10

EMERGING
TECHNOLOGIES

KISTEP Korea Institute of S&T Evaluation and Planning

KISTEP 10 EMERGING TECHNOLOGIES

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CARBON CAPTURE AND UTILIZATION

BIO-BASED RAW MATERIALS-PRODUCTS MANUFACTURING TECHNOLOGY

HIGH-CAPACITY AND LONG-LIFE SECONDARY BATTERIES

CLEAN HYDROGEN PRODUCTION

LOW-CARBON PRODUCTION OF IRON AND STEEL

AMMONIA FUELED POWER GENERATION

GRID INTEGRATION SYSTEM

HIGH-EFFICIENCY SOLAR CELLS

LARGE SCALE OFFSHORE WIND POWER SYSTEM

RECOVERY OF USEFUL RESOURCES

10 EMERGING TECHNOLOGIES

KISTEP 10
Emerging Technologies
that will Contribute to
Achieving the
2030 NDC Targets

10

KISTEP 10

Emerging Technologies
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2030 NDC Targets

Abstract

Research Background

- It is necessary to present the future direction of science and technology in response to future issues of the society through the selection of emerging technologies.
- The KISTEP 10 emerging technologies have been selected to prepare for future issues, and comprehensive analysis data is provided for each technology to provide future outlooks.

Research Process

- The research was carried out in four main steps including identification of future issues, selection of technology candidates, selection of KISTEP 10 emerging technologies, and comprehensive analysis of the selected technologies.

Results

- Under the topic of “carbon-neutral era”, which will bring dramatic changes to the Korean society in 5 to 10 years, emerging technologies were selected and comprehensive analysis was conducted.
- KISTEP 10 emerging technologies that will contribute to achieving the 2030 NDC (nationally determined contributions) targets: ① Carbon capture and utilization ② Bio-based raw materials/products manufacturing technology, ③Low-carbon production of iron and steel, ④ High-capacity and long-life secondary batteries, ⑤ Clean hydrogen production, ⑨ Ammonia fueled power generation, ⑦ Grid integration system, ⑧ High-efficiency solar cells, ⑨ Large scale offshore wind power system, and ⑩ Recovery of rare earth elements

Conclusion and Implications

- Each emerging technology shows a complementary relations to other technologies, which is expected to create positive synergy effects to contribute to achieving the 2030 NDC targets.
- To promote the commercialization and development of emerging technologies, it is necessary to improve related laws and regulations, to foster human resources, and to develop technology infrastructures.

※This issue paper is not the official opinion of the Korea Institute of Science & Technology Evaluation and Planning (KISTEP) but the author’s personal opinion.

01 RESEARCH BACKGROUND

As the world undergoes accelerated transition to the digital society, societal changes and industrial restructuring are expected and the global competition for technological hegemony heats up.

- To take the lead the amid such environmental changes, it is important to predict future societal changes and acquire emerging technologies that can stimulate the advancement of science and technology.
- It is necessary to present the future direction of science and technology in response to future issues of the society through the selection of emerging technologies.

With the accelerated energy transition to carbon neutrality, it is expected that the Korean society will experience dramatic changes in 5 to 10 years.

- The global community has announced its commitments to achieve carbon neutrality and tightened restrictions on carbon in order to tackle climate change.
- An in-depth discussion is needed to identify measures and timelines to reach net-zero greenhouse gas emission.

The KISTEP 10 emerging technologies have been selected every year since 2009.

- Undertaking research to identify emerging technologies is the task specific to KISTEP. which will also improve its capability for technology forecasting. Also, selection of Korea's own emerging technologies is meaningful as Korea has entered the stage of a first-mover from a fast-follower.
- KISTEP 10 emerging technologies are the most widely recognized among those announced by research institutes in Korea and have been utilized for developing future strategies (Lim Hyeon et al., 2019)

※Information on the emerging technologies is mainly used to 'discover the ideas for planning new R&D projects and programs.' For this purpose, information for technology planning is presented such as definition and description of emerging technologies, relevant social and economical issues, technological trends, related technologies, and technological challenges.

02 RESEARCH PROCESS

The issue of 'carbon-neutral era' was identified as the topic of KISTEP 10 technologies and the emerging technologies were selected through literature review, surveys, and expert meetings.

- **Step 1 - Identification of future issues**
  The candidates for future issues were explored by reviewing published literatures and by gathering opinions from experts. Then, the issue was finally selected by a survey of foresight experts and KISTEP's policy customers.

<Table 1> Survey evaluation indicators for the selection of future issues

Indicators	Description
Novelty	Redundancy with the previous topics selected by KISTEP 10 emerging technologies
Social interest and timeliness	Social interest in the topic for the next 5 to 10 years and the timeliness of the research
Impacts	The degree of impacts on various fields such as economy, society, culture, ethics, and environment
Relevance to science and technology	Contribution of science and technology to meet new demands and solve problems arising in relation to the topic ※ Issues that can be resolved through the measures other than science and technology (such as regulations, policies and diplomacy) are excluded.
Availability of results	The possibility that the selected emerging technologies can be utilized to develop future S&T strategies and plan R&D programs and projects

- **Step 2 – Selection of technology candidates**
  In order to identify the emerging technologies related to future issues, the technology candidates were selected based on the expected time of technology distribution derived from the 'Core Technologies for Carbon Neutrality' announced in August 2021.
- **Step 3 - Selection of 10 emerging technologies**
  The ten emerging technologies were selected in consideration of discussion with technology foresight experts and written evaluations.

<Table 2> Evaluation indicators for the selection of emerging technologies

Indicators	Description
Technological feasibility	Possibility that the relevant technology can be commercialized in 10 years in Korea
Economic impacts	The expected added value of the relevant technology in market
Contribution to reduction of greenhouse gas emissions	The extent to which the relevant technology can contribute to achieving the 2030 NDC targets

- **Step 4 - Comprehensive analysis of the selected technologies**
  A comprehensive analysis of the selected technologies, including an overview of the emerging technologies (name, definition, and scope), global trends, future outlook in 2030, and relations to other emerging technologies.

<Table 3> Research Process of KISTEP 10 Emerging Technologies in 2022

Step	Description	Methods
(1) Identification of future issues	Identification of future issues	·Building a DB on future issues based on published reports of technology foresight ※The 6th Science and Technology technology Foresight, Future Strategy 2045, NIC Global Trends 2040, WEF Global Issue, etc.
	Evaluation of priorities on future issues	·Assessing priorities based on opinions of science and technology specialists, policy experts
(2) Selection of technology candidates	Selection of the candidates for emerging technologies responding to future demands	·Setting the scope of the candidate technologies that can contribute to achieving the 2030 NDC targets ·Selection of technology candidates based on the expected time of technology distribution derived from the 'Core Technologies for Carbon Neutrality announced in August 2021 ·Adjusting technology candidates based on evaluation of experts and assessing the consistency with future issues
(3) Selection of emerging technologies	Identification of the ten emerging technologies	·Selection of KISTEP 10 emerging technologies through expert advice and discussions with KISTEP researchers
(4) Comprehensive analysis on emerging technologies	Comprehensive analysis of each technology	·Overview of the emerging technologies, global trends, future outlook in 2030, relations to other emerging technologies, etc.

