The 5th Korea Nanotechnology Initiative
(2021-2030)

Leading the Global Future

NANO 2030

April 2021

Ministry of Science and ICT, Ministry of Trade, Industry and Energy, Ministry of Economy and Finance, Ministry of Education, Ministry of Agriculture, Food and Rural Affairs, Ministry of Health and Welfare, Ministry of SMEs and Startups, Ministry of Environment, Ministry of Food and Drug Safety

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PART

I

Overview

I Overview

1 Background

Creating breakthroughs with technological innovations in uncertain future of the Next Normal Era

- Emergence of the "Next Normal" era due to global value chain reorganization as a result of the pandemic and the U.S.-China(G2) technology and trade war.

Type	New Normal	Next Normal*(Mckinsey, 2020)
Cause	2008 Global Financial Crisis	Pandemic (COVID-19)
Characteristics	Limited to financial and economic sectors	Entire economy/society
Impact	Mostly manufacturing industry	Manufacturing + digital/low-carbon industries

* Five major trends in post-COVID-19 era △ Acceleration of deglobalization △ Resilience, rather than efficiency △ Promotion of digital transformation △ Changes in consumption behavior according to income level and health interests △ Increased importance of trust

- Science and technology, along with products based on them, will create a predictable era in the newly emerging future from a crisis.

Nanotechnology is a general-purpose technology and a cutting-edge technology with a significant ripple effect

- Nanotechnology interacts with various technology sectors and is applicable in major manufacturing sectors, including AI, biotech, and energy (OECD STI Outlook, 2018).
- The cutting-edge nature gives disruptive power that is unpredictable to gauge when successful, and the general-purpose nature spreads the ripple effect of the technology by converging with various other technologies and industries.

General Purpose Technology

Ref: C. M. Shea, J. Eng. Technol. Manage. 22(2005) 185-200

▶ Definition of nanotechnology

- Technology that imparts new or improved performance to products through manipulation of equipment or manufacture of materials with dimensions in nanometers (1~100nm).

▶ Applicable sectors for nanotechnology

Type	Six major sectors	Technology characteristics
Applied technology	Nano device (electronics)	Realization of high-level integration and low power consumption by reducing circuit width in nano units
	Nano energy/ environment	Increased energy storage and efficiency by applying nano particles
	Nano-bio	Development of biocompatible tissues and rapid/accurate diagnostics with nano-sized structures
Fundamental technology	Nanomaterials	Revelation of new properties and functions by structural control at the atomic level
	Nano process/ metrology equipment	Mass production of nanomaterials, specific functions, and nano-scale analysis
	Nano safety	Establishment of a system and scientific evidence for using safe nanomaterials and product

Moreover, all-round integrated technology for material/component/equipment and semiconductor industries that are ongoing national interests

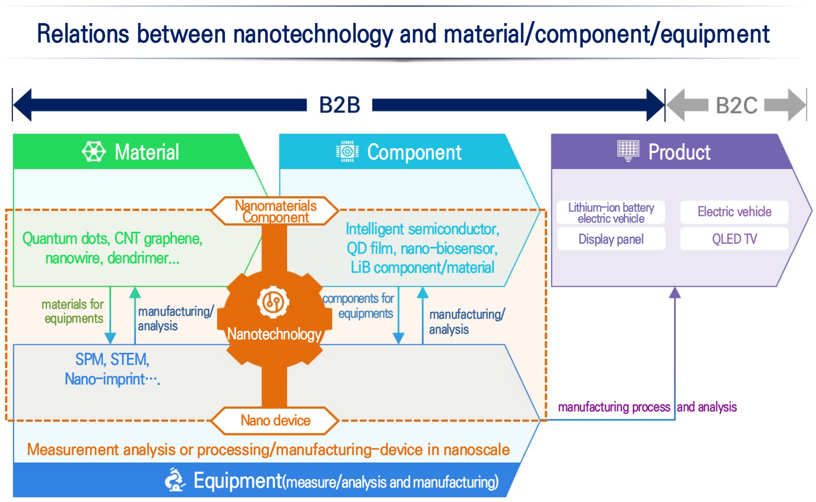
- Achievements in the field of nanotechnology are mostly realized in forms of (nano)materials and components,* semiconductor technology is an example sector in which nano material process technology has been applied.

  * The government-funded Nano-Convergence 2020 Project consists of 70% materials, 20% equipments, and 10% components.

- Nanotechnology can promote development of new industries, such as system semiconductors, and respond to changes in global value chain of six major industrial sectors.*

  * Semiconductor, display, automotive, electricity/electronics, machinery/metal, and basic chemicals

Relations between nanotechnology and material/component/equipment



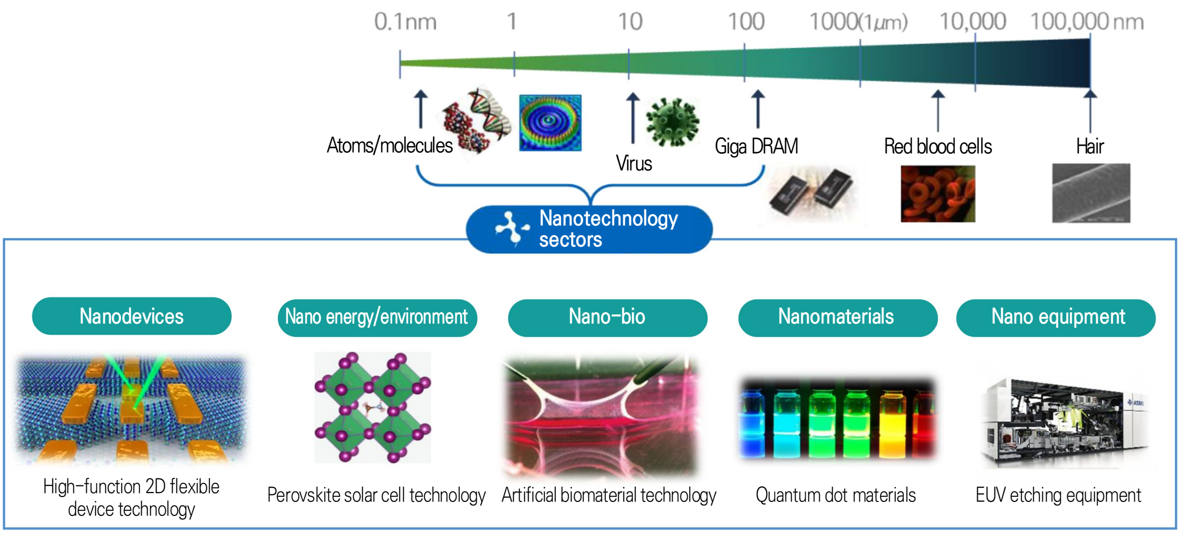
Note 1 Advances in nanotechnology

Nanotechnology is the backbone of advanced science and technology and a source of competitiveness for future industries

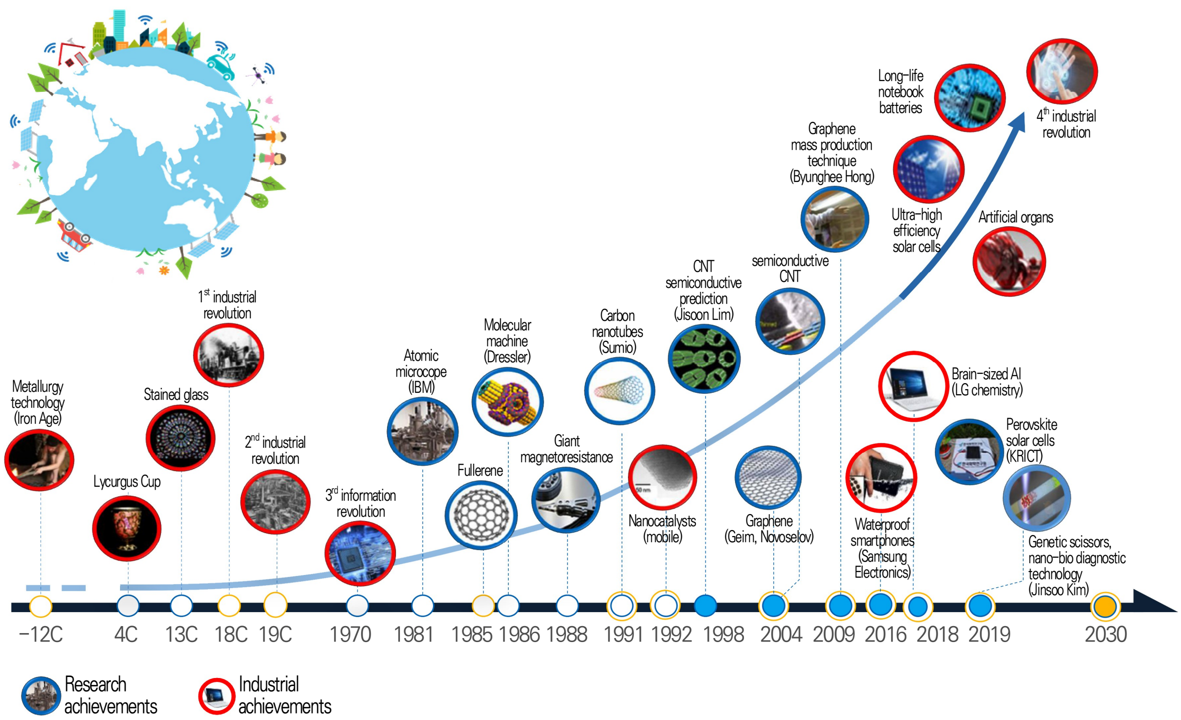
Nanotechnology

Definition: Technology that enables new or improved properties by manufacturing or manipulating nanometer-sized (1~100nm) materials

Characteristics: Strengthen manufacturing competitiveness and create new industries by realizing innovation materials, components, and systems based on convergence with core technologies, such as IT, ET, and BT



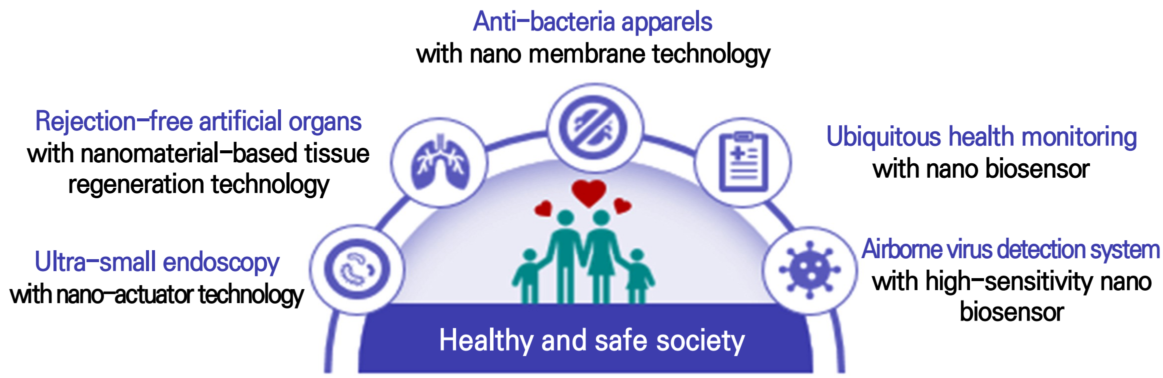
Development of nanotechnology and advancement of humanity



Note 2 Nanotechnology and future society

Entering the age of super-connected and super-intelligent with the convergence of ICT and semiconductors

Entering the age of routine prevention, diagnosis, and treatment by convergence with biotechnology



Entering the age of eco-friendly/high-efficiency energy/resource by converging with energy/environmental technology

2 Formulation rationale and status

As stipulated in the Act on the Promotion of Nanotechnology,* the government shall formulate Korea Nanotechnology Initiative every five years to implement policies and projects of relevant departments and agencies

- In accordance with the Act on the Promotion of Nanotechnology (Dec. 26, 2002) and the Enforcement Decree of the same Act (Jun. 25, 2003), Korea Nanotechnology Initiative shall be revised and supplemented every five years.

*** Act on the Promotion of Nanotechnology**

Article 4 (Formulation of Korea Nanotechnology Initiative) (1) The Government shall formulate and implement a comprehensive nanotechnology initiative (hereinafter referred to as the “initiative”) to promote research and development of nanotechnology.

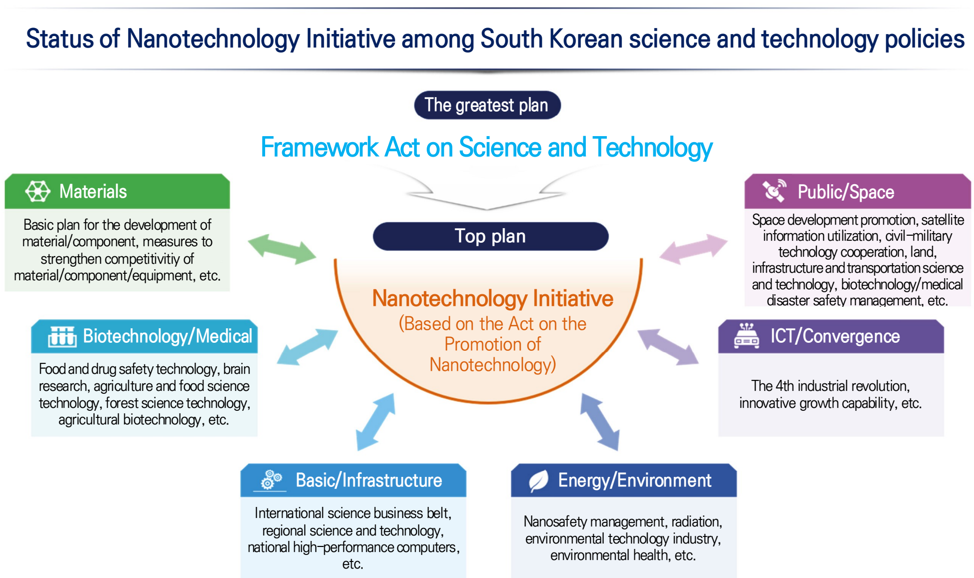
(5) Where necessary due to changes in the trends of development and conditions of research and development of nanotechnology, the government shall revise and supplement the comprehensive development initiative pursuant to Clause 3.

Nanotechnology Initiative is the greatest plan for nanotechnology in the science and technology sector in South Korea, and it is laterally linked to many basic plans

- Based on six major categories* of NTIS, nanotechnology is included in about 20 basic plans of the government.

