target various industrial sectors. Together, they are expected to capture 71.5 million tons of CO_2 per year.

With continuous R&D on the CCUS technologies, Korea has secured the core technology for the CO_2 capture process in a fluidized bed using a dry sorbent. This process is in the commercial stage for the first time in the world, and tests are being conducted for commercialization using 10 MW plants. With regard to CO_2 storage, Korea has set a masterplan for geological CO_2 storage at a 10,000 ton scale as part of the Korea CCS 2020 Project. The pilot research on geological storage for onshore basins was vigorously conducted in the fields of storage reservoir search; for this purpose, the storage strata were characterized, the behavior prediction was modeled, and a monitoring methodology was developed using physical and geochemical methods. In the Janggi basin, the onshore pilot demonstration project of 10,000 ton scale injection, storage, and management was launched in 2017.

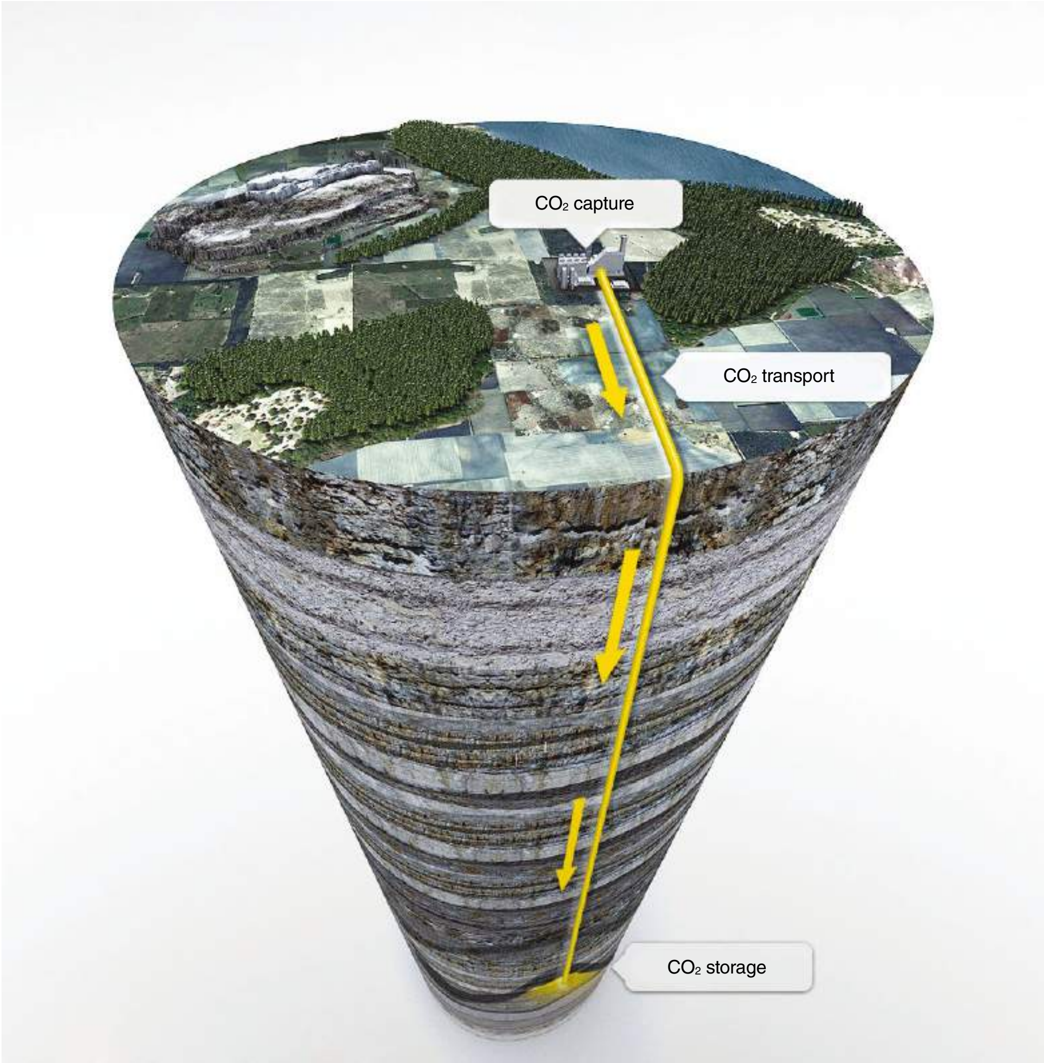


Figure 52 | Process of CO_2 capture and storage © Global CCS Institute

Non-CO_2 reduction

In the fields of non-CO_2 GHG reduction, the EU is the leader in technology development, followed by Japan, the USA, Korea, and China. The EU has the highest level of basic and applied technology for CH_4 and N_2O reduction, whereas Japan and the USA possess high levels of SF_6 technology. CH_4 and N_2O are generated mostly by the environmental infrastructure and chemical industry. Because SF_6 is the most commonly emitted material from the electronics industry, the technological development status of individual countries in the related industries affects the level of reduction technology.

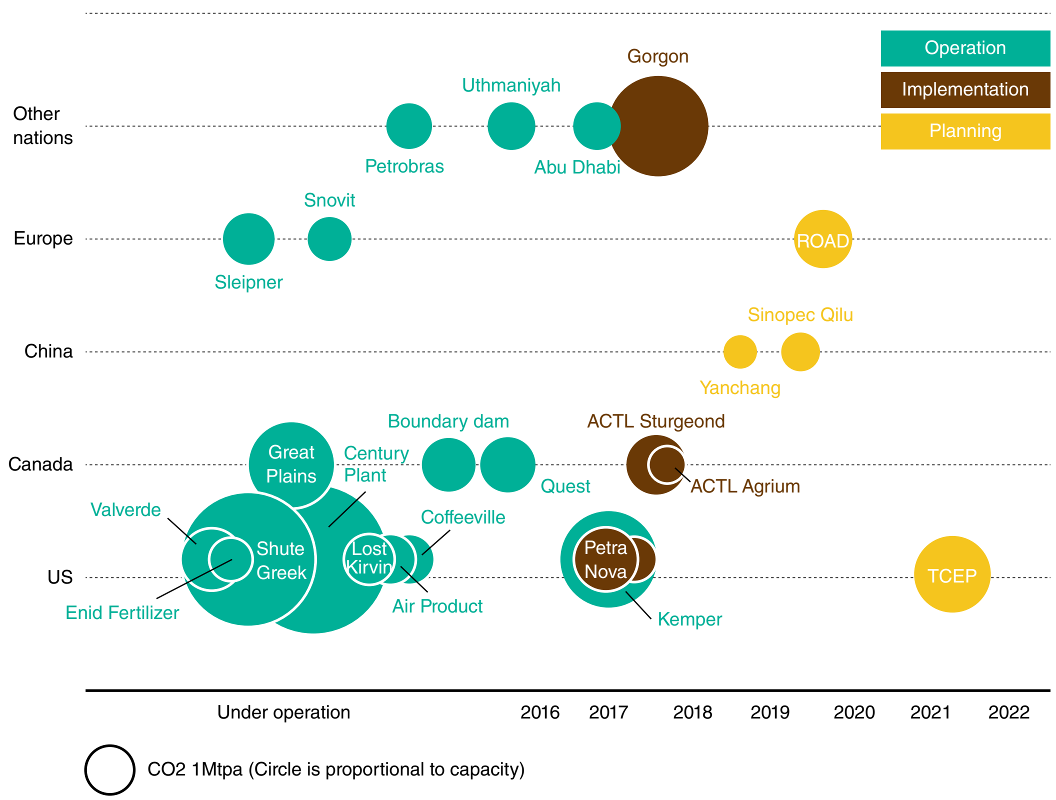


Figure 53 | The global CCS project status

In Korea, there is an urgent need to develop reduction technology for non-CO_2 GHGs because all the six gases recognized as non-CO_2 GHGs are emitted and artificially produced, utilized, and distributed. However, majority of the CDM projects adopted technologies from Europe and Japan because of the lack of awareness of the importance of non-CO_2 GHG reduction when the Clean Development Mechanism (CDM) projects were launched under the Kyoto Protocol. The development of mitigation technology for non-CO_2 GHGs has been under the central management of a project group since 2013; the first-phase project was conducted from September 2013 to April 2017, and it is currently in the second phase since May 2017.

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Carbon Capture, Utilization, and Storage (CCUS)

Definition and Scope of Technology

CCUS is the process of capturing the CO_2 produced via the combustion of fossil fuels in thermal power plants, steel, cement, and petrochemical factories and utilizing or storing it. The captured CO_2 is stored in a safe underground layer and isolated from the atmosphere. The CCUS technology includes an isolation technology with CO_2 recycling, wherein the captured CO_2 is used to recover oil or natural gas or with the conversion of CO_2 into useful materials, including polymers or liquid fuels.

The capture technology includes subtechnologies such as post-combustion capture, pre-combustion capture, and oxy-fuel combustion. Post-combustion capture deals with the capture of CO_2 from an exhaust gas with high N_2 content, which is emitted from power plants and various combustion processes. Pre-combustion capture eliminates CO_2 from syngas before it undergoes combustion in a gas turbine. Oxy-fuel combustion isolates almost pure CO_2 by emitting highly concentrated CO_2 after burning fuel with almost pure oxygen instead of air.

The CO_2 utilization options can be classified as the direct use of CO_2 and conversion of CO_2 into valuable chemicals, fuels, and materials. The direct utilization of CO_2 includes its use in the food and drink industry and for enhanced oil recovery. CO_2 can also be utilized by converting it into chemicals, fuels, and materials.

Storage technology includes storage site selection to discover promising storage sites through geophysical research, a technology for injection well designs that can be used to optimize and stabilize the injection conditions at storage sites, an integrated monitoring technology for efficient management of storage sites, an environmental impact analysis, and the plant operation management technology.

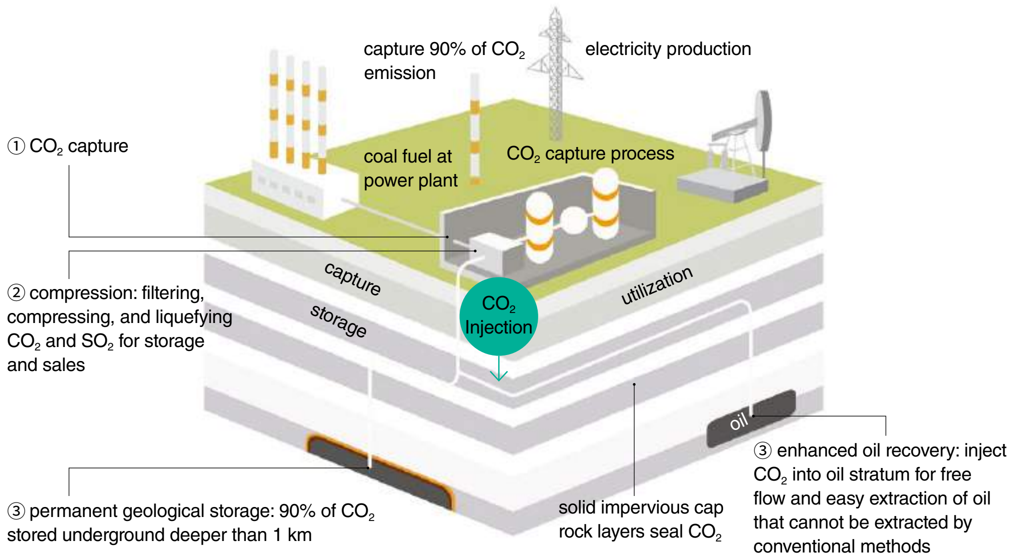

Figure 54 l CO_2 capture, utilization, and storage

Key Technology and Research Trends

The USA is currently working on a pilot demonstration project for the commercially available first-generation CCS technologies in large-scale plants and developing a second-generation and transformative technology that can reduce the capture and sequestration costs and energy penalties. Under the Petra Nova Carbon Capture Project operated in 2017, a facility that can capture 90% of the CO_2 emitted from a 240 MW coal-based thermal power plant is currently in operation. This is the world's largest capture facility in the power generation sector and can process 1.4 million tons of CO_2 per year. The objective of R&D for the next-generation capture technology focuses on developing a low-cost and low-corrosive absorbent that can handle a large volume of CO_2 and improving the reduction and response rates of renewable energy. Research on amine, non-aqueous, and phase variation absorbents is also underway.

The EU has created a EUR 9 billion carbon reduction project fund (NER400), equivalent to 400 million tons of carbon credits (certified emission reduction) to achieve a 40% reduction in CO_2 emissions by 2030 compared with the 1990 levels. It also plans to expand investment in technology for CCS and renewable energy. Currently, many countries are conducting large-scale CCUS demonstration programs, including the Horizon 2020, a test program conducted by Norway, and the Rotterdam Capture and Storage Demonstration Project in the Netherlands. In Switzerland, the world's first direct air capture plant that can capture the CO_2 in the atmosphere has been established and is currently in the demonstration phase.

Since the establishment of the CCS roadmap in 2010, Japan has been engaged in research on the chemical absorption and membrane capture technology. The Research Institute of Innovative Technology for the Earth under the Ministry of Economy, Trade, and Industry is in charge of the innovative R&D projects, including the COCS and COURSE50 projects. These projects aim to apply the CCS technology to the steel industry. The capture technology development led by the private sector, for example, the KS absorbent of Mitsubishi Heavy Industries used in the USA Petra Nova Project, has been successfully applied to the large-scale facilities in Europe and North America.

In Korea, KEPRI has developed Kosol, an alkanol–amine-type absorbent, in 2006. Further, a 150 MW front end engineering design was implemented after a 10 MW scale demonstration. The technology for capturing the dry CO_2 sorbent has been jointly developed by KIER and KEPRI with the support of the CO_2 project group since 2002. Thus, Korea has developed a core technology for the CO_2 capture process in a fluidized bed using dry sorbent, which is in the commercial stage for the first time in the world. Korea has also been conducting tests for commercialization using 10 MW plants. 0.1 and 0.7 MW testbeds have been established for the pre-combustion technology and oxy-fuel combustion, respectively. The Korea Carbon Capture & Sequestration R&D Center has led technology development to build wet, dry, and membrane-integrated testbeds in conjunction with 2 MW coal-based thermal power plants for research purposes to secure key technologies.

The CCU technology is recognized as one of the six core technologies in the National CCS Comprehensive Implementation Plan (2010. 07), Key Technology Development and Industry Expansion Plan on Combating Climate Change (2014. 07), and Technology Innovation and Industry Promotion Support Plan on Combating Climate Change (2015. 03). This technology is currently under development. With regard to CO_2 utilization, the Ministry of Science and ICT leads the basic research on electrochemical processes, mineralization, polymer conversion, and bioconversion. The Ministry of Trade, Industry, and Energy and private corporations have promoted demonstration research on polymer fabrication, mineralization, bioconversion, and fuel production.

With regard to CO_2 storage, Korea has established a masterplan for geological CO_2 storage at a 10,000 ton scale in 2011 as a part of the Korea CCS 2020 Project. The pilot research on geological storage for onshore basins has been vigorously conducted in the field of searching storage reservoirs; in this regard, the tasks involved include the characterization of storage strata, modeling of behavior prediction, and development of the monitoring methodology using physical and geochemical methods. In the Janggi basin, the onshore pilot demonstration project of the 10,000 ton scale injection, storage, and management commenced in 2017. The Ministry of Trade, Industry, and Energy initiated the offshore CO_2 injection demonstration project on the scale of tens of thousands of tons in the Pohang basin. Meanwhile, the Ministry of Oceans and Fisheries conducts R&D on infrastructure for large-scale storage demonstration projects, including offshore CO_2 transport storage process design and technology development for ocean environment management.

02

Non-CO_2 Reduction

Definition and Scope of Technology

The non-CO_2 reduction technology refers to the technology used to reduce global warming caused by six types of non-CO_2 GHGs (CH_4, N_2O, SF_6, HFCs, PFCs, and NF_3). The objectives are to replace these six types of GHGs with other materials that have less or no impact on global warming, minimize the use of non-CO_2 GHGs, and recover, recycle, and destroy the non-CO_2 materials in an ecofriendly and highly efficient manner.

The subtechnologies include the CH_4 separation and purification technology to recycle or process the methane generated from anaerobic fermentation in an ecofriendly and highly efficient manner, the chemical processing technology, and a technology to reduce the highly concentrated N_2O emitted from chemical processes and the semiconductor industry in an ecofriendly and highly effective manner. Other subtechnologies include a technology to replace gases with other materials that have less impact on global warming and a technology to separate, purify, recover, and destroy SF_6 to minimize the use of SF_6 in various industrial processes.

Key Technology and Research Trends

In the field of non-CO_2 greenhouse gas reduction, the EU ranks first in terms of technology development, followed by Japan, the USA, Korea, and China. The EU also has the highest level of basic and applied technologies for CH_4 and N_2O, with Japan and the USA possessing a relatively high level of SF_6 technology. This is because the technological development status of individual countries with respect to the related industries affects the level of the reduction technology. CH_4 and N_2O are generated mostly in the environmental infrastructure and chemical industry, whereas SF_6 is commonly emitted from the electronics industry.

Table 24 l Technology level and gap compared to countries with world's top technology levels

Country	Basic research level&gap		Applied development level&gap		Overall level & gap	
	Level(%)	Gap(year)	Level(%)	Gap(year)	Level(%)	Gap(year)
Korea	83.0	3.4	88.2	2.3	85.6	2.9
China	55.7	7.5	58.3	8.1	57.0	7.8
Japan	93.7	1.7	98.4	0.7	96.1	1.2
EU	100.0	0.0	100.0	0.0	100.0	0.0
USA	95.3	1.3	94.9	1.3	95.1	1.3

In Korea, there is an urgent requirement to develop a reduction technology for non-CO_2 GHGs because all the aforementioned gases are emitted and artificially produced, utilized, and distributed. However, majority of the CDM projects have adopted technologies from Europe and Japan because of the lack of awareness of the importance of the non-CO_2 GHG reduction projects at the time of launch of the CDM projects under the Kyoto Protocol.

Figure 55 | CRNG at ENVEX 2016 © CRNG

In September 2013, the Ministry of Environment integrated the technology development projects conducted sporadically under the system of the R&D Center for Reduction of Non-CO_2 GHGs (CRNG) to ensure comprehensive development. This integration has accelerated the pace of technology development in this sector, rapidly improving the country's technology level compared to its level in 2014. The reduction technology development projects were conducted by the central management of the project group since 2013; the first-phase project was conducted from September 2013 to April 2017, and the project is now in the second phase since May 2017: The performance of the non-CO_2 GHG reduction technologies is well documented in reports related to the performance of the CDM projects under the Kyoto Protocol. From March 2005 to July 2013, the number of registered CDM projects worldwide reached 7696, with 6550 cases (85.1%) related to CO_2 and 1146 cases (14.9%) related to non-CO_2 GHGs. The Certified Emission Reduction (CER) achieved by reducing the GHG emissions through CDM projects is reported to be 1,652,382,000 t of CO_2. Because 707,521,000 t of CO_2 (42.8%) originated from CO_2 and 943,861,000 t of CO_2 (572%) originated from non-CO_2 emissions, the unit reduction volume of the non-CO_2 reduction projects is considerably higher than that of the CO_2 reduction projects.

During the same period, i.e., from March 2005 to July 2013, the CDM projects registered in Korea were 91, with 72 cases related to CO_2 (79.1%) and 19 related to non-CO_2 gases (20.9%). Also, the CER equivalent to 135,533,000 t of CO_2 was obtained, among which 4,258,000 t of CO_2 (3.1%) originated from CO_2 and 131,275,000 t of CO_2 (96.9%) originated from non-CO_2 emissions, indicating that non-CO_2 emissions account for the majority of reduction performance. This is because Korea's export competitiveness can be attributed to industries such as the industries manufacturing automobile, ship, refrigeration equipment, chemical products, and electronics, including semiconductors, LCDs, and household appliances.

As such, Korea's GHG reduction is mostly related to non-CO_2 emissions. The non-CO_2-related CDM projects operated until now can be categorized as follows: 6 projects for methane, 6 projects for nitrous oxide, and 7 projects for F-gases. These projects are implemented using the technologies mostly provided by Japan and EU. In September 2013, the Ministry of Environment integrated the technology development projects conducted sporadically in universities and research institutes under the system of R&D Center for Reduction of Non-CO_2 GHGs (CRNG) to secure and advance the related technologies

Part

3

Adaptation Technology

Agriculture and Livestock

Water

Climate Change Prediction and Monitoring

Oceans, Fisheries, The coast

Health

Forest and Land

AGRICULTURE AND LIVESTOCK

Overview

Definition and Scope of Technology

Climate change because of global warming is expected to cause desertification and water shortage, which will ultimately disrupt the ecosystems in the future. Hence, tremendous efforts are being made in the agriculture and livestock industries to ensure diverse genetic resources, develop new cultivars, and improve the cultivation and livestock farming environments to prepare for future climate change. The efforts also include the prevention of livestock diseases, pest control, and innovation with respect to the distribution and processing technology of the agricultural/livestock products. Eventually, all these efforts should efficiently streamline the production process to cope with future food shortages.

The technology related to germplasm and genetic improvement intends to collect the genetic resources required for breeding and develop strategic varieties as well as explore and discover new food resources alternative to the crops and livestock that are currently being consumed.

The crop cultivation and production technology deals with the advancement of the growth and production processes to cope with the changes in vegetation and the expansion of the water-scarce areas owing to climate change. The technology covers not only the improvement of cultivation environments but also the overall production and harvesting processes, including the irrigation, fertilization, seedling culture, and crop protection processes as well as the convergence technologies integrated with IT such as plant factories and smart farms.

Table 25 | Subtechnology classification

Subtechnology		Technology description
Genetic resources, genetic improvement	Genetic resources and improvement of crops	• Technology for securing, managing, and evaluating genetic resources to improve the agricultural characteristics in staple, horticultural, and specialty crops • Basic technologies related to genome information analysis, gene function research, genetic engineering, and genome editing • Conventional breeding, molecular breeding, and biotechnology to improve the varieties of major crops
	Genetic resources and improvement of livestock	• Improvement of heat-tolerant varieties for global warming • Development of microbial control and feed manufacturing technologies to reduce the greenhouse gas emissions • Livestock production management and technology development
Crop cultivation and production		• Establishment of various cultivation facilities, including farmland, greenhouses, and plant factories • Integration of overall technologies such as raising seedlings, sowing, fertilization, irrigation, crop protection, and harvesting
Livestock disease management		• Technology for improving livestock health and productivity to produce safe livestock products • Technology for prediction, analysis, prevention, and quarantine of livestock diseases caused by climate change • Forecasting technology for ecological changes in disease vectors such as insects and migratory birds
Processing, storage, and distribution		• Energy saving technology in the processing, storage, and distribution stages from production to consumption • Waste minimization and recycling technology to minimize the carbon dioxide emissions • Establishment of the food safety prediction and management systems for climate change

Livestock disease management technology deals with the improvement of animal health and livestock productivity, disease prediction, analysis, and prevention, and quarantine management through simulation. Research on the ecological changes in insect vectors and migratory birds is also conducted for disease management.

The processing, storage, and distribution technology deals with the improvement of the energy use efficiency in every stage, i.e., from production to consumption, not only to ensure reliability but also to develop and distribute alternative processing technologies. Specific targets include the reduction of CO_2 emissions, the development of ecofriendly technology, recycling technology, and waste minimization, and the establishment of the food safety regulation and management systems.

Technology Trends and Industry Outlook

More than 2 billion people currently reside in areas with water scarcity; such areas are predicted to expand exponentially. Accordingly, there is an urgent need to develop crops having high heat and drought tolerance and high efficiency of water use. According to a UN report published in 2013, the world population of 7 billion as of 2012 will approach 10 billion by 2050. Rapid climate change accompanied by high-temperature and drought conditions is likely to accelerate the food shortage in underdeveloped countries, especially in Africa.

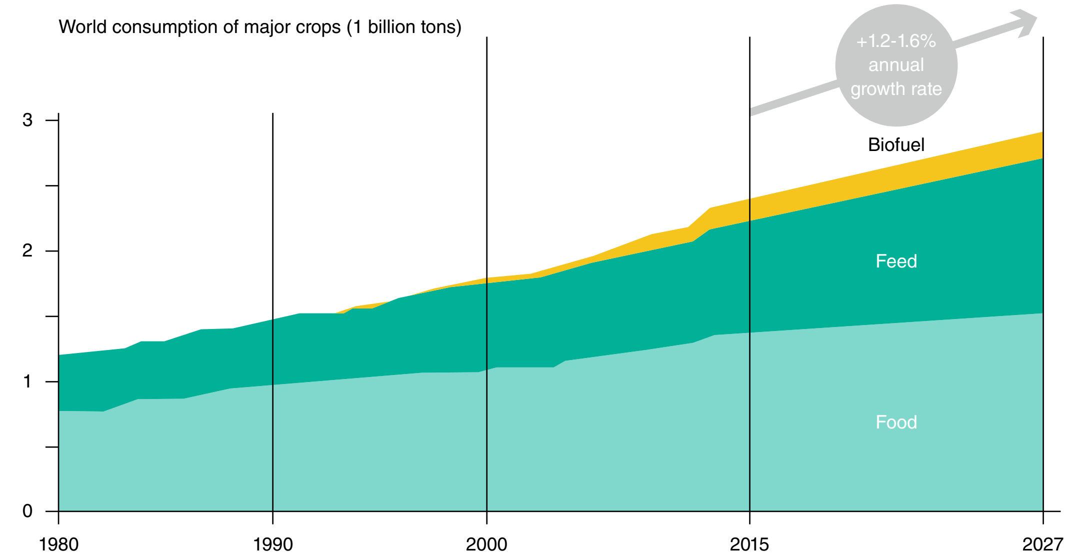

Figure 56 | Changes in the global demand for crops © USDA, FAPRI, Syngenta, 2016

Recent efforts have been conducted by several advanced countries to address the food shortage issues likely to result from climate change and population growth in the future when providing continuous R&D investment to improve the breeding and cultivation technologies for maximizing the use of limited cultivation areas. The breeding of livestock and crops relies on hybridization between the existing varieties. However, the reckless destruction of ecosystems and industrialization have accelerated the extinction of a considerable number of animals and plants, depleting various natural genetic resources. With the early recognition of the importance of genetic resources, the USA, China, Japan, and major

European counties have introduced measures to collect and preserve several genetic resources and select useful resources because this is directly related to the future food security of every country.

One of the long-term strategies for providing an active response to climate change is to discover new species as alternatives to the crops and livestock that are currently being widely cultivated or raised. To achieve this, major seed companies, national research institutes, and universities in the USA, the EU, and China are working on the interpretation of the genomic information and identification of the gene functions related to particular characteristics of plants and animals. Genetic improvement using genome editing technology is also expected to facilitate the development of varieties to cope with future climate change.

In Korea, technological development with respect to the agriculture and livestock industries in response to climate change is largely supported by the government. Genomic research regarding climate change was initiated by the RDA and national universities, with the government support for crop plants and livestock animals, such as rice, pepper, and cattle, observed to be of significant economic value in Korea. Systematic breeding is being attempted in private seed companies using molecular breeding technology with the aid of genome information and molecular markers. Korea is known as a pioneer in the development of genome editing technology, and such technological prowess has been applied to the development of new varieties in the fields of medicine and pharmaceuticals as well as in the agricultural and livestock industries. However, Korea lags in other technological areas, including cultivation, pest and disease management, distribution, and processing, which require considerable investment and support.

01

Genetic Resources of Crops and Gene Improvement

Definition and Scope of Technology

Crop genetic resources refer to every plant species and cultivar that can be used as food resources essential for ensuring human survival. Because of the emergence of rapid climate change as a serious problem, R&D has become an imperative part of the stable food supply to secure genetic resources with respect to the oncoming changes.

The development of genetic resources to prepare for climate change requires integrated research on basic science and applied technologies. Research on gene functions is underway to obtain fundamental knowledge as well as knowledge to cope with climate change issues, including high temperature, drought, and waterlogging stress. Biological and genetic research has contributed to the development of technologies to introduce genes and/or improve the traits associated with crop plants. Notably, with the recent advancements in the genome editing technology, attempts have been made to apply advanced breeding technologies such as genome and epigenome editing.

The subtechnologies deal with the fields of germplasm collection and management, conventional and molecular breeding, introduction of useful foreign genes, and genome editing. Germplasm collection and management involves the collection of the genetic resources of plants, forming the basis of the plant biotechnology industry. The germplasm information of the national agricultural genetic resources owned by local institutions and universities are currently collected and efficiently managed by the RDA Genebank Information Center.

The conventional and molecular breeding technologies, which use molecular markers to easily and rapidly develop new varieties, make it possible to overcome the limitations associated with traditional cross breeding by relying on phenotypic selection. Further, the introduction of useful foreign genes refers to inserting useful foreign genes into an existing organism to obtain desirable traits rather than performing plant hybridization. These technologies can drastically reduce the time required for molecular breeding and also introduce genes derived from other species that cannot cross-pollinate in nature.

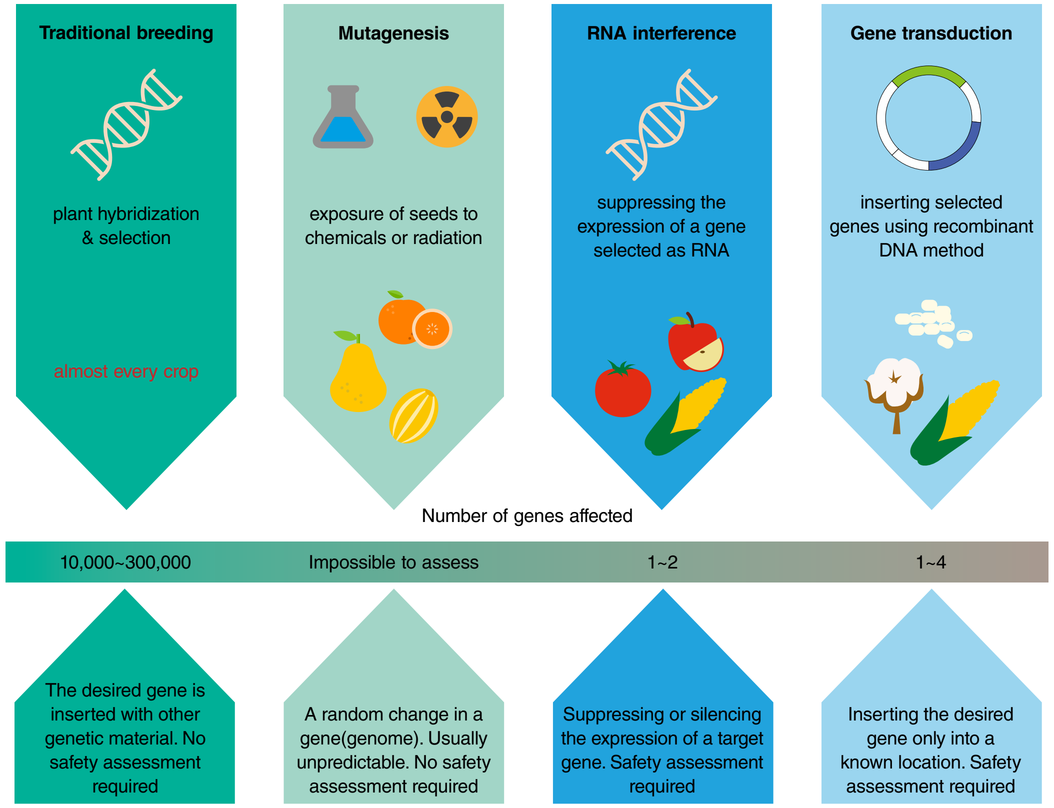

Figure 57 | Methods for the genetic improvement of crops

Using the genome editing technology, one can insert, replace, or delete the DNA in the genome by artificially manipulating the nuclease or molecular scissors. The genome editing technology has witnessed steady development, and novel crop varieties are being extensively developed in preparation for climate change using CRISPR/Cas9, a third generation genome editing tool.

Key Technology and Research Trends

The USA has strived to secure the germplasm necessary for performing biotechnology research, and the National Center for Genetic Resources Preservation gathers genetic resources worldwide that are required to ensure food security. In particular, many USA-based international seed companies have attempted to file patents for the genes associated with high tolerance to drought, waterlogging, high temperature, and high salinity. Such companies are also aggressively pursuing M&A to legitimately procure genetic resources from the acquired company.

In addition to securing genetic resources, the USA has been encouraging research on developing new varieties using various molecular biology technologies in public and private sectors. To reduce the production costs and increase the yield, the research has focused on the development of breeding technology as well as the cultivars that exhibit improved stress tolerance to environmental changes. Monsanto, headquartered in the USA, is a leading company in the area of third-generation genome editing technology and possesses a wide range of key technologies and patents.

The EU proposed the infrastructure setup for biological resources and its cooperative operation in the four key areas of the 7th R&D Framework Program (FP7, 2006). However, they are reluctant to develop new varieties using genome editing technologies because of the more stringent GMO regulations when compared with those in the USA. Regardless, unlike the current genome editing technology, recent attempts at epigenome editing do not affect the gene sequence; therefore, once the technology is practically available, it is expected to expedite the development of new varieties that meet the EU regulations.

Japan has undertaken projects that secure, manage, and utilize genetic resources at the highest level with the support of the National BioResource Project (NBRP, since 2002). The country has also set a plan to invest 90 billion JPY from 2016 to 2020 for the development of the exclusive genome editing technology to develop a technology that can control the gene expression in plants according to their growth conditions.

In Korea, many native genetic resources have been removed from the country via various routes before completely recognizing their importance. However, since 2007, a large number of genetic resources originating from the Korean Peninsula are being sent to Korea from other countries under the leadership of the Rural Development Administration. In 2006, a world-class germplasm facility was built for long-term seed storage; it is equipped with a top-notch robotically controlled tracking system and can also withstand a 7.0 magnitude earthquake on the Richter scale. Currently, the RDA Genebank Information Center has 192,777 germplasm items of 2,773 plant species, making it the sixth largest agricultural genetic resource center in the world. With the collection and storage of these seeds, the government aims to fully support the development of new varieties.