03 RESULTS

1. Identification of future issues

Published literatures were thoroughly reviewed in order to identify the topic (key trend) of 2022 KISTEP 10 emerging technologies.

- Major trends in the future society were derived from political, economic, social, environmental, and technological perspectives by analyzing the trends and issues from recently published reports on future prospects, reports on the technology foresight, and Future Strategy 2045.
  - **Politics** Restructuring in the global value chain and businesses, prolonged sluggish growth of the global economy and the rise of emerging economics, the strong tide of nationalism, threat to democracy, discrepancy between existing systems and governance, escalating political conflict, return of big government, etc.
  - **Economy** The rise of 'ontact' economy, growing influence of platforms, spread of the subscription economy, advent of the cashless society, activated digital finance, spread of optimized customization/personalization services, changes in the job market and unstable jobs, increase in the services providing indirect use experience, etc.
  - **Society** Change in the demographic structure, smart city with hyper-connectivity, growing demand for remote work, mega city, mega region, decline of small and medium-sized cities, contactless society, spread of the 'ontact' culture, cyber/data security, etc.
  - **Environment** Climate change, natural disasters, threat of environmental pollution, air pollution including fine dust, energy transition for carbon neutrality, greenhouse gas reduction, increase in demand for electric vehicles, securing water resources and shortage of water supply, virtuous circle of resources, resource shortage and decrease in biodiversity, microplastics, etc.
  - **Technology** Age of space commerce, smart materials, smart production, management of infectious diseases and medical service robots, low-carbon cement, accelerated transition to the cloud, digital medicines, green hydrogen, exploration of deep-sea resources, blockchain, quantum sensors, etc.

The five trends highly likely to emerge as major issues in the next 10 years and particularly relevant to recent social issues were identified as the candidates for the topic (Table 4).

- The trends that had been selected as KISTEP 10 emerging technologies were excluded to avoid redundancy with previous research results.

• The survey on preference were carried out among KISTEP's policy customers and technology foresight experts who have a profound understanding of the overall S&T/policy trends and additional topics were also identified.

<Table 4> Candidates for topic of 2022 KISTEP 10 Emerging Technologies

Topic	Description
Emerging technologies preparing for megalopolis	·Forecasting the issues that may arise from overcrowding of cities, absorption of surrounding regions, and accelerated hollowing out of local areas and identifying the technologies that can respond to the issues ·Relevant issues: - Economic revitalization of the metropolitan areas (mega cities) - Discrepancy in the infrastructure such as cultural life - Degeneration of depopulated areas into slums
Emerging technologies preparing for aging society	·Forecasting the issues that may arise from aggravated population aging caused by slowdown in population growth and the world's lowest fertility rate and identifying the technologies that can respond to the issues ·Relevant issues: - Supporting the anti-aging and disease prevention sectors - Developing and industrializing regenerative medical technologies - Automation of 3D jobs
Emerging technologies preparing for the space era	·Forecasting the issues that may arise from development of a huge industry for living in space and identifying the technologies that can respond to the issues ·Relevant issues: - Establishing the system for payload launch and operation - Expanding the concept of security on a national scale - Space industry led by private sector
Emerging technologies preparing for the carbon-neutral era	·Forecasting the issues related to the plan of carbon neutrality to achieve net zero emissions in response to climate change and identifying the technologies that can respond to the issues ·Relevant issues: - Technological independence of renewable energy technologies - Recycling plastics and wastes into resources - Developing sustainable future energy sources
Emerging technologies preparing for the platform economy	·Forecasting various issues arising from economic and social activities stimulated by platforms and identifying the technologies that can respond to the issues ·Relevant issues: - Establishing the economic system with a wide variety of products in small quantity - Providing services without limitation of time and space - Industry led and controlled by a small number of companies

• A survey on topics was carried out with science and technology specialists, policy experts

<Table 5> Survey results on the topics of 2022 KISTEP 10 Emerging Technologies

Indicators	Candidates for topic				
	Mega-lopolis	Aging society	Era of space industry	Carbon-neutral era	Platform economy
Novelty	4.08	4.45	4.98	5.09	5.01
Interest and timeliness	5.06	5.82	4.57	5.95	5.29
Impacts	5.00	5.70	4.83	5.97	5.52
Technological relevance	4.29	5.52	6.33	6.09	5.19
Availability of results	4.67	5.59	4.87	5.88	5.42
Total	4.62	5.42	5.12	5.80	5.29

※ Score by evaluation indicator: 1 (very low) - 4 (moderate) - 7 (very high)

Based on the survey results, the 'carbon-neutral era' was identified as the topic of 2022 KISTEP 10 Emerging Technologies.

• The 'era of space industry' scored the highest for the 'technological relevance' indicator but the 'carbon-neutral era' scored highest for every other indicators.

2. Selection of Candidates for 10 Emerging Technologies

The carbon neutrality to achieve net zero emissions in response to climate change has become a global trend.

• The carbon neutrality has become a global agenda with an adoption of the 'Kyoto Protocol' and the 'Paris Agreement' to recognize and address the seriousness of climate change.

• The global community is making efforts to control the increase in the average global temperature not exceeding 1.5℃* compared to the pre-industrial level in accordance with the 'Paris Agreement.'

* 1.5℃ significantly decreases the risks to biodiversity, health, livelihood, and food security compared to the increase of 2℃.

• Korea has also joined this endeavor and announced its vision for 2050 carbon neutrality (in October 2020) for changing its industrial and energy structure.

The technologies that will contribute to achieving its 2030 NDC targets* were selected as emerging technologies as they are based on the issues that may bring about a significant change in the Korean society for the next 5 to 10 years.

* Reduction of greenhouse gas emissions by 40% compared to those in 2018

- Selection of the candidate technologies was based on the expected time of technology distribution and technology classification system from the 'Core Technologies for Carbon Neutrality' announced in August 2021.

- Based on the above-mentioned classification system for carbon-neutral technologies, a total of thirteen emerging technologies were selected by evaluation by experts.

- The candidate technologies were selected from a total of 257 technologies based on the evaluation of experts considering the number of recommendations, evaluation indicator scores, R&D strategies, and core technologies.

- As a result, a total of thirteen emerging technologies were selected based on high impacts and relevance to the topic after discussions with internal experts.

<Table 6> The candidates for emerging technologies that will contribute to achieving the 2030 NDC Targets