* Material, biotechnology/medical, basic/infrastructure, public/space, ICT/convergence, energy/environment

Status of Nanotechnology Initiative among South Korean science and technology policies

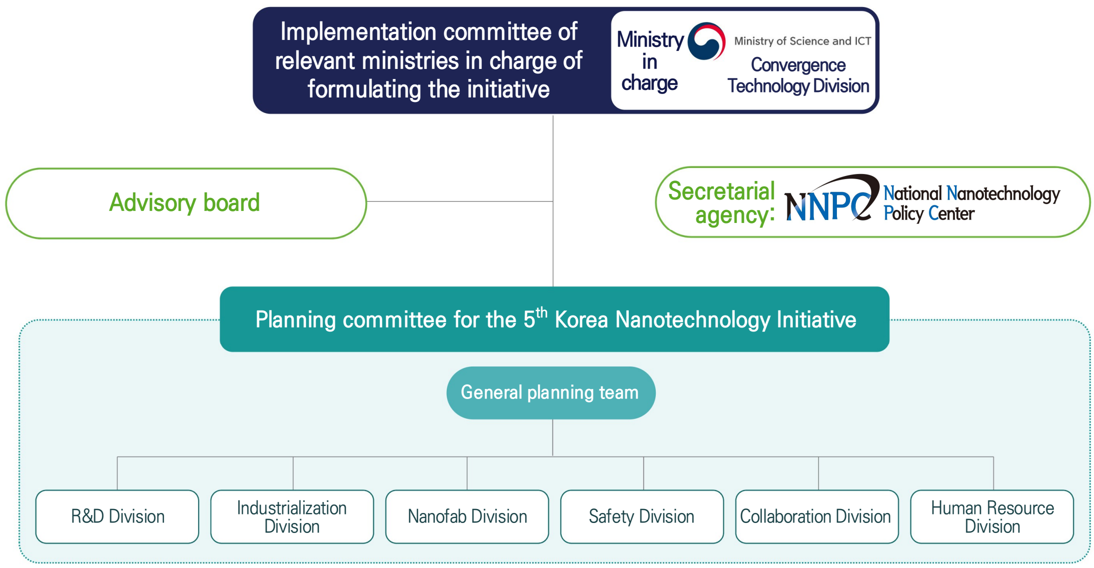


3 Formulation system and progress

(Plan formulation and implementation system) With the Ministry of Science and ICT (MSIT) in charge, an implementation committee with relevant ministries was organized, and a planning committee, consisting of various ministries, organizations, and nanotechnology experts, was formed to prepare the 5th Korea Nanotechnology Initiative (KNI)

※ (Relevant ministries) Ministry of Science and ICT, Ministry of Trade, Industry and Energy, Ministry of Economy and Finance, Ministry of Education, Ministry of Agriculture, Food and Rural Affairs, Ministry of Health and Welfare, Ministry of SMEs and Startups, Ministry of Environment, Ministry of Food and Drug Safety

Implementation system for formulation of the 5th Initiative



- Roles by planning committee division

Division		Implementation details
General planning team		▪ Conduct general review of the plan, coordinate the system between strategies and tasks
R&D	R&D strategy	▪ Formulate innovative and challenging global-leading nano research strategies and tasks ※ Hold meetings with leading researchers in nanotechnology sectors, including head of IBS
	Future R&D	▪ Presentation and discussion of major R&D issues in relevant fields with participation by young researchers ※ Identify and review new R&D candidates related to bio, energy, and ICT
Industrialization		▪ Reinforce competitiveness of the nano convergence industry led by innovative growth ※ Hold meetings with executives from buyers and suppliers in the nanotechnology sector
Nanofab infrastructure		▪ Specify operational upgrade and reorganization of nanofab infrastructure system
Human resources (HR)		▪ Establish strategies for developing nanotechnology professionals
Cooperation		▪ Establish global collaboration strategies for open innovation
Safety/standardization		▪ Establish strategies for leading nano-safety and standardization
Promotional TF		▪ Establish measures for enhancing national perception about nanotechnology

Implementation progress

▶ A total of 105 industry-academia-research (IAR) experts from nano-related fields participated in the general planning team and six specialty divisions to present strategies and tasks to be implementated by each division by holding over 50 meetings

	Implementation progress	Major details
Jan.-Mar. 2020	Analysis of the achievements from the 4th KNI	- Analyzed achievements from the 4th KNI - Analyzed foreign nanotechnology-related policy trends
Apr.-May 2020	Vision TF activities in order to composite the 5th KNI	- Planned discussions for the vision/goals/tasks and implementation direction for divisions for the 5th KNI - Assembled the 5th KNI planning committee
Jun. 22, 2020	Kick-off of implementation committee consisting of related ministries	- Discussed implementation plan for formulation of the 5th KNI around ten ministries and key experts
Jul.-Nov. 2020	Planning activities by the planning committee (general planning team and divisions)	- Assembled the general planning team and seven related divisions, constructed the plan - Held approximately 50 meetings with the general planning team and each division (as of Nov. 31)
Aug. 28	First general planning team meeting	- Reviewed composition of strategies/tasks
Oct. 12	General planning workshop meeting	- Coordinated strategy system, reviewed sub-tasks
Nov. 2-4	Agenda grouping	- Intensive revision and supplementation of sub-tasks by strategy
Nov. 4	Second general planning team meeting	- Reviewed and discussed the results of agenda grouping
Nov. 2020 - Jan. 2021	Online public hearings (two sessions)	- Announced 2021 Nano Convergence Conference (Nov. 26) - National Nanotechnology Policy Center and gathered opinions from IAR (Dec. 2020-Jan. 2021)
Feb. 2021	Opinion-gathering from ministries	- Opinion-gathering on the agenda from relevant ministries
Feb. 2021	Specialized committee of the council	- Preliminary review by the Committee of ICT and Convergence
Mar. 2021	Steering committee of the council	- Preliminary review by the steering committee of the council
Apr. 2021	Meeting with civilian members of the council	- Preliminary meeting of civilian members of the council
Apr. 2021	Introduction of the agenda from the President's Council of Advisors on Science and Technology (PCAST)	- Proposal of the 5th KNI was approved
May 2021	Booklet publication and promotion	- Promotion targeting relevant ministries, organizations, and IAR personnel

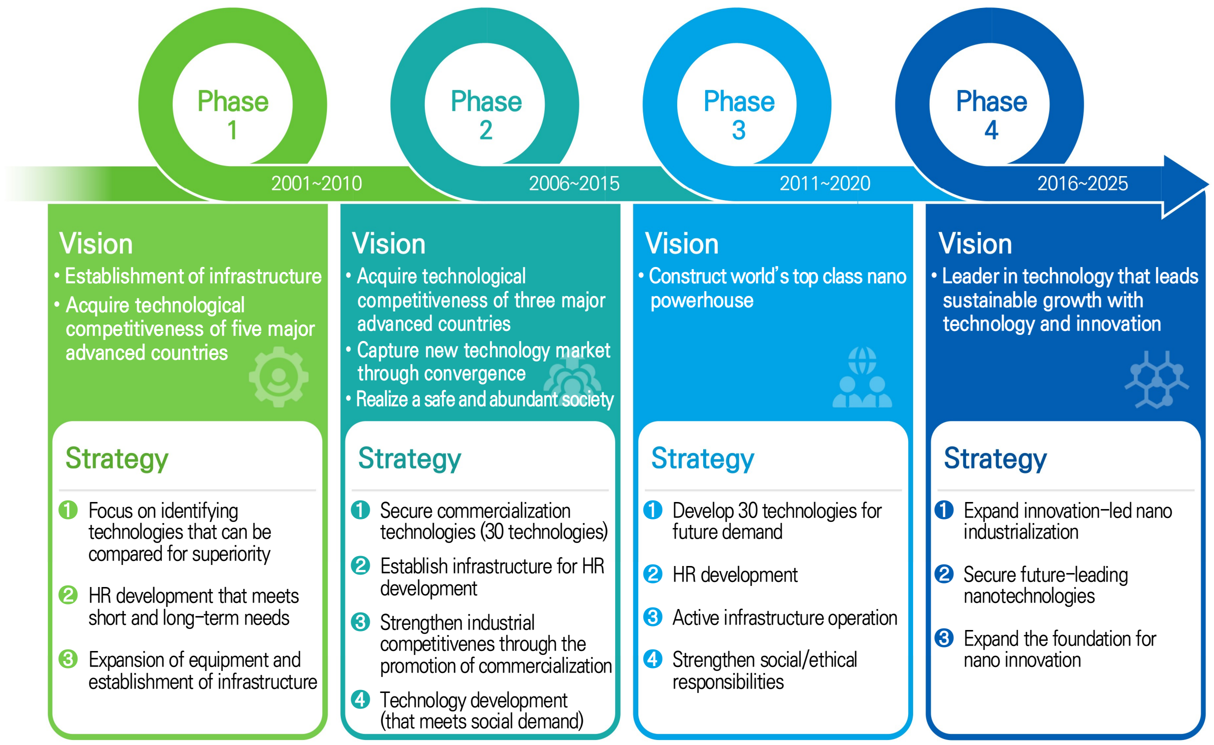
PART

II

Achievements to Date and Reflections

II Achievements to Date and Reflections

1 Progress of 1st – 4th KNI



(2001–2010, Catching-up phase) This was the phase for catching up, focusing on establishing the research infrastructure, such as nanofab, HR development, and expansion of R&D investment for nanotechnologies that were insufficient compared to advanced countries

- Up to 2009, R&D investment increased by 142%, nanotechnology grew from 25% to 75%, compared to that of the US, owing to the establishment of six major nano infrastructure facilities.
- Semiconductor and display industries have developed as leading industries in South Korea that have reached world-class status through ultra-precision nanotechnology innovations.

(2011–2020, Growing phase) Along with quantitative growth, qualitative growth was also pursued by promoting the commercialization of nanotechnology convergence and next-generation nanotechnology R&D

- Starting from the 3rd plan, quantifiable targets have been presented, including investment weight and workforce size.
- Development of future-oriented nanotechnologies, including 'Future 30 Nanotechnologies', and operation of various programs, including joint nanotechnology commercialization project between the MSIT and MOTIE (Nano-Convergence 2020 Project).

Note 2 Summary of 20 Years of Policy on Nanotechnology

Summary of 20 Years of Policy on Nanotechnology

Developed as a country of the world's 4th best in nanotechnology by cumulative investment of approximately 7.9 trillion won in R&D through establishment of the 1st nanotechnology initiative in 2001 and enactment of the relevant law in 2002

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

Enactment of law

Act on the Promotion of Nanotechnology (2002. 12~)

Establishment of policies

1st Nanotechnology Initiative

Established in July 2001(for 2001~2010).
Acquired technological competitiveness of five major advanced countries.
Establishment of major infrastructure for development of nanotechnology.

2nd Nanotechnology Initiative

Established in December 2005(for 2006~2015).
Acquired technological competitiveness of three major advanced countries.
Establishment of infrastructure for education and public use.

3rd Nanotechnology Initiative

Established in April 2011(for 2011~2020).
Became the leading country in nanotechnology.
Strengthened nanotechnology R&D responsibilities.

4th Nanotechnology Initiative

Established in April 2016(for 2016~2025).
Expansion of innovation-led nano industry.
Secured future-leading nanotechnologies.
Expanded the foundation for nano innovation.

1st National Nanotechnology Roadmap

Established in April 2008(for 2008~2017).
Detailed technology roadmap for 49 minor groups and four major sectors (nanodevices, nano-bio, nano process/equipment, and nanomaterials).
Detailed technology roadmap for classified technologies.

2nd National Nanotechnology Roadmap

Established in February 2014(for 2014~2025).
Technologies in 25 minor groups and five major sectors that include nano-energy/environment.

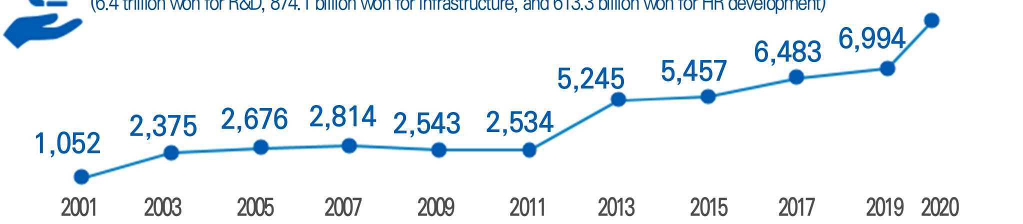
3rd National Nanotechnology Roadmap

Established in June 2018(for 2018~2027).
Technologies in 26 minor groups and six major sectors that include nanosafety.

※ Strategy for developing original technology for future materials (for 2018~2027. published in 2018.4.) in order to identify 30 future material for each 4 megatrends

Current status

Total R&D investment of 7.9 trillion won (2001–2020) for nano/future materials
(6.4 trillion won for R&D, 874.1 billion won for infrastructure, and 613.3 billion won for HR development)



※ Based on the nanotechnology development implementation plan

Current status

- Technology level: Ranked 4th in the world
- Employment: 15.2 million workers
- Revenues: 142.5 trillion won
- Number of firms: 809

2 Key achievements and reflections from the 4th KNI

☻: Excellent, ☺: Average, ☹: Poor

Strategy 1 Expand innovation-leading NT industrialization

(☻ Support the commercialization of nanotechnology by companies)
Achieved commercialization of outstanding nanotechnology through Nano-Convergence 2020 Program, which is a joint program between the MSIT and MOTIE

- Achieved 685.3 billion won in commercial sales (amount accounting for contribution rate /actual total sales of 1.1677 trillion won), 83 cases of commercialization, 615 patents, and 740 jobs created (as of Dec. 2020, a total of 93 projects).
- 477% cumulative sales relative to government input (143.7 billion won), and the time required for commercialization was shortened by 2.3 years.

Product name	Fingerprint recognition module	High refractive index prism coating solution/film	Nanoporous hydrogen generator	Transparent electrode coating equipment	High-temperature superconducting cable	Air quality improvement system
Achievement	Economic impact (used by 17 global smartphone companies)	#1 product in the world (8K TV)	Future growth engine (hydrogen manufacturing)	Successfully opened laboratory	#1 in the world for performance and cost effectiveness	Resolved social issue (fine dust)
Product photo						
Cummulative sales	297.8 billion won	26.0 billion won	6.1 billion won	14.3 billion won	14.6 billion won	9.3 billion won

(☺ Develop key technologies that can facilitate industrialization)
Facilitated the industrialization of seven major strategic sectors and developed key technologies for graphene commercialization, but relevant commercialization achievement was rather insufficient

- Current cumulative total sales of 333.4 billion won (as of 2019) was generated by securing core technologies for the industrialization of the seven major strategic sectors* and commercializing technology in the nano convergence industry.

* 3D nano electronic devices, IoT application environment nano sensors, food safety nano sensors, functional nano fibers, nanomaterials for non-precious metal catalysts, nanomaterials for non-rare element industry, and low-energy water treatment systems

- There have been some achievements regarding graphene, such as obtaining original technology and developing 11 application products, but achievements leading to actual revenues have been inadequate, and it is necessary to continue to identify sources of demand in the future.

(☹ Enhance enlargement of nano-convergence infrastructure)
Smartization of fab processes using accumulation/management of fab data and simulation technology has not been implemented due to budget shortage

▶ Progressive succession of outstanding nanotechnology commercialization programs that achieved distinguished results, organization and promotion of customized R&D by considering technology level and market(industry) maturity, enhancement of a supporting system for nano-infrastructure that can accommodate demands from research and industry.

Strategy 2 Develop future-leading nanotechnology

(☻ Systemize national nanotechnology investment)
Respond preemptively to new social changes, including the 4th industrial revolution, population aging, climate change, and set a strategic direction of nano R&D for efficient nanotechnology investment strategies*

* Along with the strategic technology roadmap with 30 future technologies and 70 core nanotechnologies, establish an advanced technology roadmap for six major nanotechnology fields reflecting recent technological changes.

(☺ Implement efficient operation of government investment and connect private innovation activities)
Facilitate linkage and collaboration between industries and academia based on MSIT-MOTIE joint program and a collaboration system at all times

※ Absence of the Korea Nanotechnology Development Society for efficient implementation of nanotechnology development is unfortunate.

▶ Establish the 4th National Nanotechnology Roadmap, which reflects changes in domestic and overseas trends on technology and industry, and need a pan-ministerial communication system for efficient nanotechnology development.