The research team led by Jin-Soo Kim and Sung-Hwa Choi of Seoul National University is at the forefront in the field of third-generation genome editing technology, which is well recognized as a new breeding technology. The team modified the genes in tobacco, Arabidopsis, rice, and lettuce by delivering the pre-assembled CRISPR/Cas9 into the plant protoplast. The team also successfully re-differentiated the lettuce plant from the protoplast, the genes of which had been edited.

Genetic Resources of Animals and Gene Improvement

Definition and Scope of Technology

Livestock improvement refers to the improvement of the genetic traits of livestock using genetic resources to help human life. The livestock improvement process involves defining the traits to be improved, conducting performance tests, selecting superior genes based on the test results, and applying them to breeding. Thus, livestock breeding in response to climate change requires the selection or development of traits and an efficient measurement to evaluate the genetic capabilities.

In the field of livestock improvement, the climate change response strategies include the improvement of livestock to enable it to adapt itself to climate change and the reduction of the methane gas generated by the animals to reduce carbon emissions. Accordingly, the subtechnologies in this sector include the improvement of heat-tolerant varieties resistant to hot weather and the development of methane reduction technology for livestock.

To breed livestock for heat tolerance, the method of breeding sheep with a heat-tolerant breed can be applied. Further, the slick hair gene discovered in the 20^{th} chromosome of high-heat-tolerant cattle in South America can be used. This method has been proposed for breeding with superior heat tolerance considering the rectal temperature of cows or the temperature–humidity index.

An improvement in the productivity of livestock reduces methane production. For pigs, a 100 g increase in daily gain (the average weight gain per day) can reduce approximately 0.7 g of methane gas per kg of meat production. Because approximately 80% of methane gas is generated from manure, efficient treatment of the livestock manure can reduce methane gas generation.

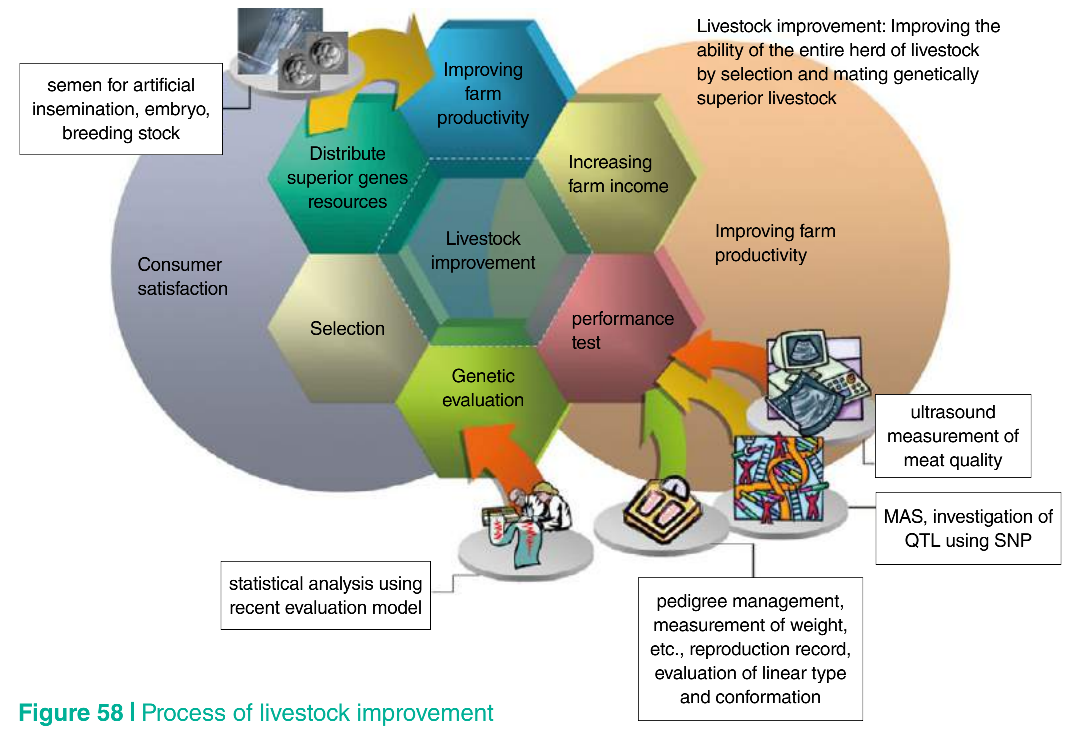

Figure 58 | Process of livestock improvement

Key Technology and Research Trends

In the USA, the research on the heat tolerance of livestock has focused on temperature and relative humidity along with the development of various Temperature–Humidity Indices (THI) and the improvement of heat-tolerant breeds using this index. Studies have also been conducted on improving livestock by mating with heat-tolerant breeds as well as discovering and utilizing the genes related to heat tolerance.

The EU has strived to adopt comprehensive and fundamental measures for climate change. These measures include the implementation of the carbon emission trading schemes, the establishment of the European knowledge base on climate change, and joint responses through public–private partnership. To minimize the impact of climate change on agriculture, the EU has been working on developing species adapted to climate change as well as cultivating management technologies to develop breeds that consume less water and are resistant to diseases as well as cultivation methods to stabilize production in response to climate change.

Since the late 1980s, Japan's efforts to address climate change were categorized as mitigation, adaptation, and international cooperation. For adaptation to climate change, the evaluation of effect of abnormal weather on livestock breeds have been analyzed in a scientific and systematic manner. To respond to the climate change with respect to agriculture, Japan identified the status of production sites for each species and prescribed tasks for the present and measures for the future.

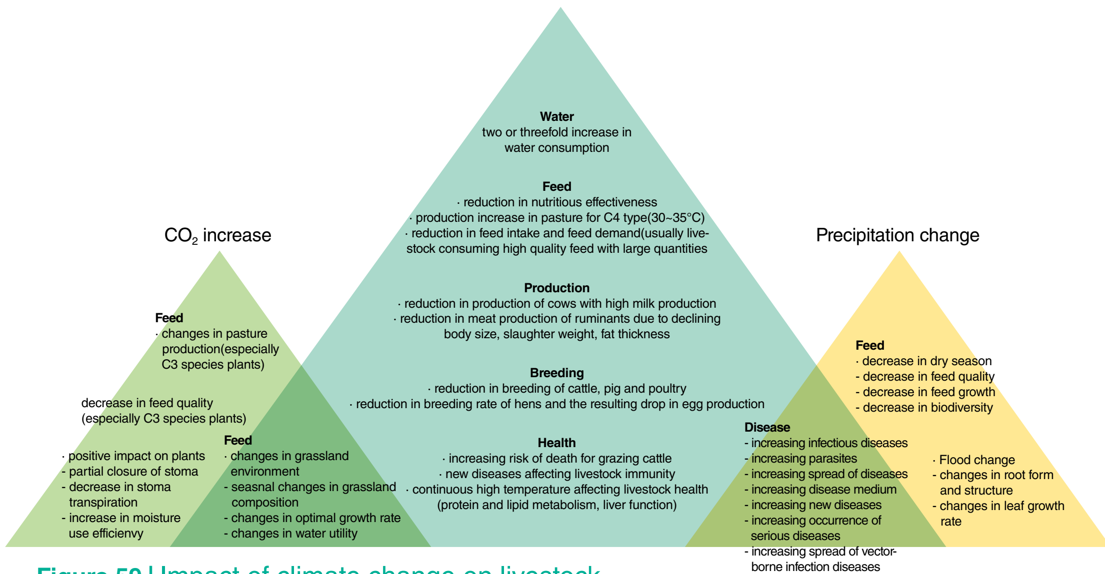

Figure 59 | Impact of climate change on livestock

In Korea, the experience of operating the Dairy Herd Improvement (DHI) program for several decades has shown that a certain level of heat tolerance has been secured for cows; however, it becomes difficult to guarantee its stability under continued global warming. The fields related to developing feed for reducing methane emission, improving production facilities, and developing cultivation technology in response to climate change are being actively researched; however, Korea still lags behind countries having advanced agricultural technology in terms of quantity and quality of the research. Because the development of livestock varieties requires substantial time and costs, attempts to develop new breeds have been very limited.

03

Crop Cultivation and Production

Definition and Scope of Technology

The crop cultivation and production technology refers to various element technologies related to the cultivation and production of crops for agricultural purposes in cultivating facilities such as rice paddies, fields, orchards, greenhouses, and seedbeds. The technology for crop cultivation and production is a convergence technology that determines the price, quality, and reliability of each crop, encompassing overall element technologies in the process of crop cultivation and production, and the technologies for facilities, equipment, and materials are used to realize individual element technologies.

Crops can be categorized as grain crops, including rice, beans, corn, wheat, and barley, root/tuber crops, including potatoes, sweet potatoes, and cassava, oilseed crops, including rapeseed, sunflowers, and sesame seeds, vegetable crops, including leafy vegetables and fruit vegetables, fruit crops, nut crops, flower crops, stimulant crops, including tobacco and tea, and medicinal crops, including ginseng and peppermint. Crops can also be classified by their function into food crops providing carbohydrates, protein and lipids, horticultural crops providing fiber, vitamins, sugar, and minerals, and specialty crops improving health and providing scent and flavor. Subtechnologies cover technologies related to seeds, seedling cultures, protected cultivation, crop protection, and agricultural machinery.

The first stage of crop cultivation and production is sowing. The production and supply of high-quality seeds is a technical field indispensable to crop cultivation and production. The core technology in this field is molecular breeding technologies, and various technologies are integrated to develop new varieties. The seedling culture technology is used to nurture seeds or propagate specimens in nurseries rather than to sow seeds to secure the early seedling stand of crops and shorten the process of cultivation and production, which is essential for the intensive and controlled agricultural environment in Korea.

The protected cultivation technology is necessary when crops are cultivated and produced in facilities, including greenhouses and plant factories, and it includes fully as well as partially protected cultivation (cultivation under rain shelters, etc.), for example, protected cultivation for fruit crops. Crop protection is a technology to protect crops from diseases, pest insects, and weeds during cultivation and production. It is an essential input factor for crop cultivation and production, and there exists an industry that focuses on the crop protection technology. Agricultural machinery is used in several farming activities, such as plowing, irrigation, sowing, transplanting, fertilizing, spraying crop-protecting agents, and harvesting, during crop cultivation and production, and the related industry has been established.

Key Technology and Research Trends

The USA is the largest agricultural producer in the world and is the world leader in terms of every element of the crop cultivation and production technologies. National level research on the crop cultivation and production technology is led by the Agricultural Research Service under the USA Department of Agriculture, and the state universities of each state lead the state-level research on the specialty crops in each state. In the private sector, the professional agricultural corporations that focused on each element technology are leading R&D and industrialization. Companies, such as Monsanto, DuPont, and Dow, are taking the lead in seed and seedling technologies and applying transformation and gene editing technologies to improve breeding.

The EU has secured mature crop cultivation and production technologies and has established a distinctive and competitive agricultural industry with various types of agricultural infrastructure based on the fundamental industries of each country. Among the EU members, the leaders in traditional agricultural industries (e.g., France, Germany, the UK, Italy, and the Netherlands) have been taking the lead in crop cultivation and production. The EU-funded joint research has also been vigorously conducted by the member countries.

Japan possesses the most advanced technologies for crop cultivation and production in Asian countries with its prowess in related element technologies and industries. National-level research on crop cultivation and production technologies has been conducted in research institutions under the National Agricultural Research Organization. Many seed companies, such as Sakata and Takii, and crop-protecting agent companies, such as Sumitomo, ISK, and Kumiai, are engaged in the industrial commercialization of various technologies in the private sector.

China lags behind Korea in crop cultivation and production technology but still has the greatest growth potential in the world. National level research is conducted in research centers under the Chinese Academy of Agricultural Sciences, whereas province-level research is led by the Provincial Academy of Agricultural Sciences. In the private sector, CNCC has been at the forefront of securing key technologies in the advanced agricultural industry via aggressive investments, including the takeover of the multinational agricultural corporation Syngenta.

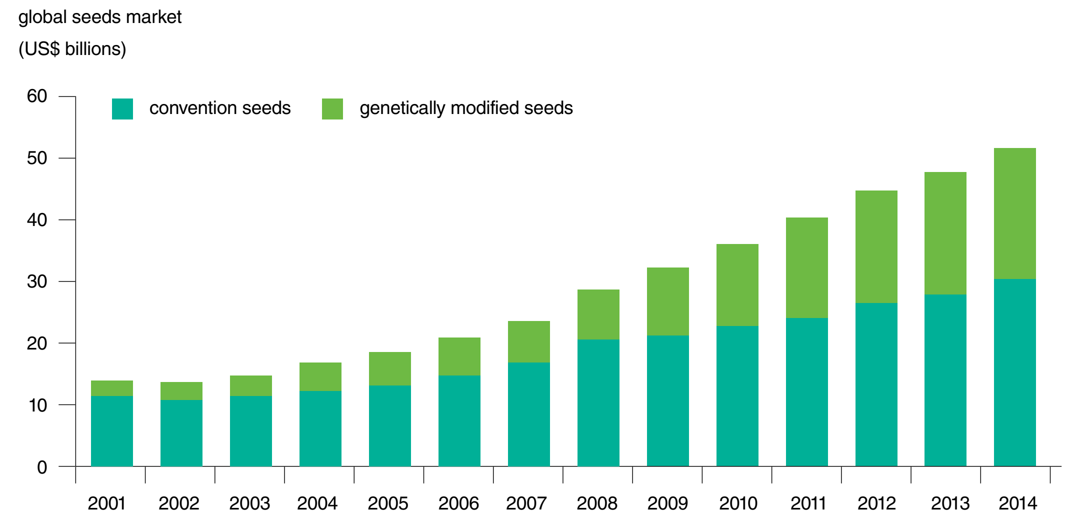

Figure 60 | Changes in the non-GM and GM crop seeds in the global seed market
© Syngenta, 2016

In terms of the advanced crop cultivation and production technologies, Korea is second only to Japan in Asia. Korea has the second highest level of related element technologies following Japan and is the third largest market after Japan and China in terms of the size of the element technology-related industry. Research on the crop cultivation and production technology is conducted more or less by three research institutes (NICS, NIHHS, and NAAS) under the RDA. The provincial institutes of agricultural sciences in each province focus on the cultivation and production technologies for the locally adapted crops, and major national and private universities across the nation have been engaged in basic and applied research in coordination with the central or local governments. In the private sector, agricultural corporations, specializing in seeds, crop protection, and agricultural machinery, have led the related research for industrialization. LG Chem and Nonghyup have acquired Farm Hannong and Nongoo Bio, respectively, when promoting R&D on seeds and the crop-protecting agents. Further, many other mid-sized companies have been conducting R&D on seeds, crop-protecting agents, and agricultural machinery.

04

Livestock Disease Management

Definition and Scope of Technology

Climate change significantly impacts the occurrence of livestock diseases. Global warming has increased the occurrence of infectious diseases spread by insects, such as mosquitos, ticks, and flies, making it difficult to control diseases worldwide. Thus, it is necessary to establish advanced technologies to control insects that carry livestock diseases along with efficient quarantine systems in airports and ports with respect to the agricultural and livestock products. Livestock management includes an appropriate stocking density with respect to high temperature and humidity situations, efficient cooling systems by improving the ventilation systems in pens, ICT convergence, and smart farm technology to make up for either the climate changes or the lack of labor force in rural areas.

The subtechnologies of livestock disease management can be categorized by the technology to control the livestock diseases caused by environmental impact and technology to establish animal disease control systems for responding to livestock diseases. The technology to control livestock diseases resulting from environmental impacts is not simple disease control; however, a technology has been developed to ensure that the livestock environmental conditions are similar to the previous climate conditions by improving the environment of the facilities with respect to the appropriate livestock density, water supply, ventilation, and process of livestock manure disposal. It also includes the technology for developing related products (temperature and humidity control devices, sprinklers, and air blowers). Customized countermeasures that combine various measures such as disease occurrence analysis, prevention, treatment, and carrier insect control are also required; in addition, the development of medicines (for treatment and prevention), the expansion of human infrastructure (workers in the field of livestock disease prevention), and investment in education are also needed. Periodic surveillance programs for emerging animal disease outbreaks in neighboring countries and efficient border quarantine systems need to be established for preventing the introduction of contagious animal diseases from abroad, and quarantine control of imported livestock products based on the systematic epidemiological analysis is also important for efficient foreign animal disease control.

The establishment of a livestock disease response systems calls for the development of models of diseases that can be introduced from neighboring countries, and major agricultural and livestock importing countries closely monitor diseases in each nation. Also, livestock disease prediction technologies and efficient, prompt response systems (animal movement restrictions, vaccination, etc.) tailored to specific diseases are necessary for early control of diseases.

Table 26 | Interspecies infection

Pathogen	Primary host	Reported year
Ebola virus	Bat	1977
Escherichia coli O157:H7	Cattle	1982
Borrelia	Rodents	1982
SIV/HIV-1	Primates	1983
SIV/HIV-2	Primates	1986
Hendra virus	Bat	1994
BSE/vCJD	Cattle	1996
Australian bat lyssavirus	Bat	1996
H5N1 influenza A	Chicken	1997
Nipah virus	Bat	1999
SARS coronavirus	Civet	2003

Key Technology and Research Trends

The USA conducts research on the overall elements of climate change that affect livestock diseases, the prediction of disease transmission by carriers, including migratory birds and mosquitos, which can travel between countries, and zoonosis that can spread between animals and humans. The USA government has established efficient countermeasures to minimize economic loss from diseases and has supported the quarantine measures of the private sector by linking the integrated system for climate change, livestock disease impact assessment, livestock disease management system, and Geographic Information System (GIS).

The EU has engaged in qualitative analysis of the patterns of livestock disease transmission by utilizing various simulation techniques and on-site tests and has conducted research based on this analysis to establish local preventive systems. In the UK, the Department of Environment, Food, & Rural Affairs has set up diverse preventive measures and strategies related to livestock diseases and also offers information services. The PLAN BLANC in France and the Heatwave Warming Network in Italy have also contributed to establish solutions for managing livestock diseases caused by abnormal climate and global warming.

Japan has identified the impacts of climate change on the agriculture and livestock industries, fisheries, and ecosystems and has developed a plan to build an information system for various livestock diseases. This was included in the 2008 Report on the Wise Adaptation to Climate Change.

Korea has investigated the domestic impact of climate change at the ministerial level and has established the Animal Health Policy Bureau under the Ministry of Agriculture, Food, and Rural Affairs to control malignant infectious diseases such as foot-and-mouth disease and avian influenza. The provincial and municipal animal quarantine agencies have been unified under the Animal Health Laboratory to improve the efficiency of the prevention and diagnosis of livestock diseases and conduct disease prevention activities. The number of livestock disease control experts has been increased for the efficient management of livestock diseases, and the Korea Animal Health Integrated System was introduced for managing prevention activities, including monitoring and diagnosis control. The government is also seeking countermeasures to respond to infectious diseases of the livestock that are likely to spread domestically or subtropical diseases caused by global warming that may be introduced into the country.

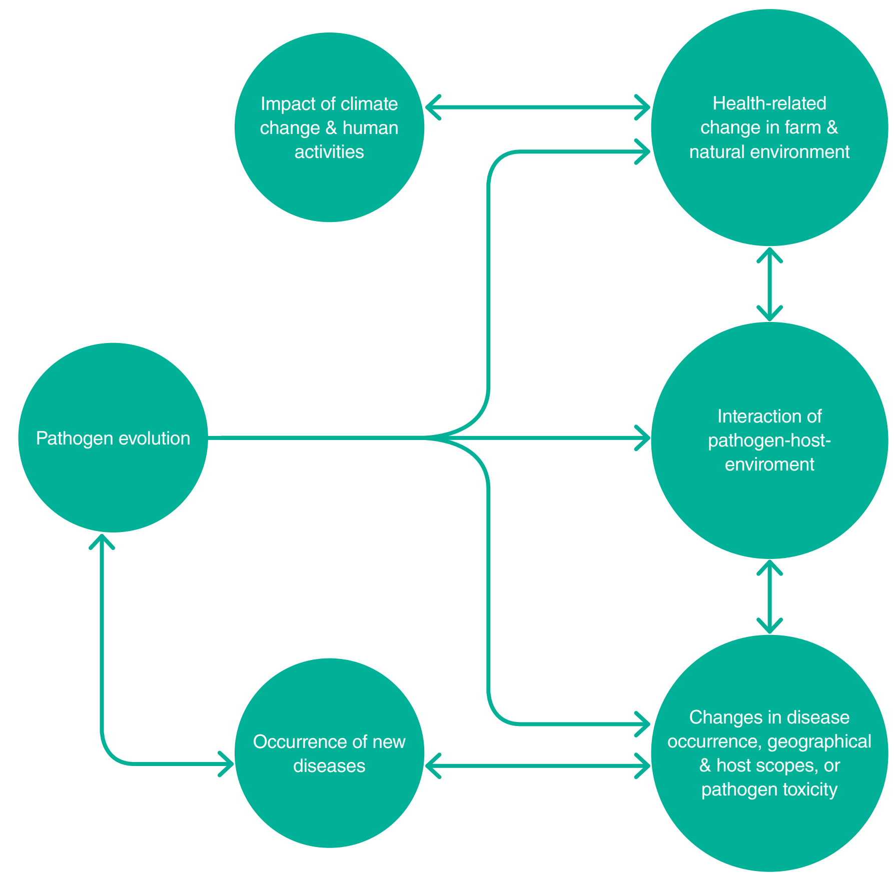

Figure 61 | Impact of climate change on disease occurrence
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05

Processing, Storage, and Distribution

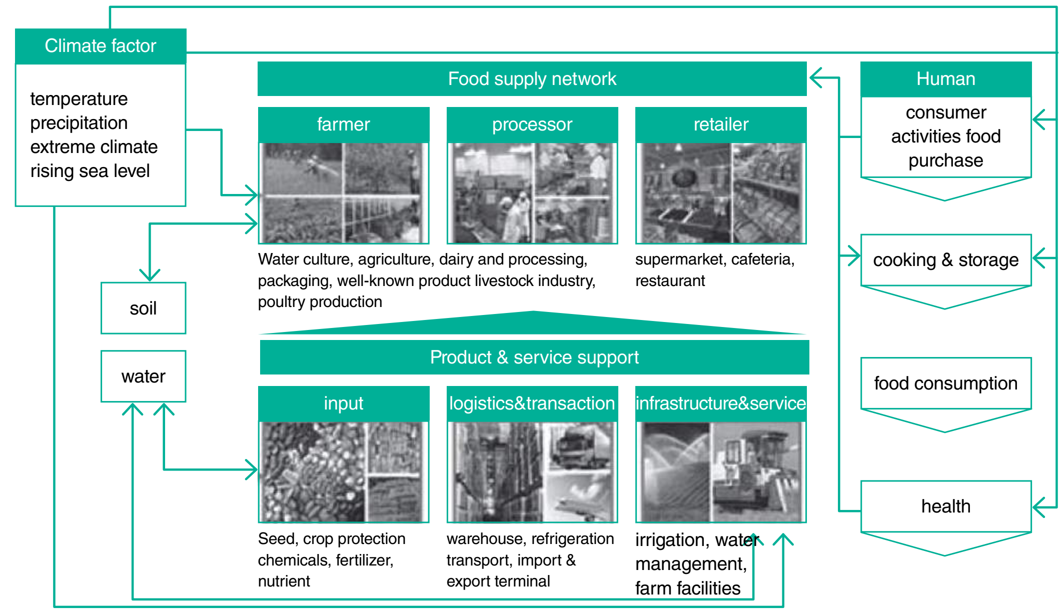

Figure 62 | Impact of climate change on the food supply systems

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Definition and Scope of Technology

Climate change has direct and indirect impacts on the food supply system, from processing, storage, and distribution to consumption. The globalization of supply and consumer markets has increased the transportation distances of agricultural and livestock products. This increase has resulted in a greater consumption of energy, and the risk of occurrence of food hazards during processing, storage, and distribution has increased, adversely affecting the quality, nutrition, freshness, and safety of the agricultural and livestock products. Accordingly, alternative processing technologies should be established to reduce the CO_2 emissions during the processing, storage, and distribution of the agricultural and livestock products; furthermore, a technology should be developed to ensure food safety.

There is a need for energy target management, efficient logistics, food waste-minimizing technologies, and related administrative measures to reduce the transportation distances and increase energy efficiency in the processing, storage, and distribution of agricultural and livestock products. In addition, the concept of local food, which can reasonably reduce the storage and distribution processes and is supported by the local farmers, environmental organizations, and local society, should be considered. The subtechnologies in this sector include an alternative processing technology for energy reduction and a technology for food safety issues.

Alternative processing technology for energy reduction refers to the technology for food processing and distribution, whereas the innovative technology for distribution and logistics aims to reduce the CO_2 emissions. Non-thermal pretreated processing technology with relatively higher energy efficiency when compared with that of heat-treated sterilization can be considered as an example. In terms of satisfying the consumer preferences for fresh ecofriendly products, processing technologies to minimize the process steps when securing flavor are useful for energy reduction.

Climate changes toward high-temperature and high-humidity conditions pose a threat to food safety with regard to the storing and distribution of domestic and imported agricultural as well as livestock products. In this regard, food safety technology is required to analyze and predict the impacts of climate change by identifying the hazards during processing, storage, and distribution through climate change simulations. Based on this technology, it is necessary to evaluate the risks associated with each food industry and process and continuously improve the current sanitation management systems (e.g., good manufacturing practice, GMP; hazard analysis and critical control point, HACCP).

The quality of food and the safety of public health can be improved by transforming the sanitation management standards for the overall food industry, restaurants, and households through alternative processing technologies for energy reduction as well as through food safety forecast and assessment of the impact of climate change.

Key Technology and Research Trends

Research on the impacts of climate change on the processing, storage, and distribution stages of agricultural and livestock products has mainly focused on food safety management rather than on direct project implementation. Further, few countries have performed such research because of the lack of information available with respect to bacterial food poisoning.

The USA has actively pursued research on food safety. Basic infrastructure and simulated observation systems have been firmly established and operated to minimize the uncertainty associated with climate change and support various relevant research projects. Research has also been conducted on potential food poisoning because of viruses, microorganisms, and insect vectors under conditions of poor temperature control; furthermore, research has been conducted on the direct and indirect impacts of risk exposure for infants and the elderly with relatively weak immune systems. An attempt has been made to commercialize the non-thermal sterilization technology for agricultural and livestock products to reduce the micro-organic hazards associated with the food distribution processes.

In the UK, genetic variations of the norovirus can be observed because of the dryness and low temperatures caused by climate change. Even though certain European countries have conducted a meta-analysis on the impact of climate change for other food-poisoning bacteria, statistical and microbiological risk assessment of fresh agricultural products has been analyzed considering the impact of packaging, logistics, climate change, and globalization. A study on reducing the energy consumption in the distribution process has proved that reducing the irrigation water consumption by 25% in the field was effective for lettuce, proving that reducing water consumption can increase the shelf life of lettuce and reduce the farming costs.

The Research Group on Food Safety Control Against Climate Change examined the establishment of countermeasures by impact assessment and monitoring the food safety hazards caused by climate change in Korea in 2010–2014. This group also dealt with the development of the food safety technology and management systems for manufacturing, processing, and distributing food. The results implied that the high-temperature and high-humidity conditions caused by the climate change in Korea are likely to affect the growth of food-poisoning bacteria, which will cause a 42% increase in food poisoning cases by 2090. The research also indicated that the southern areas, such as Jeju and Western Honam, are likely to be the most vulnerable to climate change. Further, juveniles under the age of 14 and elderly persons over 65 are the most vulnerable generations. Meat and egg products are recognized as the most sensitive to climate change. Furthermore, climate change will increase campylobacteriosis by up to 143% by 2050. The increasing average temperature is predicted to increase the probability of mycotoxin pollution caused by Aspergillus when storing fertilizers as well as agricultural and livestock products.

Limited research is underway with respect to the climate change simulation for horticultural crops. Technologies for hydrogen peroxide steam sterilization, electron beam irradiation, and pulsed-light sterilization have been explored. Attempts have been made to develop new packaging materials containing natural insecticides or antimicrobials. The amount of CO_2 generated by the electron beam irradiation technology is approximately $1/6^{th}$ of that generated by the conventional heat treatment or the chemical treatment, with increased sterilization effects.

WATER

Overview

Definition and Scope of Technology

Water constitutes 70% of the Earth's surface. 97.2% of Earth's water is present in the oceans as salt water, whereas the remaining 2.8% is present on land. Of this 2.8%, only groundwater (0.62%) and surface water (in lakes and rivers; 0.03%) are available to humans. Thus, even though water is abundant on Earth, only a tiny fraction is available to humans.

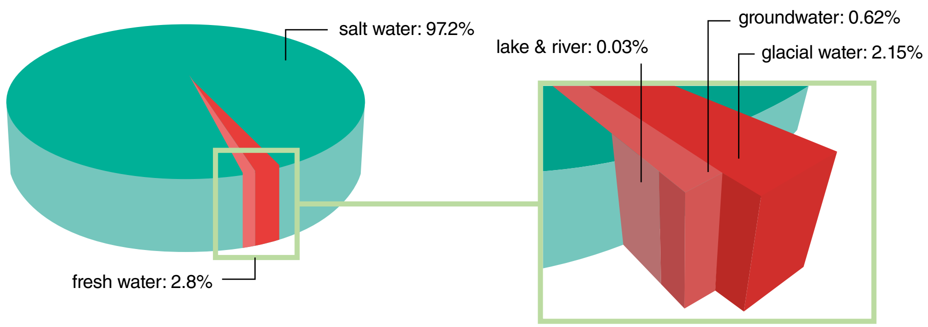

Figure 63 I Water on the Earth's surface

Table 27 | Subtechnology classification

Subtechnology		Technology description
Water system and aquatic ecosystem management	① Investigation & assessment of the habitat environment	Assessment of the external aquatic ecosystem and its surrounding environment
	② Assessment technique for utilizing algae	Assessment technique using the community structure of the epilithic algae
	③ Assessment technique for benthic macroinvertebrates	Assessment technique using the benthic community and its characteristics
	④ Assessment technique for fish	Assessment technique using the fish community and its characteristics
	⑤ Assessment technique for changes in communities due to climate change	Assessment technique using the model for changes in communities due to climate change
Securing and supplying water resources	① Desalination	A technology to produce fresh water by eliminating salt from seawater
	② Sewage water reclamation	A technology to treat and reuse sewage and wastewater
	③ Rain reuse	A technology to efficiently use and manage rainwater on building roofs, roads, and other impervious surfaces as water for irrigation, flood control, and the environment
	④ Underground dam	A technology to construct artificial cutoff walls in aquifers, where underground water flows, and to collect water using facilities such as pumping wells
	⑤ Use of riverbank filtration	A technology to collect river water and underground water, which permeate from streams to the riverside by drilling 20–40-m collector wells on riverbanks located 50–300 m away from the streams
Water treatment	① Optimization of technology for drinking and waste water, public treatment	A technology to restore the ecosystem with small-scale & dispersal paradigm for effective response to new pollutants in conjunction with the water-energy linkage (Nexus) and sustainable development
	② Technology related to harmful chemical substances	A technology to control refractory chemical substances from the total periodic perspective
	③ Technology to control algae material	A technology to safely process toxic substances and taste and odor compounds derived from algae
Water disaster management	① Water treatment monitoring-assessment-prediction technology	A technology to analyze and predict water disasters in response to climate change
	② Flood & drought disaster management and preemptive response technology	A technology for management and proactive response to reduce flood and drought damage
	③ Establishment of water disaster information platform	A technology to establish an information platform to utilize technologies for water disaster management and preemptive responses

Water-related technology deals with the efficient use of water in all areas related to water, including the ecosystem. Previously, such technologies intended to eliminate the pollutants in water and prevent water pollution to conserve and secure clean water. With changes in water cycle due to climate change, water-related technology has grown to encompass all the technologies that deal with the efficient storage of water to address the challenges of localization and inequality of water resources, conservation of the aquatic ecosystem against the background of increasing demand, and prevention of water-related disasters in view of the increasing occurrences of disasters due to the changes in precipitation patterns. Accordingly, the usage of water-related technology to remediate the adverse effects of climate change has expanded to include water management systems and aquatic ecosystems, water resource management, water treatment, and management of water-related disasters.

Technology Trends and Industry Outlook

Against the background of climate change, the keyword of “pollution” for water-related technology has been replaced with broader keywords, including “conservation of ecosystem and health,” “water resources,” and “water disaster.” Further, the water-related technology has expanded from merely environmental technology to environmental technology to conserve the aquatic ecosystems in response to climate change.

The usage of biological analysis for obtaining the composition of the species in the ecosystem plays a major role because the management technology for water systems and aquatic ecosystems evaluates the entire water environment instead of only the physicochemical water quality. Securing and supplying water resources involves developing alternative water resources that cannot be directly utilized by humans; such measures include the construction of structures, including multipurpose dams, dams for power generation, multifunctional weirs, seawater desalination facilities, wastewater reclamation facilities, and artificial rainfall. Water treatment technology has reached a mature stage in terms of quantity, and the quality of technologies, such as controlling non-degradable harmful substances, have been gradually developed and demonstrated.

The changes in rainfall patterns, such as days of rainfall and heavy rainfall, have increased the frequency and scale of the extreme weather events and droughts that cause water disasters. In the field of water disaster management, a technology to improve and maintain the accuracy of disaster forecasting is being actively researched, supported by the Hazard Disaster Analysis Program (Hazus-MH) in the United States, Damage Scanner in the Netherlands, and FLEMO in Germany to manage water disasters and respond preemptively.