No.	Sector	Technology name	Description
1	CCUS	CO_2 capture technology	Technology to capture CO_2 from the gases generated during industrial processes
2	CCUS	CO_2 utilization technology	Technology to separate/utilize useful carbon sources (CO or methane) or to convert them into fuels or chemical products
3	Industry	Bio-based raw materials and products manufacturing technology	Technology to reduce greenhouse gas emissions by converting petroleum-based plastics into biomass-derived plastics
4	Industry	Low-carbon production of iron and steel	Iron making technology to reduce carbon emissions by replacing carbon-based fuels and raw materials used in the blast furnace-converter process and using a large amount of scrap in the converter
5	Industry	Technology to increase the content of admixtures and to manufacture new admixtures	CO_2 reduction technology by increasing the content of cement admixture (from the current 10% to 20%) in order to reduce production of cement clinker
6	Trans-portation/ Traffic	Fuel cell technology for hydrogen-powered electric vehicles	Fuel cell technology for hydrogen-powered electric vehicles including the fuel cell stack, hydrogen/air suppliers, and thermal management devices
7	Trans-portation/ Traffic	Secondary battery technology for electric vehicles	Secondary battery technology for electric vehicles including lithium ion battery, secondary battery management, battery module/pack/ system, etc.
8	Energy	Hydrogen production technology	Technology to produce hydrogen from natural gas, naphtha, and LPG or through water splitting that uses regenerative or existing power
9	Energy	Grid integration system	Technology that supplements and stabilizes intermittency and variability of renewable energy, improves efficiency in power conversion, and advances integration of the electrical grid
10	Energy	Next-generation solar cells	Next-generation solar cells with improved efficiency, such as perovskite solar cells and multi-junction solar cells
11	Energy	Offshore wind power generation	Technology for offshore wind power generation including installation of fixed foundation on the seabed with materials such as cement and steel piles
12	Environ-ment	Recovery of useful resource	Technology to collect, separate, and sort out resources to recover useful (metal) resources
13	Environ-ment	Advanced technology for recycling waste plastics	Technology for thermal decomposition (pyrolysis) of waste plastics and for using pyrolysis to produce petrochemicals

3. Selection of 10 emerging technologies

KISTEP 10 emerging technologies were selected taking into consideration the discussions with technology experts on each candidate technology and evaluation indicator scores.

- Ammonia fueled power generation (with the goal of commercialization by 2030) was added to the list of 10 emerging technologies after reviewing the 17 focus areas for carbon-neutral R&D and the roadmap for revitalization of the hydrogen economy.

- The scope and description of the technologies were adjusted in consideration of the greenhouse gas emissions generated by the candidate technologies, global trends and the expected time of technology realization. The direction toward which these technologies would follow was included in the names of technologies.

<Table 7> KISTEP 10 Emerging Technologies that will contribute to achieving the 2030 NDC targets

Sector	Name of the emerging technology	Description
CCUS	Carbon capture and utilization	Technology to capture CO_2 from the gases generated during industrial processes and to convert them into fuels or chemical products
Industry	Bio-based raw materials/ products manufacturing technology	Technology to reduce greenhouse gas emissions by converting petroleum-based basic/applied raw materials and plastics into biomass-derived basic/applied raw materials and plastics
Industry	Low-carbon production of iron and steel	Technology to lower CO_2 emissions by reducing carbon use necessary for reduction in the blast furnace and by increasing the use of scrap in the converter instead of molten iron.
Trans-portation/ Traffic	High-capacity and long-life secondary batteries	Secondary battery technology for electric vehicles and ESS(Energy Storage System) including lithium ion battery, secondary battery management, battery module/pack/system, etc.
Energy	Clean hydrogen production	Technology to produce hydrogen in conjunction with the technology to capture CO2 from natural gas, naphtha, and LPG or through water splitting that uses regenerative or existing power
Energy	Ammonia fueled power generation	Technology for carbon-free power generation that uses clean fuels (hydrogen and ammonia) and for step-by-step increase in the percentage of ammonia in the mixture of ammonia and other fuels for power generation
Energy	Grid integration system	Technology to resolve the instability of the electricity system caused by variability of renewable energy and increase in the number of electric vehicle charging stations, to assure electric power quality, to improve efficiency in converting distributed energy, and to advance integration of the electrical grid
Energy	High-efficiency solar cells	Next-generation solar cells to break the efficiency limit, such as perovskite solar cells, tandem solar cells, and multi-junction solar cells
Energy	Large scale offshore wind power system	Technology to install and operate the large scale offshore wind power system
Environment	Recovery of useful resources (rare earth elements)	Technology to collect, separate, sort out, and recover rare earth elements

04 COMPREHENSIVE ANALYSIS OF KISTEP 10 EMERGING TECHNOLOGIES

01) Carbon capture and utilization

Definition **Technology to capture CO_2 generated from energy and industrial processes and to convert the captured CO_2 into useful materials**

Scope **This technology is classified into carbon capture technology and conversion technology.**

- **Capture technology** This technology effectively captures and disposes of the CO_2 emitted during power generation, combustion, industrial processes (steel, petrochemicals, cement, hydrogen production, and etc.) by applying the optimal capture technique to each source. It is classified into the following techniques: Post-combustion capture for commercialization, industrial process capture, pre-combustion capture, and direct air capture.
- **Conversion technology** This technology converts CO_2 into the products with economic value and is classified into the followings by conversion technique: Chemical conversion, biological conversion, and mineral carbonation conversion.

Necessity **As it takes a considerable amount of time and financial resources to achieve the total conversion from fossil fuel-based energy to low-carbon renewable energy, achieving carbon neutrality requires the development of technologies that can suppress carbon emissions by capture, storage, and utilization of CO_2.**

Global trends **The number of carbon capture and storage (CCS) facilities in the world including those capable of large scale capturing is 65. Among them, 26 facilities are in operation, 3 are under construction, and 21 are at the initial development stage and relevant technologies are actively developed.**

- **Korea** CO_2 capture technology is under development and demonstrating research with the collection capacity of 1 to 10 MW are being carried out. Korea's conversion technology is at the initial stage centered around the academia.

- **The US** Skyonic Corporation in the US has developed and operated SkyMine, an industrial process using mineral carbonation conversion to convert CO2 into sodium bicarbonate and other industrially usable materials.
- **Japan** Japan has demonstrated its capture technology for industrial use in Southeast Asia for a long time and started to capture 1.4 million tons of CO2 per year emitted from a coal-fired power plant in the US for the first time in the world.

Future outlook in 2030 **It is expected that adoption and advancement of CO2 capture and conversion technologies accompanied by investment in the eco-friendly infrastructure and creation of eco-friendly jobs can reduce greenhouse gas emissions while minimizing the impact on the existing industrial sectors.**

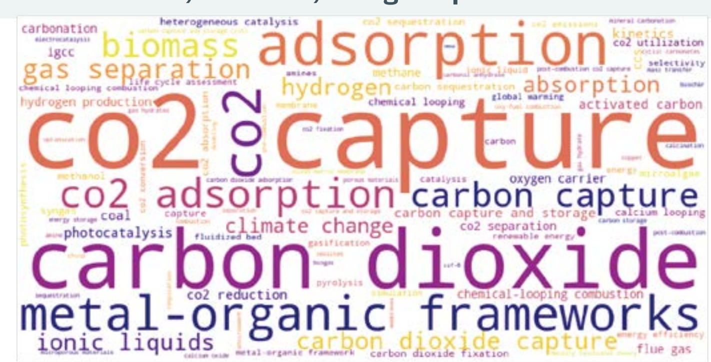
- It is also expected that 1 million tons of CO2 emitted after coal combustion will be captured, fuel conversion yield will reach 30%, and 100 thousand tons of CO2 will be converted through mineral carbonation conversion into construction materials.

Relations to other emerging technologies **This technology shows a complementary relation to low-carbon production of iron and steel but a competitive relation to high-capacity and long-life secondary batteries.**

- As the technology for secondary batteries with high capacity and long life (used for electric vehicles and the energy storage system) becomes widely used, fuel production based on carbon capture and utilization (CCU) and technologies for renewable energy storage could lose their comparative advantage.

- It is necessary to reduce carbon emissions from the steel industry through the combination of low-carbon production of iron and steel and the CCU technology based on by-product gases.