Strategy 3 Expand infrastructure for NT innovation

(☻ Develop a management system of nanosafety)
By enrichment of nanosafety evaluation technology standardization and international cooperation, standardized nanosafety evaluation technology, such as by developing and providing seven certified reference materials, and expanded internationally cooperative research such as NANoREG, EU Horizon 2020

(☺ Create a new international cooperation system)
In order to strengthen establishment of an international collaboration system, existing collaboration system among South Korea, China, and Japan has been expanded to some ASEAN countries

- Continued networking among researchers through regular annual South Korea-US and South Korea-EU workshops, holding NANO KOREA, technology/industry exchange/collaboration.

(☹ Create an information system for innovation)
Establishment and operation of a unified user-centric information distribution system has not been implemented due to governance issues among stakeholders

▶ In keeping with increased need for being in the forefront of international standardization and nano-product safety, established an information system in line with data-based technology development trends, accelerated research on nanosafety, and encouraged international collaboration reflecting international prestige of nanotechnology.

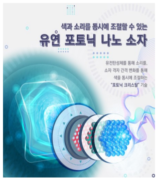
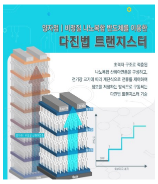
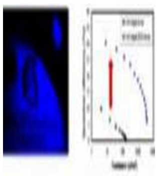
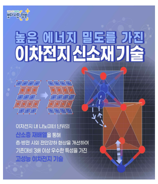
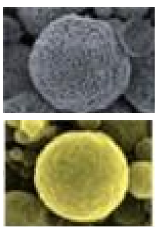
Note 1 Assessment results for each task in the 4th KNI

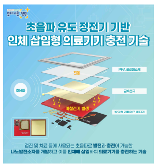
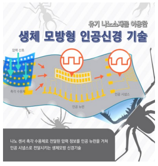
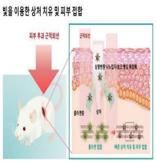
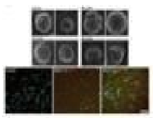
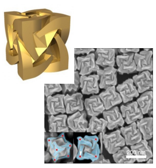
●: High, ◑: Middle, ○: Low

Strategy	Task			Key achievements and reflections
1. Expand innovation-leading NT industrialization	1	Develop key technologies that can facilitate industrialization	◑	• Cumulative total sales generated by linking major nanomaterial-related projects for promoting seven major strategic sectors are 333.4 billion won (cumulative amount as of 2019) • Despite the efforts to commercialize graphene, outcomes have been poor compared to the plan due to the failure to discover decisive commercial products (killer applications)
	2	Support the commercialization of nanotechnology by companies	●	• Achieved commercialization of outstanding nanotechnologies through Nano-Convergence 2020 Project – Achieved 685.3 billion won in sales relative to government investment of 143.7 billion won (477%) – 83 successful commercialization cases among a total of 93 tasks, shortened commercialization period by 2.3 years – Successfully established platform (model) for supporting the commercialization of original technology
	3	Enhance enlargement of nano convergence infrastructure	○	• Although the nanofab information system was established, process development based on case analysis and development of new processes using data analysis and process simulation have not been implemented • As a new infrastructure to encourage nano innovation cluster, the Nano Convergence National Industrial Complex has been under construction in Miryang, Gyeongsangnam-do province since 2016
	4	Breaking through the barriers of commercialization	◑	• Established a foundation for affiliation and collaboration between nano companies and buyers through the "T+2B Project," support for resolving bottleneck technologies through Nanoplus • Nano bio-connect Project was carried out as a small-scale pilot project for diagnostic device group and therapeutics for commercialization of outstanding nano-bio technologies
2. Develop future-leading nanotechnology	1	Implement strategic basic nano research	◑	• Basic nano research development strategy report (2017) was published to strengthen the strategy of initial government investment in nanotechnology, used for planning original technology development for nano/future materials • Operating five subcommittees under the Korea Nanotechnology Research Society (KoNTRS), strengthening researcher network by holding Nano Convergence Conference (NCC) annually
	2	Development of Future Nanotechnologies 30	●	• "Future Nanotechnology 30" reflecting South Korean and international research/industry trends has been constantly updated through the 3rd and 4th KNI and are being used for planning R&D projects • During 2016-2018, the amount invested in "Future Nanotechnology 30" accounted for approximately 89% of all government investment in nano R&D
	3	Four major nano-challenge projects	◑	• Among the four nano-challenge projects, two projects (next-generation ultra-low-power semiconductors and new-concept innovative nanomaterials) are being implemented at the commercialization level – Two other projects (implantable/attachable nano bio-devices and ultra-high-capacity next-generation secondary batteries) are being implemented at the individual task level
	4	Systemize national nanotechnology investment	●	• National nanotechnology roadmap was created for preemptive response to rapidly changing economic and social environment at home and abroad and for more efficient nanotechnology investment strategy, contributed to setting the strategic direction for R&D in nanotechnology sectors
3. Expand infrastructure for NT innovation	1	Develop in-the-field "nano people"	●	• Continued to develop next-generation of nano convergence researchers and field-tailored professionals – Operated nanotechnology-related online education (e-nano), developed professionals using national nanofab facilities, and implemented forever NT-School • Operated Nano Korea Public program targeting the general public and youths, special hall for Nano Korea, designation of ten major nanotechnologies, and Nano Young Challenge
	2	Create a new international cooperation system	◑	• NANO KOREA has been held every year, technology/industry exchange/collaboration • Continued networking with leading countries through regular South Korea-US and South Korea-EU nano workshops • Expanded private collaboration from existing South Korea-China-Japan collaboration to include some ASEAN countries
	3	Develop a management system of nanosafety	●	• For the standardization of nano safety evaluation technology and expansion of the international collaboration, the standards for nano safety evaluation technology were established, including the development and deployment of seven certified reference materials, and international joint research was expanded, including NANoREG and EU Horizon 2020
	4	Create an information system for innovation	○	• Strengthened statistical reliability by upgrading nano convergence industry surveys, focusing on securing consistency and reliability in industrial statistics • Establishment and operation of a unified user-centric information distribution system has not been implemented due to governance issues among stakeholders

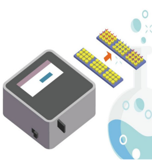
Note 2 Examples of Outstanding Achievements

R&D achievement

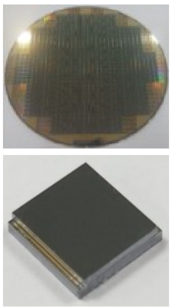
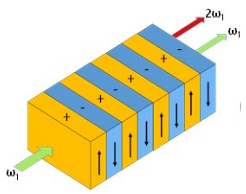
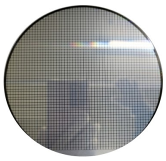
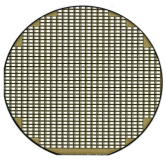
Nano devices		Chip-integrated, high-density, ultra-small micro-supercapacitor technology (UNIST) • Developed chip-integrated, high-density, ultra-small-sized micro-supercapacitor using nanomaterial-based ink and high-precision electrohydrodynamic printing process
		Flexible photonic nano device that can simultaneously control color and sound (Seoul National University) • “Photonic crystal” technology that simultaneously controls sound through a dielectric elastomer and color through changes in the device grid-gap
		Polynary transistor using quantum dot/amorphous nano-complex semiconductors (Hanyang University) • Polynary transistor technology consisting of nano-complex zinc oxide layer deposited as super lattice structure and operated with the method of storing information by controlling current in a stepwise manner according to the size of electric field
		Nano fiber material-based hazardous environment and respiratory gas analysis sensor technology (KAIST) • Technology that can detect “trace gases of 1 ppm or below” through ultra-small, ultra-low-power nano sensors that uniformly bind high-performance catalysts on the surface of nano fiber
		True-blue OLED material and device technology with world’s best quantum efficiency (Sungkyunkwan University) • Developed high-efficiency blue phosphorescent and fluorescent light-emitting material that is at least three times more efficient than conventional devices (achieved world’s best efficiency)
Nano energy and environ-ment		New material technology for secondary batteries with high energy density (Seoul National University) • Developed high-performance electrode material with at least three times better performance than conventional materials by achieving symmetrical migration characteristics of transition metals through rearrangement of the oxygen layer in the secondary battery
		Development of flexible color cooling radiation nanomaterial that operates without electricity (GIST) • Nanomaterial technology that effectively cools heat by sequentially stacking insulators (silicon nitride and silicon dioxide) and displays color by controlling the thickness of the silicon dioxide layer
		Carbon nanotube sponge particle manufacturing technology for high energy density lithium-sulfur batteries (Sogang University) • Developed nano-structured material that can easily absorb sulfur by controlling the pore structure of film with aggregation of carbon nanotubes, which was applied to lithium-sulfur battery electrodes to achieve a high energy density, at least twice as high as that of a conventional lithium battery

Nano-bio		Ultrasound-induced static electricity-based implantable medical device charging technology (Sungkyunkwan University) • Developed an implantable nano power generating device that can generate and charge electricity using static electricity induced by ultrasound
		High-sensitivity cancer diagnosis biosensing technology using RNA-nano structures (Sogang University) • Developed electrochemical/surface-enhanced Raman spectroscopy biosensor that enhances micro-RNA detection sensitivity by at least 7-fold compared to existing technology using a single tri-directional conjugated RNA/gold nano particle complex
		Biomimetic artificial neuron technology using organic nanomaterials (Seoul National University) • Biomimetic neuron technology that relays pressure information transmitted to nano sensor tactile receptors to artificial synapses via artificial neurons
		Wound healing and skin bonding technology using photosensitive nanoparticles (POSTECH) • Photomedical technology that allows convenient and fast bonding of cut skin area by inducing collagen bonding within the skin using nanoparticles sensitive to near-infrared ray
		Physiological substance transport technology using nano-coated human immune cells (Chung-Ang University) • First in the world to individually coat immune cells with nano-thickness film to verify the potential for physiological substance transport and immune cell therapy
Nano -materials		Low-cost metal/graphene composite ink manufacturing technology (Korea Electrotechnology Research Institute) • Developed commercial technology that uses a liquid-phase synthesis of graphene oxidation barrier to overcome the fatal oxidation problem with copper, which has similar electrical conductivity, but 1/10 the price of silver
		Web-based nano simulation platform technology for easier nanomaterial design (KIST) • Established web-based nano design platform for each task based on quantum mechanics or molecular dynamics-based nanomaterial design and process simulation, this platform technology was used to launch Virtual Lab, Inc. for commercialization
		Protein-mimicking 3D metal nanoparticle synthesis technology (Seoul National University) • Based on the understanding of the specific surface interaction between proteins and gold, a new paradigm in nano structure fabrication was presented by being the first in the world to synthesize uniform gold nanoparticles with a chiral structure that could not be obtained artificially
Nano process /metrology /equipment		Non-planar photolithography technology using flexible photomasks (Yonsei University) • Used flexible photomask that can adhere tightly to the substrate to develop non-planar substrate patterning technology that was previously impossible for forming patterns below the diffraction limit of tens of nanometers without expensive exposure equipment
		High-speed large-area coating technology for coating perovskite solar cells under 20 seconds (Sungkyunkwan University) • Large-area solar cell manufacturing technology by preparing a coating solution containing perovskite cluster nano powder and film-coating within a short time

Industrialization achievements

Nano devices		3D full-color hologram large-area diffraction optical device design and manufacturing technology (Korea Institute of Machinery and Materials) • Large-area, low-cost manufacturing platform technology for film and device products capable of realizing 3D color holograms with a wide viewing angle
		Ultra-high-speed driving CNT-based field emission X-ray original technology (VSI) • The world's first 100% digital, miniaturized, and lightweight "low-exposure, high-durability X-ray source" technology that is capable of using carbon nanotubes instead of conventional filament for high-speed control of X-ray in accurate pulse wave
Nano energy and environ-ment		Nano heating material and flexible film heater technology for improving the efficiency of electric vehicles (Teraon) • Developed nano carbon-based high-efficiency flexible heating material and film heating technology for improving the energy efficiency and driving range of electric vehicles
		High-efficiency nanoporous hydrogen-generating catalyst technology (Elchemtech) • Commercialization of the world's largest hydrogen generator with ≥ 90% hydrogen generation efficiency and 20% reduction in energy consumption by applying nanoporous structure created by electrochemical dealloying of anode microstructure that acts as water splitting catalyst
Nano-bio		Metal nano-pattern sensor-based portable real-time food toxin meter commercialization technology (Teltron) • Technology for commercialization of a real-time testing device that can be used in the field to detect trace amounts of residual toxins and pesticide in food by using the principle of localized plasmon generation based on metal nano-patterns
Nano -materials		Development of high-refractive nanocomposite coating solution and high-brightness prism film (SMS) • Organic/inorganic nanocomposite technology film produced using high-refractive, high-brightness prism coating solution with improved dispersibility by binding a hydrophobic compound on the surface of hydrophilic nanoparticles ※ 30 billion won in sales, designated as a small-giant company for material/component/equipment, 11 patents
		Configuration-controllable carbon nanotube fiber manufacturing technology (A-Tech System) • Developed carbon nanotube fiber manufacturing technology for sensor filament and low-heat resistor application
Nano process /metrology /equipment		Development of eco-friendly metal coating equipment as a replacement for the plating process (Selcos) • Commercialization of highly reliable, large-area inline metal coating equipment that uses surface-planarizing nano dispersant to produce high-quality colors without generating toxic substances and wastewater ※ 20.5 billion won in sales, four patents
		Technology using conductive nano ink for stretchable heating module and outdoor apparel applications (Paru) • Developed a technology based on roll-to-roll printing technology using conductive nano ink applied to a flexible and stretchable substrate for stretchable heating module and outdoor apparel applications
		Atomic force microscopy technology providing semiconductor inline nano metrology solution (Park Systems) • Developed an atomic force microscope that can be used for nano-metrology for the development and testing of semiconductor processes, which has been commercially marketed to global semiconductor companies

Nano infrastructure support achievements

Institution	Technology	Achievements
National Nanofab Center (NNFC)	 Wafer-level package (WLP)	**Successful in mass production of ultra-small uncooled thermal imaging sensor (Truwin)** ◇ Successful in using original technology of nanoscale infrastructure and commercialization of system semiconductors ▪ Applied compatible semiconductor (CMOS) process differentiated from conventional MEMS process → Ultra-miniaturization and improved yield ▪ Avoided patent infringement of foreign technology (Honeywell, US), ultra-miniaturization/low price - Sold 100,000 units in South Korea and internationally in 2020 (approximately 14.5 billion won in sales) - Import substitution effect for thermal imaging cameras accounting for several hundred billion won (86%)
Korea Advanced NanoFab Center (KANC)	 Conceptual diagram of polarity switching structure of wavelength converting elements	**Support of technology start-up through technology transfer for wavelength converting element manufacturing technology (Raon Moa)** ◇ Successfully supported commercialization and use of original technology for nano infrastructure ▪ Secured critical technology elements through technology transfer of patent for UV laser light source, start-up support, bottleneck technology consulting, and prototyping support - Secured UV LED Epi process technology and product competitiveness through structural improvement - Maximized bactericidal effect using 265nm UV-C LED - Optimal design of driving circuit through the integration of LED driver and SMPS
National Institute for Nanomaterials Technology (NINT)	 Prototype of 650-VSiC MPS diode  Prototype of 1200-V SiC MOSFET	**Support for SiC power semiconductor (SiC MPS diode and SiC MOSFET) prototyping (Yes Power Technix)** ◇ Successful commercialization through process optimization service using nano infrastructure equipment ▪ Supported optimization of hard mask etch profile process and photolithography for the formation of ion implantation hard mask structure - Market entry via SiC MPS diode and SiC MOSFET prototyping and prototype reliability testing (new product launch)
Nano Convergence Practical Application Center (NCPAC)	 Silicon Ingot grower for solar cell/ semicondoctor	**Support growth as a global small-giant company through joint R&D, technology, and infrastructure support (S-tech)** ◇ Current development of critical equipment components from conventional simple process equipment manufacturing ▪ Solar and semiconductor single crystal silicon ingot grower ▪ R&D and joint technology development during 2012–2018 (seven years) ▪ Support for major corporate support projects during 2014–2018 (five years) ▪ Support for global small-giant company in 2018 - 42.3 billion won in sales and $30 million in export (as of 2018) - Industrial property: 26 cases in South Korea and two cases internationally, TUV/CE certification

3 Nanotechnology investments and achievements in South Korea

(Investment) For the past five years between 2015 and 2019, approximately 3 trillion won was invested in nanotechnology sectors, with 2.53 trillion won (84.4%) invested in R&D

- In 2019, government investment in nanotechnology sectors was 699.4 billion won, accounting for 3.4% of total government R&D investment of 20.5 trillion won.