Figure 64 | Hoover Dam, a multipurpose dam built on the Colorado River on the border between Arizona and Nevada, USA © shutterstock.com

In Korea, water-related technologies have rapidly advanced in terms of the treatment and prevention of pollution. A wide range of pollution treatment technologies is available. Further, with regard to the technology for water system and aquatic ecosystem management, efforts are being made to continuously evaluate the health of aquatic ecosystems and develop Korean-type techniques. Simultaneously, means to actively utilize the experience of developing a model to predict the changes with respect to the ecosystem community are being explored. The technology to secure and supply water resources has reached a certain level in specific fields, including dam construction and operation management, water and sewage management, water resource survey, and integrated flood management. However, there is growing recognition that the individual control of each sector is insufficient to effectively secure and supply water resources.

Table 28 | Scale and prospect of the world water market

Unit: $ million

Classification	2013	2014	2015	2016	2017	2018	2019
Water Resource Development	29,835	28,567	29,963	31,760	36,623	42,048	87,148
- water resource development	25,662	25,016	24,295	25,632	27,886	30,458	38,714
- desalination	4,173	3,552	5,669	6,128	8,737	11,590	48,434
Water Supply	264,432	269,984	277,784	287,838	299,153	311,356	393,536
- water supply network	51,512	52,528	54,460	54,460	62,492	66,709	95,802
- purification facility	25,205	25,703	28,027	28,027	29,836	31,622	43,440
- operation maintenance	187,715	191,753	201,351	201,351	206,825	213,025	254,294
Sewage	232,093	239,843	258,882	258,882	271,605	287,855	371,946
- sewage network	65,781	68,009	74,952	74,952	74,952	85,847	124,624
- sewage treatment facility	35,753	37,093	39,290	39,290	41,126	44,208	59,507
- sludge treatment	8,874	9,568	10,656	10,656	11,217	11,994	18,286
- operation maintenance	121,686	125,173	133,984	133,984	139,437	145,807	187,815
Industrial Water	53,352	55,418	58,325	58,325	60,750	63,759	85,540
- industrial water facility	17,652	19,718	21,183	21,183	22,865	25,116	41,152
- operation maintenance	35,700	35,700	37,142	37,142	37,885	38,643	44,388

1. 2013-2018 data from Global Water Market 2015 (GWI 2014)
2. '13-'18 weighted average growth rate applied to the estimation of '19-'25 in water resource development & water supply/sewage
3. Industrial water estimated to grow 3% annually as of 2013

In the field of water treatment technology, the utilization and conversion of efficient water treatment technologies based on the fourth industrial revolution are being researched. The safety treatment technology is gaining attention as a sector for future technology to minimize the adverse effects of any newly detected harmful substances to ecosystems and humans. Also, the integration of individual technologies by utilizing world-class IT in Korea in the new era of the fourth industrial revolution has received considerable interest.

In the field of water disaster management technology, R&D projects that intended to improve the accuracy of water disaster prediction were undertaken by various agencies, including the Ministry of Land, Infrastructure, and Transport and the National Fire Agency; thus, technologies were developed to achieve the level of advanced countries. Further, in Korea, various technologies have been developed based on the past experience of managing and recovering from water disaster

01

Water System and Aquatic Ecosystem Management

Definition and Scope of Technology

The management of freshwater ecosystems refers to the technologies and activities that scientifically evaluate the integrity of the freshwater ecosystems. In case of freshwater health assessment, the status of an ecosystem is determined via a comprehensive examination and analysis of the physicochemical, hydrological, and biological elements with respect to the landscape. Because an ecosystem close to its natural state is generally considered to be healthy, it is crucial to assess the biotic integrity of the ecosystem and assess whether the carrying capacity of the given ecosystem can support the biotic community close to its natural status.

To comprehensively assess an ecosystem, the physical, chemical, and biological factors associated with the ecosystem should be surveyed. Thus, the assessment of aquatic ecosystem health includes various techniques, such as habitat and waterside assessment, assessment of the biotic indices using specific taxa (such as algae, benthic macroinvertebrates, and fish), assessment of the biotic community indices, and assessment using prediction models with respect to the changes in the biotic community.

Key Technology and Research Trends

In the USA, MultiMetric Indices (MMIs), such as the Rapid Bioassessment Protocols (RBPs), Benthic Index of Biological Integrity (BIBI), and Invertebrate Community Index (ICI), are employed.

In the EU, an integrated Assessment system was developed for evaluating the ecological Quality of streams and rivers throughout Europe using benthic Macrovertebrates (AQEM) and ASTERICS, a program for assessment and analysis. Sweden employs the Waterbody Assessment Tools for Ecological Reference Conditions and Status in Sweden (WATERS) developed in the country; Sweden also evaluates the program with the help of a reference group focusing on the biological factors used in water quality assessment based on the Water Framework Directive (WFD) (WATERS, 2013). Further, the EU has provided standards with respect to the minimum disturbance status of rivers and streams by considering land use, watersheds, and physical and chemical variables.

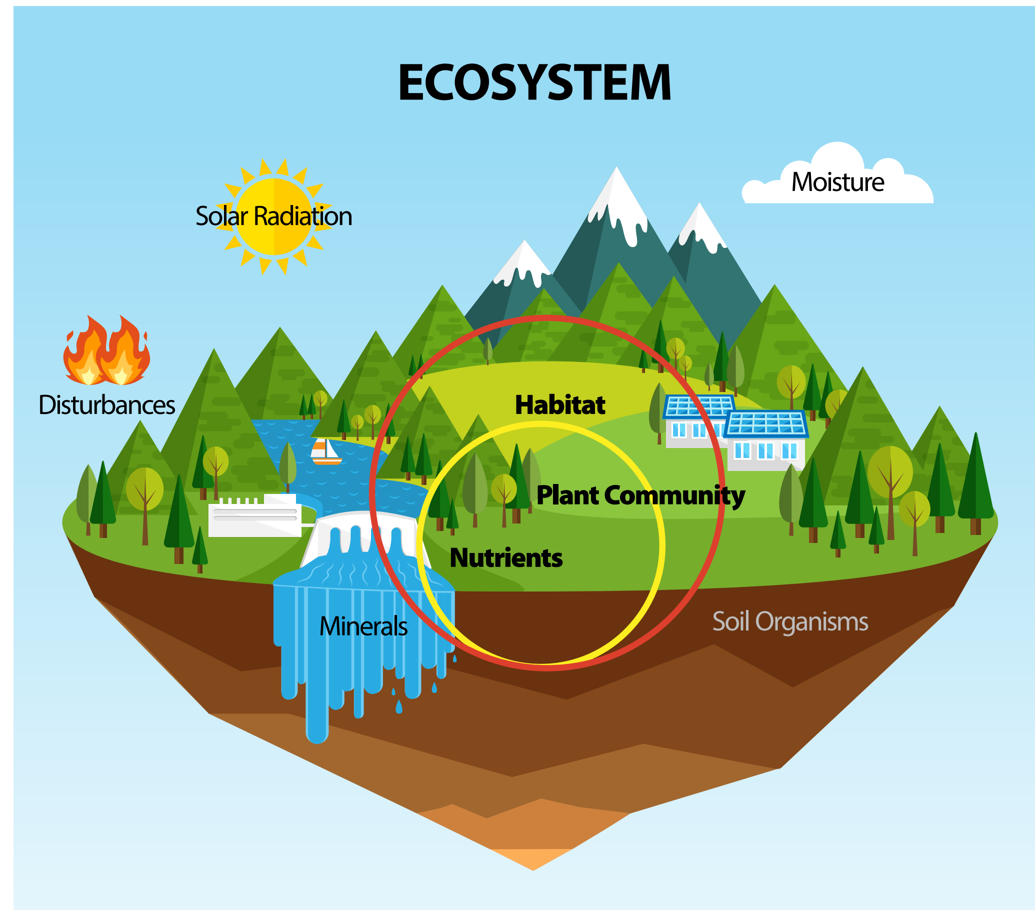

Figure 65 l A schematic of an aquatic ecosystem

The recent developments in molecular biology and biotechnology have simplified the analysis of responses below individual levels. The EU has been actively reviewing these techniques. The EU has currently systemized the aquatic ecosystem monitoring techniques into three categories, i.e., bioassays, biomarkers, and ecological indicators, and has reviewed the application of various omic technologies to monitor below-individual levels, including genomes, gene pools, and proteins.

Japan employs the Beck–Tsuda technique and the modified Zelinka–Marban technique (Gose, 1978) considering the biotic indexes for water quality assessment. Only a total of 30 taxa of benthic macroinvertebrates are used for freshwater ecosystem assessment with four water quality grades. In addition, Japan has utilized the Diatom Assemblage Index of organic water pollution (DAIpo) to assess organic pollution. This technique offers the advantages of easier calculation and classification of indicator species because it uses only the information of pollution-sensitive and -tolerant species.

In 1992, the saprobic value of each taxon was suggested in Korea based on the tolerance value and occurrence of aquatic invertebrates below the family level. These values were used to develop the Group Pollution Index (GPI) to identify the water environment characteristics. In 1995, the GPI was also improved based on the Korean biotic index and the Ecological Score of Benthic macroinvertebrate community (ESB), which can be calculated quickly using only 29 primary taxa.

In 2006, the Korean Saprobic Index (KSI) was established to reset the saprobic value and the indicator weight value of the indicator taxon for GPI. Using the KSI, the benthic macroinvertebrate index of biological integrity was developed based on a comparison with the reference streams. The benthic macroinvertebrate index, which standardized the KSI, has been used since the 2012 assessment of the aquatic ecosystem. In the 2000s, LOCOPEM was developed as an aquatic ecosystem assessment tool utilizing community prediction models, including RIVPACS and AUSRIVAS. When foreign models refer simply to specific areas of the aquatic ecosystem, LOCOPEM was used to build the hypothesized river continuum model, which adopts the river continuum concept.

The tolerance value of periphytic diatoms has been adopted as a health assessment technique employing periphyton; the community structure and DAIpo of periphyton were also used for assessment. The trophic diatom index is commonly used as a diatom index, and the health assessment is performed by calculating the range of each index based on the environmental quality grades.

Fish are useful taxa for assessing ecological health in a wide area. In the past, a specific species or multiple species were used as the indicator species. Since the 2000s, the use of multivariate models with respect to fish has been considered to evaluate the health of the aquatic ecosystems. Here, fish include the major predators in the freshwater ecosystem and indicate the stability of the nutritional structures of the ecosystem. The technique using eight metrics has been recently applied mainly to investigate and assess the aquatic ecosystem health. Accordingly, the ecosystem health status can be ranked using four grades.

02

Securing and Supplying Water Resources

Definition and Scope of Technology

The term water resources generally refers to the water that can be used by humans. Majority of the water resources are freshwater sources, including the surface water in rivers and lakes and groundwater. The technology to secure and supply water resources involves evaluating the water supply capability of the dams, establishing operating systems that link dams and weirs, providing stable water supplies by integrating urban and rural water supply systems based on region, and addressing regional imbalances in terms of water supply. Alternative water resources have been explored since the late 1990s to secure new water resources by desalination, rain reuse, and underground dam construction rather than from the direct intake of water from sources, including dams, surface water, and groundwater.

With the effect of climate change, large-scale flood and drought disasters more severe than those in the past are becoming frequent worldwide. Hence, it has become necessary to use, secure, and manage water resources efficiently and develop alternative water resources. The subtechnologies for this purpose include desalination, sewage water reclamation, rain reuse, underground dam construction, riverbank filtration, wastewater reclamation (facilities to reuse wastewater from buildings), and artificial rainfall creation.

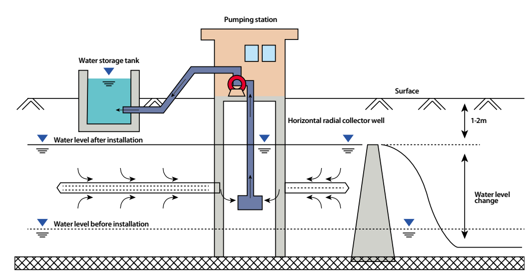

Figure 66
A schematic of an underground dam
© Korea Water Resources Corporation, 2002

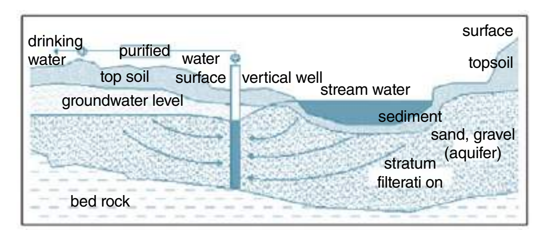

Figure 67
A schematic of riverbank filtration
© Ministry of Land, Infrastructure and Transport, 2016

Table 29 | Scale and prospect of the world water market

Group	Nation	Research description
Water Factory 21	USA	• Reusing the effluent from the sewage treatment systems - Reprocessing the effluent from the secondary sewage treatment systems
PGDER	USA	• Developing LID - Securing water resources from ecofriendly rainwater management and improving drainage systems and rainwater storage systems - Managing rainwater by establishing the Stormwater LID Ordinance in 2011 in Los Angeles, USA
Water Plaza	Japan	• Developing and managing water circulation systems - Developing and managing MBR and UF filtration processing systems for wastewater purification and sewage treatment systems - Reducing energy consumption of the entire system by 30% by producing recycled water through MBR and RO treatment and attenuating salinity by injecting RO concentrated water produced from this treatment into the desalination process
South East Queensland (SEQ)	Australia	• Conducting the SEQ Watergrid projects - Based on the 535-km water distribution network connecting areas where water is sufficient and where water is scarce, 12 dams, 10 water purification plants, 3 advanced treatment facilities for reused water, 1 desalination facility, 28 reservoirs, and 22 pump stations are installed - Making efforts to secure long-term water resources, diversification of risks by integrating regional-level facilities, and utilizing various water sources efficiently
Public Utilities Board (PUB)	Singapore	• Reusing effluent from sewage treatment systems - Reusing sewage and wastewater via the MBR technology and supplying drinking and industrial water - Using NEWater for 100% recycling as industrial and landscaping water - NEWater system purified by microfiltration, RO, and advanced oxidation processes
TaKaDu	Israel	• Reducing leakage rate of the water supply & sewage systems - Developing water management infrastructure monitoring systems and software - Securing water resources by reducing the leakage rate to 4% or less by utilizing sensors, climate data, sound data, and GIS data
Siemens	Germany	• Research technology to minimize the desalination energy - Research on system development to reduce the energy required for desalination by 50% or more via the Electroanalysis method
Beijing Enterprises Water Group (BEWG)	China	• Projects for environment conservation, water supply (water treatment & water supply service), and sewage treatment - 36 projects, including the Shahe water retreatment facility (90,000 m^3/day), Xinhua sewage treatment facility (200,000 m^3/day), and Jinzhou City water retreatment facility (180,000 m^3/day)
Veoliawater	France	• Operation of the desalination processes - Maycon purification plant in Maycon city as a key case, collecting and purifying water from suction wells and purification facilities for water resource management and drinking water supply systems, and operating riverbank-filtrated water suction wells and purification facilities for the purification process - 200 L of the daily water supply per person, 99.0% of the water supply rate, 96.5% of the revenue water ratio, 224,000 ton/day of the daily average output, and 420,000 ton/day purification facility capacity as of 2012
Inima	Spain	• Operation of desalination processes - In operation since 1965, supplying water to approximately 350,000 consumers with a daily production capacity of 65,000 m^3 - RO membrane as a major process, with a 43% recovery rate and 3.75 kWh/m^3 of power consumption
Saline Water Conversion Corporation (SWCC)	Saudi Arabia	• Construction for desalination - Researching desalination and providing measures to reduce freshwater production costs, with scientific solutions for technical issues of freshwater plants and water resource supply systems - Planning to build the world's largest desalination plant, producing 600,000 m^3 of water per day using the RO system in Lavik, Northwest of Jeddah

Key Technology and Research Trends

Technologies to secure alternative water resources were developed overseas by focusing on reusing the effluents from sewage treatment systems and managing water resources using water circulation systems such as the Smart Water Grid. The USA, Australia, and Singapore have conducted various projects for securing water resources to ensure a stable supply of water to countries with water scarcity and achieve long-term water resources. In Europe, desalination and riverbank filtration techniques were developed when obtaining resources and developing energy reduction technologies.

Although Korea's technology for securing water resources lags behind that of advanced countries, Korea has actively engaged in the development of patents for desalination, plant construction, sewage treatment, and facility technologies. These technologies are in the commercialization stage at the industrial level, and active efforts are being made to secure the related patents and build models for export.

The research team led by In-Soo Kim at the Global Desalination Research Center leads the research on seawater desalination in Korea. Meanwhile, Doosan Heavy Industries & Construction and Daelim Industrial Co., Ltd are developing the related technologies. The provincial offices for waterworks have strived to reuse the effluents from sewage treatment systems. The sewage treatment facility operated in Pohang has the largest capacity in the world.

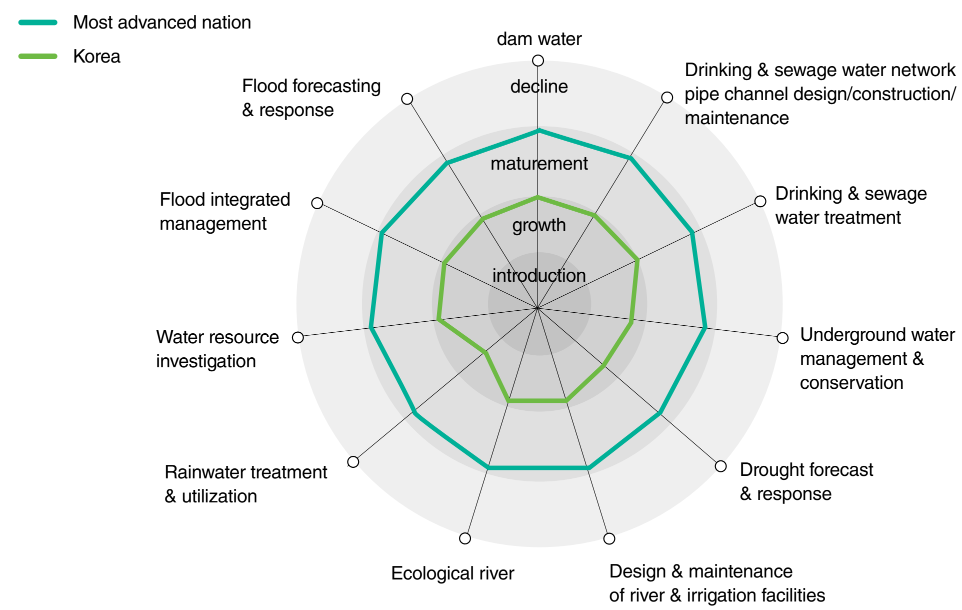

Figure 68 | The technology development processes of water resources

© Korea Agency for Infrastructure Technology Advancement, 2015

03

Water Treatment

Definition and Scope of Technology

Water treatment technology is used to effectively treat the contaminated water from sources such as drinking water (drinking water treatment plant), sewage and waste water (sewage treatment plant), and animal manure (livestock manure treatment facilities) to a required level. With the recent environmental changes resulting from climate change and industrial upgrading, the target of water treatment has shifted to non-degradable micro-pollutants (environmental hormones, chemical contamination accidents, antibiotics, antibiotic-resistant bacteria, algae, and algae-based hazardous substances).

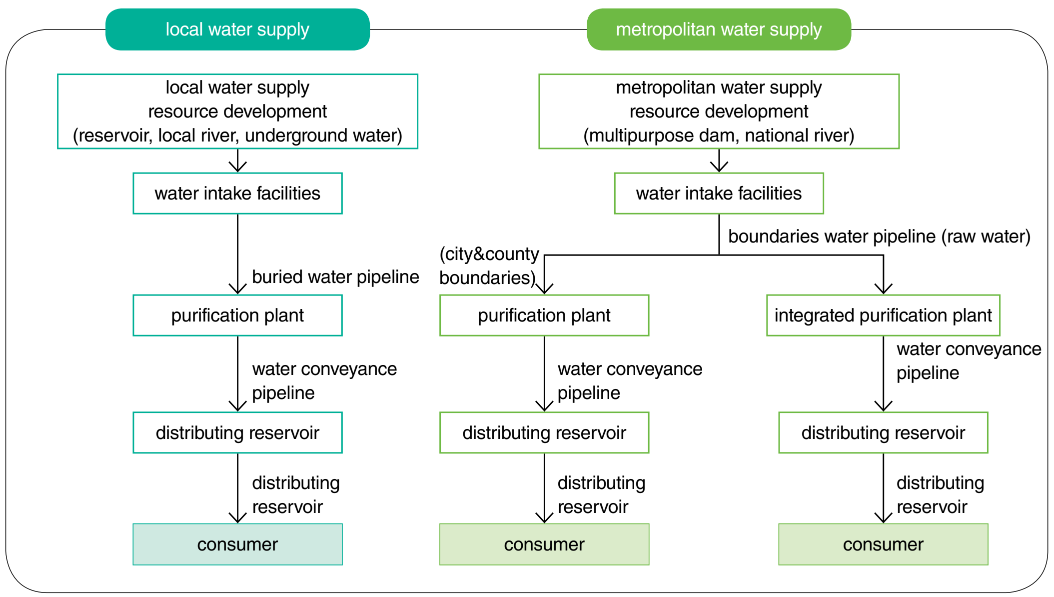

Figure 69 | A schematic of a water supply system
© Environment White Paper, Ministry of Environment, 2016

Subtechnologies include those for the optimization of water and sewage, public treatment, hazardous chemical substances, control of harmful algae, sustainable water treatment, and the water-energy nexus. These technologies involve the development of facilities and treatment processes for the water, sewage, and public treatment facilities, controlling and preventing contamination because of hazardous chemical substances, eliminating the sources of algae and inhibiting its growth, establishing sustainable water treatment measures and policies, identifying the interdependence of water and energy, which is important because water is needed for energy production and energy is needed for water production, and the efficient utilization of these resources.

Key Technology and Research Trends

The USA Environmental Protection Agency (EPA) promotes sustainable development of the chemical industry by developing green chemical technologies under the Presidential Green Chemistry Challenge Program. The EPA developed alternative experimental techniques for new chemical substances; for instance, it published the Omics T/F White Paper to assess the risks of chemical substances. As a major leader in the field of algae research, the USA Department of Agriculture and the University of Maryland developed a cleaning system using the ecofriendly algae removal technology to extract nutrients from polluted rivers and lakes and restore oxygen levels using sunlight. The ITT Corporation of the USA is the world's largest supplier of water equipment, including from its pump business, and offers facilities and equipment for biological treatment and filtering and pumps to public sectors and industries, and they are expanding the scope of business into measuring equipment via a recent M&A. Texas A&M University established the Water–Energy–Food Initiative to overcome water shortages in Texas and find methods for sustainable resource management to ensure a stable resource supply. This initiative supports efficient policy decisions based on scientific understanding for optimized resource management.

Table 30 | Major overseas research groups related to water treatment

Country/Institution	Research description
The USA/ITT Corporation	• World's largest supplier of water equipment - Pumps, biological treatment, filtering equipment, and measuring devices
Germany/Siemens	• Manufacturing, construction, operation, and management
France/Veolia Water	• Actively engaged in the government-commissioned market of environmental infrastructure • Advancing into the Middle East and Africa • Advantages with respect to the desalination facilities and wastewater treatment
Japan/Kubota	• Developing PE separator technology
Canada/Trojan Technologies	• Developing UV water treatment (world's largest UV water treatment company)

In the EU, the use of fish predators that eat phytoplankton has been explored to mitigate the water pollution caused by blue–green algae. Considerable water quality improvement effects were obtained by applying the results to enclosures and lakes. The EU has also conducted research on the technology to purify contaminants and heavy metals in the constructed or natural wetlands using vegetation as a mediator and utilize the attached algae and aquatic

Water-Energy-Food Nexus System

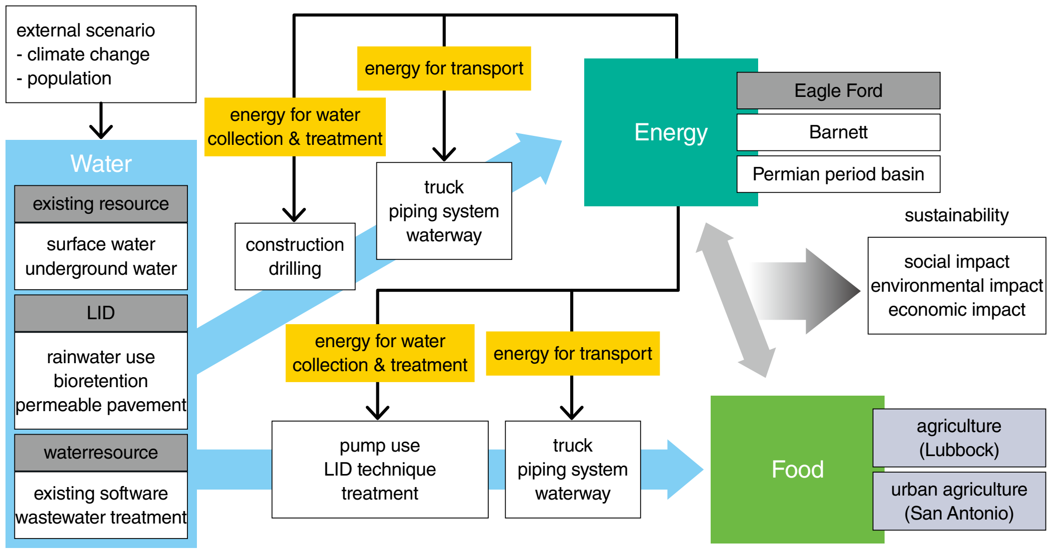

Figure 70 l Assessment of the water resource management using the Water–Energy–Food Nexus in Texas

plants; research has also been conducted on the technology of the sand–plant systems by simultaneously applying sand and aquatic plants. Because there is a growing trend in which the municipal governments entrust or privatize public services, such as water and sewage, to private companies, Veolia Water of France has been actively engaged in the rapidly growing government-commissioned market of environmental infrastructure with considerable success. Veolia Water has also vigorously expanded its business in the Middle East and Africa, with its strengths in desalination facilities and wastewater treatment. Siemens of Germany aims to provide total solutions in the value chain of every stage of business, including manufacturing, construction, operation, and management and has entered the market in North America and Europe by acquiring the local manufacturing and operating companies.

Japan's Ministry of Economy, Trade, and Industry promotes the technology development required to reduce the hazards associated with chemical substances by establishing a technology map for the comprehensive assessment management of chemical substances under the Technology Strategy Map 2009. Japan has proposed a roadmap to build a society that addresses the hazards of chemical substances through hazard communications considering the balance between hazards and benefits by setting the period until 2020 as the third generation of chemical substance management. Japan has also been working on the establishment of a molecular classification system for blue–green algae and identification of the physiological and ecological characteristics of toxin production along with the development and deployment of the ecological engineering technology that integrates ecology, environmental engineering, and civil engineering.

The operating services encounter barriers with respect to market entry because Korea's water and sewage projects are mainly operated by local governments and public enterprises. Majority of the domestic companies enter the market in the fields of water and sewage facilities and sewage management. Taeyoung Engineering & Construction has been engaged in most of the construction projects in Korea, including 57 sewage and wastewater treatment facilities, 49 water purification plants, and 113 water and sewage pipes and culverts, and is also involved in the operation of 58 out of 192 of the sewage treatment plants entrusted to the private sector. Daewoo Engineering & Construction has completed the construction and installation of more than 50 water and sewage treatment facilities, and it possesses the technology for establishing underground treatment facilities and constructing gardens on upper areas as well as new technologies for sewage treatment. Ecoset has built several ultraviolet disinfection and oxidation facilities of low- and mid-pressure conduit-type and low-pressure waterway-type as well as facilities for ships and air sterilization. The UV disinfection facilities were NEP certified by the Ministry of Trade, Industry, and Energy (Korea's only UV certification) and earned California's Title 22 (first in Korea, fourth in the world) and the EU's CE mark; subsequently, these facilities have been exported to the USA, China, and Hong Kong.

Although more research has been conducted in fields related to hazardous chemical substance management when compared with that in other areas, further quantitative and qualitative expansion of such research is essential for their effective implementation through environmental health policies. Further, 255 Science Citation Index papers on hazardous chemical substances were published in Korea between 2001 and 2010, accounting for 1.97% of the total surveyed papers. However, because these papers mostly focused on the study of hazardous metals, further studies on direct exposure to chemical substances, new hazardous factors, and endocrine-disrupting chemicals are necessary. Research on algae control technologies has been conducted primarily by government-funded research institutes and universities and companies, focusing mostly on the development of algae removal technologies and ecofriendly materials.

Korea launched the Presidential Committee on Sustainable Development in 2002 and announced the first National Sustainable Development Strategy and Implementation Plan (2006–2010) to integrate the management strategies and implementation plans associated with the economic, social, and environmental fields for the first time in Korea. The Basic Act on Sustainable Development, announced in August 2007 and implemented in February 2008, has established a legal framework for achieving sustainable development. Subsequently, the Basic Act on Sustainable Development has been renamed as the Sustainable Development Act, and the Committee on Sustainable Development was established under the Ministry of Environment. Further, the 2^{nd} (2011–2015) and 3^{rd} (2016–2035) Basic Plan for Sustainable Development were established in 2011 and 2016, respectively. The Sustainability Center, named JiWoo, and the Korea Environment Institute have been evaluating policies and conducting consultations for achieving sustainable development.

Water Disaster Management

Definition and Scope of Technology

Management of water-induced disasters refers to the technology to analyze water-induced disasters, such as floods, droughts, typhoons, and heavy snowfalls, which can occur under extreme weather and climate conditions and are caused by climate change; predict water-induced disasters caused by extreme weather events; develop water management technologies to prevent damage from water disasters, such as floods and droughts; and to establish information platforms to effectively utilize these technologies to prevent risks or hazards.

The subtechnologies include a technology for monitoring, evaluating, and predicting the water-induced disasters, the flood and drought disaster management and preemptive response technology, and disaster information platforms. The monitoring and evaluation technology includes the water disaster impact analysis technology to assess the changes in the global climate system based on observation sensors, satellite images, and radar information and a technology to predict short-, mid-, and long-term climate change in the future as well as water disasters based on the current trends in climate change and provide preemptive responses.

The disaster management and preemptive response technology for floods and droughts is used to analyze the causes of extreme weather events, predict the accurate range and timing of flooding using sophisticated flood forecasting models, predict the drought types and duration, and provide flood and drought disaster forecasts.

The technology for the water disaster information platform allows efficient management of water disasters via information exchange and integrated management of the research related to water disasters conducted by relevant ministries. The technology that enables non-government stakeholders to engage in the development of water disaster management facilitates national climate change response networks, establishes governance, and creates national consensus.

Key Technology and Research Trends

Flood management in the USA is governed by federal and state governments. The National Weather Service (NWS) under the National Oceanic and Atmospheric Administration (NOAA) is in charge of federal-level flood management. The NWS collects hydrological data at the national level, predicts flash flooding, and issues alarms based on flood prediction. State-level flood management is led by the Local Flood Warning System (LFWS). The main tasks of the LFWS are flood forecasting and evacuation of the residents at the city and national level. The USA has established and operated the National Drought Mitigation Center to assess the drought vulnerability and reduce the risk of drought-related impacts and achieve preemptive response.

In the UK, the Ordnance Survey and the Environment Agency have established an online platform to exchange information about disasters, including floods and droughts. The Ordnance Survey predicts the areas and extent of floods using Ordnance Survey Mapping and surveys conducted by the Environment Agency and offers prediction data on the online platform. The data provided through the online platform are utilized by various users, including emergency rescue teams, home buyers, and congressmen; the insurance companies use these data to assess the flooding risks. The progress of flooding is continuously monitored after a flood, and the data are provided through a web/mobile platform so that the users, such as emergency rescue workers, who need real-time flood forecasting can utilize this information to determine whether the people living in these areas are at risk.