Keyword frequency analysis **The keyword frequency extracted from the publications on the Web of Science was analyzed. Except CO2-related expressions, most frequent keywords included "absorption", "metal-organic frameworks", "biomass", and "gas separation".**



2) Bio-based raw materials/ products manufacturing technology

Definition **Production and demonstrated material technologies of base chemicals based on the bio-refinery platform derived from sustainable plants or lignocellulosic biomass to replace a fossil-based raw material (naphtha), bio-chemistry to replace petroleum-based plastics and synthesis, polymerization, and manufacturing of bio-plastics**

Scope **This technology is classified into technology to produce bio-based raw materials, technology to produce bio-based applied raw materials, and technology to synthesize, polymerize, and manufacture/produce bio-plastics.**

- **Technology to produce bio-based raw materials** This technology is for separation, purification, high-purity manufacturing of bio-refinery platform monomers such as bio-naphtha based on plants or lignocellulosic biomass, bio-alcohol, C2/C3/C4, and C6/C5-carbohydrate.

- **Technology to produce bio-based applied raw materials** This technology is a material technology starting from bio-based raw materials, expanding to bio-based applied raw materials such as bio-olefin and bio-acrylic acid, and developing into bio-products for fine/special chemistry and also a material technology for key intermediates of bio-plastics.

- **Technology to synthesize, polymerize, and manufacture/produce bio-plastics** This technology is to manufacture and produce decarbonized and low-carbon bio-plastics using bio-based raw materials and applied raw materials.

Necessity **In order to reduce carbon emissions, it is necessary to convert naphtha and olefin (raw materials in the petrochemical field) into low-carbon and eco-friendly bio-based raw materials and to link these raw materials from the upstream sector (pyrolysis) to the downstream sector (production of basic feedstock).**

Global trends **Large corporations take the lead in employing this technology in Korea, while multinational chemical companies have been active in making transitions to bio-based chemistry.**

- **Korea** Korea has been active in the development of bio-plastics for commercial use and processed bio-plastics using raw and applied materials, but relies on imports of critical raw and applied materials.

- **The US** DuPont started a joint business with Tate & Lyle to establish DuPont Tate & Lyle and is annually producing 4.5 tons of a bio-based plastic raw material, 1,3-propanediol.
- **China** The Research Institute of Physical Chemistry in the Chinese Academy of Sciences, Tsinghua University, and Sichuan University have participated in the research and development of PLA (Polylactic Acid).

Future outlook in 2030 **Petrochemistry is one of the major export industries in Korea and is expected to undergo a transition to bio-based chemistry based on decarbonized and eco-friendly biomass in order to achieve the 2030 NDC Targets and technological competitiveness.**

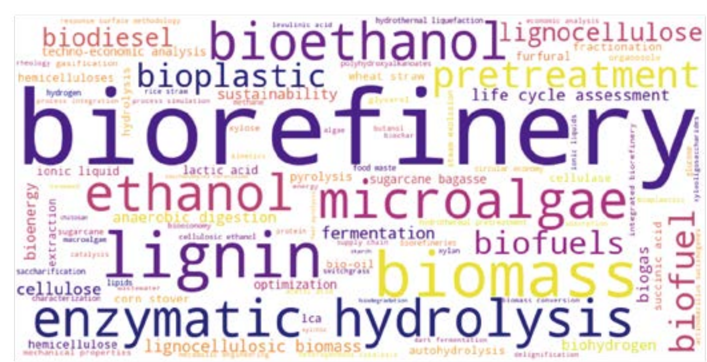
- As this technology is at the initial research stage around the world, Korea will be able to narrow down its technological gap with leading countries and take the lead in petrochemical technologies.

- It is expected to protect the environment by providing a fundamental solution to prevent land and marine pollution with the use of biodegradable plastics instead of non-degradable plastics.

Relations to other emerging technologies **This technology can be used to provide decarbonized and eco-friendly materials and parts.**

- This technology is useful for providing renewable energy materials and technologies including high-capacity long-life secondary batteries mainly used for hydrogen and electric vehicles, high-efficiency solar cells, and large scale offshore wind power system.

Keyword frequency analysis **The keyword frequency extracted from the publications on the Web of Science was analyzed. Except bioplastic-related expressions, most frequent keywords included “biorefinery”, “lignin”, “microalgae”, and “enzymatic hydrolysis.**



3) Low-carbon production of iron and steel

Definition **Process technology to replace the fuels and raw materials used for the conventional blast furnace-converter process and to be linked to carbon capture, utilization, and storage (CCUS) technologies**

Scope **This technology is classified into technology to replace carbon-based fuels and raw materials used in the blast furnace-converter process, technology to use a large amount of scrap in the converter, and technology for the pure oxygen blast furnace.**

- **Technology to replace carbon-based fuels and raw materials used in the blast furnace** This technology makes use of hydrogen-containing gas, alternative iron sources, biomass, and waste plastics to replace raw materials, carbon-based fuels, and reducing agents used in the blast furnace.

- **Technology to use a large amount of scrap in the converter** This technology uses a large amount of scrap in the converter and manufactures high-quality steel products.

- **Technology for the pure oxygen blast furnace** This technology replaces the oxygen used in the blast furnace with pure oxygen-hydrogen and can be linked to CCUS technologies.

Necessity **The efficiency of the blast furnace-converter process in Korea is one of the highest in the world and the amount of carbon used in the process almost reached the theoretical minimum required for iron production. Thus, it is necessary to develop the technology for the pure oxygen blast furnace in order to replace carbon-based raw materials and fuels used in blast furnace-converter process and to be linked to the CCUS technologies.**

Global trends **This technology is at the commercialization stage in Korea while many countries are making continuous policy efforts to demonstrate the technology.**

- **Korea** Korea is pushing ahead with the 'COOLSTAR CO2 Low Emission Technology of STeelmaking And hydrogen Reduction Project' (2017 - 2025) to develop the technology for CO_2 reduction by 15% compared to the existing steelmaking process.

- **The EU** The EU has launched the ULCOS Project with 48 companies from 15 countries to develop and commercialize the ultra low CO_2 steelmaking technology by 2050.

- **Japan** Japan has demonstrated CO_2 emission reduction by 30% during the steelmaking process by introducing hydrogen-containing gas to the blast furnace and CO_2 seperation/recovery technology.

Future outlook in 2030 **The development of low carbon production technology of iron and steel is expected to be complete by 2030 and commercialization of this technology will contribute to CO2 emission reduction.**

- The technology to replace carbon-based fuels and raw materials used in the blast furnace and the technology to use a large amount of scrap in the converter are expected to be completely developed and demonstrated by 2030 and applied to the blast furnace-converter by 2040.

Relations to other emerging technologies **This technology is linked to carbon capture and utilization technology.**

- Although the technology for the pure oxygen blast furnace does not directly reduce carbon emissions, it can contribute to carbon reduction in connection with carbon capture and utilization technology.

- The removal of nitrogen which accounts for a large portion of the exhaust gas by replacing heat air used in the blast furnace with pure oxygen-hydrogen will enable the establishment of CO2 capture and utilization facilities.