※ (by sector) R&D: 583.6 billion won (83.4%), HR development: 59.2 billion won (8.5%), infrastructure: 56.6 billion won (8.1%)

(Research achievements) In the five years between 2015 and 2019, 46,060 SCI articles from South Korea on nanotechnology were published, which accounted for 6.1% of the global total which is 750,496 articles (ranked 4th in the world after China, the US, and India)

※ Number of articles (cumulative for 2015–2019): China (n=282,779), the US (n=120,1679), India (n=55,807), and Germany (n=42,317)

※ Top 1% of cited articles by major countries (cumulative for 2015–2019): China (#1, n=6,258), the US (#2, n=3,053), Germany (#3, n=601), South Korea (#7, n=498), and Japan (#10, n=420)

- In 2019, the number of SCI articles from South Korea on nano sectors increased by 0.4% relative to the previous year of 9,569 articles, which ranked 4th globally.

※ (2019) #1: China (n=72,706), #2: the US (n=24,244), #3: India (n=12,906), #5: Germany (n=8,568)

- Ranked 2nd globally for SCI articles relative to R&D expenditure (PPP dollar) among major competitors (#1: China).

(Patent achievements) In the five years between 2015 and 2019, the number of patents registered with the US Patent and Trademark Office (USPTO) by applicants with South Korean nationality was 5,298, which accounted for 7.4% of all patents registered (n=71,198), and ranked 3rd in the world after the US and Japan

※ Cumulative for 2015–2019: US (n=36,262), Japan (n=7,551), China (n=3,767), and Germany (n=3,290)

※ Comparison of cites per patent (CPP) between major countries (cumulative for 2015–2019): the US (5.11), China (4.03), Japan (3.20), Germany (2.99), and South Korea (2.74)

- In 2019, the number of patents registered with the USPTO for South Korean nano sectors increased by 6.8% relative to the previous year to 1,121 cases, maintaining the 3rd place since 2008.

※ (2019) #1: the US (n=7,811), #2: Japan (n=1,510), #4: China (n=1,047), #5: Germany (n=720)

- Ranked 2nd globally for patents registered relative to R&D expenditure (PPP dollar) among major competitors (#1: the US).

(Infrastructure) Cumulative service provided for the five years between 2015 and 2019 was 303,121 cases, with 148,833 (49.1%), 98,793 (32.6%), and 55,495 (18.3%) cases for industry, academia, and research, respectively

- Six nanofab facilities* were used as service hubs for different research fields and regions to provide a total of 67,565 cases of IAR (industry–academia–research) services in 2019 (an increase of 8.3% relative to the previous year).
  * NNFC (Daejeon), KANC (Suwon), NINT (Pohang), Jeonbuk National Center for Nanomaterials Technology (NCNT, Jeonju), Gwangju NCNT (Jeonju), and NCPAC (Daegu)
  ※ Industry: 36,853 cases (16.7%↑), university: 18,031 cases (4.9%↓), research: 12,681 cases (6.9%↑)

(Loyalties and commercialization achievements) **In the five years between 2014 and 2018, the number of technology transfer cases was 2,168, loyalty collected was 85.9 billion won, and the number of commercialization cases was 6,436 in nano sectors, each representing an average annual increase of 8.8%**

- In 2018, the number of technology transfer cases was 503, loyalty collected was 19.5 billion won, and the number of commercialization cases was 1,472 (decreased relative to 1,539 cases in the previous year).
  ※ (2014) Technology transfer: 358 cases and commercialization: 1,049 cases

(HR development) **In the five years between 2015 and 2019, the number of core research personnel* and enrolled students increased at an annual average of 7.1% and 3.7%, respectively**

※ (2015) Core research personnel: 9,142 and enrolled students: 32,994
* Criteria for core research personnel: Government-funded researchers involved in nanotechnology projects and researchers in university laboratories

- In 2019, the number of core research personnel and enrolled students was 12,007 and 38,087, respectively (21.0% and 0.7% increased relative to the previous year, respectively).

Nanotechnology investments and achievements

Type		Investment (billion won)	Research (cases)	Patents (cases)	HR development (persons)	Infrastructure service (cases)	Technology transfer (cases)	Commercial -ization (cases)
Single year	2019	699.4	9,569	1,121	12,007	67,565	503 (2018)	1,472 (2018)
	2015	545.7	8,800	985	9,142	55,197	397	913
	Compound annual growth rate (CAGR)	6.4%	2.1%	3.3%	7.1%	5.2%	8.2%	17.3%
Cumulative	Fourth Ver. (2016-2019)	2,452	37,260	4,313	-	247,924	1,413 (2016~2018)	4,474 (2016~2018)
	Third Ver. (2011-2014)	1,593	28,965	2,574	-	203,477	651 (2011~2013)	1,550 (2011~2013)
	CAGR	54.0%	28.6%	67.6%	-	21.8%	117.1%	188.6%

※ Achievements for 2020 have not been tallied, compared in five-year cycles relative to 2019 statistics, cumulative = 4 year cumulative value

4 Nano convergence industry in South Korea[1)]

▶ The size of nano convergence industry in South Korea is 143 trillion won (2019). Nanomaterial and nano equipment sectors accounted for the majority of companies, while revenues were concentrated in nano electronics, such as semiconductors and displays.

(Number of nano convergence companies) The number of nano convergence companies in South Korea grew at an average rate of 7.4% per year (2015–2019) to reach 809 at present (SMEs accounting for 97.8%)

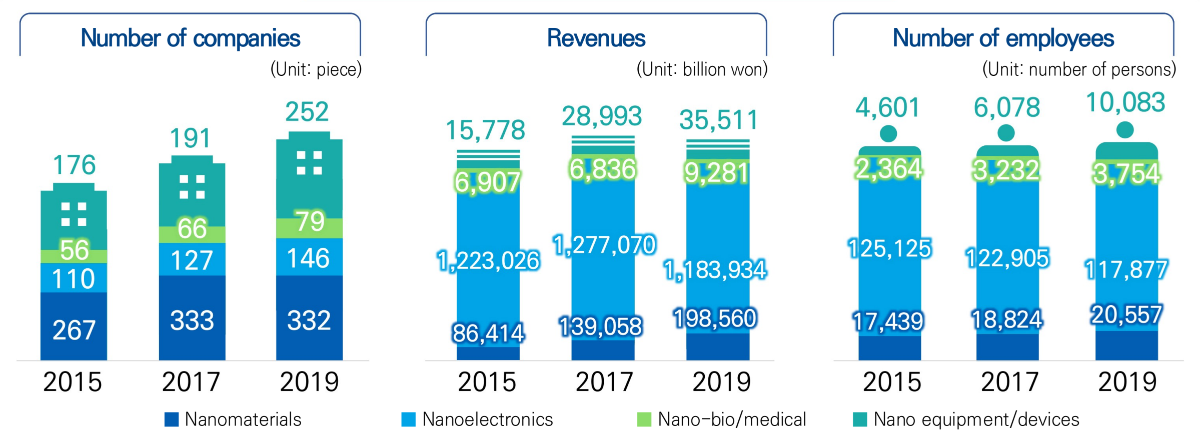
- By sector, the order appeared as nanomaterials (n=332, 41.0%), nano equipment/devices (n=252, 31.1%), nano electronics (n=117, 16.3%), and nano-bio/medical (n=70, 9.7%).

(Revenues of nano convergence companies) The revenues of nano convergence companies grew at an average rate of 1.7% per year (2015–2019) to reach approximately 143 trillion won at present (manufacturing accounting for approximately 10%)

- By sector, the order appeared as nano electronics (83.1%), nanomaterials (13.8%), nano equipment/devices (2.5%), and nano-bio/medical (0.7%).
- SMEs accounted for 8.5% of total revenue, and it took 8.7 years to generate revenues after starting the business, mid-to-long term investment support is needed to strengthen the industrial ecosystem.

(Labor force) The number of workers grew at an average rate of 2% per year (2015–2019) to reach 152,271 workers at present

Major indicators for nano convergence industry



1) Results from the 2019 Nano Convergence Industry Survey: The Nano Convergence Industry Survey is a government survey conducted since 2012. With the formation of a large market for nanotechnology-based products, the nano convergence industry has been classified as a separate industry, and the survey is conducted annually

Questionnaire Survey of Nano Companies about Bottlenecks

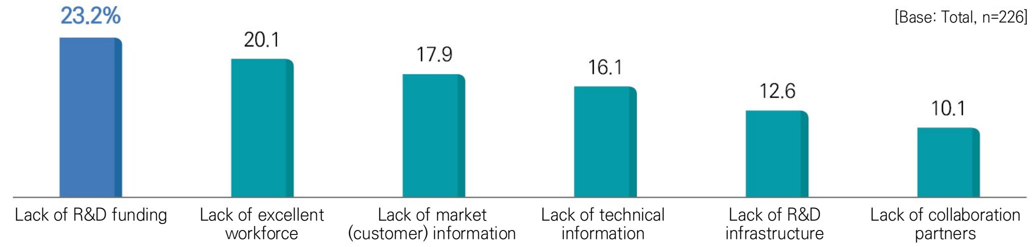
▶ Survey of 226 nano companies about bottlenecks

- Survey* on bottlenecks related to nano product performance and safety regulations during R&D and commercialization

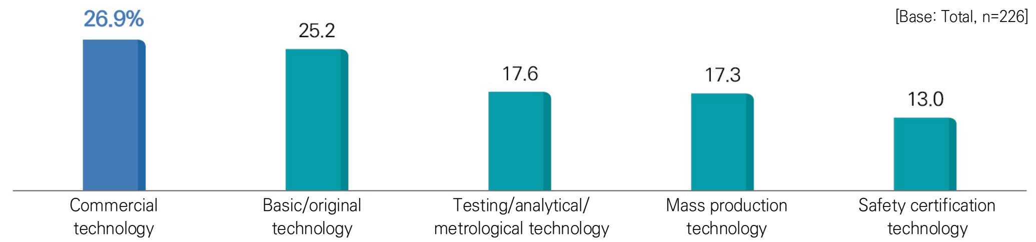
* 2020 Questionnaire Survey of Nano Companies (nano suppliers and buyers) about Bottlenecks, Nano Technology Research Association

(R&D bottleneck) Survey of 226 nano companies about R&D bottlenecks

- Complained about difficulties due to lack of funding: Lack of R&D funding (23.2%), lack of outstanding workforce (20.1%), and lack of market (customer) information (17.9%).

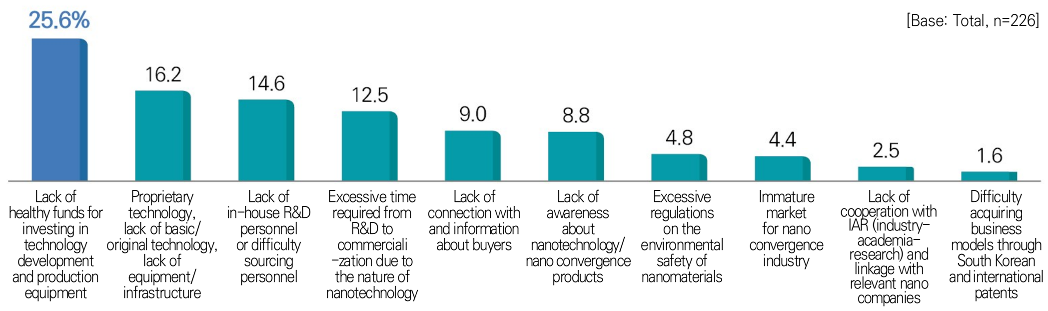


- Nanotechnology-related government R&D funding allocation appeared in the order of commercial technology (26.9%), basic/original technology (25.2%), and testing/analytical/metrological technology (17.6%).

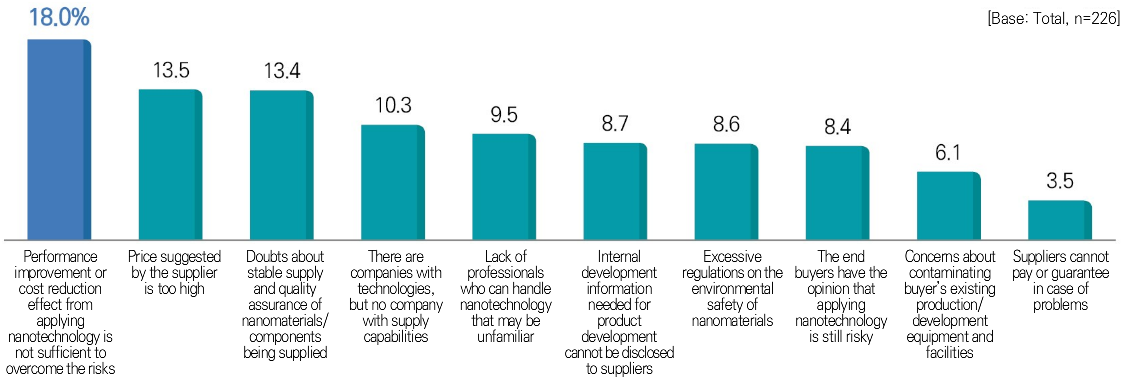


(Commercialization bottleneck) Survey of 224 nano suppliers and 79 buyers about bottlenecks in the commercialization process

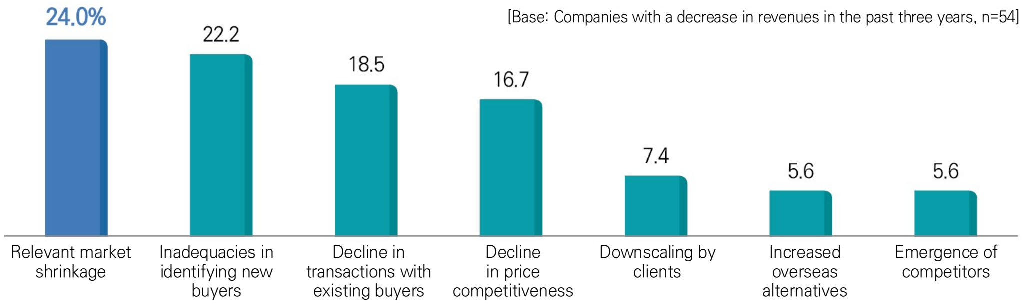
- In a survey of 224 nano suppliers about commercialization bottlenecks, "lack of healthy funds for investing in production equipment and technology development" was the most common response with 25.6%.