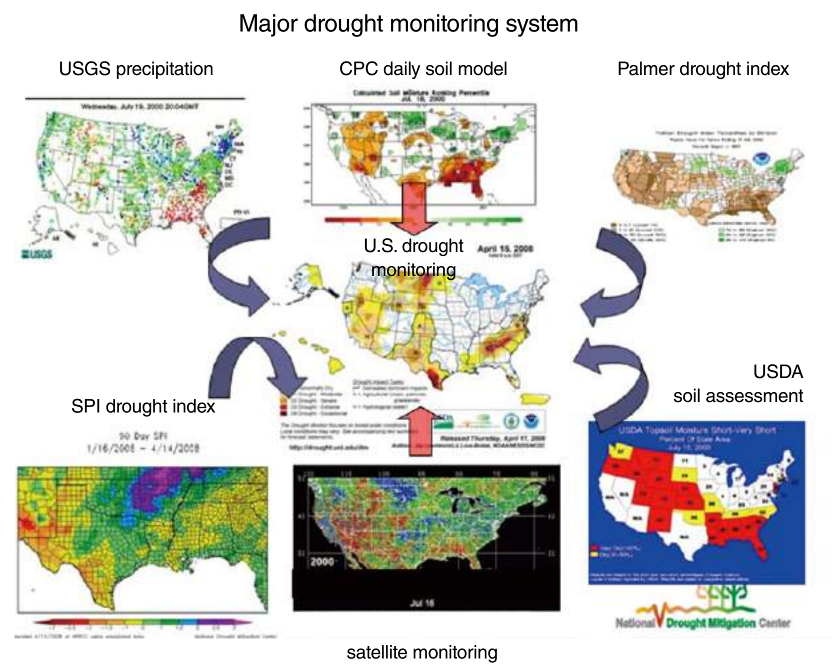

Figure 71 l Monitoring system of the USA National Drought Mitigation Center
© National Drought Mitigation Center webpage, 2017

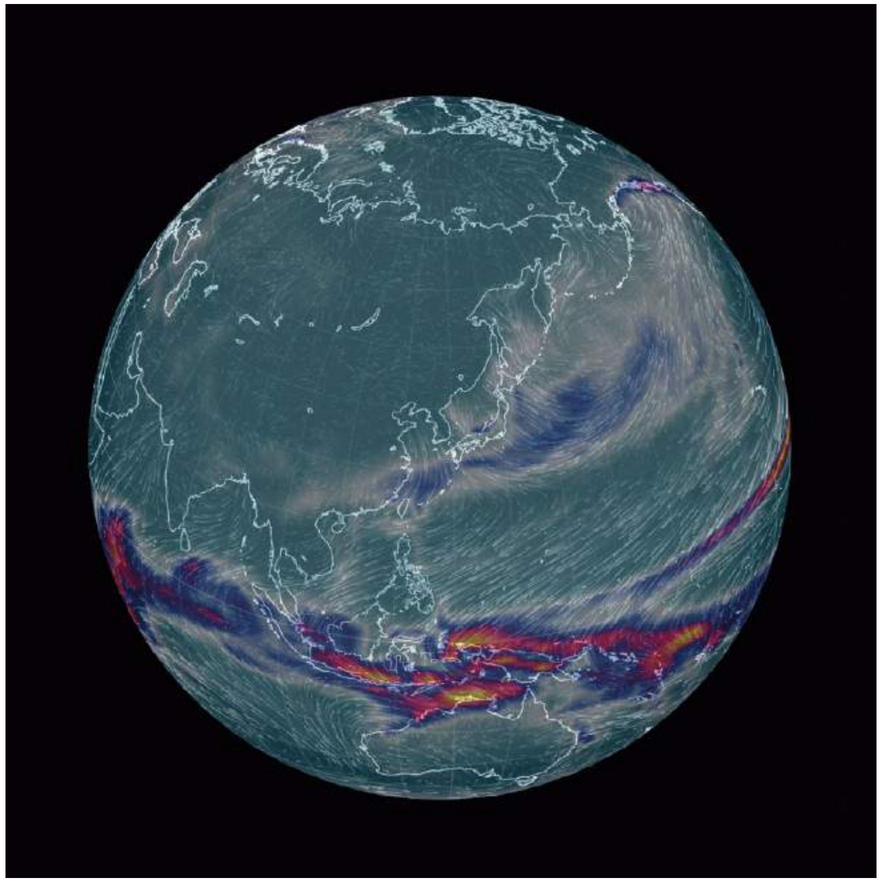

Figure 72
Global precipitation status forecasted by the Korea Advanced Climate and Earth System Model developed by the National Institute of Meteorological Research
© National Institute of Meteorological Research

JJapan has suffered from various large-scale natural disasters since a long time because of the characteristics of its geographical location, and these experiences have contributed to a wide range of research on disaster prediction, prevention, and management. Japan has established the Automated Meteorological Data Acquisition System (AMeDAS) spread over 1313 locations to function as an automated local meteorology observation system offering hourly precipitation data, wind direction and speed, air temperature, and atmospheric pressure. Japan has also developed and deployed the technology for processing integrated data from radar and AMeDAS. Further, new policies and facilities are being developed to strengthen the function of disaster prevention in preparation for major disasters. One example may be the project to construct super levees (high-standard levees) to prevent the collapse of embankments and minimize the flood damage in urban areas. Japan has also built a circular concrete tunnel as an underground regulating reservoir with a diameter of 12.5 m and extending 4.5 km with a storage capacity of approximately 540,000 m^3. This tunnel can store an average of 51 mm of rainfall in the area of the Kanda River, which covers 10.5 km^2 of the underground space in Tokyo.

Korea has also conducted several R&D tasks in accordance with the overseas trends to develop water disaster monitoring–assessment–forecasting technologies. These R&D tasks are undertaken under the leadership of the Korea Meteorological Administration, the Ministry of Environment, the Ministry of Land, Infrastructure, and Transport, and the Ministry of Oceans and Fisheries. The National Institute of Meteorological Sciences has developed the currently used Korea Advanced Climate and Earth System Model. An ocean circulation model is being developed by the Korea Institute of Ocean Science & Technology, and an atmosphere-environment integrated model is being built by the Ministry of Environment. The Korea Meteorological Administration has developed a real-time drought monitoring and forecasting system for the Korean Peninsula and East Asian region through the three-year national R&D research projects "Monitoring and Prediction of Climate Change Impact and Enhanced Support of Government Policy" funded by the Korea Meteorological Administration. To devise efficient water management measures using the technologies developed through the research projects, the 2nd National Climate Change Adaptation Plan (2016–2020) was confirmed and jointly established by 20 agencies, including the Ministry of Environment, the Ministry of Land, Infrastructure and Transport, the Ministry of Public Safety and Security, the Korea Meteorological Administration, the Ministry of Economy and Finance, the Ministry of Education, the Ministry of Science, ICT and Future Planning, and the Ministry of Foreign Affairs. In 2014, K-water and various research institutes as well as universities jointly organized the Research Group on the "Water Hazard Information Platform in Korea," which is currently in progress. Technologies have also been widely studied to ensure that water disasters can be prevented using the disaster prevention facilities. A research group for low-impact development, establishment, and operation technologies for urban water cycle infrastructure has been in operation since 2012; this group has studied various low-impact development technologies to control the rainfall runoff. The Seoul Metropolitan Government is currently constructing the Sinwol underground water discharge tunnel, which was scheduled to be completed in May 2019. This will be the first such facility in Korea. It is similar to the tunnel-type underground regulating reservoir in Tokyo, Japan, and was temporarily operated for the first time in the summer of 2017.

CLIMATE CHANGE PREDICTION AND MONITORING

Overview

Definition and Scope of Technology

The Fifth Assessment Report (AR5) of the United Nations Intergovernmental Panel on Climate Change (IPCC) indicates that it is highly likely that the recent climate change can be attributed to human activities rather than natural factors. The climate has been changing worldwide with the increasing GHG emissions that can be attributed to the human activities since industrialization. These GHG emissions have resulted in an increase in the temperature of the Earth's surface and melting of the ice in the polar regions. Because of the seriousness of climate change, the global community has started to monitor climate change and perform climate predictions to establish a scientific system in response to climate change.

In the field of atmospheric science, the impact of anthropogenic factors on climate change has been analyzed using the Earth System Model. This model simulates the changes in the atmosphere, ocean, land surface, and vegetation and plots them against future scenarios of human activities. The IPCC AR5 has predicted future climate change by adopting the Representative Concentration Pathways (RCPs) into the Earth System Model. It has also developed a warning system that considers the climate change and regional vulnerability as well as an extreme weather warning system.

Table 31 | Subtechnology classification

Subtechnology	Technology description
Climate prediction and modeling	• Development of a global climate model to predict the global climate change • Development of a regional climate model to predict the local climate • Development of a prediction technology for future climate scenarios incorporating human adaptation and responses
Climate information warning system	• Development of an extreme weather warning system through real-time monitoring • Development of an alarm system that considers the climate change and regional vulnerability

Technology Trends and Industry Outlook

The IPCC was established in 1988 to understand the climate change scientifically and its social and environmental impacts. Initially, climate change was analyzed through the Atmospheric Model Intercomparison Project (AMIP) using only an atmospheric model. This model was later advanced to the Earth System Model that incorporated the land surface, ocean, and sea ice models into the atmospheric model. Currently, as a part of the Coupled Model Intercomparison Project, which is a step forward from AMIP, the Earth System Models developed at the climate model centers in various countries are compared to enhance the understanding of the Earth System Models and realize better predictions and analyses of the future of climate change.

The recent technological trends in Earth system modeling are connecting the dynamic global vegetation models to the Earth System Model by considering the impact of climate change at the biogeochemical and biogeographical levels and integrating the atmospheric chemical model to predict the concentration of atmospheric chemicals in the future climate. A wide range of climate change scenarios have been produced, and active research on the climate predictions based on the RCP scenario considering a radiative forcing of GHGs is underway at the AR5 of IPCC. For the Sixth Assessment Report (AR6), IPCC plans to create Shared Socioeconomic Pathway (SSP) scenarios by combining social scenarios that consider human response and adaptation and predict the future climate based on these scenarios.

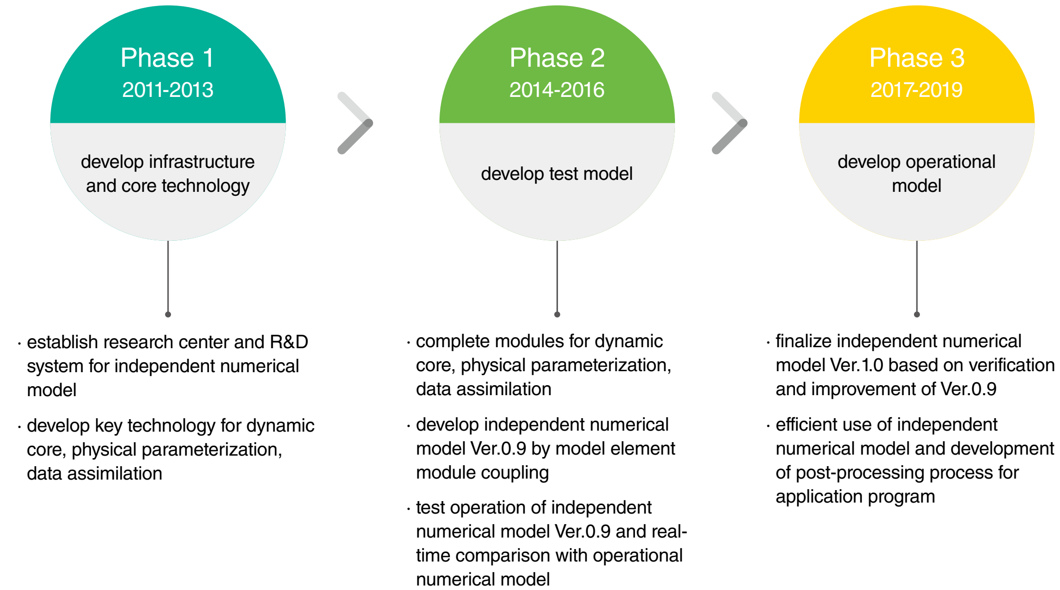

Figure 73 | Plan for developing Korea's next-generation numerical model (Korean Integrated Model; KIM)

© Korea Institute of Atmospheric Prediction Systems, KIAPS

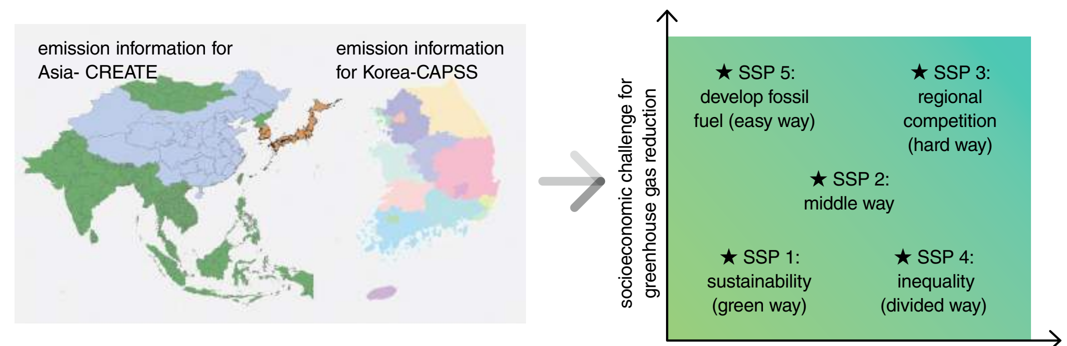

Figure 74 | The SSP scenario based on detailed greenhouse gas emissions information in East Asia and the Korean Peninsula

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Regardless, research on the extreme weather events associated with global/local climate changes is being actively conducted. Because the grid size of the Earth System Model imposes limitations on the simulation of the regional extreme weather events, the outputs of the Earth System Model can be modified into a higher resolution using statistical techniques. Further, a regional climate simulation can be conducted for extreme weather studies. Recently, dense grids are being used for regional climate models to accurately simulate the regional climates; the use of such grids improves the parameterization of the physicochemical process.

In Korea, the future climate was predicted using the Earth System Model developed by overseas institutions. Korea has adopted Earth System Models, including Had-GEM2-AO of the UK Met Office and CESM of the USA National Center for Atmospheric Research. These models are known to have excellent performances. Korea used these models in the Fifth Coupled Model Intercomparison Project (CMIP5), which produced future climate change information based on the RCP scenarios.

To reduce the reliance on overseas technologies, a project to develop a next-generation numerical model has been promoted in Korea (Korean Integrated Model; KIM) since 2011. KIM has some strengths, e.g., dynamic core and physical parameterization. This model is expected to be fully developed by 2019 and will be utilized in AR6 of IPCC for climate change prediction. A wide range of regional climate models (HadGEM3-RA, RegCM4, SNU-MM5, SNU-WRF, and YSU-RSM) have also been used in Korea to obtain high-resolution climate predictions in East Asia and the Korean Peninsula.

The current climate change scenarios led by advanced countries have limitations because they do not fully reflect the human activities in the East Asian region. Recently, Korea independently generated SSP scenarios that reflected human activities, reaching the technology level of advanced countries. Continuing in this direction, Korea is expected to lead the climate technology industry in the future.

01

Climate Prediction and Modeling

Definition and Scope of Technology

Climate prediction and modeling is the technology to predict and analyze the past and present climate and predict future climate change using numerical models based on the understanding of the cryosphere, hydrosphere, atmosphere, and biosphere constituting the Earth system. Climate prediction and modeling technology can be approximately divided into global and regional climate simulations. The global climate simulation technology is used to understand the Earth system and predict the future global climate. It predicts the climate of large areas for a long time scale with a low spatial resolution and simplified physical processes. The regional climate simulation technology focuses on the thorough understanding of regional climates and localized future changes and simulates local and short-term weather and climate characteristics that cannot be obtained via global climate modeling.

The global climate simulation technology uses the Earth System Model to understand the Earth system and predict the future climate. Currently, the Earth System Model comprises submodels of the atmosphere, land surface, ocean, sea ice, and chemistry constituting the Earth system and presents various internal physical processes in each sphere (i.e., the component of the Earth system) using numerical equations and parameterization. The Earth System Model can produce reliable climate predictions on a larger spatiotemporal scale than the continental and seasonal scales and is widely used for long-term predictions of the future climate.

The regional climate simulation technology utilizes regional climate models or statistical methodologies to understand the characteristics of the local climate and long-term changes in a specific region. The Earth System Model is not suitable for simulating temporal and spatial changes of the short-term weather and climate characteristics in local areas, especially in areas, such as East Asia, which have complex geographical characteristics. The regional climate simulation technologies are effective at producing high-resolution predictions of the local climate using regional climate models that can simulate a detailed physical process with a high spatiotemporal resolution.

RCMs have been used for future regional climate prediction and various weather and climate research because of their advantage of having accurate simulations for the meso-scale atmospheric phenomena. The high-resolution climate data produced by RCMs can also be utilized as background information when estimating the local hazards related to future climate change and determining the adaptation and response policies appropriate with respect to the climate change at an administrative level.

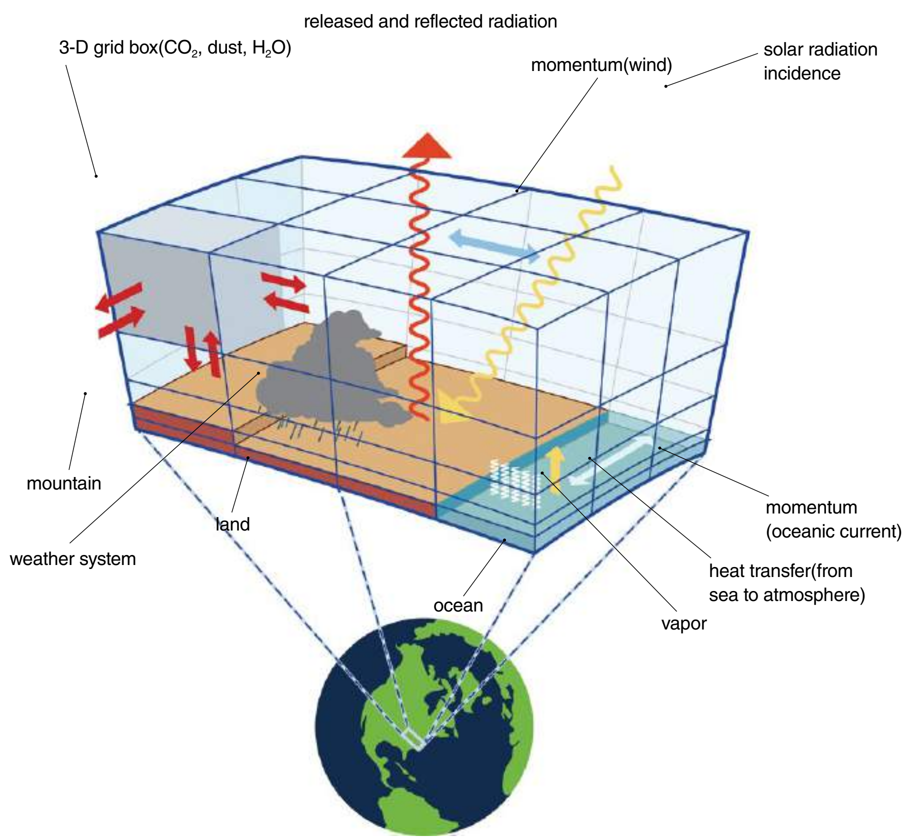


Figure 75 | Climate modeling diagram
© W. F. Ruddiman (2000)

Technology Trends and Industry Outlook

Earth System Models and RCMs have been developed by various research institutions to obtain climate analyses and predictions. The climate models in CMIP5 (CMIP phase 5) include BCC-CSM1 and BNU-ESM from China, CanESM2 from Canada, CESM and GFDL-ESM from the USA, HadGEM2-CC from the UK, IPSL-CM5A from France, MIROC-ESM from Japan, MPI-ESM from Germany, and NorESM from Norway. These models offer long-term climate simulations based on the RCP scenarios and the results are actively used for various research purposes, such as future climate prediction, predicting changes in various extreme weather events, and comparison and verification between different model predictions. The climate simulations under CMIP5 with common test specifications enable intercomparison between models and multi-model ensembles which further enhance the reliability of future climate data. The data have been widely used in climate studies that address changes in fundamental climate characteristic such as future temperature rise, changes in precipitation, changes in extreme weather (e.g., cold waves, heat waves, and droughts), and changes in vegetation activity and distribution.

Regional climate simulations are also performed in various research institutes for various research domains. The World Climate Research Program has established a Task Force for Regional Climate Downscaling and a Coordinated Regional Climate Downscaling Experiment (CORDEX) for detailed regional climate projections. CORDEX aims to provide climate simulation data for specific regions such as North America, Europe, and East Asia. Such data may be used for studies on climate change impacts, adaptations, and responses. Researchers from different countries, including the US, Germany, Spain, Japan, and China, participate in CORDEX to produce and distribute regional climate downscaling data.

Along with active development and improvement of the Earth System Model of overseas research institutes, simulations and projections of global and regional climates have also been conducted in South Korea. After adopting the Had GEM2-AO climate model of the Hadley Center from the UK Met Office, the National Institute of Meteorological Sciences has produced and offered future climate change simulation outputs based on RCP scenarios by participating in CMIP5. Additionally, the National Institute of Environmental Research under the Ministry of Environment has performed RCP scenario experiments and future climate analyses based on CESM, the global climate model developed by the US National Center for Atmospheric Research. In terms of regional climate modeling, several research teams formed by the National Institute of Meteorological Sciences, Kongju National University, Seoul National University, and Yonsei University have produced climate specification simulation data for East Asia by using five regional climate models (HadGEM3-RA, RegCM4, SNU-MM5, SNU-WRF, YSU-RSM).

Also, research teams from Pohang University of Science and Technology, and Ulsan National Institute of Science and Technology, have operated regional climate models and have calculated climate change on the Korean Peninsula and in East Asia with a spatial resolution of 50 km. The Korea Meteorological Administration (KMA) has performed dynamic and statistical specifications using five regional climate models based on the output of the Earth System Model, and has produced a detailed climate change ensemble scenario for South Korea with 1km resolution. The research team from Yonsei University is currently developing GRIMs, which is an integrated Earth System and regional climate model.

02

Climate Information Warning System

Definition and Scope of Technology

A climate information warning system predicts and warns of short- and long-term extreme weather events by incorporating real-time observations, radar and satellite measurements, and statistical and/or dynamic models. The objective is to minimize the damage caused by extreme weather events. The scope of this system includes a technology for predicting extreme weather, real-time monitoring, delivering forecasts and warnings, and vulnerability assessments with respect to extreme weather. Many organizations worldwide have attempted to establish the best climate information warning systems by combining various technologies.

The techniques for extreme climate prediction are categorized into statistical and dynamic prediction. The statistical prediction technique predicts extreme weather events by utilizing linear and nonlinear statistical models and combining climate variables and indices as predictors. For example, this technique estimates the relation between the occurrences of extreme weather events (e.g., heat waves, heavy rain, typhoons, and droughts) and presents climate variables, such as wind, temperature, and humidity, in a statistical manner to predict extreme weather. In contrast, the dynamic prediction techniques predict extreme weather events through numerical models based on the knowledge of fluid dynamics, atmospheric radiation, and hydrology.

In case of both statistic and dynamic extreme weather predictions, observation data are necessary as model input. The observation techniques can be classified into point, satellite, and radar observations. Point observation refers to various data gathered from ground weather stations, ship observations, radiosonde and dropsonde observations, and flights. Satellites process the radiation energy emitted from the Earth to retrieve the temperature, wind, and weather conditions; these data are essential to understand the overall weather conditions considering the satellite's capability of covering wide observation areas. The radar is used to monitor the intensity and extent of precipitation, and it can efficiently identify the regional differences in precipitation and changes in weather conditions.

Vulnerability assessments can be used to assess the level of damage that may be incurred to life and properties in case of extreme weather events. The vulnerability of exposed subjects is evaluated by examining the characteristics of subjects, which is a controlling factor of vulnerability (e.g., age and geographical features of the housing) and facilities extreme climate adaptation and response. For example, because the elderly are more vulnerable to heat waves, areas with large elderly populations are more susceptible to heat waves. The technology for forecasting and warning delivery rapidly sends warnings when deemed necessary based on the extreme weather predictions and vulnerability assessments.

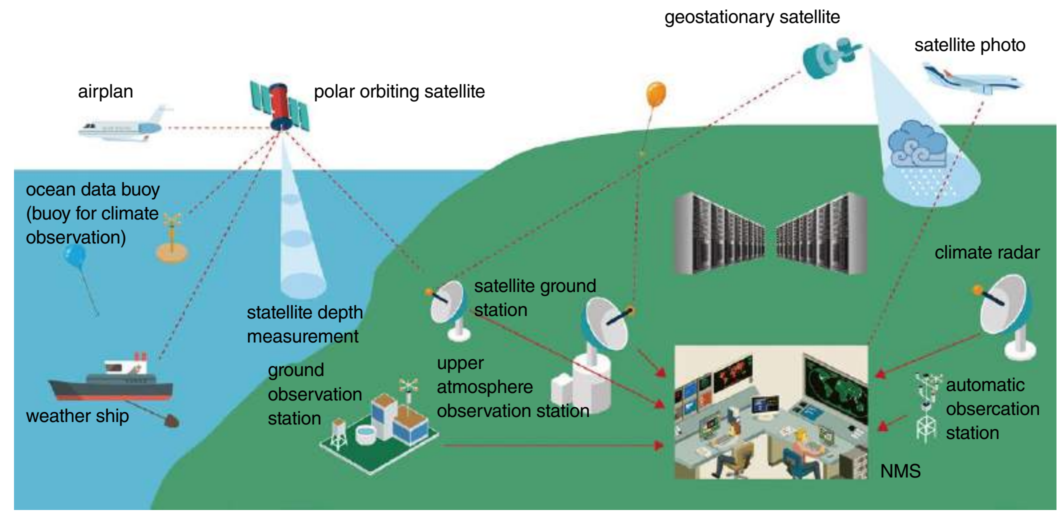


Figure 76 l Global observation network

Technology Trends and Industry Outlook

Leading international research institutes have laid the theoretical foundation for changes in extreme weather (e.g., tropical cyclones and droughts) induced by climate change. Among various kinds of extreme weather events, tropical cyclones are the most destructive phenomena in terms of scale and impact, and their influence and damage are anticipated to continuously increase. At AR5 of IPCC, tropical cyclone simulations based on numerous climate change scenarios were performed using the CIMP5 global models. Based on this theoretical foundation, the USA National Hurricane Center and the Joint Typhoon Warning Center are equipped with a system that predicts the tropical cyclone-induced precipitation, wind direction and speed, and possibility of storm surge occurrence based on the dynamic climate models. These centers share these data with other countries.

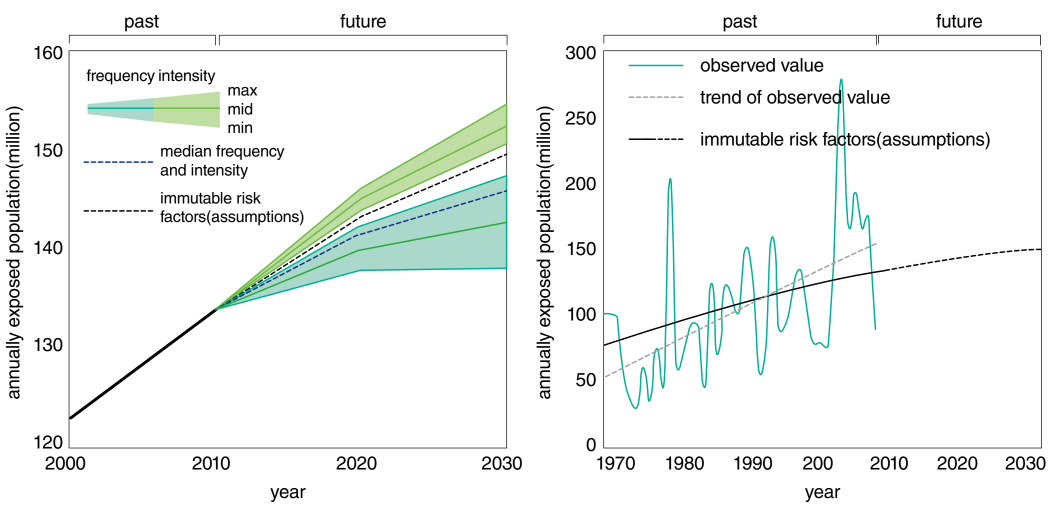


Figure 77 | Changes in the tropical cyclone frequency and increased exposed population caused by future climate change

© Peduzzi et al., 2012

Heat waves are extreme weather events that occur frequently in the global warming scenario; countries worldwide operate various early warning systems to minimize the damage caused by heat waves. Germany provides weather information using a combination of a human heat balance model and city-scale dynamic models. The USA NOAA and the NWS issue step-by-step warnings based on the heat wave indices that consider the perception of the temperature. Additionally, high-temperature alarm systems have been established and operated in big cities in Italy, China, and Canada.

With regard to droughts, the USA National Drought Mitigation Center offers drought information by presenting drought indices from the atmospheric, hydrological, and agricultural aspects on a weekly basis. In addition, the USA Geological Survey provides information by calculating the river discharge rates compared with the previous rates, and the USA Department of Agriculture provides seasonal forecasts regarding this type of information.

When the climate change information is collected and warning systems are constructed, the changes and reactions for various sectors, including the society, economy, and politics, should be carefully considered. Accordingly, studies that develop a representative index that combines and evaluates the information obtained from various sectors are underway. By defining approximately 17 proxy variables for each sector, the vulnerability resilience indicators are calculated, and the theoretical basis to establish a national level climate change response system has been presented by adding the indicators for agriculture, education, and technology.

Recently, an abrupt climate change occurring on the Korean Peninsula resulted in frequent extreme weather events. In South Korea, several research institutes supported by national level projects have offered climate change forecasts for the Korean Peninsula and established alarm systems for extreme weather events. However, there is a need for a control tower to collect and organize the information to overcome the problem of the lack of coordination between relevant authorities. For example, even though KMA provides and manages standard future climate change scenarios, government agencies, such as the Ministry of Environment and the Ministry of Agriculture, Food, and Rural Affairs, universities, and research institutes, produce and utilize individual climate change scenarios. Therefore, a comprehensive management system is required.

South Korea has secured a relatively sufficient climate change monitoring system when compared with that in other countries. The meteorological information is collected using the densely dispersed observation stations distributed across the country, long-range radars, and weather satellites. A forecasting system tailored to the geographical characteristics of the Korean Peninsula is under development by KMA using Korea's next-generation model (Korean Integrated Model; KIM) and artificial intelligence models.

Currently, the climate model of KMA and the National Typhoon Center along with a prediction system developed by a research team at the Seoul National University are being used as an extreme climate warning system to predict and provide information about the frequency, trajectory, and intensity of the extreme weather events. The warning systems for heat waves should be improved because KMA provides a conventional type of warning system that activates an alarm when the temperature becomes greater than a certain level. Drought forecasting and warning services are recently being operated by the National Disaster Management Research Institute and the Ministry of the Interior and Safety.

The domestic technology for issuing extreme weather event warnings by incorporating the social and economic factors is under development. A vulnerability assessment indicator has been proposed for each administrative district along with a vulnerability-related technology that reflects the geographical and regional characteristics of the Korean Peninsula. The objective is to establish a forecasting and warning system that reflects the predictions of extreme climate change and the vulnerability of various administrative districts.

Climate change also transforms the characteristics, such as frequency and intensity, associated with extreme weather events. The current climate information warning systems provide information about the quantitative aspects of extreme weather events, including the amount and duration of precipitation. However, it is necessary to develop a technology that informs about the possible extent of social and economic damage to the public rather than simply about the occurrence of extreme weather events.

Such warnings will benefit those who are highly likely to suffer from the damage caused by extreme weather events if the information is not appropriately delivered. Even if the information is delivered, the damage cannot be prevented if there is a lack of public awareness and appropriate responses. It is necessary to establish a rapid forecasting and warning technology, offer information about the extent of the damage by considering regional risks, and provide public guidelines for extreme weather events.

OCEANS, FISHERIES, THE COAST

Overview

Definition and Scope of Technology

The ocean is a broad and large water body and is used as a medium for research in the fields of physics, geology, chemistry, and biology and port logistics. The term fisheries refers to the technology that utilizes biological resources in the marine ecosystem. The technologies related to ocean, fishery, and coast can be divided into those dealing with the marine ecosystem, which seeks to understand and analyze the living and nonliving things in the ocean; the fishery resources, which provide food for people; and coastal risk management, which understands and predicts the impact of physical changes in the ocean on coastal areas.

Technology Trends and Industry Outlook

Studies on the classification of the seagrass species, the preliminary stage of marine ecosystem restoration, have been conducted since 1900. The habitats of seagrass have been declining in Europe since the 1930s; the scope of research on the improvement of marine ecosystems and seagrass habitat restoration has expanded since the 1970s and 1980s. The USA conducted a long-term project on seagrass habitat restoration for more than a decade based on the studies of the ecophysiological characteristics of seagrass with the recognition of the role of coastal ecosystems and their importance. Japan has spent JPY 100 billion annually for long-term marine ecosystem restoration and technology development. China has also been focusing on improving the marine environment to restore the marine ecosystems.

Table 32 | Subtechnology classification

Subtechnology	Technology description
Fishery resources	• A technology for the development of survey equipment and analysis of survey data for fishery resource management • A technology for the analysis of the condition of fishery resources and their sustainable utilization (numerical modeling, statistical analysis, and forecasting techniques) • A technology for the development of textiles for fishing gear, fishing gear, and ecofriendly fishing gear for optimal fishing and farming • A technology for seed production to enhance marketability and restoration of fishery resources, food production, and disease management
Marine ecosystem	• A technology for the large-scale transplant of Zostera marina • A technology for retaining Zostera asiatica in the sedimentary layers • A technology for attaching surfgrass to rocks for transplanting • A technology for the restoration of sea algae colonies using artificial reefs • A technology for direct supplemental planting of sea algae in coasts with albinism
Coastal disaster management	• A technology for observing and analyzing information regarding coastal disaster-causing factors such as sea level, flow, waves, and weather • A technology to predict the occurrence, time, location, and scale of disasters through numerical modeling, correlation, and statistical analysis using the observed information and to issue alarms • A technology to assess the individual vulnerabilities of each disaster factor (vulnerability and risk assessment technology) • A technology to predict, reduce, and recover from disasters • A technology to manage overall disaster by law, systems, and guidelines

The fishery resources are expected to be directly affected by the changes in the marine ecosystem because of the increasing seawater temperature. Accordingly, the major consumers of fishery products, such as the USA, the UK, Japan, and China, have been working on technologies and policy development that focus on the sustainability of the fishery resources. Under the Common Fisheries Policy (CFP), the EU plans to invest EUR 1 trillion annually in 2014–2020 to develop a responsible and sustainable fishery industry.

The USA Federal Emergency Management Agency (FEMA), an agency responsible for disaster management, has operated a center to monitor the increase in sea level and established a regional vulnerability assessment system with the USA NOAA. Further, the EU Joint Research Center developed and offered the European Marine Causality Information Platform, flood prediction and alarm systems, and GISs for achieving disaster visualization.

Japan, which experiences frequent coastal disasters, has managed disasters by continuously improving its response capabilities by strengthening the disaster prevention and prediction systems and establishing systems to obtain disaster information.