Keyword frequency analysis **The keyword frequency extracted from the publications on the Web of Science was analyzed. Except blast furnace-related expressions, most frequent keywords included "biomass", "torrefaction", "pulverized coal", and "wood pellets".**

4) High-capacity and long-life secondary batteries

Definition **A device that store energy in the form of chemical energy, which it then converts into electrical energy upon demand**

Scope **Secondary batteries include lithium ion battery, solid-state battery, metal-air battery, lithium–sulfur battery, redox flow battery, sodium-ion battery, and multivalent ion-based battery and relevant technologies for materials, parts and cells**

- **Technology for the four main materials** A secondary battery consist of four main materials (cathode, anode, separator, and electrolyte) and the composition of these four main materials makes a considerable impact on the characteristics and performance of secondary batteries.

- **Cell technology** This technology is to manufacture cylinder-type or pouch-type cells by using main materials as well as other parts and materials.

- **Parts/materials technology** This technology is related to the parts and materials which constitute a secondary battery including pouches, cans, lead tabs, current collectors, conductive additives, binders, and electrolyte additives.

Necessity **The demand for secondary batteries is increasing with various purposes such as electric vehicles and storage of renewable energy. It is essential to develop next-generation secondary batteries as lithium-ion batteries have reached the theoretical performance limit.**

Global trends **Policy and financial support for this technology have been accelerated globally.**

- **Korea** LG Energy Solution, Samsung SDI, and SK Innovation have achieved strong growth as manufacturers of the secondary cells for electric vehicles. However, most of the materials, parts, and equipments used to produce the secondary cells are highly dependent on imports and therefore relevant measures are urgently needed.

- **The EU** The supply of secondary batteries in the EU relies on non-EU member countries. As a result, major companies in the field of automobiles, chemical, raw material, and engineering formed the European Battery Alliance to take the competitive edge in the next-generation market for secondary cells.

- **China** Based on its domestic market, China maintains the No.1 global market share and also takes the lead in parts and materials market based on its abundant mineral resources.

Future outlook in 2030 **Secondary batteries are expected to play a critical role as renewable energy, energy storage system, and eco-friendly vehicles have become more widely used.**

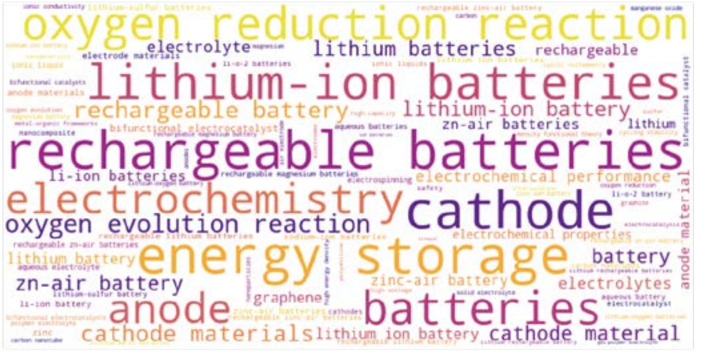
- Downstream industries such as materials, parts, and equipment sectors and upstream industries such as electric vehicles, power storage, and electronics are expected to grow together with secondary battery industry, making positive contribution to the Korean economy including job creation.

Relations to other emerging technologies **This technology is complementary to high-efficiency solar cells, large scale offshore wind power system, and clean hydrogen production.**

- The grid integration system, high-efficiency solar cells, and the large scale offshore wind power system will be completed when closely linked to the technology for secondary batteries and can achieve continuity, efficiency, and high-quality of electric energy.

- Secondary batteries are also complementary to clean hydrogen production and ammonia fueled power generation. These technologies create a synergistic effect as secondary batteries are for short-term storage while other technologies produce power after long-term storage.

Keyword frequency analysis **The keyword frequency extracted from the publications on the Web of Science was analyzed. Except battery-related expressions, most frequent keywords included "oxygen reduction reaction", "electrochemistry", and "oxygen evolution reaction".**



5) Clean hydrogen production

Definition **Technology to produce hydrogen in a way that does not emit CO_2 or emits significantly less CO_2 during production process**

Scope **This technology can be classified into green hydrogen, blue hydrogen technology, etc.**

- **Green hydrogen** This technology uses water splitting to produce hydrogen from the electricity generated from renewable energy such as wind and solar power.

- **Blue hydrogen** This technology is to produce hydrogen through the combination of the technique of extracting hydrogen from fossil fuels such as natural gas and CO_2 capture technology

- **Small-scale production** This technology is to produce hydrogen from bio-energy.

Necessity **As Korea is trying to achieve its goal of carbon neutrality, hydrogen is drawing attention as a new means to reduce carbon emissions for energy-intensive industries (such as steelmaking, petrochemistry, cement, and aluminum). Hydrogen can be utilized during the full cycle of the energy sector (production, delivery, and consumption) and provides opportunities for creating new industries and revitalizing existing industries.**

Global trends **A demonstration program for green hydrogen production is in progress in Korea. However, there is a significant technology gap in production quantity between Korea (hundreds of kWs) and leading countries (MWs).**

- **Korea** Korea's green hydrogen production volume is an average of 8.9 kg/hr and still is at the demonstration stage. It is necessary to develop the technology for mass-production of green hydrogen and establish the foundation for blue hydrogen production and industry by 2025.

- **The US** The US operates the 17 MW water splitting system for hydrogen production (as of June 2021).

- **The EU** The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) has established the water splitting system of 140 MWs, which accounts for 40% of global supply.

Future outlook in 2030 **In the transition to carbon neutrality and energy conversion, investment in infrastructure and conversion cost are expected to increase. As a result, social acceptability issues are expected to arise.**

- Green hydrogen and blue hydrogen are expected to expand market in order to secure environmental and economic feasibility, and importing hydrogen from overseas will also be possible.

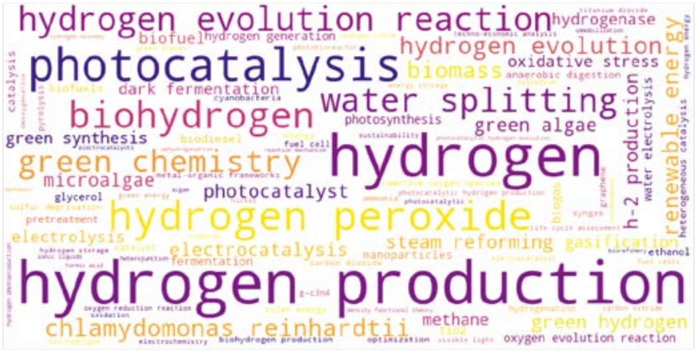
- In 2030, it is expected that energy conversion technology such as clean hydrogen production and fuel cells will have a significant impact on national competitiveness. Also, companies and nations will possibly experience difficulty in fostering new industries and transforming industries.

Relations to other emerging technologies **This technology is expected to be applied in conjunction with other technologies, and its efficiency will be relied upon level of technological development, price competitiveness, and environmental characteristics of each technology.**

- As high-capacity and long-life secondary batteries and grid integration system are used for the water splitting system, these technologies should be jointly developed with clean hydrogen production.

- The blue hydrogen production technology cannot be realized without carbon capture and utilization technology.