- In a survey of 79 buyers about commercialization bottlenecks, "performance improvement or cost reduction effect from applying nanotechnology is not big enough to overcome the risks" was the most common response with 18.0%, followed in order by "high price" and "doubts about quality assurance."



- In a survey of 54 nano companies that had a decrease in revenue over the past three years on the reasons for their decrease in revenues, "relevant market shrinkage" was the most common response with 24.0%, followed by "inadequacies in discovering new customers" (22.2%) and "decline in transactions with existing buyers" (18.5%).



- A survey found 31 companies of various types with "experience related to nano product safety regulations." For "the need for performance and safety certification system and centers for nano convergence products," 57.1% responded that they are important, indicating the need for a long-term preparation.

Implications

- With respect to "priority in the allocation of government funding for R&D projects," the results were 26.9% for commercial technology and 25.2% for basic/original technology, indicating simultaneous need for not only commercialization of existing technologies but also mid-to-long-term investment in basic/original technologies.
  - As nano companies are still at the market entry stage, they need to develop competitive and differentiated technologies, as well as support strategies, for expansion of market application.

※ Instead of engaging in fierce competition with existing companies that already have a market share, they are attempting technology business based on a "World First, World Best" strategy to open up new markets for nano convergence products.

- "Complaints about difficulties due to lack of funds" could be attributed to a lack of revenues due to delays in research and commercialization over a long period, indicating the need to establish a response measure for this.
  - This indicates that most suppliers are still in R&D stage, and there is a need to establish policies that would allow them to get closer to actual commercialization.

  ※ The types of fund that are lacking and the equipment investment that is necessary necessary during R&D should be specified to provide not only funding support but also the use of joint research facilities and test beds.

- With respect to "performance improvement or cost reduction effect from applying nanotechnology is not big enough to overcome the risks," it is necessary to change the perception of buyers.
  - This could be attributed to a significant difference in the positions between the buyers and suppliers for nanotechnology applications, for dynamic market entry and the creation of new markets, ground-breaking performance improvement and price competitiveness are essential, rather than simply improving existing products. Therefore, it is important to form a consensus that the utilization of cutting-edge nanotechnology is essential. Additionally, there is a need for nano convergence innovation production development with both suppliers and buyers participating from initial development stage.

- With respect to "the need for performance and safety certification system and centers for nano convergence products," the majority of the respondents stated that they are important, indicating the need for long-term preparation and response measures.

5 Evaluation of the level of nanotechnology in South Korea

(Technology level) The US has the highest level of all nanotechnologies and South Korea is upto 85.7% relative to that of the US (the leader group), which is an improvement of approximately 4.2% from the 2014 survey, but remains in the 4th place

※ The US (100%) > Japan (92.0%) > Germany (90.2%) > South Korea (85.7%) > China (81.4%)

- For the five nano sectors (middle classification), the US has the highest level of all nanotechnologies, while South Korea ranks 4th in the technology level for all five sectors.

(Technology gap) The technology gap between South Korea and the US is 2.5 years, which has decreased by 0.5 years since 2014 that is believed to be correlated to the technology level

- Japan and Germany trail the US by 1.3 and 1.6 years, respectively, and the gap remains the same as in 2014.

- For five nano sectors (minor groups),* the technology gap was assessed to be within three years relative to the US, the country with the highest level of technology.

  * Next-generation nano device technology for meeting future demand, nano-biotechnology for the realization of a healthy life, nano energy/environment technology for a sustainable society, nanomaterial technology that serves as the foundation for future industries, and nano process/metrology/equipment technology that will lead manufacturing

  - Among the five sectors, "next-generation nano device technology for meeting future demand" was assessed to have the smallest technology gap, reconfirming the competitiveness of the South Korean semiconductor industry.

division	2014			2016			2019		
	Technology level (%)	Technology level group	Technology gap (years)	Technology level (%)	Technology level group	Technology gap (years)	Technology level (%)	Technology level group[2]	Technology gap (years)
US	100(1)	Best	0.0	100.0(1)	Best	0.0	100	Best	0.0
South Korea	81.5(4)	Leader	3.0	83.1(4)	Leader	2.7	85.7	Leader	2.5
Japan	91.9(2)	Leader	1.3	93.4(2)	Leader	1.0	92	Leader	1.3
China	71.0(5)	Follower	4.4	75.6(5)	Follower	3.8	81.4	Leader	3.1
Germany	89.4(3)	Leader	1.6	91.4(3)	Leader	1.5	90.2	Leader	1.6

Source: Nanotechnology Level Assessment, National Nanotechnology Policy Center (2019)

2) Leader (100%): The best in the world
Leader group (80% to < 100%): Group that leads a technology sector
Follower group (60% to < 80%): Capable of copying/modifying advanced technologies
Late group (40% to < 60%): Capable of implementing and applying advanced technologies
Underdeveloped group (< 40%): Poor R&D capabilities

6 Current level relative to the goals in the 4th Initiative

(Science and technology development indicators) A goal for the investment size can be achieved, as the level of nanotechnology moves upward, even more investment and efforts are needed to narrow the gap

- The goals for core research personnel, and the number of patents registered with the USPTO have been met.

(Industrial development indicators) Goals for the number of companies and the proportion of sales are expected to be achieved by 2025, but the goal for the accompanying workforce is yet to be met

<table>
<tr><th colspan="2">division</th><th>2015</th><th>2019 (Current)</th><th>2025</th><th>Remarks</th></tr>
<tr><td rowspan="4">Science and technology development indicators</td><td>Nano science and technology level</td><td>81%</td><td>85.7%</td><td>92%</td><td>Based on 2019 future 30 nanotechnology level evaluation results</td></tr>
<tr><td>Government R&D investment in nanotechnology (proportion of government R&D investment)</td><td>545.7 billion won (2.9%)</td><td>699.4 billion won (3.4%)</td><td>880.0 billion won (4%)</td><td>Based on 2020 Nanotechnology development implementation plan</td></tr>
<tr><td>Core research personnel</td><td>9,142 persons</td><td>12,007 persons</td><td>12,000 persons</td><td>Based on nanotechnology yearbook</td></tr>
<tr><td>Number of patents registered with the USPTO</td><td>985
(#3 in the world)</td><td>1,121
(#3 in the world)
5,298
(cumulative for 2015–2019, #3 in the world)</td><td>5,000 (cumulative for 2015–2024)</td><td>Major countries
(cumulative for 2015–2019)
US: 36,262
Japan: 7,551
Germany: 3,290
China: 3,767
Taiwan: 3,075

Based on 2020 Nanotechnology development implementation plan</td></tr>
<tr><td rowspan="4">Industrial development indicators</td><td></td><td>2015</td><td>2019</td><td>2025</td><td rowspan="4">2020 Nano Convergence Industry Survey (MOTIE, 2020)</td></tr>
<tr><td>Proportion of sales by nano convergence products (100% manufacturing in South Korea)</td><td>9.3%</td><td>9.7%
(2018)</td><td>12%</td></tr>
<tr><td>Number of nano convergence companies</td><td>609</td><td>809</td><td>1,000</td></tr>
<tr><td>Number of workers in nano convergence industry</td><td>149,529</td><td>152,807</td><td>250,000</td></tr>
</table>

※ The goals for 2025 are from the 4th KNI

The 5th Korea Nanotechnology Initiative(2021-2030)

Leading the Global Future

NANO 2030

PART

III

Analysis of Global Nanotechnology Policy Trends

III Analysis of Global Nanotechnology Policy Trends

1 Overseas nanotechnology policy trends

US

▶ The Biden administration is expanding the federal government's public R&D spending, including the development of advanced nanotechnology, to stimulate the economy and maintain global technological hegemony

The Biden administration is strengthening the government's role in science and technology policies to get prepared for the next corona era, conversion to eco-friendly energy, and maintaining global technological hegemony

- To stimulate the economy that has been diminished by COVID-19, the expansion of investments at the federal level and strengthening of "High-risk, High-return" type of research projects for future challenges are expected.
  - Continued R&D in nanotechnology/nanomaterials, information science and technology, life science/clinical medicine, and environment/energy, in particular, the expansion of the National Nanotechnology Initiative (NNI) from 2001 is forecasted.

  ※ Green New Deal, clean energy, bio, aerospace, and small business innovation policies are similar to those of the Obama administration

▶ Five characteristics of the Biden administration's science and technology policies (NICHE) (KISTEP Report, 2021.01)

- **(N-Next corona)** (1) Establish a rapid R&D system for a disaster response focusing on expanding and contributing to public R&D infrastructure, (2) Activation of advisory function of science and technology community during national emergencies
- **(I-Industrial innovation)** (1) Strengthen the international competitiveness of South Korean products and technologies based on fair competition, (2) Prepared for the Biden administration's national protection policies by securing a stable supply chain
- **(C-US-China hegemony competition)** (1) Strengthen international collaboration in major technology hegemony areas, such as 5G, AI, and bio, (2) Continue expansion of R&D investment for strengthening technological competency
- **(H-Science and technology HR)** (1) Secure highly trained personnel for the science and technology sector, (2) Actively recruit outstanding foreign talent
- **(E-Energy/Climate change)** (1) Prepare for impact on export due to stricter fossil fuel regulations, (2) Establish strategies for incorporating clean energy businesses into the US value chain, (3) Bolster the supply and demand for clean energy R&D personnel

NNI(National Nanotechnology Initiative), which began in 2001 is currently in the 5th implementation stage

- It consists of vision, goals, and program components areas (PCAs), and vision and goals have been maintained without significant changes from 2004 to the current time.
- **(Budget)** Over $1.5 billion (approximately 1.8 trillion won) has been invested annually since 2013

Implemented as a linked policy for departmental projects rather than as an independent R&D program

- Nanotechnology is a core base technology that can drastically enhance the competitiveness of the manufacturing industry, and accordingly, it is recognized as a key for enhancing the industrial competitiveness of the US.
- NNI also acts as a blueprint that presents directions for nanotechnology-related R&D efforts that different departments are carrying out.

Implementation through five PCAs

- The five PCAs are (1) Signature initiatives and grand challenges of nanotechnology (2) Fundamental research (3) Nanotechnology-enabled applications, devices, and systems, (4) Research infrastructure and instrumentation, (5) Environment, health, and safety.
  - PCA2 (Fundamental research) has continuously been emphasized from the beginning of the NNI and accounts for the highest budget allocation (approximately 40% of the total budget).
- In the 5th NNI, infrastructure for data storage, sharing, and usage emerged as a new issue.

China

▶ Overcoming US-China trade war through strengthened investments in advanced science and technology, including nanotechnology, while also establishing itself as a modernization powerhouse by 2049 (100th anniversary of the establishment of New China)

The "14th Five-Year Plan(2021-2025)," which is a key national plan, has the goal of realizing modernization of socialism, with a "dual circulation strategy focusing on demand within South Korea" as the basic economic operating principle

- **(Dual circulation strategy)** Development of South Korean market by identifying new demand and establishing an independent supply chain.*

* Promising industries: Increase in demand is forecasted for the digital economy, eco-friendly industries, silver economy, and untact industries

With the goal of establishing a science and technology powerhouse by 2035, the 14th Five-Year Plan focuses on self-reliance and self-strength in science and technology with priority on science and technology innovations

- The Ministry of Science and Technology presented eight strategic directions* for enhancing science and technology capabilities.
  * 1) Enhance the ability to systematize science and technology innovation, 2) establish national strategic science and technology capabilities, 3) strengthen fundamental research, 4) enhance corporate technology innovations, 5) improve science and technology innovation system, 6) science and technology HR innovation, 7) foster character and academic tradition, and 8) strengthen open collaboration

China is implementing policies for science and technology, including nanotechnology, through the 5-Year Plan, which is the National Mid-to-Long Term Science and Technology Development Plan, and Made in China 2025

- **(Foundational research)** Researching seven major nanotechnology sectors* through the special projects focusing on nano science and technology (National Mid-to-Long Term Science and Technology Development Plan).
  * 1) Controllable manufacturing, auto-assembly, and functionalization of nanomaterials, 2) mechanisms, properties, and control mechanisms of nanomaterials, 3) nano processing and integration principles, 4) nano devices, nano electrical engineering, and nano-bio/medicine in conceptual- and principle-stage, 5) optical, electrical and electronic properties and information transfer of molecular aggregates and biomolecules, 6) behavior and control of single molecules, and 7) molecular machinery and nano metrology
- **(Industrialization research)** Industrialization research is being conducted with the inclusion of nanotechnology in the new materials sector among the ten growth engine industries in the Made in China 2025 policy (science and technology innovation special plan for materials sector).
  - The new materials sector was presented to accelerate alternative materials and improve base materials through the development of advanced new materials and core technologies.
- **(Infrastructure creation)** The 5-Year Plan includes nanotechnology and is being operated by accounting for creating an infrastructure for the entire science and technology sector.
- **(HR development)** HR development is taking place at the individual program level.

Meanwhile, the science and technology innovation plan for the materials sector focuses on qualitative growth with global competitiveness by strengthening basic and original R&D of nanotechnology

- China has been focusing on advanced technology convergence, environment/health/safety, and commercialization based on nanotechnology to promote innovations in the materials sector for the goal of entering a Xiaokang (moderately prosperous) society.

> ▶ **Key technologies in Science and technology innovation plan for materials sector**
>
> 1) Graphene carbon material technology, 2) information and electronics nanomaterial technology, 3) energy conversion and storage nanomaterial technology, 4) nano-bio medical materials technology, 5) traditional industry upgrade and energy saving pollutant emission nanomaterial technology, and 6) nano processing, manufacturing, characterization, safety assessment, standard technology, and equipment

EU

▶ Solving social issues such as a response to climate change and transition to a circular economy through science and technology innovations and use them to enhance industrial competitiveness

Promotion of growth and economic/social impact is expected through "Horizon Europe (2021–2027)"

- A total of 95 billion Euros (over 35% of the total budget) was used to achieve the climate change goals while presenting three directions* with expectations of economic/social impact.

* 1) Improve EU's scientific competitiveness, strive for Excellence Science, 2) support global social problem–solving challenges, strengthening technological and industrial capabilities through clusters, and 3) establish an innovative environment through development of a European innovative ecosystem and knowledge integration (Innovative Europe)

Nanotechnology is a key enabling technology for EU policies, which can enhance industrial competitiveness and pan–national issues, such as promoting the carbon transition

- Nanotechnology promotes growth in five clusters* related to global challenges and industrial competitiveness, enhancement of outstanding scientific capabilities through basic/original research.

* Health, inclusive and safe society, digital and industry, climate, energy and mobility, and food/resources

Japan

▶ In pursuit of science and technology for continued national economic development and improvement in the quality of life of its citizens, convergence and collaboration between nanotechnology and other sectors are emphasized

In the 6th Basic Science and Technology Plan(2021–2025), the nanotechnology materials sector was expanded to strengthen its status as a major advanced technology sector

- Proposed the term "material technology" that encompasses nanotechnology, materials, and devices, presented the "social revolution through advanced materials (material revolution)."

Emphasis on convergence and collaboration with other sectors rather than on the development of nanotechnology itself

- Established a collaboration hub for the consolidation of nanotechnology capabilities at the national level.
  - Established the Tsukuba Innovation Arena (TIA), a world–class R&D and open innovation hub, to serve as a bridge to industries and HR development.
  - With the decreasing trend in people entering the science and engineering workforce, each school has expanded nanotechnology education programs and strengthened international collaboration for developing outstanding technology HR.