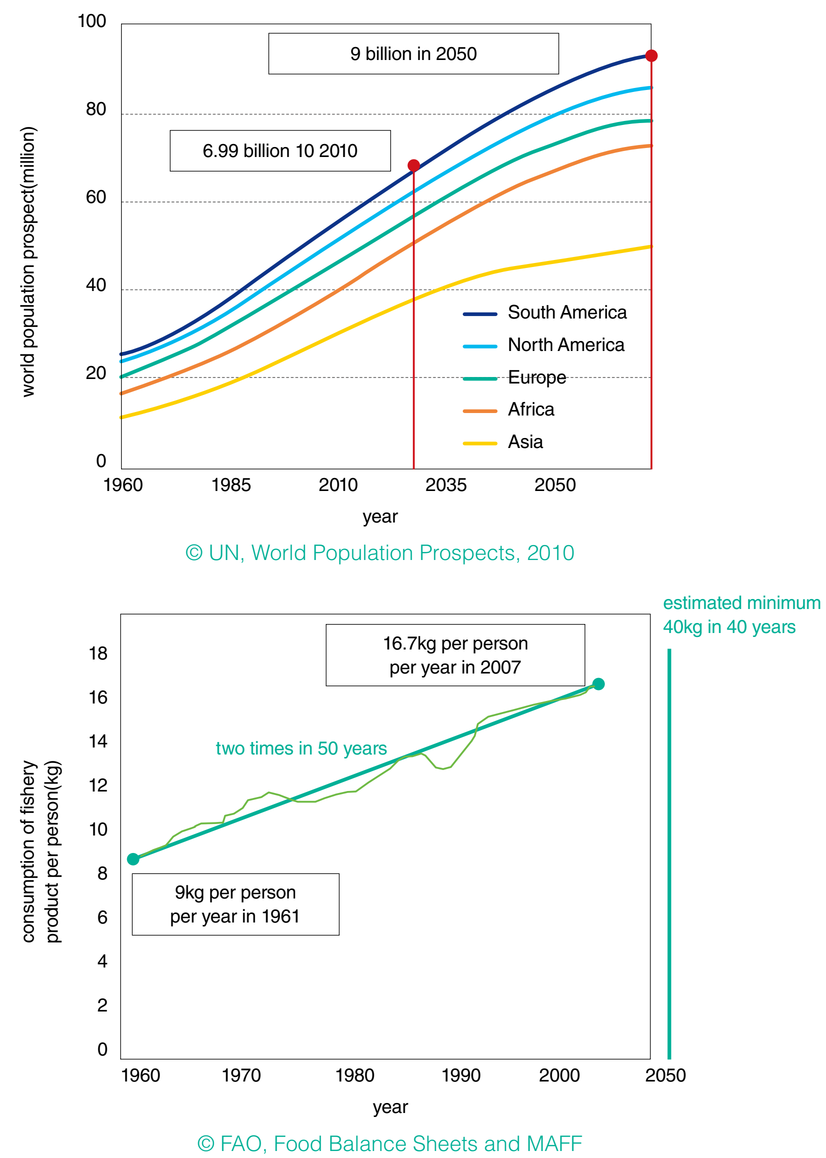


Figure 78 | World population prospects and trends in demand for fishery products

Because majority of the seagrass species are designated as protected marine species in Korea, it is required by law to create an equal area of new seagrass habitat if an existing habit is expected to be lost owing to coastal development. Some small-scale seagrass restoration projects have been undertaken. Additionally, various marine afforestation projects using artificial reefs that aim to restore marine ecosystems have been promoted under the auspices of the Korea Fisheries Resources Agency. The plan is to create 20,500 ha of large-scale maritime forest by 2020 using annual government subsidies totaling KRW 100 billion.

In 2015, the government unveiled its plan for marine fishery R&D investment under Marine Fishery Vision 2030, presenting the vision of marine renaissance through marine science and technology development under mid- to long-term R&D plans (2014–2020). Because the global fishery market is expected to grow to USD 1.2 trillion by 2020, state-level attention and policy support along with technology development are necessary to ensure market competitiveness.

The Ministry of the Interior and Safety is in charge of disaster management in Korea, and projects related to coastal disasters are being conducted by the Korea Hydrographic and Oceanographic Agency, the Korea Meteorological Administration, and the National Disaster Management Research Institute. Various projects have been conducted in the fields of management of national marine observation networks, establishment of coastal inundation prediction maps, coastal disaster vulnerability assessment, prediction of the increasing sea level, establishment of prediction systems for freak waves and rip currents, and prediction systems for storm surges and tsunamis.

01

Fishery Resources

Definition and Scope of Technology

The technologies related to fishery resources include the technology to identify the bioecological information of aquatic plants and animals and the technology that can be used to develop useful resources with respect to the national economy and life. With the recent global decline in fishery resources, bioecological research, basic surveys, and assessments have been performed to protect and manage fishery resources, and fishing-related technologies, including fishing gear development, have become essential technologies in the field of fishery resources. The subtechnologies include surveys of the fishery resources, assessments and forecasting of the fishery resources, appropriate catch management, and recovery of the fishery resources.

The fishery resource survey technology requires advanced survey techniques to expand resources for investigating the biological and ecological characteristics of aquatic plants and animals, develop survey equipment, establish big data with respect to the collected fishery resource information, and create ICT-based integrated analysis systems. The fishery resource assessment and forecasting technologies are related to the accurate assessment of the current resource status for the sustainable use of fishery resources, development of numerical models, and conducting statistical analysis and prediction. Although the extant assessments focused on single species, the focus is shifting toward the development of ecosystem-based resource assessments and forecasting technologies in the USA and Europe.

An appropriate catch management technology includes the development of acoustic echo-sounders that can identify the target species, fishing information systems for fishing gear or vessels, and the development of ecofriendly fishing gear. The technologies for the recovery of fishery resources includes the production of artificial seeds, restoration of the polluted and destroyed habitats, creation of artificial reefs, marine forests, and marine ranching to secure habitats for fishery resources.

Key Technology and Research Trends

In the USA, six research centers under the NOAA National Marine Fisheries Service and state-owned research institutes conduct research on fishery resources and offer advanced fishery resource assessments supported by accurate information about the fishing activities of commercial vessels and fishing effort based on the Fishery Conservation and Management Act (revised in 1996). Studies on the conservation and management of fishery resources are underway in relation to the ecological characteristics of the fishery resources, the impact of environmental pollution, the destruction of estuaries and wetlands, and the factors affecting the abundance of fish and the health of their habits. Although each state and the federal government have jurisdiction over fisheries by law, the state-managed fishery resources are sometimes included in the federal-level management projects. Additionally, if a state government fails to appropriately manage resources, the federal government assumes control of the fishery resources for conservation and management because they are considered to be shared resources.

Under the CFP, the EU has set the policy direction of developing “a responsible and sustainable yield” to balance the fishing capability and fishery resources and improve the transparency and effectiveness of the policy. The EU has established a plan for the long-term recovery and management of fishery resources to improve the management of the shared fishery resources. The EU also established the European Fisheries Control Agency for enhanced cooperation between the member states and the Regional Advisory Council as a monitoring agency with an assessment method to improve the monitoring functions.

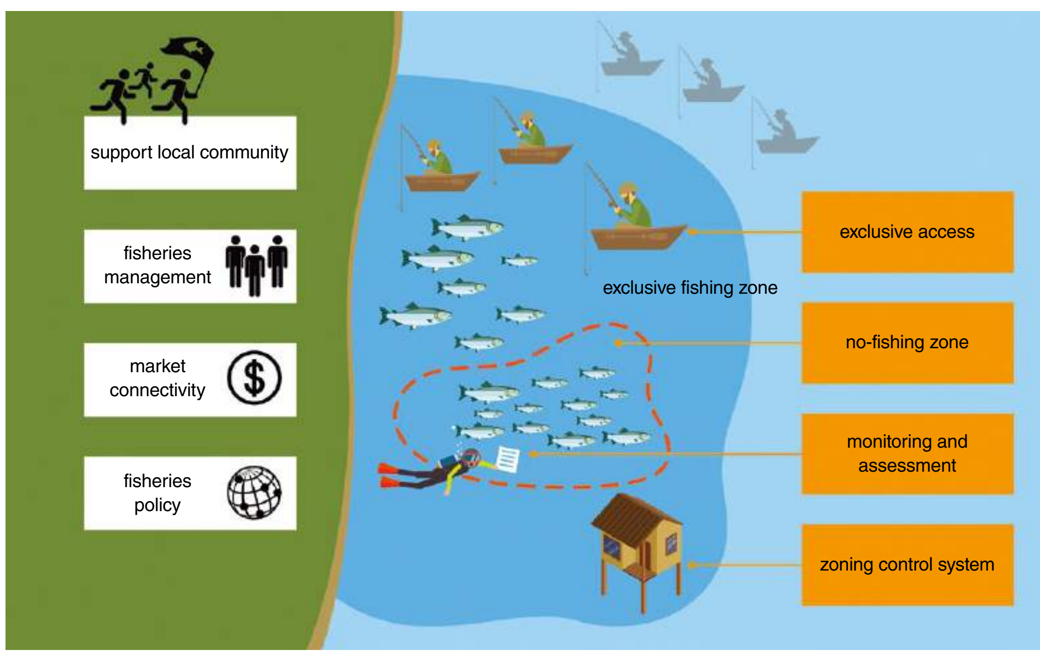


Figure 79 l Conditions for the success of the fishery industry

The objective of the EU with respect to fishery resources management is to maintain fish populations at sustainable levels for ensuring continuous fishing activities. The environmental factors were considered for all the policies with the active participation of stakeholders, including fishermen and scientists, during the policy-making process.

In Japan, the Coastal Fisheries Promotion Act was enforced in 1963. This act aims to improve the productivity and living standards of fishermen and serves as a basis for the fishery policy. The policy for fishery resource management was initially introduced in 1984 and was replaced by the comprehensive resource management policy in 1998. The Basic Law on Fisheries Policy was enacted in 2001 and intended to ensure a stable supply of the fishery products and the sound development of the fishery industry. This policy encompasses the entire fishery industry, from production to processing and distribution. In 2007, the New Basic Plan for Fisheries was established to provide critical action plans for ensuring the sustainable supply of fishery products and the healthy development of the fishery industry. Among other things, this plan promotes the artificial production of fish, such as eel and Bluefin tuna, investigation and monitoring of radioactive substances in the fishery products, and collection and management of genetic resources.

Currently, in Japan, the Fisheries Research Agency, which is an administrative organization independent of the government, announces the resource assessments performed via direct and indirect stock investigation and supports the resource management policies. In 2010, a comprehensive green and water strategy was announced for ensuring the environmental technology revolution. This strategy aimed to create new industries in the fields of materials, energy, and pharmaceuticals by utilizing the abundant resources in agriculture, forestry, and fisheries and combining the technologies in various industries.

In China, although the policies for fishery resources intend to protect fishery resources for ensuring sustainable production and preserving cultural diversity, they have failed to attract attention because of other objectives, including food security and regional economic development. In addition, no effective fishery resource management has been implemented because illegal fishing due to declining fishery resources has become a political issue coupled with territory disputes. However, China has accumulated data on biological resources and seabed minerals in its territorial waters and border areas, and the technologies for discovering future energy resources are currently under development.

Korea manages its fishery resources in accordance with the Fisheries Act, the Fisheries Resources Management Act, and the Inland Water Fisheries Act. The polices for fishery resource management can be broadly divided into fishing management, including limiting the number of fishing boats and setting a closed season and controlling the fishing stock through the total allowable catch system, the creation of artificial resources, such as artificial reefs, and seedling release. Currently, the resource recovery policy has been implemented, which customizes all these policies to suit the needs of various target species.

Marine Ecosystem

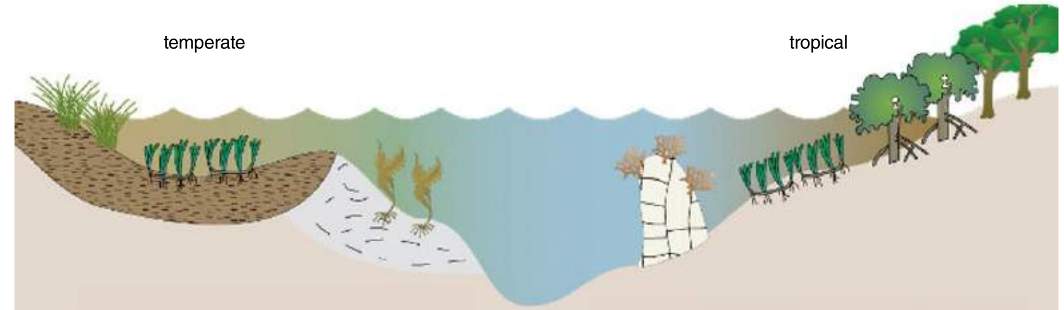
Definition and Scope of Technology

According to the Conservation and Management of Marine Ecosystem Act of Korea, the marine ecosystem is defined as the biological community of specific sea areas, and a material system or a functional system is defined as a system in which the inorganic and organic environments surrounding such community are combined. The core aspect of marine ecosystem restoration can be the restoration of the habitats of primary producers. The areas of habitats of marine plants (seagrass, halophytes, sea algae, and mangroves) account for 0.2% of the entire ocean; however, the volume of organic carbon buried by these plants reportedly exceeds 50% of the total. In this regard, the green technology for the marine ecosystem includes a technology for the preservation of halophytes in mudflats and benthic microalgae community, restoration of the seagrass habitats, and restoration of the sea algae habitats using artificial reefs.

Restoration of the seagrass habitats and marine afforestation is of considerable significance. Seagrass is a perennial aquatic flowering plant that grows in soft-bottom intertidal zones, subtidal zones, and hard-bottom subtidal zones; currently, nine species of seagrass grow in the coastal areas of Korea. Several restoration techniques have been developed for seawarck, which is one of the seagrass species growing along the Korean coast. A Korean research team also developed the technology to restore surfgrass, which grows attached to rocks. Furthermore, a restoration technology that uses fish shelters and technology to directly transplant sea algae into rocks with whitening events have been developed for marine afforestation projects by which the sea algae habitats are restored.

Key Technology and Research Trends

In the USA, the National Center for Ecological Analysis and Synthesis (NCEAS) estimates the economic value of the marine species annually and conserves and manages these biological resources. Based on the research on the ecophysiological characteristics of seagrass since the 1970s and 1980s, the role of seagrass in the coastal ecosystem and its significance has been reported. Since the 1980s, studies have been conducted for the technological development with respect to the timely restoration of the seagrass habitats, and the actual restoration projects were performed on a practical scale with a long-term plan of more than a decade.



ecosystem	area(10^6ha)	decrease rate(%/year)	value(dollar/ha/year)
sea algae	18	2~5	34000
salt mash	140	1~2	17780
mangrove	15	1~3	17780
coral	62	4~9	10870
tropical forest	1900	0.5	3590

Figure 80 | Economic value of the marine species

In the USA, the National Fishing Enhancement Act of 1984 laid down the legal framework for artificial reef projects. Subsequently, federal and state governments have secured the budget for the state-level artificial reef project. In Canada, such a project was led by the Artificial Reef Association since the 1990s, focusing on recreational purposes rather than the creation of resources.

In Europe, the habitats of seagrass were reported to have declined since the 1930s, and the data of the first seagrass transplant were obtained in 1939. Beginning with studies for improving the marine environment in the 1970s and 1980s, research on seagrass habitat restoration has continued, and restoration techniques reflecting the characteristics of each species were advanced. Since the 2000s, long-term restoration projects were promoted by applying effective restoration techniques for each nation.

In Japan, research on seagrass classification commenced in the 1900s, and ecophysiological studies were conducted since the 1980s. With the loss of large-scale seagrass habitats by coastal development, Japan launched a long-term national project to develop various seagrass restoration techniques and restore seagrass habitats. Under the artificial reef projects led by the government since the late 1970s, more than a thousand artificial reefs were developed. These reefs have become important resource enhancement projects along with fishing port projects.

Studies on seagrass in China began in the 2000s. The results have proved that only few areas are suitable for restoration because of coastal development and environmental degradation. Accordingly, the Chinese government is making efforts to improve the coastal environment and restore and manage the seagrass habitats by deploying marine habitat management programs.

In Korea, research on seagrass was initiated in the 2000s, and more than 50% of the seagrass habitats have disappeared because of the industrialization and coastal development projects since the 1970s. The development of the technology for seagrass restoration commenced with the restoration of seawarck, which is dominant on the Korean coast. Currently, various restoration technologies reflecting the characteristics of species have been developed. In particular, domestic technology to restore surfgrass, a type of seagrass that grows attached to rocks, is considered to be the most effective technology. The projects for seagrass restoration have been conducted on a small scale to ensure technology development. However, unlike in the USA and Japan, no large-scale national restoration projects have been undertaken in Korea.

Domestic artificial reef projects have been conducted since 1971, and approximately 70 types of reefs, including box-, jumbo-, pyramid-, and tunnel-type artificial reefs, have been developed. With the marine afforestation project of the Korea Fisheries Resources Agency, marine forest reefs were constructed using artificial and natural rocks for the growth of sea algae. In 2000–2009, approximately 667 ha of marine forest was created, and there are plans to create a large-scale marine forest of 20,500 ha by 2020 using the annual government subsidies of KRW 100 billion. Furthermore, artificial reef projects were undertaken to prevent illegal fishing by the Chinese fishing boats near the Northern Limit Line in the West Sea and restore the marine ecosystem.

03

Coastal Disaster Management

Definition and Scope of Technology

Coastal disaster management is the technology used to observe coastal disasters, issue relevant forecasts and alarms, and obtain assessment and responses. According to the Countermeasures Against Natural Disasters Act, the Coastal Management Act, and the Marine Environment Management Act, the term coastal disaster encompasses storm surges, tsunamis, sea fog, tides, coastal erosion, jellyfish, increase in sea level, swell waves, rip currents, abnormal temperature, and marine pollution. This section will focus on the disasters caused by waves, storm surge, and tsunamis, which cause the most considerable damage.

Although a specific technology is available for each coastal disaster, the technologies related to coastal disasters can be further classified into those related to observation, forecasting and alarms, assessment, and response and management. The coastal disaster observation technology is intended to collect scientific information on phenomena, including waves, storm surges, and tsunamis, and has underwent rapid development with the adoption of IT into real-time observation and transmission. Considering the nature of coastal disasters, the timely collection of on-site information is a priority for disaster forecasting, alarms, and response. The data collected using the coastal disaster observation technology are utilized to predict the occurrence, time, location, and scale of disasters via numerical modeling analysis, correlation analysis, and statistical analysis; this prediction is used to issue alarms. The technology for forecasting and issuing alarms on coastal disasters is under rapid development with the support of the development of computing and artificial intelligence technologies and IT.

The coastal disaster assessment technology is used to assess the vulnerability of each disaster factor; various technologies are being developed to assess the hazard, vulnerability, and risk associated with each disaster factor. The coastal disaster response technology is intended to prevent or reduce disasters in advance or recover from a disaster quickly. The technology includes structured responses for facilities and structures as well as unstructured responses, including education and training. The coastal disaster management technology is applied to systematically manage the coastal disaster observation, forecast and issue alarms, assess, operate, and manage the response technologies. Establishing laws, systems, guidelines, and manuals comes within the scope of coastal disaster management.

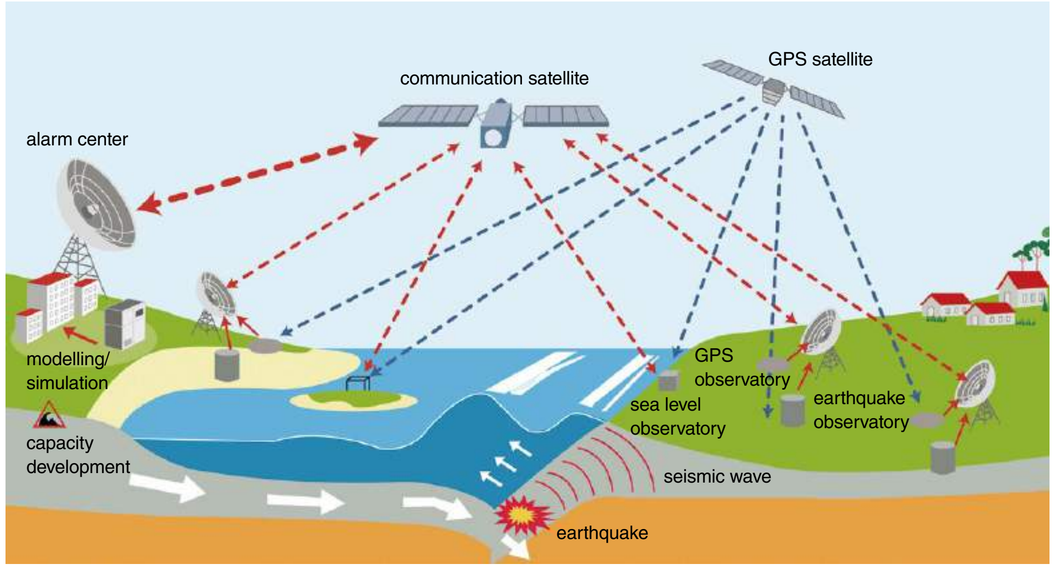


Figure 81 | Tsunami disaster management

Key Technology and Research Trends

In the USA, the FEMA is responsible for disaster management. It employs the eight principles of emergency management, i.e., comprehensive, progressive, risk-driven, integrated, collaborative, coordinated, flexible, and professional emergency management. FEMA considers all possible hazards, analyzes all impacts and possibilities, and assigns priorities. Therefore, scientific hazard assessment is conducted, and disaster response teams are being operated in conjunction with the regional communities. FEMA also operates the sea-level monitoring center and has established a regional vulnerability assessment system in cooperation with NOAA. After Hurricane Katrina, FEMA expanded its efforts to improve the mapping of the coastal inundation predictions. For ensuring coastal zone management, FEMA has established and institutionalized coastal zoning plans, including the Coastal Construction Control Line and the Coastal Construction Setback Line, to prevent rampant development of the areas near coasts and control future coastal disasters.

In the UK, the Cabinet Office, which is responsible for disaster policies, deals with disaster management based on the Civil Contingencies Act in conjunction with the neighboring NATO countries. The systematic cooperation system between the Civil Contingencies Secretariat and local governments was established to ensure an effective risk management system for response and restoration. Considering the frequent exposure to coastal disasters and damage from high waves and surges, the UK operates a specialized agency to examine the increase in sea level. Since 2002, the country has established and implemented a flood hazard management plan against climate change for the London and Thames estuaries (construction of a 2 m high barrier in the Thames estuary: the Thames Estuary Project); this project is to be completed over the next 100 years (by 2100). The Netherlands intends to invest 160 trillion KRW into embankment reinforcement by 2100 following the recommendation of the Delta Commission, which was established after the Katrina disaster in the US. These countries provide massive investments for observing and forecasting technologies when promoting coastal zoning plans (or coastal spatial plans) for unstructured countermeasures to prevent disasters.

Based on the experience of various and frequent coastal disasters, Japan has managed disasters by continuously improving its disaster response capabilities by strengthening the prevention and forecasting systems and establishing a disaster information system. The Cabinet Office, which leads disaster management, has a Director General for disaster management, and coastal disasters are managed by the Ministry of Land, Infrastructure, Transport, and Tourism, which provides a disaster information map and establishes and operates inundation prediction maps covering local governments for storm surges and tsunamis. Various types of movable and retractable barriers have been installed to reduce the damage caused by storm surges and tsunamis. Plans for reinforcing and elevating coastal structures against the increasing sea levels are being promoted.

China is among the countries that have suffered the most from coastal disasters. The statistics of the State Oceanic Administration indicate that the direct economic loss due to coastal disasters from 2011 to 2016 totaled CNY 201 billion (approximately KRW 34.536 trillion), with the economic losses from wind and surges accounting for approximately 90% of this loss. Accordingly, the State Oceanic Administration has undertaken various missions to reduce coastal disasters. The system for climate change impact assessment for coastal areas was implemented along with coastal disaster hazard assessments and planning. Protected coastal areas have been designated, and coastal ecosystem restoration projects have been launched with efforts being devoted for coastal forestation and urban vegetation restoration. Coastal disaster monitoring, i.e., detecting the changes in sea levels, and early warning systems were built for the coastal areas throughout the nation. China is successfully responding to climate change, with the selection of Hainan Dao as a pilot case, in the fields of marine ecosystem restoration, disaster prevention facilities, and coastal land readjustment.

The Ministry of the Interior and Safety is in charge of disaster management in Korea, and projects related to coastal disasters are being conducted by the Korea Hydrographic and Oceanographic Agency, the Korea Meteorological Administration, and the National Disaster Management Research Institute. Various projects were conducted in the fields of management of national oceanographic observation networks, establishment of coastal inundation prediction maps, assessment of the coastal disaster vulnerability, prediction of the increase in sea level, and establishment of prediction systems for swell waves and rip currents and for storm surges and tsunamis.

HEALTH

Overview

Definition and Scope of Technology

The impact of climate change on human health is becoming increasingly serious because of global warming, population growth, poor sanitation and health systems in developing countries, growing tourism, and increasing zoonotic diseases. The technology for infectious disease management in case of an early preemptive response is necessary to effectively deal with infectious diseases in the future.

Climate change also has a major impact on food safety. Hence, prevention measures are essential in case of foodborne diseases. Technologies should be developed to analyze the environmental factors of climate change that affect food safety to predict its hazards and assess its impacts, implement short- and long-term preemptive policies, and secure food safety.

Technology Trends and Industry Outlook

The World Health Organization (WHO) predicts the annual growth rate of the vaccine market to be approximately 179%. The market for livestock and human vaccines reached USD 58.6 billion in 2015, which is expected to grow significantly owing to the emergence of new infectious diseases and strains because of climate change. Developed countries are now expanding their investments in infectious disease prevention into developing countries because the failures in early diagnosis and prevention of infectious diseases can lead to worldwide spread via travelers. The demands for the development and distribution of vaccines and equipment for quarantine and prevention are expected to increase.

The USA Centers for Disease Control and Prevention establishes active response and prevention measures in coordination with countries where new and variant strains of infectious diseases are prevalent. It conducts joint research to collect patient and clinical information. Therapeutic vaccines using genes are also under development.

Table 33 | Subtechnology classification

Subtechnology		Technology description
Infectious disease management	Detection and treatment of infectious diseases	• Development of an early detection technology for infectious diseases and establishment of the response capability systems • Development of vaccines, diagnostic kits, and medicines for new and modified infectious diseases
	Disease control	• Development of decontamination and disease control devices
	Risk information communication	• Establishment of the rapid and transparent information and communication systems
Food safety and preventive healthcare	Prediction models	• Establishment of the food safety database and food-poisoning prediction models • Development of the prediction models via big data analysis
	Non-thermal processing	• Non-thermal sterilization technology
	Rapid detection	• Rapid detection technology for biological risk factors • Rapid detection method for chemical risk factors

With the Global Research Collaboration for Infectious Disease Preparedness (GloPID-R), the EU has established a research basis and global networks to effectively respond to new and variant infectious diseases within 48 h of the outbreak. Since the 1990s, the EU has been focusing on reinforcing quarantine and safety management following the outbreak of the mad cow disease and foot-and-mouth disease. The EU possesses several core quarantine equipment technologies and patent rights. It also possesses an HPV Generator.

China conducts prevention and detection measures for infectious and endemic diseases due to the climate change at its Centers for Disease Control and Prevention. In Beijing, a system in which a genetic sample test is reported within 2 h and the results are generated within 5 h has been established; it is equipped with fully automated laboratories to prepare for influenza and avian flu treatment.

Since 2014, Korea has become aware about the risk and importance of countermeasures for new and variant infectious diseases following the outbreak of the Ebola virus and MERS. The Korean government has supported and invested in vaccine development by domestic companies, and Zika and MERS vaccines were developed to localize 70% of the vaccines by 2020. The Ministry of Science and ICT has supported the development of core technologies for infectious diseases in the bio sector since 2018, and it plans to invest from a long-term perspective in the R&D of new and variant infectious diseases introduced into Korea from other countries as well as infectious animal diseases.

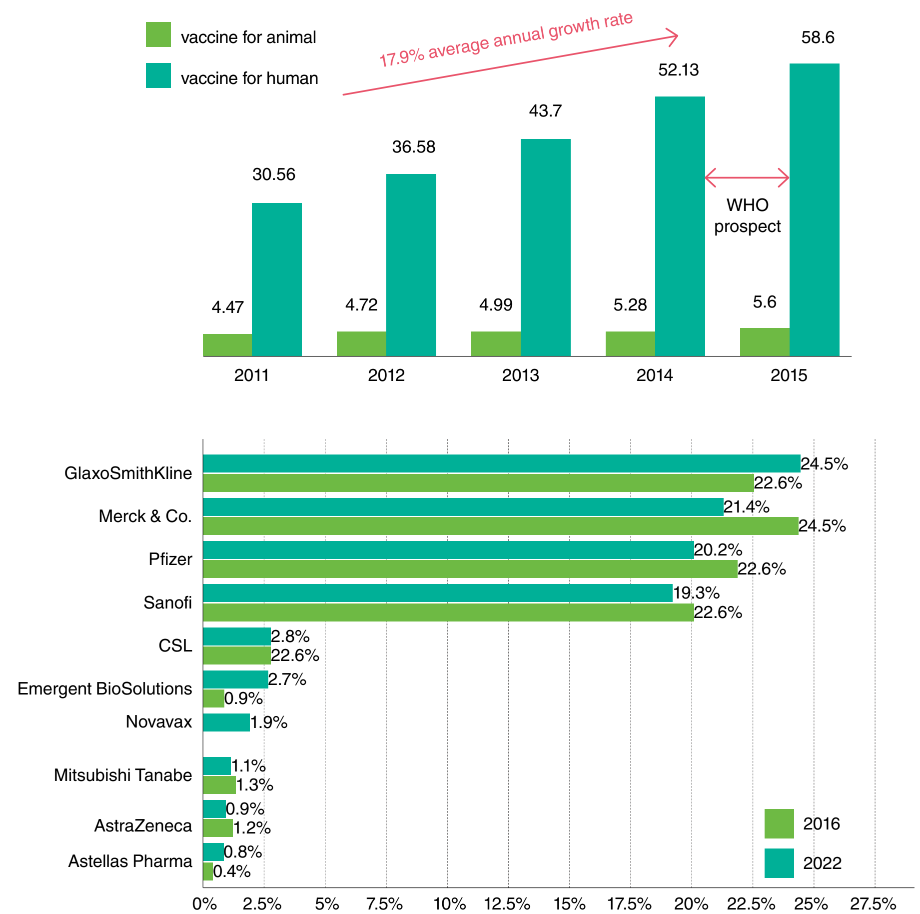


Figure 82 | Growth rate of the global vaccine market and market share of the global pharmaceutical companies, which has been calculated and predicted by WHO

In 2008, the Food and Agricultural Organization (FAO) reported “Climate Change: Implications for Food Safety,” which warns of the potential impacts of climate change on food safety and encourages related research in member countries. Vigorous research on the related policies has since been in progress in Korea and other advanced countries in the field of food safety.

In the USA, the impacts of climate change are studied by various government agencies, including the President’s Council of Advisors on Science and Technology, the Department of Agriculture, the Department of Energy, the Department of Commerce, the Department of Interior, the Department of Defense, and the Department of State. The EU implemented the Joint Programme Initiative (JPI) for agriculture and food safety in response to climate change, and it has researched climate change responses with targets of climate change observation, forecasting, and new technology development under the 7th Framework Programme (FP7).

In Korea, previous research on climate change adaptation strategies has focused on food safety in the agricultural sector. Research on food safety was conducted on a narrow scale by specific researchers. The related studies include “Climate change and socio–economic cost for food safety” and “Study on the impact analysis and control system of foodborne disease outbreak due to climate change” conducted in 2009 by the Ministry of Food and Drug Safety. A research group on food safety control against climate change was organized in 2010 for overall research on the impact of climate change on food safety management.

01

Infectious Disease Management

Definition and Scope of Technology

The WHO analyzed the impact of malaria, dengue fever, hemorrhagic fever with a renal syndrome and schistosomiasis in the report on Climate Change and Human Health published in 1996. In the 2000s, the WHO categorized global environmental issues into climate change, ozone depletion, loss of biodiversity, and desertification; identified their implications for human health; and offered action plans to address these issues.

A 1°C increase in temperature would increase the incidence rate of five infectious diseases, including scrub typhus, leptospirosis, and malaria, by 4.27%. Further, the number of new infectious diseases of humans, including SARS (2002–2003), H1N1 (2009), and MERS (2012–), and livestock infectious diseases, such as foot-and-mouth disease and bird flu, is rapidly increasing, posing a serious threat to public health and the economy.

Effective response to future infectious diseases requires the urgent development of early preemptive response technology even though post-treatment is still important. The technology for prevention of and response to infectious diseases encompasses the technologies for the early detection of infectious diseases, establishment of response systems, development of vaccines and diagnostic kits, establishment of equipment for decontamination and quarantine, and establishment of prompt and transparent information sharing and communication systems. In this regard, technologies are being used to control the inflow of infectious diseases and detect them in an early stage as well as establish response systems. Technologies are being developed to explore preventive vaccines against new and variant infectious diseases and improve the preparedness capabilities, such as by securing vaccine reliability and ensuring its effective distribution. Further, diagnostic kits need to be developed for cross-species infectious diseases that may occur simultaneously in different regions along with equipment for disinfection, decontamination, sterilization, and quarantine. Information should be provided promptly and transparently to overcome the lack of knowledge and fear of diseases, and communication systems should be established.