Keyword frequency analysis **The keyword frequency extracted from the publications on the Web of Science was analyzed. Except H2-related expressions, most frequent keywords included "photocatalysis", "hydrogen evolution reaction", and "water splitting".**



6) Ammonia fueled power generation

Definition **Technology to reduce CO_2 and fine dust emissions by converting fuels used for gas turbines/boilers at thermal power plants, LNG/coal, into ammonia.**

Scope **Ammonia fueled power generation can be classified into technology to convert existing LNG gas turbines and coal boilers into ammonia turbines/boilers, technology for secondary post-treatment of fine dust, and operation technology.**

- Ammonia turbine technology
- Technology for ammonia cracking hydrogen turbine combined power generation system
- Technology for combustion of ammonia (100% ammonia and ammonia mixture) at coal-fired power plant

Necessity **Ammonia (NH3) can be stored and transported at room temperature at low cost. This technology also maximizes CO2 emission reduction while minimizing investment in the existing infrastructure at the coal-fired plant for transition to renewable energy. It is thus necessary to develop related technologies and promote technological independence from the mid- to long-term perspective.**

Global trends **Korea is engaging in basic research by operation of hydrogen/ammonia power generation technology demonstration group. A number of demonstration research projects for power generation gas turbines are underway in foreign countries.**

- **Korea** Korea aims to develop the mixed combustion technology whose proportion of ammonia is 20% or more. It requires development of gas turbines using mixed fuels (LNG, ammonia, methane, and hydrogen), large-capacity ammonia water splitting, and high-efficiency and multi-purpose gas fuel cells.
- **Japan** Japan completed development of 50 kW gas turbines that combust 100% ammonia, 2 kW gas turbines that combust the mixtures (whose proportion of ammonia is 20%) and initiated the development of 40 kW gas turbines that combust 100% ammonia (in March 2021).

- **The US** The Electric Power Research Institute and the Gas Technology Institute planned the Low Carbon Resources Initiative which aims to generate power using hydrogen and ammonia (in 2020). Also, the US is conducting research on flame stabilization using 40 kW gas turbines.

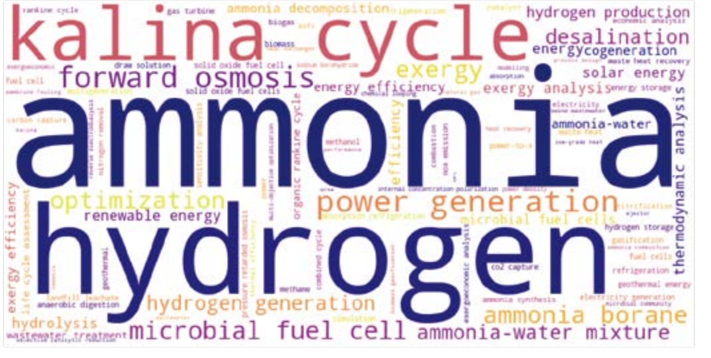
Future outlook in 2030 **As ammonia is a carbon-free fuel and is essential for decarbonization of thermal power generation, it is expected that the demand for ammonia will grow rapidly in Korea, Japan, Southeast Asia, and China where coal-fired power plants take a large portion of power generation.**

- In order to reduce carbon emissions, the industries related to burners and boilers capable of ammonia combustion are expected to grow.
- It is necessary to consider the use economical fuels using ammonia in accordance with the dependence on hydrogen import.

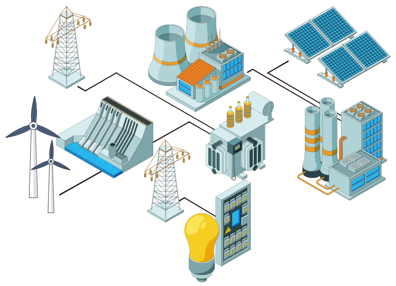
Relations to other emerging technologies **This technology is closely linked to clean hydrogen production technology.**

- When the coal-fired power plant reaches end-of-life after the plant starts to combust ammonia mixtures as a fuel, in can be converted into hydrogen turbines in order to maintain the existing infrastructures. Also, hydrogen power generation requires the clean hydrogen production from ammonia without CO2 emission.

Keyword frequency analysis **The keyword frequency extracted from the publications on the Web of Science was analyzed. Except ammonia-related expressions, most frequent keywords included "Kalina cycle", "forward osmosis", and "microbial fuel cell".**



7) Grid integration system



Definition **Grid integration system technology essential for stabilizing electrical grid used for the energy storage system and electric vehicle charging stations and for assuring electric power quality**

Scope **This technology is classified into technology to adjust virtual inertia/high-speed frequency, smart inverter technology, and technology for transportation vehicle charging stations.**

- **Technology to adjust virtual inertia/high-speed frequency** This technology is to provide fast power system inertia and to provide/control inverter-based virtual inertia.

- **Smart inverter technology** Power conversion inverter technology for renewable energy (such as solar power, wind power, and fuel cells) and for the energy storage system including technologies to improve efficiency in power conversion, advance electrical grid integration, monitor/control electrical grid, and detect malfunctions

- **Technology for transportation vehicle charging stations** This technology includes smart charging and two-way charging/discharging technologies which use the batteries for electric and transportation vehicles as flexible resources for the wired and wireless infrastructure, fast-charging stations, and electrical grid operation.

Necessity **It is necessary to resolve the imbalance in power supply and demand due to regional difference in renewable energy sources. Also, electric power systems, infrastructures and operating systems should be rearranged in accordance with power source composition.**

Global trends **Korea is dealing with the expected shortage of power system inertia while other countries are striving to advance technology standards and demonstrate technologies.**

- **Korea** Korea is promoting adoption of power system stabilizers such as the flexible power transmission system and synchronous compensators, enhancing the demand factor and stabilizing the renewable energy system.

- **The US** The US had adopted the 'California Rule 21' and the 'Hawaii Rule 14H' to advance its smart inverter standards (IEEE 1547-2018 and IEEE 1547.1), voltage control function, and continuous operation of voltage/frequency.

- **Japan** Original equipment manufacturers of electric vehicles in Japan are demonstrating a DC-based smart city.

Future outlook in 2030 **The power supply system based on high-capacity/ long-distance transmission will be converted into a power supply system that consumes locally generated power and uses the minimum amount of power with neighboring regions.**

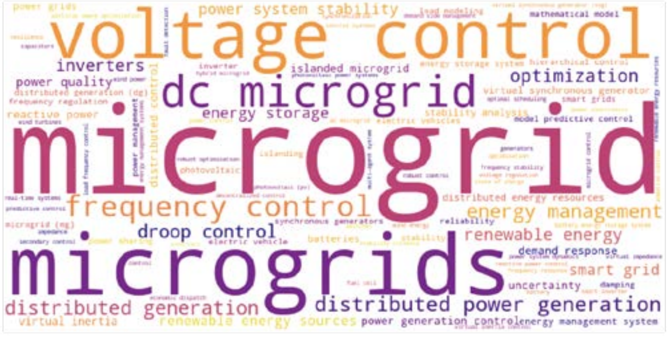
- The flow of power can be freely controllable by connecting the existing AC electrical grid with the new DC electrical grid, and the stability of electrical grid can be achieved by complementary operation of the grids.