2 Policy trends in South Korea

▶ Develop future original technologies using nanotechnology, an advanced technology, and at the same time, demand responses to issues such as self-reliance of material/component/equipment technology, system semiconductor development, and carbon neutrality

(The 4th Basic plan on Science and Technology) Proposed new science and technology innovation and challenges as a sub-task, including contents related to the quality of life of its citizens

- Emphasize on upgrading science and technology capabilities for future challenges, create active science and technology innovation ecosystems, create jobs in new industries based on science and technology, realize happy life through science and technology, and apply science and technology innovations in various fields.

(COVID-19 pandemic) Due to COVID-19 that has affected the world since the beginning of 2020, there has been an explosive increase in the number of confirmed patients and deaths, with diagnostic equipment, therapeutics, and development and distribution of vaccines as a global hot topic, the astronomical economic effect is expected from early market capture

(Self-reliance of material/component/equipment technology) To make the leap as a global powerhouse in material/component/equipment by turning a crisis into an opportunity, implemented a response to global supply chain restructuring and early positions in future markets

- **(Strengthen material/component/equipment industrial competitiveness)** Expanded core items to respond to global value chain (GVC) for material, component, and equipment, and overcome the export restrictions of Japan.
  - From 100 items in the existing six major sectors (semiconductor, display, automotive, electric/electronics, machinery/metal, and basic chemicals), items have been expanded to 338 from new industrial sectors, including the Big Three (system semiconductor, bio, and future car), environment/energy, and SW/communication (material/component/equipment 2.0).

- **(Upgrade material/component/equipment R&D)** In addition to developing an expanded line of core products within a short period to stabilize the current supply chain, implemented super-gap R&D and proactive identification of future-leading products for the creation and early presence for mid-to-long-term future supply chain.

(Develop next-generation intelligent semiconductors) Pursued securement of key enabling technology for next-generation intelligent semiconductors to respond to future demand and take an early position in new markets

- Total project costs approximately 1.01 trillion won which will be invested over ten years (2020–2029) for next-generation intelligent semiconductor technology development projects, including AI semiconductors, advanced semiconductors for major industries, low-power/ high-performance new devices, and atomic-level micro-processing technology.

(Science and Technology Future Strategies 2045) Presented science and technology challenges that would contribute to human society and enhance life and economic growth from a macroscopic view

- Three future visions and eight accompanying science and technology challenges, such as (1) a safe and healthy society (2) abundant and convenient society (3) fair and non-discriminating communication/ trusting s and (4) South Korea contributing to humanity.

Science and technology for resolving future issues (Big Questions)

Future visions	Big Questions	Science and technology challenges
Safe and healthy society	(Nature) How to cope with external factors that threaten humanity?	Coping with threats to the survival of humanity, such as climate change, disasters, and infectious diseases
	(Pollution) Can humanity sustain civilization and allow it to be prosperous without polluting the environment?	Assurance of sustainability for responding to environmental pollution, such as waste and radiation
Abundant and convenient society	(Health) Up to what age can humans lead a healthy life?	Realization of healthy life by next-generation bio/medical technology
	(Ability) How far can science and technology advance the physical and mental abilities of humanity?	Complement and expand the physical and mental abilities of humans
Fair and non-discriminating communication/ trusting society	(Resources) Will humans continue to have access to things necessary for survival?	Agriculture and fishery/manufacturing/energy innovations in preparation for resource depletion
	(Mobility) How far will living areas extend, and how much more convenient will travel be?	Realization of life in space and safe and convenient travel
South Korea contributes to humanity	(Communication) Where and how will humans communicate?	Various communication methods and reliable network
	(Expansion) How far will humanity's areas of activity expand?	Pioneering unknown space to secure new living areas
	Face the main issues of basic science that serves as the basis for resolving the challenges mentioned above	

(Korean Green Deal) In pursuit of carbon neutrality (Net-zero), acceleration of conversion to a green economy and transition of science and technology and industrial policy directions toward low carbon/eco-friendly policies

- Establishment of eco-friendly energy infrastructure, such as a "green energy dam," that serves as the foundation for energy savings, environmental improvement, and diffusion of renewable energy.
  - Green conversion of urban/space/living infrastructure, diffusion of low-carbon/distributed energy, and establishment of a green industry innovation ecosystem.

Opinions of nanotechnology opinion leaders

▶ Nanotechnology opinion leader researcher conferences (five sessions)

- Holding conferences and listening to visions in nanoscience and technology with heads of IBS in nano sectors

※ Vice chancellor of POSTECH and heads of IBS Center for integrated nanostructure physics, IBS Center for nanoparticle research, IBS center for nanomedicine, and IBS center for nanomaterials and chemical reactions

(R&D) Nanoscience and technology are expected to be most impactful in bio and energy/environment sectors

- **(Bio)** Infectious disease response and early diagnosis of dementia

※ Nanotechnology responds to keywords, such as early diagnosis, rapid diagnosis, and mass diagnosis

- **(Energy)** Batteries

※ Nanomaterials already account for a significant portion of materials used in lithium-ion batteries, and subsequent technological innovations will also be possible through nanomaterials

- **(Environment)** Carbon dioxide reduction and recycling

※ Relatively inadequate research activities by nano researchers in South Korea despite the social importance

(Commercialization) Need to accumulate successful cases of commercialization through nanotechnology

- It is important to accumulate successful experience in a small market of approximately 10 billion won based on the discovery of nano-enabled killer applications or nano- enabled products,* which is the key to nanotechnology

* (CNT case) Research groups still hold on to their dreams about semiconductor devices, whereas others have successfully entered the secondary cell electrode materials market

- Need differentiation for technology commercialization strategies based on industry type*

* (Energy/semiconductor) For industries that are already mature, collaboration with leading companies in that field is important, with a suitable technology transfer-based commercialization strategy.
(Bio/medical) Sectors without medium and large corporations need to be provided with an environment to allow as many start-ups as possible to be launched

3 SWOT analysis of nanotechnology in South Korea

	Opportunities	**Threats**
	• Increased demand for strengthening the strategy of science and technology for social challenges resolution, 4th industrial revolution, and self-reliance of material/component/equipment • Acceleration of R&D convergence and integration between technologies and industries • Establishment and use of open research data platforms	• Challenges on health, climate, and environment such as COVID-19, carbon neutrality task, etc. • Decrease in school-age population and science/engineering professionals due to low birth rate and population aging • Concerns over safety of nanoproducts
Strengths R&D: Recognition as a country with global nano-science and technology with excellent journal and patent achievements Industry: Industrial powerhouse with nanotechnology-based semiconductor/display Infrastructure: Posession of a full-cycle nanotechnoloy R&D infrastructure environment	**SO** • Strengthen major industries and resolve science and technology challenges based on nanotechnology research /infrastructure capacity • Accelerate R&D by establishing nanotechnology data platform which is linked with full-cycle research infrastructure	**ST** • Change to a belief that protecting human and nature from hazards such as COVID-19 and carbon emission can lead to economic success such as carbon neutrality • Lead international collaboration and expansion around the globe based on attractive industrial competitiveness and nanotechnology capability
Weaknesses Commerci-alization: Except for semiconductor, inadequate commercialization achievements for application of nano-convergence technology Awareness: Poor understanding on excellence and safety of nanotechnology	**WO** • Respond to the 4th industrial revolution and enhance investment in nanotechnology commercialization to prepare for future material/component/ equipment • Not only converging with ICT, but also collaborate with other fields to enhance impact of NT	**WT** • Establish a mid- to long-term nanotechnology development strategy(roadmap) to select promising industries for sustainable economy after semiconductor • Enhance awareness of the nation on safety and effectiveness of nanotechnology

4 Implications

▶ Conclude the past quantitative development made with bold and challenging investment, and need to move forward to create actual achievements by technological innovation and qualitative advancement

R&D Utilize quantitatively accumulated nanotechnology capabilities in qualitative advancement

- Successfully complete quantitative growth achieved through bold and aggressive investments during the fast follower period and establish a paradigm as a first mover.
- Maximize the use of nanotechnology by taking full advantage of its strengths and characteristics as a general-purpose technology to allow it to make definitive contributions to the advancement of other technologies and industries.
  - Self-reliance of material/component/equipment technology, develop foundational technology in non-face-to-face age and for overcoming infectious diseases, actively participate in resolving key global issues, such as carbon and energy issues.
- Continued expansion of R&D investment for maintaining and advancing world-class nanotechnology capabilities.

Industrialization In need of a supporting program to develop key technologies for industrialization and drive R&D achievements toward technical commercialization and an overall ecosystem for industrial innovation

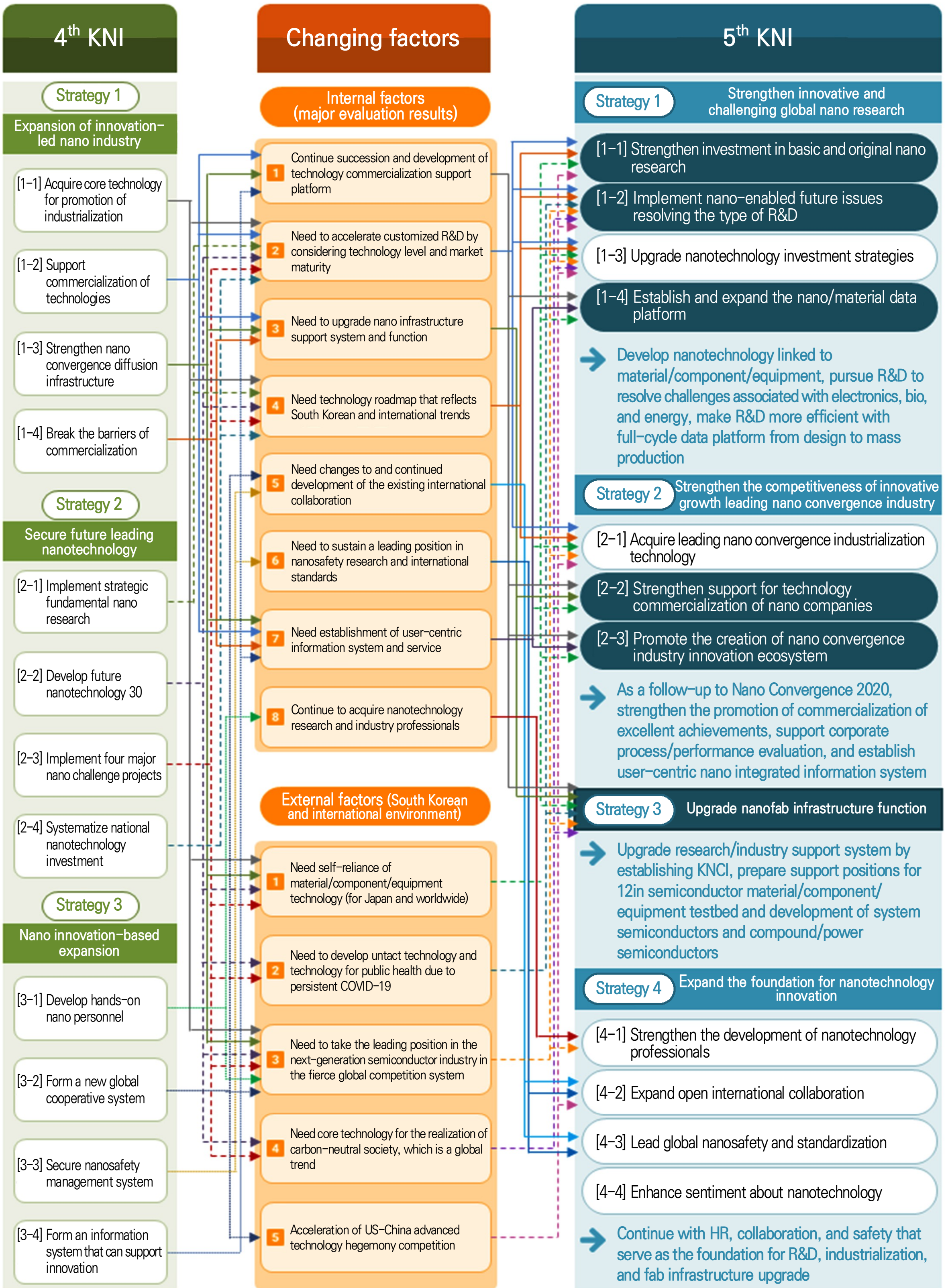
- Identify and develop future core industrial technologies that are difficult to resolve without nanotechnology.
- Need to operate a full-cycle supporting system that can overcome barriers at each commercialization stage, such as additional R&D, BM development, and demonstration.
- Establish a systematic supporting ecosystem to identify future industrial demands and provide information about corporate activities.

Nano infrastructure Need to enhance the infrastructure in order to support not only R&D in universities and government-funded research institutes, but also to support diverse demands in industry-university-research institutes such as product development by companies

- **(Fab facilities)** Establish and support service system and fab facilities exceeding basic requirements in each region to handle nationwide nano research and industrial demands.
  - In particular, establish a strategic and dynamic response system for material/component/equipment and semiconductor sectors, which are parts of government policy agenda.

- **(Expansion of foundation)** Strengthen HR development, which is the foundation for research and industrial advancement, expand various methods of international collaboration that are suitable for the economy and the level of science and technology in South Korea.
  - Active response to issues regarding nano product safety and standardization, which are gradually becoming greater issues.

Note 1 Changes relative to the 4th KNI



※ Among tasks or stratrategies in the 5th, Navy-colored part is the major change or emphasized part.

PART

Ⅳ

Vision and Goals

IV Vision and Goals

Vision

Lead global future society with nanotechnology innovation

Key goals

Secure competitiveness of global future leading nanotechnology (2030)

- Nanotechnology level of 93% relative to the world's best (85.7% in 2019)
- Acquired 20 world's top class original technologies

Leap forward as a global leader in nano convergence industry (2030)

- Nano convergence industry revenue: 200 trillion won (143 trillion won in 2019)
- 1,500 nano convergence companies (809 in 2019)

Strategic projects

Reinforce creative/challenging and globally-leading nano-research

1. Increase investment in nano fundamental and original research
2. Promote nano-based future-resolving R&D
3. Enhance nanotechnology investment strategies
4. Establish and expand the nano/material data platform

Reinforce competitiveness of innovative growth-led nano-convergence industry

1. Develop nano convergence industrialization technology in advance
2. Enhance support for technology commercialization of NT companies
3. Promote foundation of an innovation ecosystem for nano-convergence industry

Enhance the function of nanofab infrastructure

1. Enhance the supporting system for nanofab infrastructure
2. Enhance the supporting function for nanofab infrastructure
3. Create a nanofab infrastructure innovation and mid-to long-term development strategies

Expand the infrastructure for nanotechnology innovation

1. Reinforce nurturing of nanotechnology professionals
2. Expand international collaboration through open innovation
3. Lead international nanosafety and standardization
4. Enhance awareness of the nation on nanotechnology

※ (Original technology) As a technolgy with original, innovative and unique feature, technologies that meet criteria for science and technology innovation(journals within top 5% in JCR) and industrial innovation(AA class patent registration in SMART INDEX and technology transformation over 500 million won advanced payment).