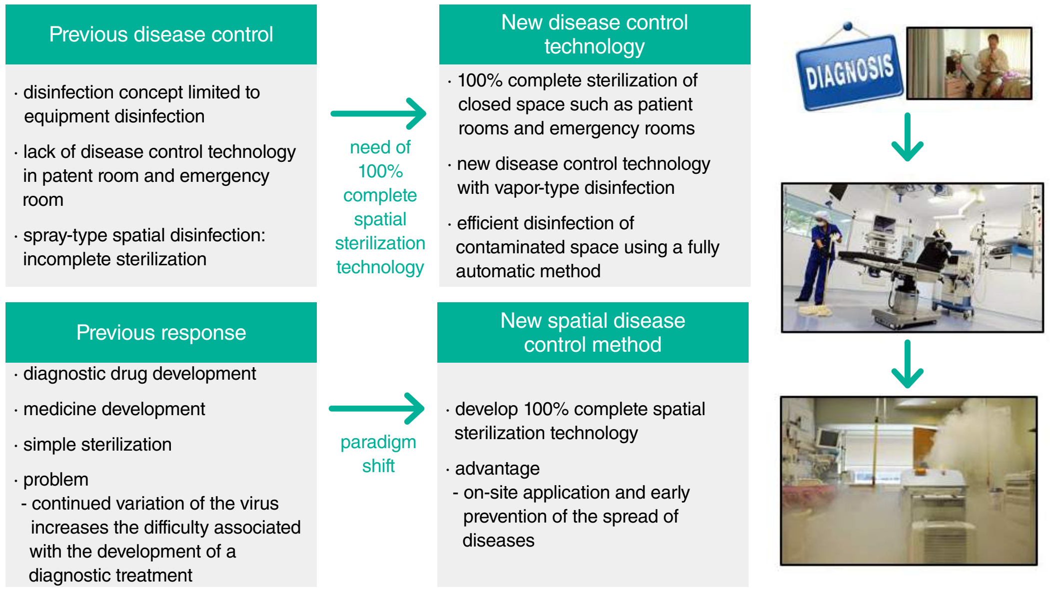


Figure 83 | Paradigm shift of virus disinfection

Key Technology and Research Trends

The USA Centers for Disease Control and Prevention establish active response and prevention measures in coordination with the countries in Africa, South America, and Southeast Asia, where new and variant strains of infectious diseases are prevalent. These centers conduct joint research to collect patient and clinical information. Therapeutic vaccines using genes are also under development. Inovio Pharmaceuticals of the USA is developing vaccines for the Zika and MERS viruses by producing DNA-based vaccines using weakened or dead forms of the viruses. Bill Gates announced the launch of the Coalition for Epidemic Preparedness Innovations at the World Economic Forum in Davos, Switzerland, with the plan of investing KRW 1.18 trillion in vaccine development over the next five years. The Abbott Diagnostics Center in San Francisco established a database by analyzing the DNA of 8 million species of virus and bacteria and developed a technology to promptly identify new strains of pathogens that pose a danger of outbreak.

Along with the Global Research Collaboration for Infectious Disease Preparedness (GloPID-R), the EU has established a research basis and global networks to effectively respond to new and variant infectious diseases within 48 h of the outbreak. In 2008, the EU approved Fredericks, a highly effective vaccine for influenza A virus subtype H5N1 of Avian Influenza (AI), for the first time and invested EUR 200 million (KRW 264 billion) to develop Ebola vaccines.

Since the 1990s, the EU has focused on reinforcing quarantine and safety management after the outbreak of the mad cow and foot-and-mouth diseases, with farm-level management for pigs and chickens as well as an individual identification system for cattle. With respect to the quarantine equipment, Bioquell Ltd. of the UK and Steris of the USA developed an HPV Generator.

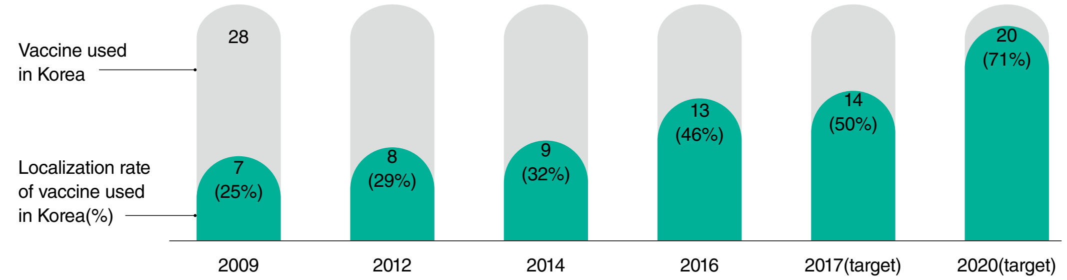


Figure 84 | Annual status of domestic vaccine development

© Ministry of Food and Drug Safety

The EU possesses a number of core quarantine equipment technologies and patent rights.

China conducts prevention and detection projects for infectious diseases and endemic diseases because of climate change at the Centers for Disease Control and Prevention. In Beijing, a system has been established, where a genetic sample test is reported in 2 h and the results are generated in 5 h in fully automated laboratories to prepare for influenza and avian flu treatment. In 2017, the Chinese government approved its own vaccine for Ebola; this vaccine was developed to allow reliable storage in African climates prior to the approval of vaccines by multinational pharmaceutical companies, including GlaxoSmithKline (GSK) and Merck (MSD). The vaccine was used in Sierra Leone where Ebola was prevalent, resulting in a high antibody response.

A new strain of AI that was initially detected in China became a global pandemic, with 759 cases reported for 11 months since 2016, and the incident rate increased by almost six fold. Because this variant of virus travels through various transmission routes, such as bird-to-human or human-to-human transmission, the UN recommended that multiple countries jointly participate in the development of vaccines. Although Korea conducted research on domestic infectious viruses and not on new and variant infectious diseases, including Zika, dengue fever, and MERS, the country is now aware of the risks associated with new and variant infectious diseases and the importance of appropriate response since the prevalence of the Ebola virus and MERS in 2014. Korea has been vigorously supporting and investing in vaccine development by domestic companies, including Green Cross, SK Chemical, CJ Healthcare, and Ilyang Pharm, as well as in the development of Zika and MERS vaccines to localize 70% of the vaccines by 2020.

The Ministry of Agriculture, Food, and Rural Affairs of Korea introduced a remote monitoring livestock disease control system in 2013 for the early detection of livestock diseases, which has been used to analyze the current disease control status. A smartphone application for fast and accurate on-site analysis was developed by adopting an IT system that supports imaging diagnosis. The Ministry of Science and ICT has supported the development of core technologies for infectious diseases in the bio sector since 2018, and it plans investments from a long-term perspective in the R&D on new and variant infectious diseases originating from other countries as well as infectious animal diseases.

02

Food Safety and Preventive Healthcare

Definition and Scope of Technology

The direct impact of climate change on food safety has been identified by the changes in foodborne risk factors (pathogens, mycotoxins, and shellfish toxins) and the increasing use of chemical risk factors, including veterinary medicine and pesticides. The 5th IPCC report has also recently warned that the global food crisis will affect food safety from 2030. This requires the prompt detection of chemical, biological, and physical risk factors; analysis of their impact; prediction of future risk factors; and development of technology for preemptive responses to prepare for the effect of climate change on food safety.

The technologies for food safety include non-thermal sterilization, establishment of a food safety database, development of prediction models based on big data analysis, and rapid detection of biological and chemical risk factors. Non-thermal sterilization methods are developed to ensure the safety of non-thermal, powdered, or ready-to-eat foods, and the food safety database is established to assess the impact of climate change on food safety. Based on the individual food intake survey (the National Health and Nutrition Examination Survey) and field data related to climate change, the risks from pesticide residue in food and intake amounts are calculated, and a prediction model is developed by verifying the correlation with food safety and the effect of climate factors. To prevent the damage arising from foodborne diseases caused by biological risk factors, the research on risk factors should be supported by technological development to detect the biological risk factors. Technology development is also required for rapid on-site detection of the chemically hazardous substances used to control the microorganisms susceptible to climate change.

Key Technology and Research Trends

The international organizations conducting food safety research related to climate change include the IPCC, the FAO, and the WHO. The IPCC provides education and promotion related to climate change. It has issued five reports on the subject. In 2008, the Food and Agricultural Organization reported “Climate Change: Implications for Food Safety,” which warns of the potential impact of climate change on food safety and encourages related research in member countries. Subsequently, vigorous research has been conducted on the associated policies in Korea and other countries that are advanced in the field of food safety.

In the USA, the impact of climate change is examined by various government agencies, including the President’s Council of Advisors on Science and Technology, the Department of Agriculture, the DOE, the Department of Commerce, the Department of Interior, the Department of Defense, and the Department of State. The USA holds 22% of the rapid detection patents related to food safety among patents related to climate change.

The EU implemented the JPI for agriculture and food safety in response to climate change. It has been conducting research on climate change response to observe climate change, forecast, and develop a new technology under the 7th Framework Programme (FP7). JPI is part of FP7, which focuses on the relation of the food sector with climate change, with the aim of establishing strategic plans for food security and safety in Europe.

Table 34 l Policy status of the European climate-related agencies

Country	Collaborative	Country
UK	FSA	The 2010 FSA report indicates that climate change affects the consumer food choices because of an increase in raising food prices and has an impact on the biochemical mechanisms generated by food processing, production, processes, and consumption in the nutrition and safety sectors
	DEFRA	In 2004, the FSA established FCRN in the University of Surrey in collaboration with EPSRC and DEFRA is conducting research to examine and reduce the GHGs produced in the food industry
EU	ERA	The DEFRA Climate change plan 2010 was proposed in 2010, and the departments of agriculture, forestry, and ocean in DEFRA are creating climate change guidelines and implementing action plans
	JPI	In 1997, DEFRA joined the 2011 partnership with UKCIP established by the Oxford Environmental Change Institute and has been seeking ways to respond to climate change by studying the damages from climate change

The objective of the Methodology for Effective Decision-making on Impacts and Adaptation (MEDIATION) is to support the implementation of the EU Climate Change Adaptation White Paper. This research focuses on the analysis of the decision-making context, the inventory of methods and metrics for impact and vulnerability analysis, the review and further development of such methods and metrics, the inventory for costs of impacts and adaptation strategies, the review and further development of such impacts and strategies, the development of an overarching integrated methodology, the development of a flexible and interactive common platform for knowledge sharing, and the dissemination of this knowledge through training programs.

In the UK, the Food Standards Agency (FSA) and the Department for Environment, Food, & Rural Affairs (DEFRA) conducted related research. The FSA studies climate change and food safety, and the agriculture, forestry, and ocean-related departments in DEFRA intend to establish and implement the climate change guidelines. In 2010, the FSA reported that climate change affects the consumer food choices via increases in food prices and affects the biochemical mechanisms involved in food processing, production, and consumption in the nutrition and safety sectors.

In Korea, 23 studies related to climate change were conducted from 2000 to 2009. Research on climate change impact assessment was led by academic and research institutes that focused on academic aspects or driven by some institutions focusing on impact analysis and assessment technology development in some areas. The studies related to food safety deal with climate change and the socioeconomic cost of food safety and the impact analysis and control system of foodborne disease outbreak due to climate change, both of which were examined in 2009 by the Ministry of Food and Drug Safety.

The Research Group on Food Safety Control Against Climate Change was organized in 2010 for overall research on the impact of climate change on food safety management. The objective of this research was to ensure a safe and healthy diet for people and encourage green growth of the food industry. The research group aims to establish climate change adaptation strategies and a relevant management system to reinforce public safety awareness by predicting the effects of climate change on food, analyzing the impacts of the chemical, biological, and physical risk factors, developing a processing technology to reduce the CO_2 emissions, and developing technologies for risk factor management.

Figure 85 | Post-management system webpage of the Research Group on Food Safety Control against Climate Change

Figure 86 | Grain inspection at the Incheon Port. Climate change has made quarantine-related technology an urgent requirement to ensure food safety © Incheon Port Authority

FOREST AND LAND

Overview

Definition and Scope of Technology

Forests absorb CO_2 from the atmosphere via photosynthesis. The trees that actively absorb carbon from the atmosphere grow well. Thus, a technology is required to maintain the health of trees for increasing the sequestration of carbon into forests. This involves technologies for reforestation using suitable tree species exhibiting good traits of adaptation and mixture of tree species, inducing monolayered forests into multilayered forests by selective cutting, extending carbon sinks in the form of urban forests, and increasing the use of wood products. In a broader sense, the technology to enhance carbon sequestration into forests means the improvement of forest productivity; thus, this technology can mitigate GHGs by improving the forest management systems.

The forests and terrestrial ecosystems store large amounts of carbon in living organisms and soils, and their rate of exchange with the atmosphere via photosynthesis and respiration is considerably higher than that of other ecosystems. Adaptation is closely related to mitigation because maladaptation of the forest and terrestrial ecosystem to climate change directly leads to the emission of GHGs. The climate change adaptation technology in forests and terrestrial ecosystems refers to the technology that can be used to monitor the impacts of climate change on the biodiversity of forests and terrestrial ecosystems and their functions, analyze vulnerabilities to reduce the negative impacts and damage, and use the positive effects as an opportunity. The climate change adaptation technologies for forest and terrestrial ecosystems can be categorized by the technologies for ecosystem monitoring, impact forecast model development, vulnerability assessment, forest disaster reduction, biodiversity conservation, and restoration. Among these technologies, the technologies for forest disaster reduction, ecosystem monitoring, biodiversity conservation, and restoration can be categorized as an ecology monitoring and restoration technology.

Table 35 | Subtechnology classification

Subtechnology	Technology description
Reduction of forest damages	• Forecasting, prevention, and reduction of forest fires • Vulnerability assessment, prevention, and reduction of landslides • Monitoring, change prediction, and control of diseases and pests • Monitoring of forest decline and improving resilience
Promotion of forest production	• Reforestation using suitable species with good traits • Multilayered forest development by selective cutting • Extension of new carbon sinks • Increased use of wood products
Ecology, monitoring, and restoration	• Monitoring of the ecosystem changes caused by climate change • Ecological restoration for climate change adaptation

Technology Trends and Industry Outlook

Among the international community, forests are gaining attention as a means to reduce GHG emissions. Many countries plan to utilize forests to meet their national reduction targets. In countries, such as the USA, Canada, Germany, France, and Japan, promotion of forest production is a crucial part of establishing long-term strategies for GHG reduction. The technology for forest damage reduction requires consideration for forest fires, heavy rain, pests and disease, and forest degradation. In particular, forest fires, heavy rain, and pests and disease have caused continuous damage to forests for a long time. The level of technology is high in this sector because the efficiency of technology has been improved by integrating technologies, including big data, IoT, and remote sensing (satellite images, aerial photos, and drone photos). The USA and Canada developed advanced technologies to prevent and reduce forest fire damage. For instance, models for estimating the forest fuel load using data from on-site investigations, such as forest resource surveys and remote sensing, models for forest fire risk assessment considering factors, such as forest fuel load, climate, and human activities, and models for predicting the forest fire spread by correlating the microclimate of forests, changes in microclimate during a fire, and the conditions of forests have been developed.

Japan has the most advanced technology to reduce landslide hazards, soil erosion, and damage to life, facilities, and property because of heavy rain. Japan possesses geospatial information with respect to the locations and areas affected by previous landslides. Various floodgates and soil models have been developed based on this information, and basic studies, such as those on identifying the relation between the tree root systems and soil strength, have been conducted in Japan.

The changes in forests and terrestrial ecosystems are monitored by the national and regional networks in many countries. The examples of such monitoring networks include the Long-Term Ecological Research (LTER, http://www.lternet.edu/) and the International Long-Term Ecological Research (ILTER) (http://www.ilternet.edu/) networks, the Global Observation Research Initiative in Alpine Environments (GLORIA) network (https://gloria.ac.at/), the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT, https://www.fs.fed.us/psw/cirmount/), and the Global Network of Mountain Observatories (GNOMO, http://gno- mo.ucnrs.org/). In Korea, the National Institute of Forest Science (NIFoS) started monitoring the forest ecosystems in 1996. A LTER site was established at the Gyebang-san Mountain and extended to six sites, followed by additional research sites established by the Ministry of Environment. NIFoS also established tower flux sites and monitored the exchanges with the atmosphere with respect to carbon, energy, and water in case of forest ecosystems. Recently, field research and monitoring of the conifer species in subalpine zones are underway along with the research on genetic diversity assessment and proliferation for restoration.

The Korea Forest Service recently announced the “2030 Forest Carbon Management Strategy,” which aims to improve the ability of forests to absorb carbon via specific targets and implementation strategies, including reforestation using suitable trees with food traits, multilayered forest development by selective cutting, expansion of urban forests, and increased use of wood products.

Figure 87 | The Gwangneung LTER site and a flux tower © Korea Forest Service

With the increasing frequency of natural disasters and increasing damages resulting from them, the investment in the development of the forest damage reduction technology has been growing recently. The technology to prevent forest fires, landslides, diseases, and pests has been under development led by the NIFoS. Regardless, Korea lags behind advanced countries with regard to the development of technologies for nationwide models to estimate the forest fuel load and predict its changes, accurate weather forecasting that can reflect the characteristics of the mountain areas, simulations of the spread of forest fires, early detection of the trees damaged by diseases and pests, and early warning systems for forest disasters; these topics require further research. The disaster detection and prevention technologies are expected to be advanced by incorporating the technologies that are being developed, including sensor networks, wireless communications, big data, drones, and artificial intelligence. The Ministry of Science, ICT, and Future Planning plans to develop five satellites via a two-phase project for obtaining a next-generation mid-sized satellite. Commercialization of the satellite for agriculture and forestry (2019–2022) will contribute to the near-real-time monitoring of forest damage, the identification of forest damage in areas with limited access, such as North Korea, and the monitoring of seasonal changes; such satellite data are likely to yield crucial information.

01

Reduction of Forest Damage

Definition and Scope of Technology

The technology for forest damage reduction is applied to monitor the abnormal weather caused by climate change as well as the damage caused by forest fires, landslides, pests and disease, forest dieback, and decline, predict and assess the risks and vulnerability associated with future climate conditions, and establish and control the preventive forest management technology and early warning systems to minimize the damages. This technology also encompasses a wide range of areas, including improvement of the accuracy of mountain climate forecast and prediction, forest fire risk forecast, forest fuel load estimation, prediction of the spread of forest fires, forest fire fighting simulator development, technology for firefighter safety, prediction of landslides and their risk, early warning system development, monitoring and prediction of diseases, pest and forest dieback damage, and forest management, to reduce the damages and improve resilience. Accordingly, the subtechnologies include those used to predict, prevent, and reduce forest fires, prevent and reduce landslides and assess landslide vulnerability, monitor, predict, and control disease and pest occurrences, and monitor forest degradation and improve resilience.

Figure 88
Climate change is changing the timing, frequency, and scale of forest fires. The role of hardware such as drones and of software such as diffusion prediction models is important in responding to forest fires © shutterstock.com

Table 36 | Major overseas research groups

Group	Nation/Institution	Research description
Climate change, reduction, and adaptation science	USA/USA Forest Service (Pacific Southwest Research Station)	• Climate change, change assessment, impact of climate change on ecosystem • Reduction and adaptation technology development • Operation of CIRMOUNT
Missoula forest fire science laboratory	USA/USA Forest Service (Rocky Mountain Research Station)	• Forest fire monitoring, forest fire ecology, environmental impact of forest fires, firing burning
Disturbance and Restoration Ecology Team (DARE)	USA/USA Forest Service (Pacific Northwest Research Station)	• Response of ecosystem, species, and invasive exotic species caused by climate change • Long-term impact of forest fires, vegetation, fuel change, forest fire location management, forest fires and biodiversity, historical changes in forest fires, and resilience • Assessment, modeling, and management of landscape scale
Department of natural hazards	Austria/Federal Research and Education Center for Forest, Natural Disaster, and Landscape	• Research on snow and avalanches • Research on flood and torrent monitoring and processes; hydrology • Physiological ecology of timber lines in high mountain areas
Department of disaster prevention, meteorology, and hydrology	Japan/Forest Research and Management Organization	• Mountain climate; hydrology • Research on forest disasters and risk

Key Technology and Research Trends

The impact of climate change on the forest and terrestrial ecosystems and vulnerability assessments were studied in different countries for more than two decades by establishing the monitoring data and simulation models. Considerable investment has been made into research on forest fires and pests and disease, causing the most damage to forests. Along with individual technology development for each sector, efforts have been made to define ecosystem resilience enhancement, develop forest management options for climate change adaptation and forest damage reduction, and advance the technology to analyze the impact of these options on the ecosystem. The USA National Aeronautics and Space Administration (NASA) provides artificial satellite images and possesses advanced-level technologies for aviation light detection and ranging, unmanned aerial vehicles, and observation sensors for use in forest management and disaster monitoring. The United States Geological Survey (USGS) is developing risk mapping for debris flow and rockslide and is investigating the forest dieback caused by climate change.

Table 37 | Major research groups in Korea

Group	Institution	Research description
Forest center for climate change	National Institute of Forest Science	• Operation of the mountain climate observation networks • Development of the impact forecast systems such as forest fire risk forecast • Development of the monitoring and adaptation technologies for forest degradation caused by climate change • Promotion of field research on the impacts of climate change on forests (2018–)
Forest fire prevention and control division	National Institute of Forest Science	• Development of the forest fuel estimation models • Development of the forest fire spread prediction models • Development of the landslide risk prediction models and early warning systems
Forest health protection division	National Institute of Forest Science	• Development of forest disease and pest occurrence monitoring and early detection technology • Development of forest disease and pest prevention technology
Pine wilt disease monitoring center	Korea Forestry Promotion Institute	• Early detection of the trees damaged by pine wilt disease

Pests and diseases, forest dieback, and decline and ecosystem changes have been monitored for long-term research to examine their relation with air pollution. Europe has substantially invested in climate change adaptation. The Netherlands and other countries are actively researching water management in response to flooding and increasing sea levels, and countries near the Mediterranean examine the damage of pine tree dieback because of drought and high temperature. Meanwhile, in the Alps region, research and technological developments related to landslides with respect to global warming are actively underway.

Japan has advanced levels of technology in the fields of monitoring and forecasting of landslides and forest soil sediment disasters, early warning systems, and prevention facilities. Japan is also spearheading research on pine wilt and oak wilt diseases, which are causes for concern in Korea.

In Korea, NIFoS conducts research mainly on reduction technology and monitoring of pests and disease along with ecosystem changes owing to climate change. The institute has considerably improved the accuracy of predictions of forest fire risks based on mountain climate networks with 200 locations nationwide. This network is planned for adaptation to the landslide risk prediction systems. The institute also improves models for forest fuel load estimation, upgrades the forest fire spread prediction models, and develops safety equipment for firefighters.

Research on forest pests and disease has focused on detecting damaged trees and developing prevention technologies; research has also been conducted with respect to the occurrence of newly invading pests and diseases and their relation with climate factors. Further research on the changes in species composition, structures of the forest ecosystems, and their relations with climate and other biological factors is necessary.

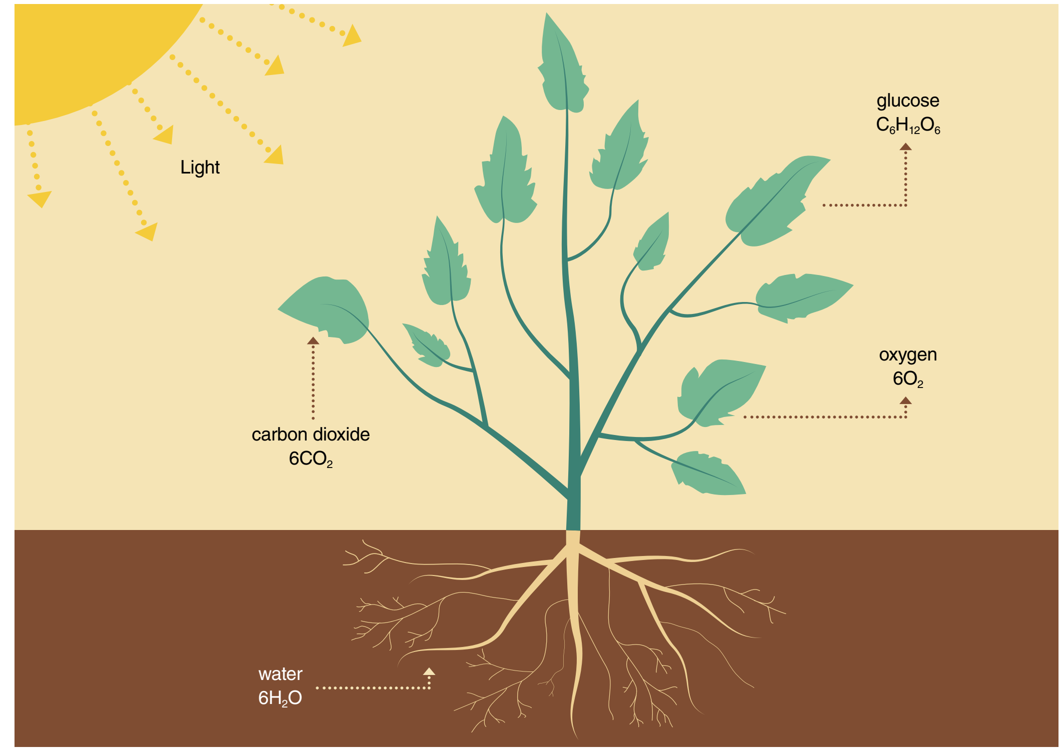
Promotion of Forest Production

Definition and Scope of Technology

Forests absorb CO_2 from the atmosphere via photosynthesis. The CO_2 absorbed during photosynthesis is separated into oxygen and carbon; the chlorophyll in the leaves combine the water and carbon absorbed from the roots and the atmosphere to produce organic matter. Some organic matter is released into the atmosphere during respiration, and the remaining organic matter is stored in the form of roots, branches, and leaves. Trees that grow well indicate that they are actively absorbing carbon from the atmosphere. Thus, the technology promoting the creation of more forests implies technologies that keep trees healthy and help the forests to absorb more CO_2. This includes technologies for reforestation using high-quality species of trees, multilayered forest development through selective cutting, securing carbon sinks through urban forests, and increased use of wood-based products.

Key Technology and Research Trends

In the USA, forests are a vital pillar of the ecosystem, accounting for more than 90% of the USA carbon sink. In the United States Mid-Century Strategy for Deep Decarbonization (2016) aimed at reducing GHG emissions, the USA government included forests as a major sector for reductions. The USA government plans to create up to 20 million ha of forest and increase the absorption of CO_2 by forest management activities such as reforestation, tree thinning, and promotion of forest growth. The USA urban forests currently account for 10% of the total carbon sink; yet, the urban forest cover is gradually declining. To maintain the absorption function of urban forests, tree species refinement and activities, such as weeding, have to be implemented. Further, wood processing technologies, such as Cross-Laminated Timber (CLT), will be developed and distributed to continuously increase the number of wood buildings and expand the use of wood-based products.



$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$$

Figure 89 | Carbon absorption by trees via photosynthesis © shutterstock.com

Canada established Canada's Mid-Century Long-term Low-Greenhouse Gas Development Strategy to reduce GHGs and proposed various measures to cope with climate change. Because Canada has the third largest area of forest cover in the world, forests have been an important part of its long-term strategy for combatting GHG emissions. Under this long-term strategy, Canada has been considering various forest management approaches, including the restriction of deforestation, utilization of thinned logs, controlling the burning of byproducts, and reforestation. Further, Canada has focused on expanding the use of wood-based products and utilizing urban forests because of the difficulties associated with increasing afforestation. The construction of an 18 story wooden dormitory building in the University of British Columbia shows the country's growing interest and investment with respect to the creation of tall wood buildings with the development of new wood processing technologies. Research on urban forest monitoring and improvement in the resilience of urban forests is also underway.

Germany has established a long-term strategy called the Climate Action Programme 2050 to reduce GHG emissions and has proposed measures to maintain and enhance the role of forests as carbon sinks. Under this program, Germany plans to pursue afforestation efforts, reforestation after deforestation, the use of wood-based products as

Figure 90
Dormitory building in the University of British Columbia, Canada © British Columbia University

building materials, and support R&D on expanding the use of wood. France established the National Low-Carbon Strategy based on the Energy Transition for Green Growth, with the aim of reducing the country's GHG emissions by approximately 19% using the forests. Therefore, the country will push ahead with its plans to manage the forest ecosystem, increase wood-based products' carbon storage, and develop overseas afforestation and reforestation projects.

Japan's Plan for Global Warming Countermeasures that intends to achieve its goal of GHG reduction by 2030 has proposed reduction targets and alternatives along with specific objectives for absorbing 278 million tons of CO_2 through forests by 2030. The government plans to promote active forest management activities such as the expansion of tree thinning, the development of multilayered forests, the adoption of the long-term reduction of deforestation, securing of forest roads, the development of high-quality tree species, reforestation after reforestation, and the promotion of a nationwide afforestation campaign. Japan also aims to increase the use of wood- based products by encouraging the use of wood in public buildings and expand urban forests by greening urban parks and unused spaces. Under the Promotion for the Use of Wood in Public Buildings Act implemented in 2010, public buildings are encouraged to increase the use of wood materials by more than 50%.

In Korea, forests account for 64% of the country's total land area with 6.33 million ha as of 2015, absorbing approximately 490 million tons of carbon. Annually, 48 million tons of CO_2 are absorbed by forests as of 2015, offsetting around 7% of Korea's annual total CO_2 emissions. Carbon storage, which was only 140 million tons in 1990, increased 3.5 times to become 490 million tons in 2015; and CO_2 absorption increased from 35 million tons in 1990 to 48 million tons in 2015. However, aging forests are likely to cause a gradual decrease in CO_2 absorption.

In case of stable CO_2 absorption from domestic forests, an evenly aged forest distribution should be achieved by cutting old trees and replacing them with young trees. However, the excessive deforestation of old forests may lead to massive short-term GHG emissions and negatively impact the remaining functions of forests, including water storage, air purification, biodiversity enhancement, and recreation. Thus, efforts should be devoted to ensure the active deforestation of forests exhibiting weak growth and reforestation with healthy species to achieve the mid- and long-term goals of achieving evenly aged forest distributions. Recently, the Korea Forest Service has announced the 2030 Forest Carbon Management Strategy, which aims to improve the forest's ability to absorb carbon based on specific targets and delineates implementation strategies, including reforestation using high-quality species, multilayered forest development through selective cutting, expansion of urban forests, and increased use of wood products.

03

Ecology, Monitoring, and Restoration

Definition and Scope of Technology

The technology for ecology, monitoring, and restoration can be classified into the monitoring technology for ecosystem changes owing to climate change and the ecological restoration technology for climate change adaptation. The former technology is intended to monitor the intraspecies changes and changes with respect to the species, community, ecosystem, and biome level to quickly and accurately detect the responses of the ecosystem to climate change. The technology mainly focuses on the response analysis of the living organisms and includes modeling and database establishment when required. The subtechnologies include the monitoring technology for vegetation zones and the stand level as well as at the species and intraspecies levels.

The ecological restoration technology for climate change adaptation requires a technology for diagnostic evaluation, improvement of the polluted environment, collection of the reference information, obtaining restoration plans by combining this information, monitoring and adaptation management at the levels encompassing species, communities, ecosystems, and landscapes. Expertise in general ecology, restoration ecology, and landscape ecology is an essential part of ecological restoration. The subtechnologies include technologies for improving the polluted substrate, selecting and introducing the adopted living organisms, and monitoring and adaptation management.

Key Technology and Research Trends

With regard to ecosystem monitoring in the context of climate change, the USA recognizes LTER as a window for observing changes at the global level and monitors the ecological changes at 24 locations representing the various ecosystems present throughout the USA (http://lternet.edu/sites). The LTER project identifies the plants and animals in each location by taxon and conducts long-term research on the dynamics of each population. It also examines various ecological phenomena at the community and ecosystem levels, such as primary production, energy flow, and biogeochemical cycles, in relation to environmental changes, including the climate change in the region. Combining the findings of LTER across the USA makes it possible to spatiotemporally compare the ecological phenomena with respect to each climate and vegetation type. Currently, the National Ecological Observatory Network has been operated as a system to monitor ecological changes at a broader level by focusing on climate change, biodiversity, biogeochemical cycles, ecohydraulics, disease, exotic species, and land use changes.

Figure 91 | Researchers from GLORIA are conducting an outdoor survey at Mount Hochschwab in the northeast of the Alps © Schrankovie/Wikimedia

The USA also applies ecological restoration technology as a means of climate change adaptation to realize GHG reduction through ecological restoration, resulting in a broad scale of restoration. A novel ecosystem is proposed as an adequate restoration model in this Anthropocene epoch, where several environmental changes, such as climate change, are occurring. The USA is also seeking for assisted migration to help with the migration of living organisms to protect species or ecosystems that are endangered owing to climate change.

The EU established the European Phenology Network (EPN) to provide plant phenological data for assessing the impact of the global climate change adaptation strategies. Currently, the EPN database contains the plant phenological data obtained from 30 European countries and 9 million records collected from 20,000 branches by 21 cooperating organizations across Europe, including the records collected with respect to 33 growth stages of the 139 plant species.

Since 2003, the EU's LTER has monitored the primary production, population dynamics, energy flow, biogeochemical cycle, disturbance types, and meteorological factors, which constitute a common theme of the ILTER.The Global Observation Research Initiative in

Table 38
Major overseas research groups: Monitoring of the ecosystem change caused by climate change

Group	Nation/Institution	Research description
Richardson group **Ide group**	USA/Harvard University Japan/NIES	• Continuous monitoring of the phenology using the digital camera and satellite image information • Collecting and combining various physiological information, including carbon cycle, using various facilities installed in the ecological tower to support the results acquired from monitoring, interpreting the ecosystem response to climate change from various perspectives
Allen group	USA/USGS	• monitoring of global-level drought and forest dieback due to high temperature
Franks group	USA/Fordham University	• leading research on rapid assessment by molecular biological response to climate change

Alpine Environments (GLORIA) network is a monitoring program for alpine vegetation, which is sensitive to climate change, and its biodiversity. Established in 2001, the GLORIA network monitors the movement of the plant species caused by climate change using permanent quadrats installed at locations from polar to tropical regions, where nature is appropriately preserved.

Japan launched the Japan LTER (JaLTER) project in 2007 in accordance with the ILTER and monitored forests, lakes, oceans, grasslands, and farmlands at 20 core sites and 36 associate sites by focusing on the responses of biodiversity and ecosystem functions to climate change and the relation between the hydraulic and biogeochemical processes and ecosystem functions at various levels and scales. The ecological response to climate change was mainly monitored by the Biodiversity Center of Japan by strongly emphasizing on biodiversity. Currently, the Asia–Pacific Biodiversity Observation Network (AP-BON), the regional network which monitors the biodiversity and ecosystems in conjunction with the Global Earth Observation-Biodiversity Observation Network (GEO BON), is being operated.