Relations to other emerging technologies **This technology is complementary to high-efficiency solar cells, large scale offshore wind power system, and high-capacity and long-life secondary batteries.**

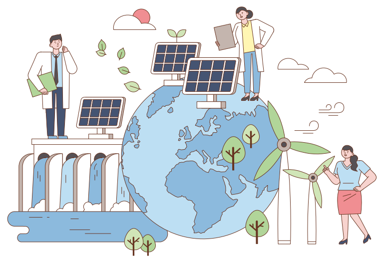
- The technology to adjust virtual inertia/high-speed frequency and the smart inverter technology are core technologies that can contribute to power system access and systemic stability of high-efficiency solar cells and large scale offshore wind power system.

- It is expected that the technology for electric vehicle charging stations can create a synergetic effect with the energy storage system using high-capacity and long-life secondary batteries in order to alleviate sudden fluctuations in power demand due to increasing number of high-capacity fast-chargers.

Keyword frequency analysis **The keyword frequency extracted from the publications on the Web of Science was analyzed. Most frequent keywords included "microgrid", "voltage control", and "frequency control".**



8) High-efficiency solar cells



Definition **Technology for ultra-efficiency solar cells to overcome the theoretical limiting efficiency**

Scope **This technology consists of the following:**

- **Perovskite solar cells** Solar cell technology using perovskite as a light absorption layer

- **Ultra-efficient tandem solar cells** Two solar cells each of which is located at the top and the bottom operate as one in tandem. Each solar cell has different absorption wavelength spectrum, maximizing the efficiency.

- **Technology for high-efficiency crystalline silicon** This technology is relatively more efficient than the passivated emitter rear cell technology and mainly used for tunnel oxide passivated contact (TOPCon) solar cells and hetero-junction (HJT) solar cells.

Necessity **Although the installation of high-efficiency solar panels has grown every year, the output of solar cells needs to be greatly improved while reducing manufacturing cost to increase the LCOE[8].**

Global trends **Korea has achieved the highest efficiency in perovskite solar cells (next-generation solar cells) in the world. Germany also reported that it achieved the highest efficiency in tandem solar cells based on perovskite/crystalline silicon.**

- **Korea** Crystalline silicon solar cells are taking the lead the market. The mass-production efficiency of the solar cells is 22 to 23 % and that of modules is 20 to 21 %, which are generally similar to that of global competitors.

- **The US** The US formed the US Manufacturing of Advanced Perovskites (US-MAP) Consortium where major solar cell researchers and industry representatives including First Solar, NREL, and Swift Solar.

- **China** In China, production of the solar cells based on the p-PERC cell technology is in the mainstream. China has developed the modules with an output of over 500 Wp by increasing the size of cells, making larger modules, and maximizing cell areas in the module.

[8] Levelized cost of electricity

Future outlook in 2030 **It is expected that the use of fossil fuels will greatly decrease and the proportion of renewable energy, especially solar and wind power, will significantly increase due to the policy drivers for carbon neutrality and drop in the technical cost of renewable energy.**

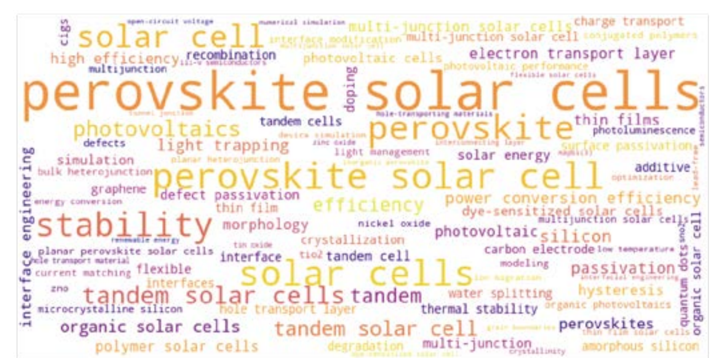
- Although crystalline silicon and passivated emitter rear cell technologies are currently taking the lead in the global market, their market share is expected to significantly decrease due to their limited efficiency. Also, the market share of TOPCon and HJT solar cells, highly-efficient crystalline silicon solar cells, are expected to increase in the future.

Relations to other emerging technologies **This technology is directly related to clean hydrogen production..**

- Clean hydrogen production without CO2 emission can be achieved through water splitting using the power generated by solar energy.

- High-voltage power generated from highly-efficient tandem solar cells can increase water splitting efficiency. One of the disadvantages of renewable energy generation is that the energy is transmitted only when it is connected via electrical grid. However, this disadvantage can be offset by improved storage capacity and mobility after conversion to hydrogen.

Keyword frequency analysis **The keyword frequency extracted from the publications on the Web of Science was analyzed. Except solar cell-related expressions, most frequent keywords included "perovskite", "tandem", and "photovoltaics".**



9) Large scale offshore wind power system

Definition **Technology to install and operate the large scale offshore wind power system**

Scope **The technology for large scale offshore wind power includes design of wind power complex, parts, system, installation and construction, operation, and maintenance.**

- **Design of wind power complex** This technology is to design wind power complex in consideration of connectivity with power system, fishery, and vessel navigation routes.
- **Parts** This technology includes generators, blades, fixed sub-structures, foundations, floating objects, and mooring line.
- **System** This technology is to design system with economic efficiency and stability.
- **Installation and construction** This technology is for transportation, installation, and construction of the extra-large offshore wind power system.
- **Operation and maintenance** This technology is for condition monitoring system, predictive maintenance techniques, and the scheduling technique to establish the optimal maintenance plans.

Necessity **The main sources of renewable energy are solar and wind power. As offshore wind power can be achieved by domestic production without import, it emerged as one of fast growing technology-intensive national infrastructure programs.**

Global trends **Denmark, the US and Germany are leading countries in offshore wind power generation. Several parts manufacturers in Korea are being recognized for their technological competitiveness but systems in general are lagging behind those of overseas competitors.**

- **Korea** Doosan Heavy Industries & Construction is developing an 8 MW offshore wind power turbine and Unison is developing 8 to 10 MW turbines.
- **The US** GE Renewable Energy had its Haliade-X 12 MW wind power turbine certified in 2019, upgraded it to 13 MW in 2020, and demonstrated its operation at 14 MW in 2021.
- **Germany** Siemens-Gamesa, a joint venture between Germany and Spain, has installed the largest number of offshore wind turbines in the world and has a real-time monitoring system for all turbines installed in the world.

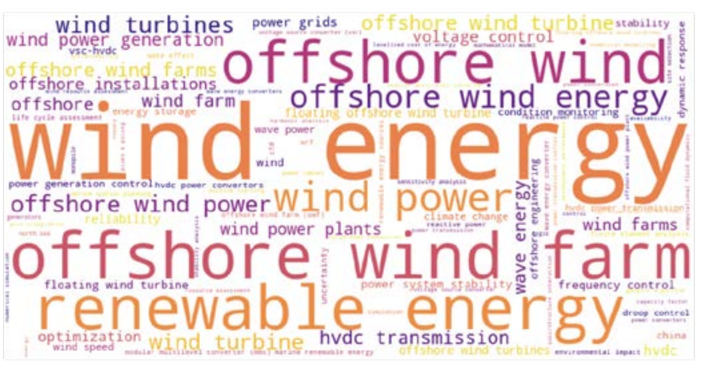
Future outlook in 2030 **As the maintenance of large scale offshore wind turbines is considered as a difficult task, the levelized cost of electricity (LCOE) for wind turbines with high-reliability will be improved compared to the LCOE for cost-efficient wind turbines.**

- Korea aims to develop 15 MW wind power turbines with a life of 30 years.
- The benefits earned through wind power generation will be shared with local residents by giving them incentives based on the wind power integration system and participatory operation of wind power complex.