Development indicators | Quantitative goals for nanoscience and technology and industrialization

Science and technology development indicators

	2020	2025	2030
Nanoscience and technology level	85.7%	90%	93%
R&D investment from the government in nanotechnology field (percentage compared to total R&D investment)	699.4 billion won (3.4%)	1.2 trillion won (4%)	1.5 trillion won (4%)
Number of core researchers	12,007	16,000	19,000
Number of patents registered in USPTO	1,121 (Top three in the world) 5,298 (2015-2019 cumulative)	1,300 (Top three in the world) 6,100 (2020-2024 cumulative)	1,500 (Top three in the world) 13,200 (2020-2029 cumulative)
Number of the World's best nano-original technologies (2020~2029 accumulative)	-	10	20

Industrial development indicators

	2019	2024	2030
Revenues of nano-convergence products	142.5 trillion won	170 trillion won	200 trillion won
Number of nano convergence companies	809	1,100	1,500
Number of workers in nano convergence industry	152,000	162,000	170,000

※ Target year is the year when the results are tallied, and the subject of the total is the achievement from the previous year.

The 5th Korea Nanotechnology Initiative(2021-2030)

Leading the Global Future

NANO 2030

PART

V

Implementation Strategies and Tasks

V Implementation Strategies and Tasks

1 Reinforce creative/challenging and globally-leading nano research

1.1. Expand investment in nano-fundamental and original research

▶ Expand investment in fundamental research in order to advance nano-science and technology and reinforce development of core and original technology that can contribute to future industry and accommodate current issues in material, component, and equipment

Expand investment size of fundamental research in nanotechnology sectors

- Continue to expand the scale of basic nano research projects to secure challenging future technologies and enhance the level of nano science and technology.
  ※ (2019) Funded 235.1 billion won for 2,459 projects → (2025) will fund 300 billion won for 2,600 projects
- In particular, focus on expanding investments in group fundamental research projects to assure effectiveness and invigoration of creative and innovative fundamental research based on interdisciplinary convergence.
  ※ (2019) Funded 39.9 billion won for 54 projects → (2025) will fund 60 billion won for 75 projects

Develop original technology in advance in order to accommodate future demand

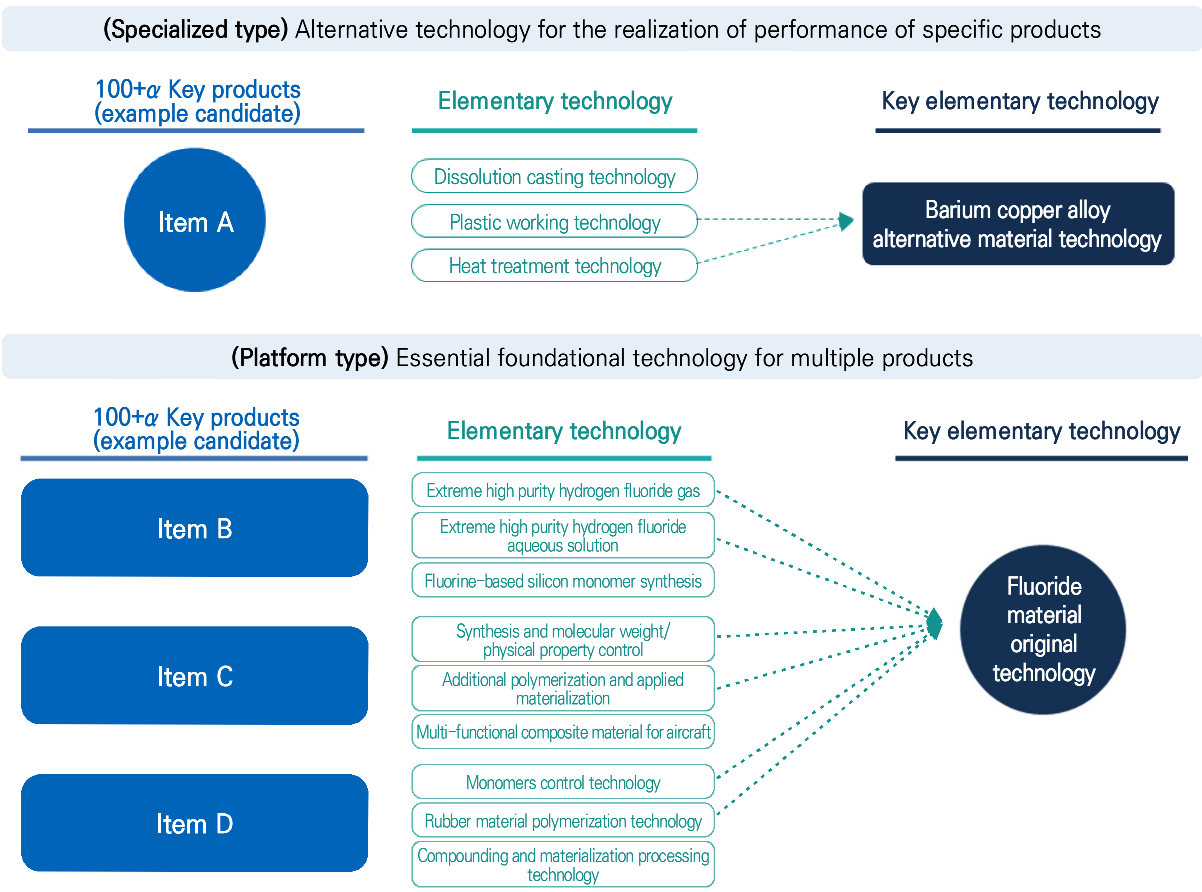
- To prepare for major future society issues after ten years from now,* identify "promising future technologies" in the nanomaterials sector and derive technical challenges in each sector.
  * (Examples) Quantum computing, future displays, green energy, energy storage, biomaterials, recyclable plastics, etc.
- To resolve the technical challenges of promising future technologies, more than 100 (cumulative) "future technology research centers"* for the nanomaterials field will be selected by 2025, and strategic R&D will be supported.
  * Implement customized project planning for each research project with consideration for technology level and industry maturity.
- Instead of solving short-term problems, adopt the "renewable long-run"* project operation to accumulate long-term original technologies and develop research groups.
  * Move away from the existing method of supporting 3–5-year projects, evaluate the excellence and industrial impact of original technology development achievements in applicable sectors to determine whether to continue the support.

Secure key technologies to create a supply chain of material, component, and equipment

- Integrate key R&D items (n=185) for early position and creation of global supply chain of material/component/equipment sector to support nano-based core technology development.
  ※ Major industries (five sectors): Semiconductor, display, electricity/electronics, automotive, and machinery/metal New industries (four sectors): Future materials, biology, green energy, and non-face-to-face digital

- Expanded designation of "National Core Material Research Groups" based on the IAR (industry-academia-research) collaboration model (32 in 2020 → 100 in 2025, cumulative) and expand research achievements through inter-ministerial running relays and running together.
  - Implementation of securing original technologies in specialized and platform types for self-reliance of key products with public research institutions, universities, and corporations forming a single team.
  - Analyze intellectual properties (IP) in applicable field before embarking on research and provide strategic IP R&D once research begins, including a technology acquisition strategy and design to avoid patents belonging to other parties.
  - Develop materials and packages that include applying the developed materials and components system and setting a goal of completing technology transfers (1 billion won for each research group) within the research period (five years).

Type of support for National Core Material Research Groups



Develop professional research committees in the nanotechnology field

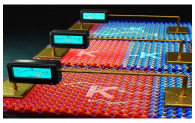
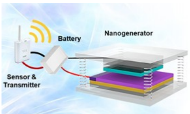
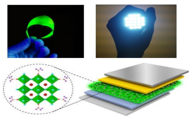
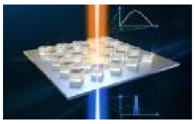
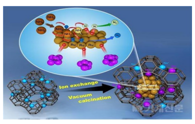
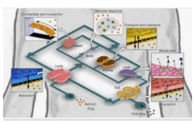
- Operate "Expert Research Committees for Nanotechnology Sectors" with participation by a large group of intellectuals, including IAR(industry–academia–research) experts, for systematization of the process of identifying research topics in nano sectors.
  - Avoid the method of identifying research topics proposed by a small number of researchers and constantly reflect the needs in the research field in an open format, including holding open workshops.

Technology needs survey and research topic selection methods

Type	Current status	Improvement
Technology needs survey	Personal interest of researchers being submitted as technology needs	Reflect the opinions of various experts, in addition to the person(s) proposing research, through expert research committees
Research topic selection	Research topics selected by a small number of experts	Make the final selection by gathering opinions from researchers in applicable fields through open workshops

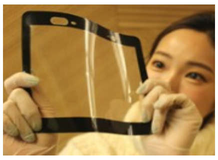
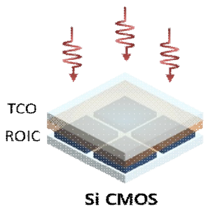
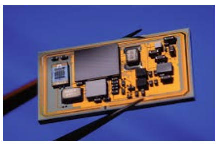
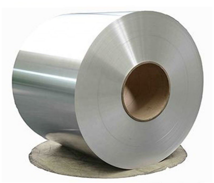
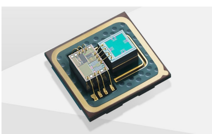
Promising future original technologies (examples)

▶ Develop world class original technologies based on national nanotechnology roadmap and future materials' original technology acquisition strategies that are in sync with future nanotechnology trends (four major sectors)

Sector	Original technology		Technology overview (applicable fields/strengths and characteristics)
New IoT		Valleytronic device for quantum computing	- Used in quantum computing as the valley hole effect appearing from 2D nanomaterials that could be used to store binary information and superimposed quantum information
		Autonomous power for smart mobility sensor networks	- Stably supply power to wireless sensor modules by harvesting surrounding micro-energy using nanomaterials and nano structures
		Perovskite light-emitting material and device for next-generation displays	- Promising technological alternative that can satisfy the REC2020 standard, the next-generation high-performance display standard, and has superior optical properties compared to existing OLED
		Complex light modulator dynamic metamaterial for holograms	- Dynamic metamaterial that enables high-definition, wide viewing angle holograms with nanostructures that can be controlled in real-time
		High-power, high-radiation, ultra-high frequency material for next-generation communication	- New material that has the characteristics of low signal loss, high heat dissipation, and low dielectric properties that can overcome the physical limitations of conventional materials that will be used for 6G communication
Green energy		Nano catalyst material for ammonia fuel cells	- As a fuel cell catalyst material that enables the direct application of ammonia as fuel, which can overcome the problem of using pure hydrogen with existing fuel cells
		Non-toxic photoelectrode for high-efficiency hydrogen production and separation	- Based on a nano catalyst with assured stability, sunlight could be used directly to produce high-purity hydrogen without by-products
Public safety		Broadband infrared sensor material for hyperspectral imaging	- Near/short/medium wavelength infrared (IR) band-detecting epi substrate material based on compound semiconductors, which could be used for new identification and analysis, including lipid composition analysis, crop/vegetation distribution, gas leak monitoring, and marine pollution
		Dynamically bonded crosslinked polymer material and process for recycling waste plastics	- Recovery of monomers through repetitive shape changes, recycling, and decomposition is possible without losing excellent physical properties and chemical stability of existing thermosetting resins
100 years of healthy life		3D artificial tissue material	- Can be used in the development of various medical devices based on the materialization of 3D artificial tissues, including blood vessels, to enable in vitro evaluation of implantable medical devices
		Intractable disease targeting digital therapeutic/feedback sensor integration system	- Artificially controlling bio-signals based on nano processing and materials technologies to treat intractable diseases and receive immediate feedback on the efficacy of therapeutics to maximize the efficacy of digital therapeutics

Original technologies linked to key products (examples)

▶ For securing core technologies linked to major industry products, provide support as classified by (1) specialized type (alternative technology for realizing the performance of specific products) and (2) platform type (foundation for performance enhancement of multiple products)

<table>
<tr><th>Sector</th><th colspan="2">Original technology</th><th>Technology overview (applicable fields/strengths and characteristics)</th></tr>
<tr><td>Semiconductor</td><td></td><td>Medical semiconductor laser core material</td><td>- Development of laser light source material based on compound semiconductor optoelectronic devices for medical devices</td></tr>
<tr><td>Display</td><td></td><td>Roll-to-roll glass for next-generation displays</td><td>- Development of high-impact, high-hardness flexible transparent sealing film with the flexible display substrate</td></tr>
<tr><td>Automotive</td><td>
</td><td>Key components in hazard-detecting automotive, optical sensors</td><td>- Development of broadband optical module and high-sensitivity optical detection sensor for autonomous vehicles</td></tr>
<tr><td>Electricity /electronics</td><td></td><td>High heat dissipation, low-loss multilayer heat-dissipation circuit board</td><td>- Development of millimeter wave-compatible printed circuit boards and component packages for next-generation electronic devices</td></tr>
<tr><td>Machinery /metal</td><td></td><td>Aluminum material for transport equipment</td><td>- Development of aluminum plate using structural control and alloy design for next-generation transport equipment (automobile and aircraft)</td></tr>
<tr><td>Basic chemicals</td><td> </td><td>Plastic biomass natural polymer</td><td>- Development of high-performance natural polymer plastics based on biodegradable and recyclable biomass for eco-friendly vehicles</td></tr>
<tr><td>Environment</td><td></td><td>High-performance gas sensor for hazardous environment monitoring</td><td>- Development of high-sensitivity sensing materials and sensor materials based on nanomaterials for air pollutants and nitrogen oxide detection sensors</td></tr>
<tr><td>Energy</td><td></td><td>Large-area perovskite technology for next-generation solar cells</td><td>- Manufacturing of solar cell-alternative silicon perovskite wafers and solar cells for high-efficiency, high-safety solar cells</td></tr>
</table>

1.2. Promote nano-based R&D that can resolve future issues

▶ Identify R&D topics and promote programs that can provide solutions for major social and economic issues with nanotechnology as a technical solution.

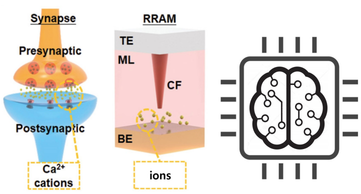
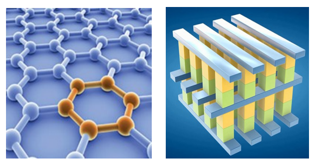
❯ Promote invention of nano-electronic device technologies, which is essential in the untact era

- For the realization of ABC (AI, big data, and cloud) technologies, which are keys to digital transformation, develop nano device technologies that can overcome the limitations of existing electronic devices (power consumption, performance, etc.).

※ Implementation of next-generation intelligent semiconductor technology development (new devices) projects (MSIT)

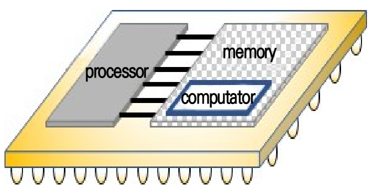
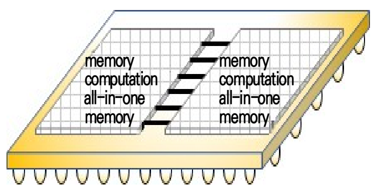
- Link efforts to develop original technology for ultra-low-power, high-performance nano devices to realize AI and wafer-level integrated verification technology.

① Next-generation intelligent semiconductor technology and applicable fields

Nanotechnology-enabled intelligent semiconductors	Next-generation ultra-low-power, high-performance nano devices
	
Cloud data center, PC, IoT, and robotic devices that perform AI computations at ultra-high speed and low power	Next-generation memory and logic semiconductors, next-generation sensors, and biochips

- Secure a core technology for new-concept semiconductors (processing in memory, PIM) with the integration of memory and computation (processor), which is a new paradigm in semiconductors.