In China, LTER began in the late 1950s when the Chinese Academy of Science established the Xishuangbanna Biogeocoenosis Research Station in the Yunnan Province. LTER in China adopted ILTER, which is operated primarily by the USA, to monitor the ecosystem structure and functions, forest resources, and changes in environment.

In Korea, LTER networks for forest and terrestrial ecosystems were established by the NIFoS in 1996–2004 at Gwangneung in the Gyeonggi Province, Mount Gyebang in the Gangwon Province, Mount Geum in Namhae, South Gyeongsang Province, and Mount Halla in Jeju. The networks have been expanded to Mount Gariwang in Jeongseon, Gangwon Province, pine forests in Samcheok, and Anmyeon Island in Chungcheongnam-do to monitor the stand dynamics, biodiversity, phenology (leaf unfolding and flowering), ecosystem flux, and soil respiration. The flux towers collect the data to observe the flow of CO_2, water, and energy between the atmosphere and ecosystem and the microclimate of forests. Further, the Phenological Eye Network (PEN) system has been operated since 2008 to monitor plant seasons using digital cameras.

Expansion of the LTER into diverse ecosystems, such as forests, rivers, coasts, farmlands, and cities, has been conducted since late 2004 with the support of the Ministry of Environment. The monitoring subjects at those sites include vegetation dynamics, primary production, biogeochemical cycles, phenology, and biodiversity through international data sharing to detect the environmental changes occurring at the global level. In addition, monitoring of the ecosystem changes due to climate change includes a national inventory focused on vegetation and biodiversity and a national inventory of the natural environment of specific islands by the Ministry of Environment, plant phenology monitoring by the Korea National Arboretum and the National Park Research Institute, and a national inventory of forest resources and forest health monitoring by the Korea Forest Service. In addition, monitoring of the stand structure, abiotic environment, tree health, microclimate, etc. has been in progress since 2015. A survey of the decline of the subalpine needle-leaved forest has been conducted since 2017 by the NIFoSs. However, the application of ecological restoration as a means of climate change adaptation is still to be achieved as it is only in the early stage in Korea.

Table 39
Major research groups in Korea: Monitoring of the ecosystem change caused by climate change

Group	Institution	Research description
Research team of Prof. Lee, Chang-Seok **Korea National Arboretum National Park Research Institute**	Seoul Women's University Korea National Arboretum National Park Research Institute	• lower-case monitoring of phenology using the digital camera and satellite image information • monitoring of plants' response to climate change at the physiological level
Forest ecology research division	National Institute of Forest Science	• long-term ecological research networks for forest • flux observation systems (CO_2, etc.) • biotic seasons (aestivation and anthesis) and the Phenological Eye Network (PEN) system
Forest center for climate change	National Institute of Forest Science	• mountain climate observation networks (200 locations) • monitoring of the coniferous trees in subalpine zones • pine forest degradation monitoring (3 regions, including Uljin) • operation of arthropods change the observation networks at 365 locations (2006–) and climate change impact analysis
Research team of Prof. Choi, Se-Woong **Forest ecology research division**	Mokpo National University National Institute of Forest Science	• changes in the spatial distribution of insects due to climate change
Research team of Prof. Lee, Woo-Shin	Seoul National University	• lower case in birds' breeding patterns due to climate change
Research team of Prof. Lee, Woo-Kyun	Korea University	• prediction of future vegetation distribution under climate change

Part

4

Mitigation/ Adaptation Convergence Technology

Multidisciplinary Overlap

MULTIDIS-CIPLINARY OVERLAP

Overview

Definition and Scope of Technology

Multidisciplinary technology is the technology for energy reduction, adaptation, and convergence. It encompasses technologies related to renewable energy hybrid systems, technology for low-power consumption equipment in mobile devices, homes, and buildings, energy harvesting technology for converting the surrounding energy into electric energy, and the artificial photosynthesis technology for producing fuels comprising carbon, hydrogen, and oxygen from CO_2.

The renewable energy hybrid system technology refers to the supply management system for electricity, heat, and gas, which combines more than one energy production and storage system and its subtechnologies (including power generation, heat production, energy upgrades for industrial complexes, energy for residence and living, and energy transport). Low-power-consumption equipment technology has played a major role in the recent rapid distribution of mobile devices, and it comprises technologies for processors (SoC), which are a significant component in mobile devices, along with low-power-consumption Bluetooth devices, standby power minimization, cooling systems, and smart plugs. The energy harvesting technology is related to new and renewable energy and utilizes various mechanical and thermal energies commonly generated for self-powered electrical devices and auxiliary power for batteries. The artificial photosynthesis technology involves producing fuels comprising carbon, hydrogen, and oxygen using CO_2 as the starting material. Its subtechnologies include technologies for generating CO_2 reduction catalysts, catalytic oxygen, photoelectrochemical cells, photocatalyst, and biomass.

Table 40 | Subtechnology classification

Subtechnology	Technology description
New and renewable energy hybrid systems	• Distributed and independent power; thermal production systems • New & renewable energy hybrid (NRE-H) systems with highly efficient carbon reduction • Energy independence and low-carbon NRE-H integrated solutions • Eco-friendly vehicle energy supply infrastructure • ICT convergence platform
Low-power-consumption equipment	• Next generation processors (SoC) • High-temperature ambient • Bluetooth low energy • Smart plugs
Energy harvesting	• Piezoelectric energy harvesters • Triboelectric energy harvesters • Hybrid energy harvesters
Artificial photosynthesis	• Photoelectrochemical cells • Carbon dioxide reduction catalyst • Oxygen generation catalyst • Photocatalyst • Biomass

Technology Trends and Industry Outlook

The New & Renewable Energy Hybrid (NRE-H) system is expected to be widely adopted in the field of power generation, focusing on independent or distributed generation systems tailored to each region and environment. It has significant growth potential and is backed by the green remodeling and Zero-Energy Building (ZEB) markets in the home and living sectors. In the USA, various studies on such technologies are being conducted by laboratories, universities, and companies, primarily led by the Energy Systems Integration Facility under the NREL. European countries, such as Germany, Denmark, the Netherlands, and Sweden, are also actively engaged in R&D and demonstrations for various models based on NRE-H in the areas of home and living, industrial complexes, virtual power plants, and ecofriendly transport infrastructure. In Japan, several R&D activities about new & renewable energy and NRE-H systems have been conducted in universities and government-funded research institutes, including the Fukushima Renewable Energy Institute (AIST) established in Koriyama in 2014. China too conducts R&D through government-funded organizations, such as the Renewable Energy Research Center, under the China Electric Power Research Institute.

With respect to the low-power-consumption equipment technology, companies, such as Qualcomm and Intel (the USA) and ARM (the UK), have actively conducted research on low-power SoC, which can minimize the power consumption of mobile devices and IoT. Using the node manager and data center manager technologies, system power is managed via real-time monitoring of power consumption and hot spots (where heat islands occur in the server) in a rack unit of servers. The BLE standards for low-power-consumption Bluetooth have also been established, and technology for smart plugs is under development by adopting the power consumption measurement, standby power control, and smart discovery technologies.

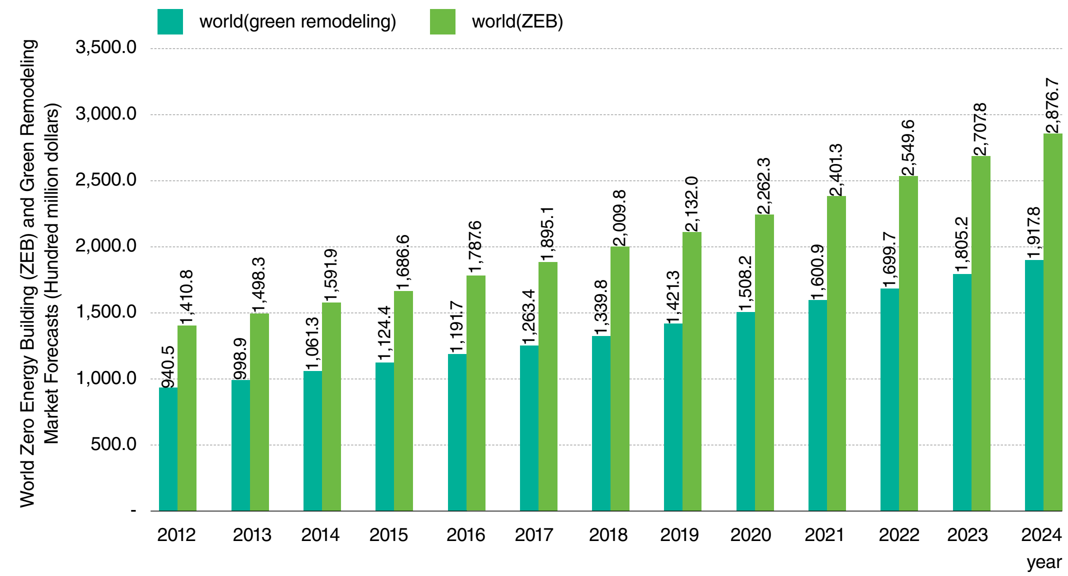


Figure 92 | Global green remodeling market forecast

© McGraw Hill Construction ('09), Navigant Research, 2014

The energy harvesting technology is being developed by universities and research institutes. Among the research groups, the teams led by Professor Zhong Lin Wang of the Georgia Tech University, Professor Xudong Wang of the University of Wisconsin, Professor Wenzhuo Wu of the Purdue University, Professor Massimo De Vittorio of the Salento University in Italy, Professor Sohini Kar-Narayan of the University of Cambridge in England, and Professors Ya Yang and Zhou Li of the Beijing Institute of Nanoenergy and Nanosystems in the Chinese Academy of Science are leaders in the field.

The development of the artificial photosynthesis technology has been explored by universities and research institutes worldwide. In the USA, research groups, such as the Craig A. Grimes Group of the Pennsylvania State University, Fujita Group of the Brookhaven National Laboratory, Kanan Group of the Stanford University, Marcel Group of the University of Illinois at Urbana-Campaign, and Bocarsley Group of the Princeton University, lead the technological development. Apart from the aforementioned research groups, the Negish Group of the Hokkaido University, Arai Group of the Toyota Central R&D labs in Japan, and the Sivula Group of EPFL in Switzerland are actively engaged in research on artificial photosynthesis.

In May 2014, the Korean government launched 19 future growth engine projects as a government-wide program and established the NRE-H system promotion team. The NRE-H system promotion team set a 10-year comprehensive plan with the objective of expanding the distribution of new and renewable energy through the convergence of traditional energy sources to overcome the limitations of the previous R&D and demonstration related to new and renewable energy. This is because considerable focus was previously devoted to the elemental technology development. Technological development for low-power-consumption equipment is led by Samsung and the Electronics and Telecommunications Research Institute (ETRI) with the release and development of products with ARM cores, and KT and LG have been making efforts to improve the efficiency of the data centers. The BLE products are produced by LG Electronics, ST Korea, Diameseco, BDE, Rooti, Jellycoaster, and InSight Power, and research on smart plugs as a standard for power-saving outlets is actively underway at the Korea Electronics Technology Institute (KETI).

Development of the energy harvesting technology is led by research teams under the leadership of Professor Sang-Woo Kim of the Sungkyunkwan University, Dr. Chong-Yun Kang of KIST, Professor Keon-Jae Lee of KAIST, Professor Duk-Hyun Choi of the Kyung Hee University, and Professor Jung-Min Baek of UNIST. Artificial photosynthesis technology has been developed mainly by universities and research institutes, including the Korea Center for Artificial Photosynthesis, and research groups led by Professor Ki-Tae Nam of the Seoul National University, Professor Byung-Kwon Min of KIST, Professor Jae-Sung Lee of UNIST, Professor Hyun-Woong Park of the Kyungpook National University, and Professor Chan-Beom Park of KAIST.

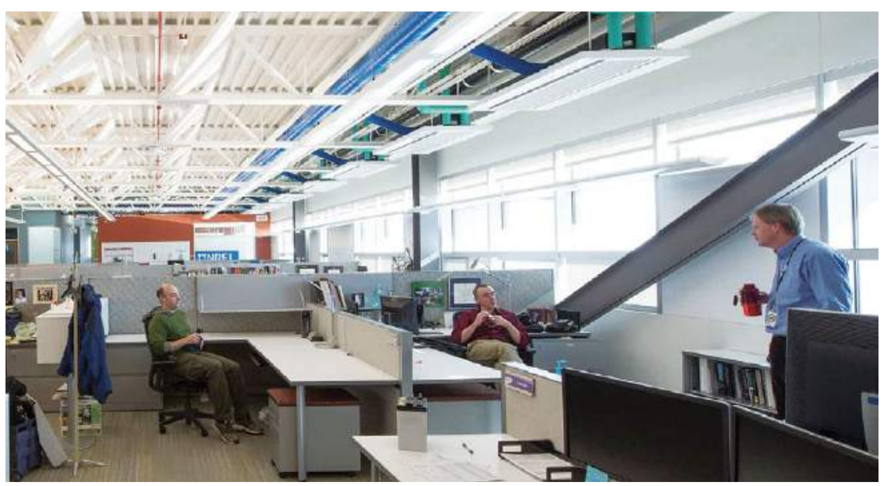


Figure 93 | Office of Energy System Integration Facility, an organization under the National Renewable Energy Laboratory, USA © NREL

01

New and Renewable Energy Hybrid Systems

Definition and Scope of Technology

New & Renewable Energy Hybrid (NRE-H) Systems refer to the integrated supply and management system in case of electricity, heat, and gas. This system includes a technology that combines more than one energy source, including new and renewable energies such as combinations of Photovoltaics (PV)–fuel cells–ESS, wind power–gas turbines, or PVs–geothermal heat–heat pumps, a technology that is equipped with ICT-based operating systems that enable the convergence of innovative energies, and a technology for obtaining convergence energy systems tailored to a region and environment. The examples of this technology include those that integrate PV–wind–cogeneration–storage, PV–geothermal–CSP, PV–wind, and PV–hydro.

The subtechnologies of the NRE-H systems comprise distributed and independent power and thermal energy production systems, high-efficiency carbon reduction-type NRE-H systems, integrated solutions for energy independence and low carbonization, ecofriendly vehicle energy supply infrastructure, and ICT conversion platforms. Specifically, distributed and independent power as well as thermal energy production systems support the convergence of various energy sources such as PV, fuel cells, ESS, heat pumps, solar thermal, thermal storage, offshore wind power, and ocean energy. High-efficiency carbon reduction-type NRE-H systems are industrial-level NRE-H systems that convert industrial energy infrastructure into high-efficiency carbon reduction-type systems. The integrated solutions for energy independence and low-carbonization NRE-H systems are NRE-H integrated solutions for ensuring the energy independence and low carbonization of ZEBs in urban environments and underdeveloped regions. Ecofriendly vehicle energy supply infrastructure refers to NRE-H-based power and hydrogen supply infrastructure for electric and fuel cell vehicles. The ICT conversion platforms support the NRE-H systems based on the engineering consulting and ICT technologies

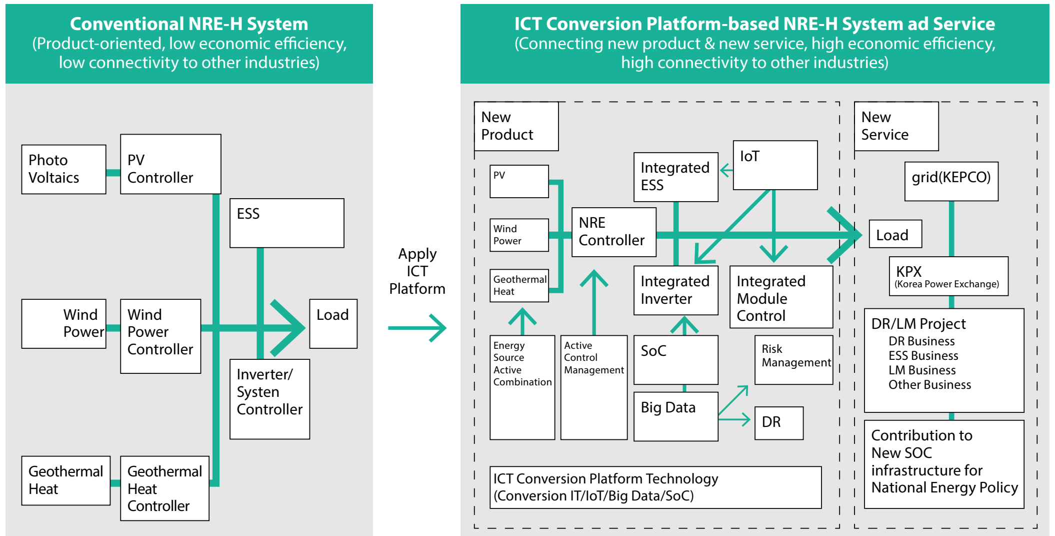


Figure 94 l ICT conversion platform-based NRE-H system and service diagram

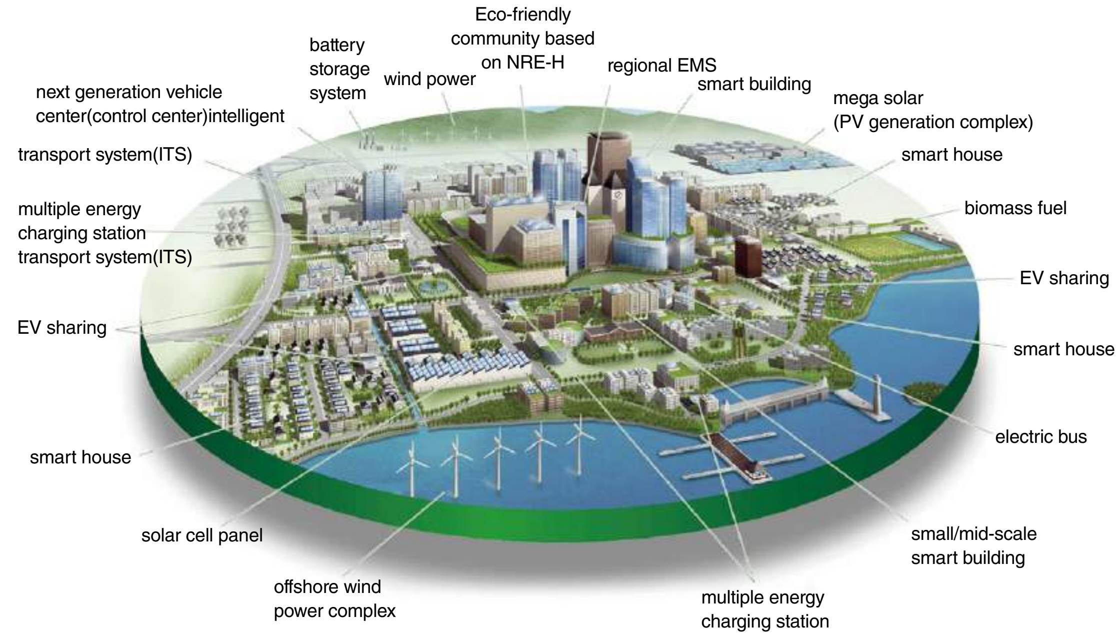


Figure 95 l Aerial view of the District of Tomorrow, designed by the EU (the Netherlands)

Key Technology and Research Trends

In the USA, various studies are conducted in laboratories, universities, and companies to expand new and renewable energies. One of the representative institutions is the Energy Systems Integration Facility (ESIF) established in October 2013. It is an organization under the National Renewable Energy Research Laboratory (NREL). ESIF develops technologies for integrating new and renewable energy sources into the conventional energy infrastructure. ESIF conducts research on the technology for achieving reliable system operations in a highly volatile energy supply-and-demand environment, the technology for reliably supplying power and fuel under abnormal and extreme weather conditions, the cyber risks and aging energy infrastructure, and the new business models and regulatory frameworks that can be effectively operated in the changing energy environment.

European countries, such as Germany, Denmark, the Netherlands, and Sweden, are also actively engaged in R&D and demonstrations of various models based on NRE-H in the home and living sector, industrial complexes, virtual power plants, and ecofriendly transportation infrastructure. One of the main projects related to home and living models is the District of Tomorrow project, which was launched in 2006 with the support of the Zuyd University of Applied Sciences in the Netherlands. The project performs several studies with respect to the Building Integrated Photovoltaic (BIPV) systems, which are mainly related to the NRE-H systems applicable to buildings or cities.

Japan is active in R&D on new and renewable energy and NRE-H systems via universities and government-funded organizations. One of the leading organizations is the Fukushima Renewable Energy Institute (FREA), which was established in April 2014 in Koriyama, a city near the 2011 Fukushima nuclear disaster site. The FREA, under the National Institute of Advanced Industrial Science and Technology (AIST), is engaged in research in three major fields, i.e., research on system integration to expand new and renewable energy supply in the existing power systems, research on reducing the costs and improving the overall efficiency of new and renewable energy, and research on providing scientific information related to the expansion of new and renewable energy.

China too conducts R&D through government-funded organizations such as the Renewable Energy Research Center (RERC), which was established in April 2016 under the China Electric Power Research Institute (CEPRI). Research conducted by RERC covers the analysis, assessment, and forecasting of new and renewable energy production plans, management and operation, meteorological application, distribution, and operation of new and renewable energy, system tests and measurement, and development of important control devices. It also conducts R&D on grid connection issues of the distributed solar and wind power sources.

Table 41 | Four technology development goals for NRE-H systems

Four technology development goals photosynthesis	1. demonstration of 100 MW scale independent & distributed NRE-H energy supply systems 2. a securing technology to achieve the energy independence ratio of the NRE-H-applied buildings (residential: 100%, commercial: 90% or higher) 3. establishing industrial ecosystems and facilitating exports: develop four models for advanced countries and 100 models for the emerging markets 4. building new eco-friendly stations using an NRE-H system (starting from zero in 2015 to 10,000 in 2024) - contribute to achieving the goal of securing renewable energy (20%) and distributed power (15%) by 2030

Figure 96
NRE-H system combines an energy storage system and more than one energy production system, including new & renewable energy such as photovoltaic and wind power © shutterstock.com

In May 2014, the Korean government launched 19 future growth engine projects as a government-wide program and established the NRE-H system promotion team. The NRE-H system promotion team has set a 10 year comprehensive plan with the ultimate goal of expanding the distribution of new and renewable energy through convergence with traditional sources of energy to overcome the limitations associated with previous R&D and demonstrations related to new and renewable energy by considerably focusing on elemental technology development. The government established comprehensive plans in the fields of R&D, demonstrations, infrastructure, training, certifications and standardization, international cooperation, and legislation and system improvements for the four major subtechnologies and ICT convergence platforms, which support the subtechnologies; further, plans to develop low-cost models of the domestic EMS & NRE-H systems and expand exports to developing countries were set.

02

Low-Power-Consumption Equipment

Definition and Scope of Technology

The low-power-consumption equipment technology has played a major role in the recent rapid distribution of mobile devices, and it includes technologies for ensuring the low power consumption of the System on a Chip (SoC), which is a significant component of mobile devices and Bluetooth low energy, minimization of the power consumption at data centers, and design of smart plugs to minimize the standby power of IT devices.

This type of equipment includes any equipment that uses electrical power. The subtechnologies include the technologies related to next-generation processors, High Temperature Ambient (HTA), Bluetooth low energy, and smart plugs. Next-generation processors are evolving into low-power, high-efficiency Application Processors (APs), which incorporate ARM processors, Digital Signal Processing units (DSPs), Graphics Processing Units (GPUs), and Neural Processing Engines (NPEs). Bluetooth low energy added a new protocol called BLE on June 30, 2010, to consume less power than the then-existing versions. The HTA technology reduces power consumption by increasing the operating temperature of the cooling systems, which accounts for the highest percentage of power consumption at data centers, from 21°C to 30°C/40°C on an average. Smart plugs are applied to smart homes and BEMS with IoT platforms based on real-time energy consumption, standby power safety shutdown, Zigbee, WiFi, and BLE.

Key Technology and Research Trends

With the rapid growth of the market for low-power SoC in the USA, companies, such as Qualcomm and Intel, are actively conducting research to minimize power consumption with respect to the processors that are to be applied to mobile devices and IoT. The power consumption of Qualcomm's flagship Snapdragon 835 is approximately 0.4 W. There are plans to improve the efficiency of the data center (Power Usage Effectiveness (PUE), the total data center power divided by the actual IT power) from 3 to 1.25. According to the Bluetooth Special Interest Group, BLE technology will be applied to 70% of the cars in three years and supported by enhanced connectivity to IoT, especially by increasing the automotive infotainment systems.

Table 42 | Major overseas research groups

Group	Nation/ Institution	Research description
Qualcomm snapdragon team	USA/ Qualcomm	• Manufacture CPU, GPU, DSP, NPE, LTE modems, BLE by a 10-nm manufacturing process; 25% improvement in chip power consumption compared to that of Snapdragon 820 (power consumption 0.55 W) • Built-in dual 14-bit Image Signal Processor (ISP) • 1-Gb download and 150-Mb upload speeds with Qualcomm's new 16LTE model • Support 802.11ac 4 × 4 MU–MMO for WiFi • Support Bluetooth 5.0
Intel/HTA team	USA/Intel	• Monitor the power consumption and hotspots (where heat islands occur in the server) in a rack unit of a server in real time, and manage system power using the node manager and data center manager
Bluetooth SIG		• BLE standards • LE advertising extensions • LE channel selection algorithms
Smart plug		• Power consumption measurement, standby power control, and smart discovery technology

ARM of the UK has actively researched low-power SoC, which can minimize power consumption and can be applied to IoT. Recognizing the need for low-power SoC in IoT, Softbank of Japan acquired ARM for GBP 24 billion and is investing in related industries. The Nippon Electric Company possesses the HTA technology and has achieved a Data Center PUE of 1.1 to 1.2 by adopting the direct free-air-cooling method.

In China, companies, such as MediaTek, Spreadtrum, and HiSilicon, possess the intellectual property rights for low-power SoC of mobile AP, which is processed by the Taiwan Semiconductor Manufacturing Company. The mobile AP market in China accounts for 40% of the entire market.

In Korea, Samsung has released products with an ARM core, whereas ETRI is working on R&D on low-power SoC with an ARM core. The PUE of domestic data centers remains at 3, and the efficiency has been improved in companies such as KT, LG, and LG U+. Korea currently has more than 150 data centers.

Table 43 | Major research groups in Korea

Group	Institution	Research description
Dr. Kyung-Jin Byun's research team	ETRI	Low-power video SoC
Dr. Kyoung-Ho Lee's research team	KETI	Low-power consumption, EH-IoT, standby power control
Dr. Kwang-Soon Choi's research team	KETI	Power consumption measurement, standby power control, smart discovery technology

The domestic technology for Bluetooth 4.2 has been applied to several products used in daily life, for example, smart bottles, blood glucose meters, and smart plugs made by LG Electronics, ST Korea, Diamesco, BDE, Rooti, Jellycoaster, and InSight Power. The technology for smart plugs has been researched mainly by KETI and has been included in the Technology Roadmap for Small and Medium Enterprises to foster smart plugs as a growth engine for SMEs with government support. Recently, companies, such as Samsung, SK Telecom, KT, and LG U+, have started selling smart plugs as a device for smart homes.

Figure 97
Development of low-power mobile chips is still important in the 5G era. © shutterstock.com

Energy Harvesting

Definition and Scope of Technology

The energy harvesting technology is a next-generation energy generation technology that encompasses renewable energy technologies for developing self-powered electric devices and auxiliary power for batteries using various mechanical/thermal energy forms commonly generated throughout the environment. Energy harvesting technologies can be used in sensors and as auxiliary energy sources for IoTs and wearable devices at the current level of technology. In the future, it may replace the existing fuel energy through continuous research and technological development.

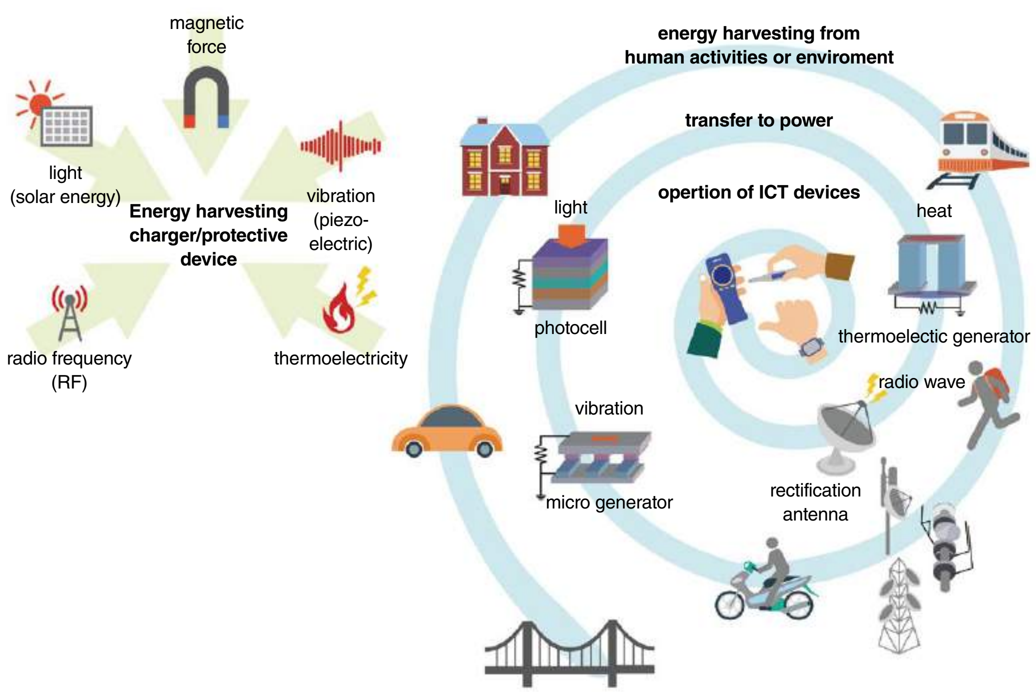


Figure 98 | A schematic of the energy harvesting technologies

Numerous energy-harvesting technologies have been reported; examples include the piezoelectric/triboelectric energy harvesters driven by the triggered mechanical forces, mechanical–thermal-coupled energy harvesters, and shape memory polymer-based vibration energy harvesters that are intended for stable and long-term use.

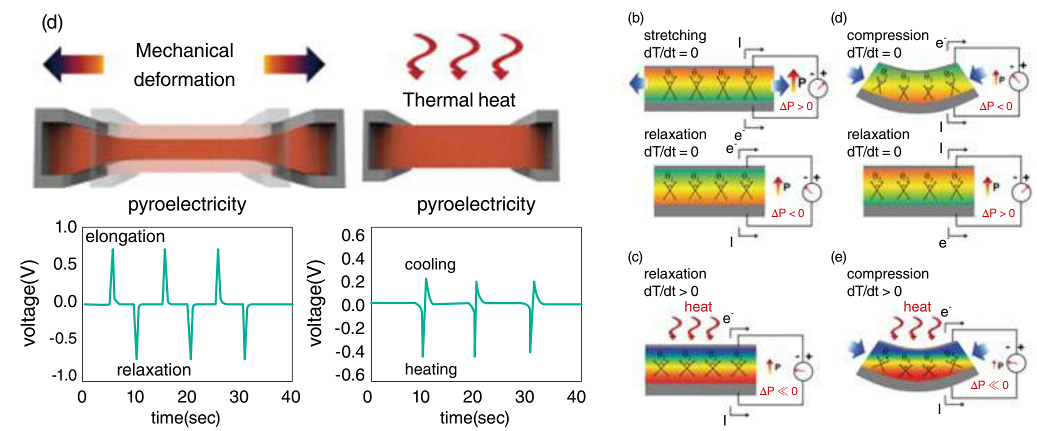


Figure 99 | Identification of human movement and body temperature with hybridized energy harvesters and the output characteristics with a working mechanism

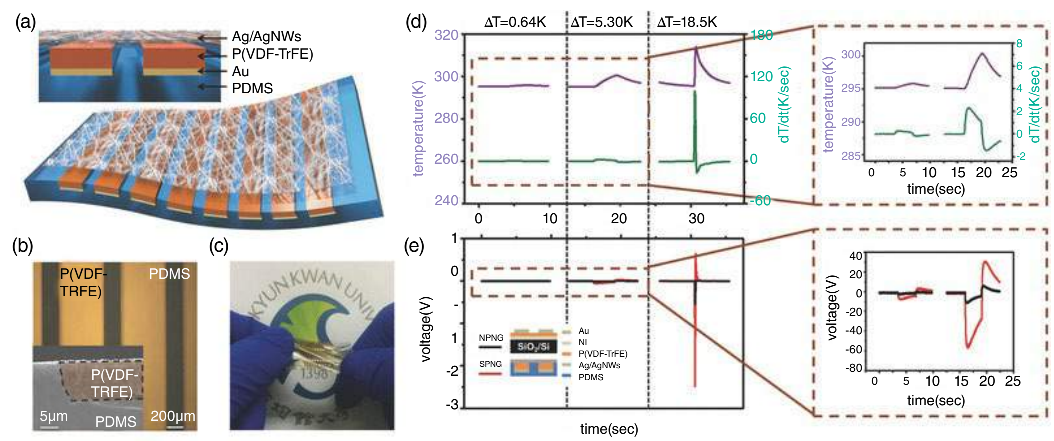


Figure 100
Thermally induced mechanical energy harvester with enhancement via nanoscale patterning

Key Technology and Research Trends

In the USA, a research team led by Professor Zhong Lin Wang at the Georgia Institute of Technology is at the forefront of research on mechanical energy harvesting and developing technologies for new and renewable energy conversion through various piezoelectricity and triboelectrification materials. This research team developed an integrated material with energy harvesting elements that function in various modes of operation (pushing, sliding, free-standing, rotation modes) based on the application.