Relations to other emerging technologies **Renewable energy sources such as wind and solar power need to be utilized in conjunction with the energy storage technology.**

- As wind speed constantly changes regardless of decrease or increase in demands, wind power generation needs to be connected to the energy storage technology in order to supply power to meet the demand. Thus, wind power generation is closely related to clean hydrogen production, ammonia fueled power generation and grid integration system.

Keyword frequency analysis **The keyword frequency extracted from the publications on the Web of Science was analyzed. Except wind energy-related expressions, most frequent keywords included "offshore wind farm", "wind turbine", and "HVDC[10] transmission".**



10) Recovery of rare earth elements

Definition Technology to recover and recycle rare earths, which are materials with highest national strategic and industrial importance among rare metals, from waste resources

Scope This technology is classified into technology for sustainable and eco-friendly recyacling of resources, technology to develop value-added materials, and revitalization of the industrial ecosystem.

- **Development of the technology for sustainable and eco-friendly recycling of resources**
  This technology is to develop highly-efficient rare earth recycling and commercialization facility with less pollutant emissions and simplified processes.

- **Development of the technology to turn rare earth minerals into value-added components**
  This technology is to identify new functionality of rare earth based on the fundamental property data of rare earth minerals and develop value-added materials.

- **Revitalization of the industrial ecosystem in preparation for diversified suppliers**
  It aims at standardization of terminology and measurement methods, establishment of the global environmental-social-governance (ESG) criteria for mining, and creation of trader order in order to utilize rare earth minerals for industrial purposes.

Necessity The demand for rare earth minerals such as neodymium necessary for permanent magnets used in wind turbines and electric vehicles are growing due to the increase in demand for renewable energy.

Global trends Research on rare earth minerals is underway in order to diversify supply chains of rare earth minerals, reduce the use of rare earth minerals, and develop alternatives to rare earth minerals in response to China's rare earth dominance.

- **Korea** There is no domestic production, production technology or materialization technology in Korea, and it is entirely dependent on imports of rare earths. Thus, it is necessary to devise a strategy to stabilize the supply chain of rare earth minerals in response to high growth demand.

- **China** China has production technology for all stages of rare earth processing including mining, separation, extraction, and manufacturing of high-purity finished products.

- **Japan** Shin-Etsu, Hitachi Metals, and TDK succeeded in commercializing the permanent magnets with decreased content of heavy rare earth minerals such as dysprosium (Dy) and terbium (Tb).

Future outlook in 2030 It is expected that the technology to recover rare earth minerals with high-efficiency and recycle rare earth materials from urban mines where waste resources are generated will be developed.

- It is also expected that the sustainable resource circulation system where resources are recovered and recycled in an eco-friendly and highly-efficient way will be developed in response to the increase in the volume of end-of-life waste products in the future.

- Stabilization of rare earth mineral supply chain will contribute to better cooperation between large companies (consumers of components and parts) and small- and mid-sized companies (manufacturers of components and parts).

Relations to other emerging technologies This technology is directly related to large scale offshore wind power system.

- One MW wind turbine uses permanent magnets with 700 to 1,200 kg rare earth minerals. This means export restrictions imposed by a rare earth exporting country might lead to uncertainty of supply price and a trade dispute. Therefore, expanding waste resources import market and taking systematic approach to waste recovery is required to secure raw materials and enhance competitiveness.

Keyword frequency analysis The keyword frequency extracted from the publications on the Web of Science was analyzed. Except recycling-related expressions, most frequent keywords included "leaching", "bioleaching", "spent lithium-ion batteries", and "hydrometallurgy".

04 CONCLUSION AND IMPLICATIONS

The 'carbon-neutral era' was identified as the topic of KISTEP 10 emerging technologies in consideration of novelty, interest and timeliness, impacts, technological relevance, and availability of results. The ten emerging technologies that will contribute to achieving the 2030 NDC targets were selected and comprehensive analysis of each emerging technology was conducted.

- Major trends in the future society were derived from political, economic, social, environmental, and technological perspectives by analyzing the trends and issues from recently published reports on future prospects, reports on the technology foresight, and Future Strategy 2045.

- The surveys were carried out among science and technology specialists, policy experts who have a profound understanding of the overall S&T/policy trends and additional topics were also identified. Based on survey results, 'carbon-neutral era' was selected as the topic of the emerging technologies.

As emerging technologies are based on the issues that may bring about a significant change in the Korean society for the next 5 to 10 years, the technologies that will contribute to achieving its 2030 NDC targets were selected as candidate technologies.

- Selection of the candidate technologies was based on the expected time of technology distribution and technology classification system from the 'Core Technologies for Carbon Neutrality' announced in August 2021.

KISTEP 10 emerging technologies were selected taking into consideration the discussions with technology experts on each candidate technology and evaluation indicator scores.

- The scope and description of the technologies were adjusted in consideration of the greenhouse gas emissions generated by the candidate technologies, global trends and the expected time of technology realization. The direction toward which these technologies would follow was included in the names of technologies.

- ①Carbon capture and utilization ②Bio-based raw materials/products manufacturing technology, ③Low-carbon production of iron and steel, ④High-capacity and long-life secondary batteries, ⑤Clean hydrogen production, ⑥Ammonia fueled power generation, ⑦Grid integration system, ⑧High-efficiency solar cells, ⑨Large scale offshore wind power system, and ⑩Recovery of rare earth elements

Each emerging technology shows a complementary relations to other technologies, which is expected to create positive synergy effects to contribute to achieving the 2030 NDC targets.

To promote the commercialization and development of emerging technologies, it is necessary to improve related laws and regulations, foster human resources, and develop technology infrastructures.

- **Improving laws and systems and systems** The incentives that can attract private investment and the support measures for efficiently developing technologies and fostering industrial sectors should be provided.

- **Building infrastructure** Foundations for standardization and certification have to be established and a test bed has to be provided by operating a demonstration center for each industrial sector or a national demonstration center which offers comprehensive services.

- **Fostering human resources** As there is a shortfall of professional researchers, programs need to be provided to foster human resources throughout overall industrial sectors.

In order to select the ten emerging technologies that will contribute to achieving the 2030 NDC targets, various research methodologies were introduced such as reviewing reports on emerging technologies and gathering experts' opinions. However, it is found that the following points need to be improved.

- It was difficult to quantitatively assess how much the emerging technologies will contribute to the 2030 NDC targets since the research methodologies did not include evaluation indicators such as economic impacts, growth stage, and market entry level.

- As research on selection and comprehensive analysis of the emerging technologies is carried out every year, it is necessary to consider measures to provide consistent information on the emerging technologies.

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KISTEP 10

Emerging Technologies
that will Contribute to
Achieving the
2030 NDC Targets

Korean Edition

Published in March 2022

Edited and published by Center for Strategy Planning, KISTEP

English Edition

Published in June 2022

Edited and published by Center for International Cooperation Policy, KISTEP

1339, Wonjung-ro, Maengdong-myeon, Eumseong-gun, Korea http://www.kistep.re.kr/eng

KISTEP Website