Professor Xudong Wang at the University of Wisconsin and his team have been focused on developing energy harvesting materials. Their research is focused on enhancing the output and reliability of the triboelectrification energy harvesters using materials such as the mesoporous piezoelectric polymer composite films, Polyvinylidenefluoride (PVDF)-based two-dimensional (2D)–3C thin composite films, and BaTiO3/polydimethylsiloxane composite films.

The team led by Professor Wenzhou Wu at the Purdue University has been studying the physical and chemical control of the semiconductor-based piezotronic/piezophototronic 2D nanowires and nanorods, such as GaN, Ge/Si, ZnO, and MoS2, and self-powered piezoelectric-based energy harvesters using ecofriendly materials.

In Europe, Professor Massimo De Vittorio's team at Salento University in Italy has investigated one-dimensional (1D) nanomaterials, piezoelectric materials, and neural interfaces. Research on piezoelectric energy harvesting using AlN materials and energy harvesters that supply power for flexible piezoelectric-based e-skins and studies on conversion based on neural interface research are currently underway.

Professor Sohini Kar-Narayan at the University of Cambridge, UK, and his research team have studied the manner in which the piezoelectric energy harvesting properties of the nanoscale materials can be optimized. Recently, studies were conducted on the usage of the AAO template to fabricate nylon nanowires based on the capillary phenomenon for obtaining piezoelectric-based energy harvesters. This research team discovered the potential of this material as an energy harvester by verifying the piezoelectric characteristics of BCT-0.5BZT material synthesis and crystal control and the growth of lead-free ferroelectric nanowires using nanowires.

In China, Professor Ya Yang's research team at the Beijing Institute of Nanoenergy and Technology has been conducting research on triboelectrification and triboelectrification–thermoelectricity hybrid energy harvesters. Their research includes the synthesis of materials, such as ZnO, TiO2, and BaTiO3, fabrication of hybrid energy cells by building heterojunctions between ZnO and other materials, building piezoelectric energy harvesters using the BaTiO3 nanotubes, and developing output-enhanced triboelectric energy harvesters using the chemically transformed TiO2.

The research team led by Professor Zhou Li at the Beijing Institute of Nanoenergy and Technology has studied self-powered implantable energy harvesters, high-sensitivity biosensors, and biodegradable energy harvesters. Their research mainly focuses on the biomechanical energy harvesting technology by employing Si nanowires and on implantable energy harvesters based on ZnO nanowires.

In Korea, Professor Sang-Woo Kim at the Sungkyunkwan University has studied piezoelectric and triboelectric energy harvesters to realize piezoelectricity and self-powered microelectronic devices using two-dimensional semiconductor materials, including MoS2, WSe2, and graphene materials. The team has also investigated highly efficient high-output energy harvesters using internal polarization control, crystal control, and ion–electrolyte polymers obtained by the coupling between the ferroelectric ceramic materials and fluorine-type polymer materials (PVDF–TrFE, PTFE, and PFA). Such materials can supply power to wearables and biomedical implants. Recently, his team reported ultrasound energy harvesting technologies based on the triboelectric effect to power implantable medical devices; this result was published in Science.

Dr. Chong-Yun Kang at KIST has studied hybrid energy harvesters that produce a high output with high efficiency, even from a very small amount of mechanical energy and stress. Therefore, an integrated technology of micrometer-sized piezoelectric and triboelectric materials was developed. The devices built using this technology can be applied in various fields because they produce high output voltage and current density.

The research team led by Professor Keon-Jae Lee at KAIST studied piezoelectric energy harvesters using the PVDF and PMN–PZT–Mn materials; their results were applied to develop self-powered, wireless, and flexible energy harvesters. The team has also conducted research on high-output triboelectric energy harvesters using the PUA resin materials.

Professor Duk-Hyun Choi from the Kyung Hee University and his research team have studied material synthesis mainly using AAO materials and developed a self-powered sensor system utilizing external environmental sources of energy, such as vibrations, pressure, and temperature, using several energy harvesting technologies. Further research is being conducted on triboelectric energy harvesters powered by vibrations in a broad range of frequencies that can convert complex mechanical energies into electric energy.

The research team led by Professor Jeong-Min Baik at the UNIST has studied three-dimensional high-efficiency triboelectric energy harvesters using nano–micrometer-sized, spherical, and hemispheric polystyrene materials; the team implemented a triboelectric energy harvester that utilizes polyurethane materials and presented a noise-canceling application using three-dimensional (3D) printers. Recently, the research team also developed triboelectric energy harvesters with a high current density based on an artificial lightening mechanism.

Artificial Photosynthesis

Definition and Scope of Technology

Artificial photosynthesis is a technology to produce fuels comprising carbon, hydrogen, or oxygen using sunlight and CO_2 (or water) as raw materials. Thus, it is named after the natural photosynthesis in plants, producing biological fuels such as glucose. Artificial photosynthesis is the process of producing solar fuels from CO_2 and water using solar energy.

The major technology in this field is a technology for CO_2 reduction from an aqueous solution using electrochemical catalysts. Its subtechnologies include the technologies for CO_2 reduction catalysts, catalytic oxygen generation, photoelectrochemical cells, photocatalysts, and biomass. Using the technology for obtaining a CO_2 reduction catalyst, solar fuels, including carbon, hydrogen, and oxygen, are selectively produced via underwater CO_2 reduction, and catalysts are developed for this process. The technology for catalytic oxygen generation involves the development of a catalyst to produce oxygen by oxidizing water with low overpotential. The technology for photoelectrochemical cells involves the development cells for CO_2 reduction by combining photoelectrodes that produce electric energy from light or solar cells with CO_2 reduction catalysts or oxygen-generating catalysts. The technology for photocatalysts involves the development of photoactive catalysts in which the CO_2 reduction and oxygen generation reactions occur simultaneously on the particle surfaces. Biomass technology involves the cultivation of bacteria to consume the hydrogen generated under water and selectively produce specific solar fuels.

Key Technology and Research Trends

In the USA, the technological development in this field is being led by research groups such as the Craig A. Grimes Group at the Pennsylvania State University, Fujita Group of the Brookhaven National Laboratory, Kanan Group at the Stanford University, Marcel Group at the University of Illinois at Urbana-Campaign, Bocarsley Group at the Princeton University, and Nocera Group at the Harvard University. The Grimes Group synthesized methane using the product obtained by the reaction of CO_2 and water under photocatalytic conditions in the presence of the copper and platinum nanoparticles. The Kanan Group conducted research on improving the CO_2 conversion efficiency and product selectivity using active sites such as grain boundaries, achieving CO production with a selectivity of 96% or more using the grain boundaries of gold nanoparticles.

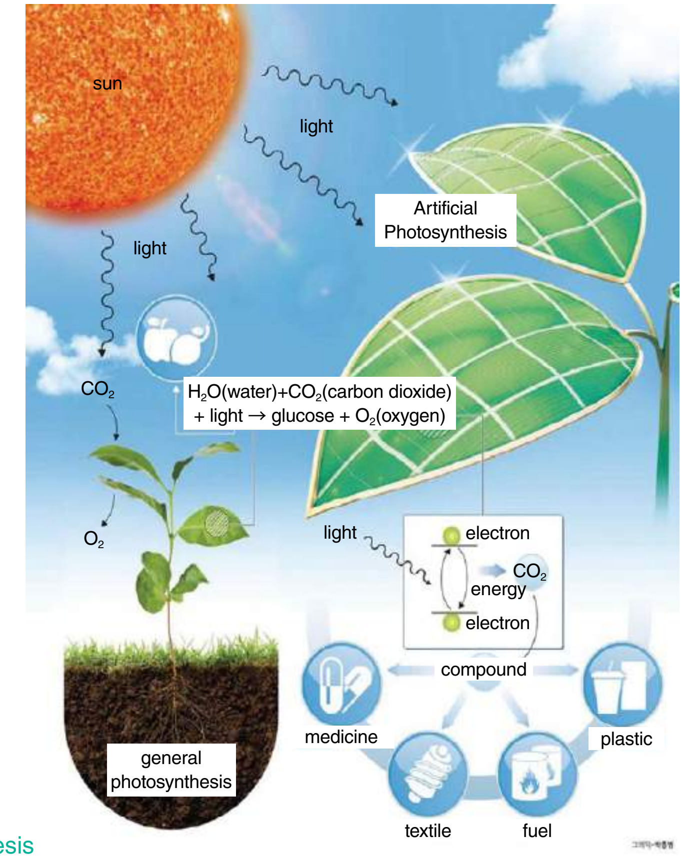


Figure 101
Application of artificial photosynthesis

As the head of Sun Catalytics, a company supported by the USA government, Professor Nocera of the Harvard University developed a plan for the mass production of hydrogen fuels by disintegrating water into oxygen and hydrogen using photovoltaics. The Nocera group also proposed photoelectrochemical cells based on a wireless silicon semiconductor in the shape of artificial leaves and compared it to a wired version.

Table 44 | Major overseas research groups

Group	Nation/Institution	Research description
Craig A.Grimes	USA/Pennsylvania State University	• Synthesis of methane by CO_2 and water reaction product under photocatalytic conditions, including Cu and Pt
Science of large scale systems from LBNL	USA/JCAP	• Developing an efficient system of producing fuels with only water and CO_2 using sunlight; recent ongoing research on liquid fuel synthesis by CO_2 reduction
Fujita	USA/Brook Haven National Laboratory	• Reaction mechanisms of carbon monoxide manufacture using the photoactivity of CO_2; water decomposition catalyst systems
Kanan	USA/Stanford University	• Improving the CO_2 conversion efficiency and product selectivity using active sites such as grain boundaries - Achieved production of carbon monoxide with selectivity of 96% or more using the grain boundaries of gold nanoparticles

Group	Nation/Institution	Research description
Masel	USA/University of Illinois at Urbana-Champaign	• Ionic liquid that reduces overvoltage and increases the solubility of CO_2 - Improved selectivity of carbon monoxide and CO_2 in silver electrodes by almost 96%
Bocarsly	USA/Princeton University	• CO_2 reduction mechanism technology using various systems, including p-block metals, dissimilar metal alloys, and organic metal complexes - Typically produces methanol from CO_2 with almost 100% selectivity by the addition of a small amount of pyridine to the p-GaP electrode
Sandia national laboratory	USA/Sandia National Laboratory	• Developing a process called "Sunshine to Petrol" to produce various fuel materials by combining the CO_2 reduction technology with solar chemical and water decomposition processes
Nocera	USA/Harvard University	• Head of Sun Catalytics, which is directly supported by the USA government, plans the mass production of hydrogen fuel by disintegrating water into oxygen and hydrogen • Proposes photoelectrochemical cells based on a wireless silicon semiconductor to take the shape of artificial leaves, comparing it to a wired version
Negishi	Japan/Hokkaido University	• Study on artificial photosynthesis using Negishi coupling, a key theory of artificial photosynthesis
Arai	Japan/Toyota Central R&D Labs	• Proposed the first photoelectrochemical model • Reported a photovoltaics–formate conversion efficiency of 0.08% by presenting an effective form of devices using the InP semiconductor and RuCP $[Ru(bpy)_2(CO)2]^2$ + metal complex hybrid photoelectrode and applying SrTiO3, which enables light absorption from the anode
Domen	Japan/Tokyo University	• Developing photocatalysts using oxynitride or oxysulfide - Absorbs visible light to allow spontaneous water decomposition using valence band level increase due to the higher electric potential of N2p or S3p orbitals than the O2p orbital when oxygen is switched to nitrogen or sulfur in metal oxide
ELCAT	Europe/ELCAT (Electrocatalytic Gas-phase Conversion of CO_2 in Confined Catalysts)	• Jointly developing a catalyst process converting CO_2 into liquid fuel and methanol by establishing joint venture groups with the participation of Germany's Max Planck Institute, France's Louis Pasteur University, and Greece's University of Patras
Sivula	Switzerland/EPFL	• Conducted a tandem photoelectrode experiment by combining semiconductor oxide with the dye-sensitized solar cells to apply sufficient voltage for water splitting and reported a maximum photovoltaic-hydrogen conversion efficiency of 1.36%.
Linde	Germany/The Linde Group	• 'Technologies for Sustainability and Climate Protection - Chemical Processes and Use of CO_2' project of the German government with the cooperation of BASF and Thyssenkrupp - Research to produce fuel materials by manufacturing synthetic gas from CO_2

Table 45 | Major research groups in Korea

Group	Institution	Research description
Korea center for artificial photosyn-thesis	Ministry of Science, ICT, and Future Planning	• Intended to produce useful compounds, such as carbon monoxide, formic acid, formaldehyde, and methanol, using CO_2, sunlight, and water - Planning to study the artificial leaf technology that produces fuels by absorbing water, CO_2, and solar energy and a "molecular catalyst" that can transform CO_2 into fuel once injected into a pond
Ki- Tae Nam	Seoul National University	• Produced a hybrid system that combines the BiVO4 semiconductors with the protein from spinach to produce hydrogen using water by exposing the system to visible light - The first case of actual ecofriendly generation of a hybrid using protein as a raw material with only water and light, showing potential for various applications in bioenergy development
Byung-Kwon Min	KIST	• Produced high-value compounds, such as carbon monoxide and formic acid, by developing an integrated artificial photosynthesis device with higher photosynthesis efficiency when compared with that of natural leaves - The device has an efficiency of 4.23% compared to 1% for leaves and 3%–4% for green algae in nature, showing the achievement of a level of technology comparable to that of advanced countries
Jae-Sung Lee	UNIST	• Succeeded in developing artificial leaves with an efficiency of 8% to produce hydrogen via sunlight using the principle applied to sea algae, showing the highest level of efficiency by improving the efficiency of photovoltaic conversion, which was approximately 5% until recently
Hyun-Woong Park	Kyungpook National University	• Achieved an efficiency of 1% for conversion to formic acid, a high-value compound, by producing a photoelectrode using economical materials such as copper and iron oxide
Chan-Beom Park	KAIST	• Developed core technologies for artificial photosynthesis using nanosized photosensitized materials - Generated cofactors by efficiently converting light energy into electric energy. Developed a response system that can produce fine chemical substances by connecting the oxidation–reductase response to the regeneration of cofactors

In Japan, research on artificial photosynthesis is led by the Negishi Group of the Hokkaido University and the Arai Group of the Toyota Central R&D Labs. The Negishi Group is focused on artificial photosynthesis using Negishi coupling, which is a key theory of artificial photosynthesis, whereas the Arai Group proposed the first photoelectrochemical model.

In Europe, various studies are being conducted by the Sivula Group of EPFL in Switzerland and the Linde Group in Germany on artificial photosynthesis. The Sivula Group conducted a tandem photoelectrode experiment by combining a semiconductor oxide with dye-sensitized solar cells to apply sufficient voltage for water splitting; a maximum PV–hydrogen conversion efficiency of 1.36% was reported in this study.

In Korea, the artificial photosynthesis technology was developed mainly by universities and research institutes such as the Korea Center for Artificial Photosynthesis and research groups led by Professor Ki-Tae Nam of the Seoul National University, Professor Byung-Kwon Min of KIST, Professor Jae-Sung Lee of UNIST, Professor Hyun-Woong Park of the Kyungpook National University, and Professor Chan-Beom Park of KAIST. The Korea Center for Artificial Photosynthesis is working to produce useful compounds, such as carbon monoxide, formic acid, formaldehyde, and methanol, using CO_2, sunlight, and water. The research team led by Doctor Byung-Kwon Min realized the production of high-value compounds, such as carbon monoxide and formic acid, by developing an integrated artificial photosynthesis device with a higher photosynthesis efficiency when compared with that of natural leaves.

Appendix

The Top 100 Climate Technology Companies in Korea

Technology field	Company Name	Website	Phone Number	Email
Clean power generation and efficiency	KEPCO E&C	www.kepco-enc.com	+82-54-421-3114	webadm@kepco-enc.
	Korea District Heating Corp	www.kdhc.co.kr	+82-31-780-4114	
	enesG	www.enesg.co.kr	+82-42-718-5000	
	BHI	www.bhi.co.kr	+82-55-585-3800	Info@bhi.co.kr
	KOGAS-Tech	www.kogas-tech.co.kr	+82-42-600-8000	
	SAMCHULLY	www.samchully.co.kr	+82-2-368-3300	
	Byucksan Engineering	www.bseng.co.kr	+82-2-767-4019	
	Kangrim Heaby Industries CO., LTD.	www.kangrim.com	+82-55-269-7759	
	DongHwa Entec	www.dh.co.kr/	+82-51-970-1000	Ide@dh.co.kr
	Korea Electric Power Industrial Development	www.kepid.co.kr	+82-2-2250-2700	
Photovoltaic	DAESUNG ENERGY	www.daesungenergy.com	+82-53-606-1000	
	SHINSUNG E&G	www.shinsung.co.kr	+82-31-788-9500	Solar@shinsung.co.kr
	S-Energy	www.s-energy.com	+82-70-4339-7100	
	TOPINFRA	topinfra.co.kr	+82-62-574-9088	
	KwangMyung Electric	www.kmec.co.kr	+82-31-494-0720	
	DASS Tech	www.dasstech.com	+82-43-218-5670	
	SDN	www.sdn-i.com	+82-2-446-6691	
	ASTRONERGY SOLAR KOREA	www.astronergy.co.kr	+82-2-2226-3911	
	KD POWER	www.kdpower.co.kr	+82-33-245-8000	webmaster@kdpower.co.kr
	GREEN PLUS	www.greenplus.co.kr	+82-41-332-6421	greenplus@greenplus.co.kr

Technology field	Company Name	Website	Phone Number	Email
Bioenergy	SEOHEE	www.seohee.co.kr	+82-2-3416-6700	
	AEKYUNG PETROCHEMICAL	www.akp.co.kr	+82-2-850-2000	
	DANSUK	dansuk.co.kr	+82-31-488-0700	
	EMCorp	www.emc-env.com	+82-31-8091-2000	
	JC CHEMICAL	www.jcchemical.co.kr	+82-2-6321-1300	info@jcchemical.co.kr
	HALLA Energy & Environment	www.hallasanup.com	+82-2-2047-5114	
	EMAX Solutions	www.emaxsol.com	+82-61-755-7295	
	Chang-Hae	www.chethanol.com	+82-63-214-7800	
	TSK corp.	www.tsk.co.kr	+82-31-489-9604	
	ECOBio	ecobio.co.kr	+82-2-3483-2900	biosulfa@ecobio.co.kr
Waste	JEONJU PAPER	www.jeonjupaper.com	+82-2-6050-5600	inquiry@s-energy.com
	Hansol EME	www.hansoleme.com	+82-31-778-5555	
	SAMCHULLY ES	www.samchullyes.co.kr	+82-368-3368	
	IK	www.ik.co.kr	+82-32-562-8114	
	SAMYOUNG PLANT	www.syplant.co.kr	+82-31-677-6048	syplant2@yahoo.com
	DAEKYUNG ESCO	krico.co.kr	+82-32-817-5100	esco03@korea.com
	EWHA ECO SYSTEM	www.ewhaeco.com	+82-2-2618-0433	
	DONGBU ENT	www.dongbuent.kr	+82-31-656-1822	
	DAEHYEONG ENVIRONMENT	www.daehyeong.co.kr	+82-41-732-0620	
	YUCHEON ENGINEERING	www.yucheoneng.co.kr	+82-2-2686-2576	yucheon@yucheon.com
Transmission and distribution systems	taihan	www.taihan.com	+82-2-316-9114	
	KEPCO KPS	www.kps.co.kr	+82-61-345-0114	
	KEPCO KDN	www.kdn.com	+82-61-931-7114	
	ENTEC Electric & Electronic	www.entecene.co.kr	+82-31-299-8400	entec@entecene.co.kr
	OMNI SYSTEM	www.omnisystem.co.kr	+82-70-4169-8637	overseas@omnisystem.co.kr
	BMT	www.superlok.com	+82-55-783-1000	
	PSTEC	www.pstec.co.kr	+82-2-3408-1700	

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Technology field	Company Name	Website	Phone Number	Email
Bioenergy	YPP	www.yppdt.com	+82-2-2104-8700	
	SEOJEON Electric Machinery	www.sjem.co.kr	+82-31-632-5620	
	YOUHO ELECTRIC	www.youho.co.kr	+82-31-828-9000	
Efficient transport	Mando	www.mando.com	+82-2-6244-2114	
	Hanon Systems	www.hanonsystems.com	+82-2-3498-5595	soh17@hanonsystems.com
	YURA	www.yuracorp.co.kr	+82-70-7878-1000	
	SEBANG GLOBAL BATTERY	www.gbattery.com	+82-1899-7300	
	MOBASE ELECTRONICS	www.seoyonelec.com	+82-31-5174-3000	
	Sejong Industrial	www.sjku.co.kr	+82-52-219-1699	
	AMOTECH	www.amotech.co.kr	+82-32-821-0363	
	UNICK	www.unick.co.kr	+82-55-340-2000	
	MOTONIC	www.motonic.com	+82-53-583-5111	
	DAEBO COMMUNICATION & SYSTEMS	www.dbcs.co.kr	+82-2-3470-7700	
Building efficiency	BYUCKSNAN	www.byucksan.com	+82-2-2260-6114	
	CLK Corporation	www.carrier.co.kr/index.asp	+82-2-3441-8855	
	HAEAHN Architecture	www.haeahn.com	+82-2-3438-8000	business@haeahn.com
	Youngbo Chemical	www.youngbo.com	+82-43-249-2000	
	Fine Technix	www.finetechnix.com	+82-31-463-8888	
	HAATZ	www.haatz.co.kr	+82-2-3438-6700	
	JUNGLIM ARCHITECTURE	www.junglim.co.kr	+82-2-708-8600	
	AluEnc.	www.aluenc.com	+82-2-597-5521	
	FEELUX	www.feelux.com	+82-70-7780-8000	
	SAMHWAACE	www.samhwaace.com	+82-2-523-2242	

Technology field	Company Name	Website	Phone Number	Email
Crop cultivation and production	TYM	www.tym.co.kr	+82-2-3014-2800	
	Kukje Machinery	www.kukjemachinery.co.kr	+82-43-730-1000	
	Kyung Nong	www.knco.co.kr	+82-2-3488-5961	
	DONGBANG AGRO	www.dongbangagro.co.kr	+82-1644-7337	
	ASIA TECH	www.asiakor.com	+82-53-580-7809	asia@asiakor.com
	Ggeumgang	www.g-geumgangpia.com	+82-62-975-1306	
	TAESUNG	www.taesung.com	+82-31-864-0671	
	DAEWON GSI	www.daewon.com	+82-54-973-2221	
	SEOWON	www.seowonco.com	+82-32-663-0033	
	GREENPLUS	www.greenplus.co.kr	+82-41-332-6421	
Water resource security and supply	DOWHA ENGINEERING	www.dohwa.co.kr	+82-2-6323-3000	
	Korea Engineering Consultants Corp	www.kecc.co.kr	+82-2-2049-2801	overseas@kecc.co.kr
	ISAN	www.isg.kr	+82-31-389-0114	
	PPI	www.ppinet.co.kr	+82-31-359-0001	
	SAMAN	www.samaneng.co.kr	+82-2-6488-8091	overseas@samaneng.com
	WARECO	www.wareco.co.kr	+82-31-724-5300	
	SEOYOUNG	www.seoyoungeng.com	+82-2-6915-7000	
	DONGBU ENGINEERING	www.dbeng.co.kr	+82-2-2122-6700	dbeob@dbeng.co.kr
	NUVOTEC	www.nuvotec.co.kr	+82-2-475-8811	nuvotec8811@hanmail.net
	Sunglim	www.sunglim.com	+82-31-373-5771~4	business@sunglim.com
Water treatment	TECHWIN	www.techwin.co.kr	+82-43-261-8114	sales@techwin.co.kr
	HTS	www.hansuts.co.kr	+82-31-789-1700	
	SYNOPEX	www.synopex.com	+82-31-379-7777	
	HANSU	www.hansu.co.kr	+82-31-492-7800	
	HYORIM	www.hyorim.co.kr	+82-31-781-6061	
	UNITECH	www.uni-tech.co.kr	+82-31-668-2697	
	SMAJIN	www.samjinvalve.com	+82-42-672-3600	
	SAMKUN89	www.samkunok.com	+82-55-338-3030	sk@samkunok.com
	BKT	www.bkt21.co.kr	+82-70-5050-5555	bkt@bkt21.co.kr
	ROYAL PRECISION	www.korearoyal.com	+82-53-583-8651~4	royal@korearoyal.com

About GTC

GTC will be your trusted partner in ensuring that the appropriate value of the climate technology is fully recognized.

VISION

A leading think tank for inclusive and innovative global growth responding to climate change.

MISSION STATEMENT

To promote the advancement of the national climate industry and contribute to the global efforts in responding to climate change by establishing Green Climate Technology policies and assisting domestic and international climate technology cooperation.

ROLES

Researches national Green Climate Technology policies for realizing a sustainable society

· Researches future-oriented Green Climate Technology policies

· Produces integrated Green Climate Technology information

Researches strategies for leading global climate technology diffusion

· Researches a full-cycle model for climate technology diffusion linked with the technology finance-carbon market system

· Assists building of the global climate technology cooperation systems

· Researches climate technology integration strategies for localization

HISTORY

GTC is continuing to advance based on its reputation and trust gained through domestic and international achievements.

2019	Jan.	Approved GCF* PPF(Project Preparation Facility) for the first time in Korea.
2018	Feb.	Published Statistics on the Climate Technology Industry in Korea for the first time
	March	Establishment of the Climate Technology Information System (CTis)
	July	Organized the 2018 CTCN* Regional Forum for NDE*s from Asia and the Pacific
2017	Feb.	First published the White Paper on Green Climate Technology
	April	Selected as a supervising institute of the MSIT*'s Climate Technology Cooperation Project
	Aug.	Dispatched an expert to the CTCN Secretariat for the first time in Korea
	Sept.	Selected as an institution for drafting national statistics for Statistics Korea
2016	Nov.	Became the first in Korea to be awarded 'Technical Assistance' from the CTCN
2015	April	Selected as institution in charge of analyzing national green technology R&D information
	May	Joined UNFCCC* CTCN
2013	Feb.	Establishment of GTC
2011	June	At the 2011 Global Green Growth Summit, then-ROK President announced planned to establish the GTC in his keynote speech

*GCF : Green Climate Fund
*CTCN : Climate Technology Centre & Network
*NDE : National Designated Entity
*MSIT : Ministry of Science & ICT
*UNFCCC : United Nations Framework Convention on Climate Change

Key Achievements

Green Climate Technology Policy Research

Supporting Policy Development on Green Climate Technologies	Developed the "3rd Five Year Plan for Green Growth" of the Prime Minister ('19.5)
	Developed a R&D investment model on fine particulate matter by operation of a coordinative committee ('18.3)
Climate Technology Classification	Developed the Korea's first Climate Technology Classification ('17.12)
	Assigned as a national "Statistical Agency"[Statistics Korea] ('18.2)
Providing Comprehensive Information about Green Climate Technologies	Published the White Paper on Green Climate Technology('17~)
	Established "Climate Technology Information System[CTis]."('18.3)
	Established Global Climate-Technology Transfer Big-Data Center ('19.10)

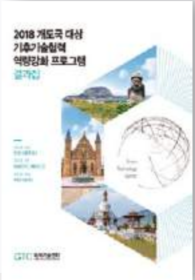
Green Climate Technology Global Cooperation

Establishment and Implementation of international cooperation project based on 'technology-financing mechanism'	The GCF approved PPF for the first time in the Korea-Bhutan Green Transport Program ('19.1)
	The Green Technology Partnership Initiative (GTPI) as a technology cooperation platformbetween South Korea and Indonesia ('19.8)
	Implementation of Korea's first P4G[1] certified Public-Private Partnership(PPP) Project ('19.9)
Establishing Global Cooperation Strategies	'Recognition of Contribution by CTCN[2]' in Climate Technology Collaboration ('18.12)
	Supported on the UNFCCC technology negotiations and the adoption of policy decision on technology agenda items ('16~'17)
Cooperation with advanced research institutes	Joint research on a climate technology classification based on information from the TNA project with the UNEP-DTU Partnership ('19.6)
	Implementation of joint research between GTC and SEI[3] to resolve Air Pollution in Northeast Asia ('19.9)

1) P4G : Partnering for Green Growth and the Global Goals 2030
2) CTCN : Climate Technology Centre & Network
3) SEI : Stockholm Environment Institute

Major Publications of Green Technology Center

2018 Climate Technology Cooperation Capacity Building Activities for Developing Countries Outcome Report
Jiwhan Kim



Climate change adaptation policy and technology
Jiwhan Kim

Analysis of the Legal Trends on Climate Change
Jiwhan Kim

GTC-GGGI MRV Project Co-operation Study
Hyunwoo Shin

MRV System for Achieving NDC under New Climate Regime
Hyunwoo Shin

Trends and Strategies of Climate Technology Cooperation in Advanced Countries
Jiwhan Kim

Climate Change Policy and Climate Technology Cooperation Trends in Japan
Hyunwoo Shin

Climate Change Policy and Climate Technology Cooperation Trends in Denmark
Hyunwoo Shin

Current Status and Implications of Climate Change Response by Technology CONVERGENCE / INTEGRATION
Hyungju Kim

Policy Trends for International Cooperation in Climate Technology under the United Nations Framework Convention on Climate Change(UNFCCC)
Chaewoon Oh

Climate Change Policy and Climate Technology Cooperation Trends - Germany
Hyunwoo Shin

Climate Change Policy and Climate Technology Cooperation Trends - Spain
Hyunwoo Shin

Climate Change Policy and Climate Technology Cooperation Trends - France
Hyunwoo Shin

A Study on the Establishment and Operation of Global Green Climate Technology Cooperation Base Center
Dukwoo Jun

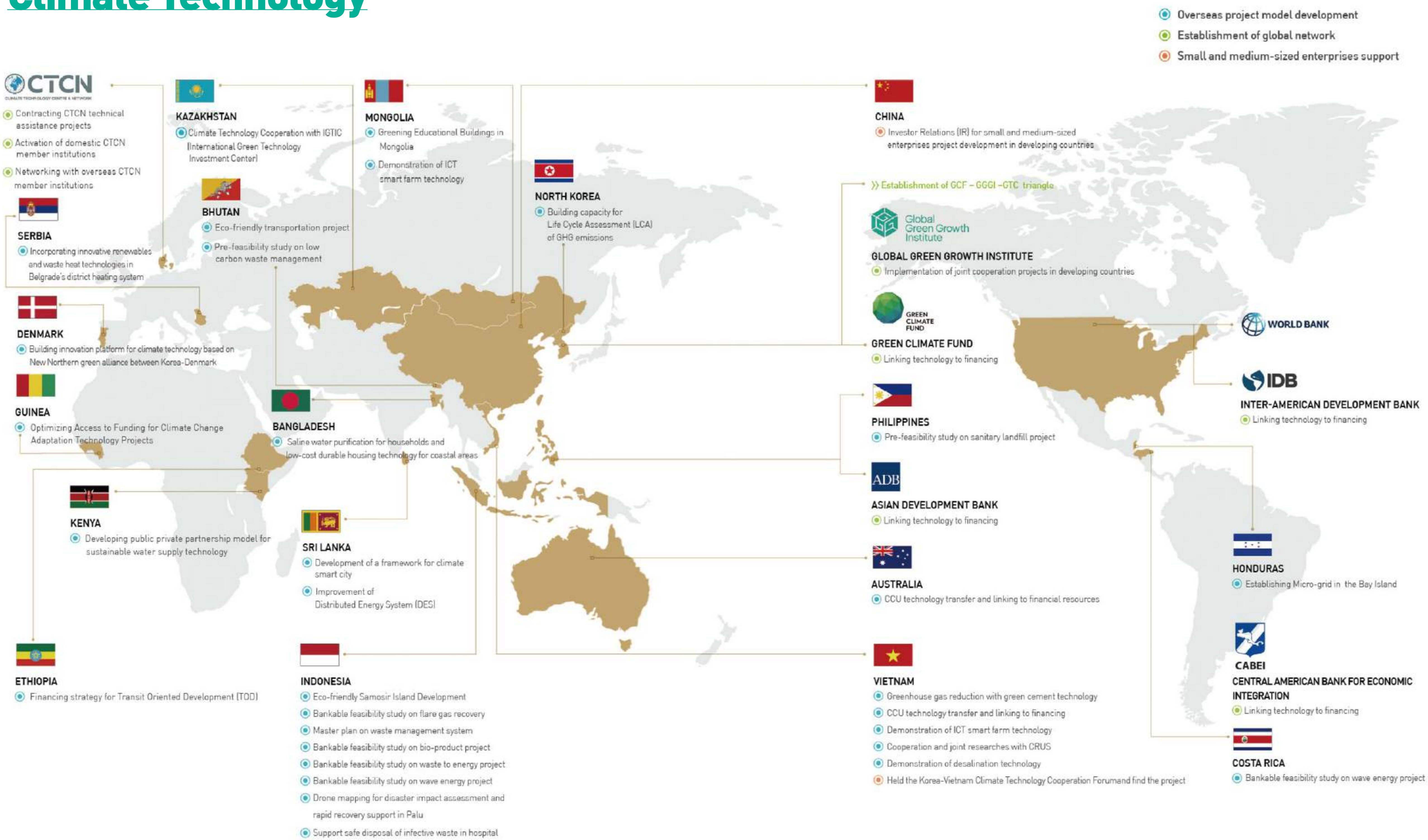
Application of the Climate Technology Center and Network (CTCN)
Kyungnam Shin

CLIMATE TECHNOLOGY
Hyungju Kim

Analysis and Implications of Hydrogen Policy in the U.S. for the Realization of Hydrogen Economic Society
Bumsuk Son

Guideline for the Application and Proposal of the Climate Green Climate Fund (GCF)
Kyungnam Shin

Overview of Global Cooperation in Climate Technology



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