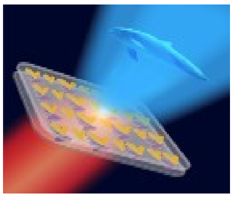
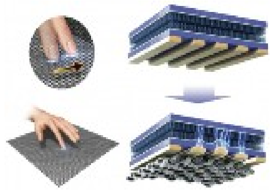
② Memory/computation integrated semiconductor technology and applicable fields

Memory-computation integrated near-memory computing	Memory-computation all-in-one in-memory computing
	
Fields related to computation-intensive AI, hardware-based AI systems	Next-generation AI system beyond von Neumann structure that needs to overcome hardware limitations

- Development of high-sensitivity, low-power nano sensors and driving technology that allows the realization of virtual/augmented reality* for non-face-to-face or untact recognition and control.

  * (Examples) Simulates not only sight and hearing, but also touch, taste, and smell

③ Nano sensors and driving technology for the realization of virtual/augmented reality and applicable fields

Nano meta technology for the realization of virtual/augmented reality	Nano tactile sensor technology
	
Virtual/augmented/mixed reality device displays, hologram displays, 3D game consoles	IoT sensors, artificial prosthetics, robots, and wearable sensors

Promote the development of nano-biotechnologies to be ready for pandemic and aging society

- Development of nanotechnology-enabled high-sensitivity, rapid on-site diagnosis, and patient-tailored therapeutic technologies for responding to infectious diseases (pandemic) and aging- related diseases.

  ※ Link to technology development in the nano-bio sector within the pan-ministerial dementia R&D project (2020-2029) and full-cycle medical devices R&D project (2020-2025).

- Implementation of nano-bio R&D convergence to upgrade the completeness of original technology for increasing the acceptability of nano convergence technology in the bio industry and promoting technologies needed to overcome infectious diseases.
  - Prototype* manufacturing and efficacy assessment/verification based on nano-bio original technology.

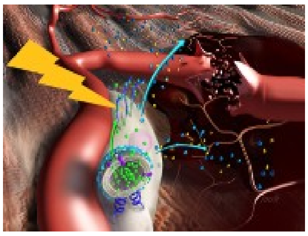
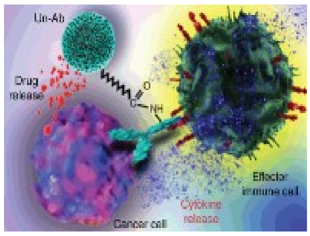
  * In forms of material/component/equipment for verification of technology performance efficacy

Development of demonstrative original technology in the nano-bio sector

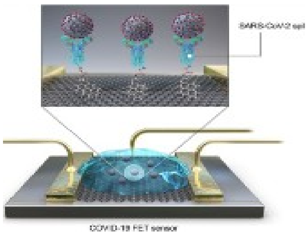
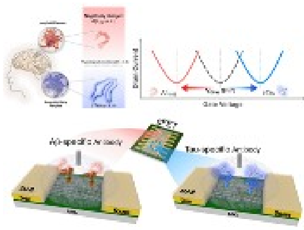
- **(Goal)** Enhance the industrial acceptability of nano-bio original technology and contribute to the promotion of commercialization
- **(Content)** Support demonstration projects for research topics applicable for technology industrialization through efficacy testing and assessment of applying nanotechnology in bio industry (technological demonstration and entering TRL6)
- **(Scope)** Medical field: diagnosis and treatment/Non-medical field: analytical process, household goods, environment, and agro-fishery foods
- **(Method)** Hosted by technology suppliers (researchers) + participation by technology consumers (corporations) → Link to transfer of outcomes

Nano-bio connect technology (examples)

① Nano-bio materials for ultra-sensitive rapid diagnostics, theranostics devices, and beauty/household products and application fields

Rapid diagnostic nanomaterial	Theranostic nano-bio material
	
Disease diagnostic sensors, antiviral/antibacterial materials	Early diagnosis and treatment of cancer, diagnosis, and treatment of vascular diseases

② Nano-bio sensor/components for checking health anytime, anywhere, and applicable fields

COVID-19 diagnostic nano-biosensor	Semiconductor device/ sensor for early diagnosis of dementia
	
Rapid on-site diagnosis of COVID-19 variants, simultaneous diagnosis of various infectious disease-causing viruses	Early diagnosis of dementia and Parkinson's disease with a single drop of blood

③ Safety, multiple analysis of environmental hazards, high value-added biochip realization process equipment

Food and atmospheric hazard detection equipment	High-precision analysis biochip realization process equipment
	
Food safety analysis equipment, on-site detection equipment for super bacteria and mold	Fluorescence analysis biochip equipment, environmental hazard analysis process equipment

Promote technology development of nano-green energy source for sustainable future

- Integrate with carbon-neutral policies that have transitioned from "adaptive reduction" based on greenhouse gas reduction to "proactive response" to new economic and social systems.
  - Develop nano green energy source core technology that can contribute to implementing a "carbon-neutral R&D strategy," including convergence/innovations using renewable energy, CCUS, and ICT.

- Develop nanotechnology-enabled new energy resource technology that can contribute to minimizing carbon emissions in the entire process from energy/resource production to consumption.

Development of Carbon Zero^2 nanoenergy technology

- **(Background)** ① Energy source is eco-friendly, but there are many elements that are not eco-friendly when considering the entire process from production to disposal of energy devices, ② Also need to develop new energy sources that can fundamentally solve environmental pollution, and ③ need to transition to a concept of "Net Zero Carbon" prioritizing environment, instead of optimizing cost-effectiveness
- **(Content)** Nanotechnology-enabled innovative new energy original technology that reduces carbon emissions or post-energy technology which can produce resources needed by using natural energy

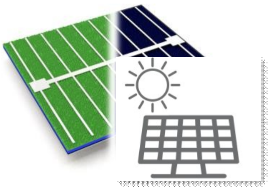
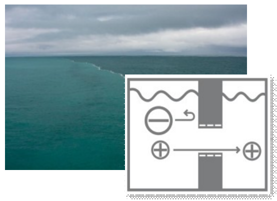
  ① New technology that drastically reduces current carbon emissions level or has no carbon emissions throughout the series of processes involving production of energy conversion equipment-energy conversion-energy use-equipment disposal

  ② Develop new production technology that can secure essential resources without using fossil fuel-based energy sources

  ③ Verification of new energy original technology that is based on AI which can harvest energy from natural circulation system

Nano green energy technology (examples)

① Green energy generation technology using eco-friendly material

Post-silicon solar cell nanomaterial	Natural material nano-ion separation membrane for seawater power generation
	
Eco-friendly energy generation system	Seawater power generation system

② New-concept technology that can be used to obtain necessary resources/environment without an external energy source

Collection and purification of clean water using natural energy	Cooling and heating technology using natural energy
	
Supply drinking water to water-scarce countries	Zero energy buildings

③ New energy original technology that can harvest energy from the natural circulation system

Atmospheric H_2O-based power generation nanomaterial/device	Atmospheric hydrogen capturing nanotechnology
	
Portable small power source	Hydrogen energy generation

1.3. Enhance the strategy for investment in nanotechnology

▶ Strengthen national nanotechnology R&D investment strategy by constructing a nanotechnology classification system and a mid to long-term roadmap reflecting international technological/industrial trends.

Establish the 4th National Nanotechnology Roadmap to enhance nanotechnology strategy (first half of 2023)

- Establish a nanotechnology roadmap that considers national strategies* by major sector linked to nanotechnology, South Korean and international technology trends, the direction of advances in future technologies, industrial demands, and global issues.

  * Major research and industrial sectors, including material/component/equipment, semiconductors, ICT/ convergence, carbon neutrality, and bio/medical

- Upgrade nanotechnology investment strategy by establishing a national nanotechnology roadmap that enhances the connection between the rapidly changing internal and external environment and the national classification system (NTIS).

The direction of establishment of the 4th national nanotechnology roadmap

- **(Rationale)** Establish every five years in accordance with Article 6 of the Act on the Promotion of Nanotechnology and Article 5 of the Enforcement Decree of the same act
- **Direction of establishment**

  ① Secure adaptive technology strategy by reflecting changes in the internal and external policy environment in the technology roadmap.

  - Identify promising items among nanotechnology-enabled future material/component/ equipment (future-leading products), present topics linked to Green New Deal, "Carbon Neutrality by 2050," and promising nanotechnologies to prepare for post-COVID-19.

  ② Enhance policy utilization by reorganizing the nanotechnology classification system linked with NTIS.

  - Confusion in investment and performance analysis related to nanotechnology due to disagreement with current NTIS classification.

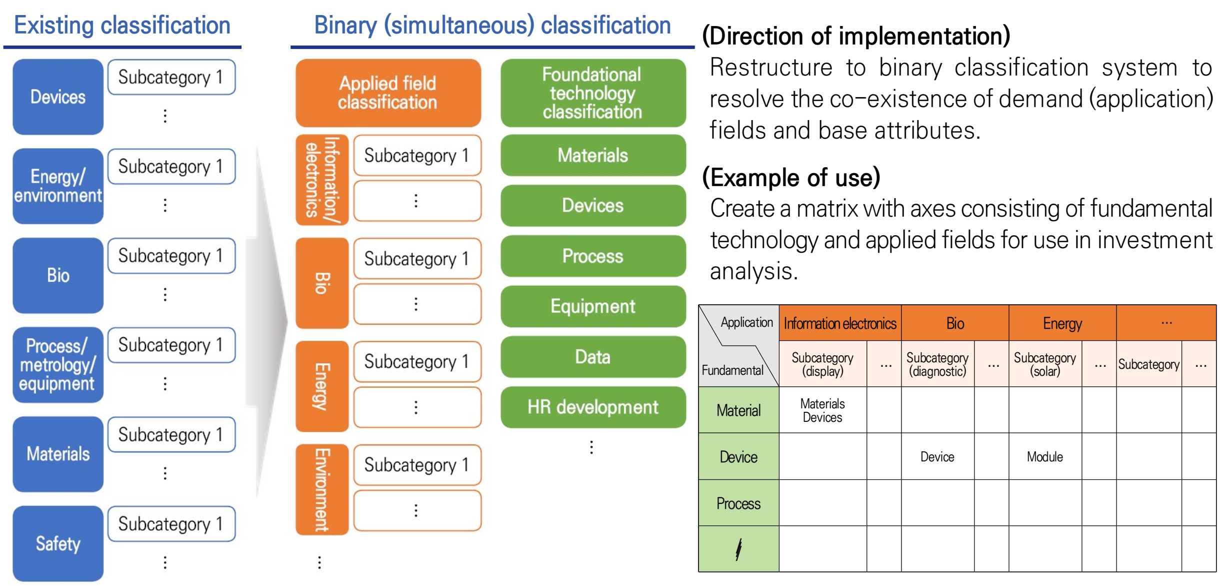
Overview of 1st–3rd national nanotechnology roadmaps

Type	1st national nanotechnology roadmap (2008~2017)	2nd national nanotechnology roadmap (2014~2025)	3rd national nanotechnology roadmap (2018~2027)
Charact-eristics	- Development of detailed technology roadmap based on quantitative indicators for 47 sub-classified technologies in four major technology fields	- Identify core nanotechnology and develop a technology roadmap to strengthen industrial competitiveness and respond to demand in the future society - Develop a detailed technology roadmap for 33 sub-classified technologies in six major technology fields	- (Strategic technology roadmap) 70 nanotechnologies for the realization of Future 30 Technologies - (Preliminary detailed technology roadmap) 97 technology roadmap in six major fields that present the direction of future technology development for all nanotechnology sectors
Limita-tions	- List-type technology roadmap	- Limitation in quantitative visualization and organization of technical information	- Limitation in mutual exclusivity with technology classification and linkage with NTIS

Reconstruction of the nanotechnology classification system

- Incorporate characteristics as a fundamental technology and actual application status in research and industrial fields into the classification and apply to the national nanotechnology roadmap.

Improvement in nanotechnology classification (example)



- Incorporate an improved classification system to the NTIS NT classification system* to upgrade nanotechnology investment strategy through efficient government R&D investment and analysis of achievements.

* The current NTIS NT classification system was established in 2001 and has remained unchanged for the past 20 years

Proposed improvement to the NTIS nanotechnology classification system (example)

NTIS NT classification system (major groups): Existing	NTIS NT classification system (major groups): Changed	National nanotechnology roadmap (preliminary classification)	
Nano device and system	Nano device and system	Application	Nano device
Nano-bio/health	Nano-bio/health		Nano energy/environment
Nano-based/process	Nano-based/process		Nano-bio
Nanomaterial	Nanomaterial	Based	Nano process
	Nano energy/environment		Nanomaterial
	Nano safety		Nano safety

Strengthen the analysis of nanotechnology information and statistics

- **(Establish investment portfolio)** Establish a policy-based investment strategy based on investment and achievement analysis for the entire cycle, from R&D to commercialization.
  - Regularly update analysis of base/original research and commercialization supporting achievements and track survey/analysis on successful and failed cases.
- Adopt and apply multi-faceted and systematic technology prediction techniques, such as data/AI and text mining, for use in technology development and investment strategies in nano sectors.

Overview of 3rd nanotechnology roadmap

3rd national nanotechnology roadmap(2018–2027, confirmed in June 2018)

- **(Background)** Re-emergence of the role and importance of nanotechnology with the arrival of the 4th industrial revolution for overcoming the technological limitations, such as ultra-connectivity, ultra-low power, large capacity, and high functionalization.
  - However, the nanotechnology level in South Korea became stagnant* with commercialization achievements concentrated mostly in the nano electronics sectors** Additionally, large corporations accounted for most of the revenue, while there is a lack of market for SMEs.

* Ranking for the number of SCI articles on nanotechnology: 8th in 2001→3rd in 2013→4th in 2017 (Order: China, US, India, and South Korea)

** Proportion of revenues by sector: nano electronics (90.1%), nanomaterials (7.5%), nano equipment/devices (1.7%), and others (0.7%)

- **(Key content)** Reflecting changes in the South Korean and international environment and direction in policy implementation and considering promising future technologies, (1) establish "strategic technology roadmap (Future 30 technologies, 70 core nanotechnologies) and (2) update preliminary technology roadmap in six major sectors.
  - Preliminary technology roadmap of six major sectors* consists of 26 medium-category technologies and 97 small-category technologies.

* (1) nanomaterials, (2) nano devices, (3) nano-bio, (4) nano energy/environment, (5) nano process/metrology/equipment, (6) nano safety

Overview of strategic technology roadmap within the 3rd nanotechnology roadmap

Challenge of nanotechnology toward future technology that human dreams of

Direction of implementation: Present preliminary technology roadmap with six major sectors and strategic technology roadmap with 30 future technologies and 70 core nanotechnologies

Process of deriving core nanotechnologies

Derive future technology candidates	Select 30 future technologies	Derive cases with nanotechnology application	Derive performance indicators and final goals	Select core nanotechnologies
demand-based	order of contribution	shaping	feasibility test	70 of 30 future technologies

※ selection criteria for future technologies: ① technologies that can overcome limitations through nanotechnology and technologies that meet technological innovation ② importance and urgency of technology acquisition ③ technological and industrial impact ④ appropriateness as future technology

Convenient and enjoyable life

Development of AI semiconductors, IoT, and future displays with faster, more accurate, and clear characteristics from using superfine nano processes

1. Portable AI at the level of the human brain
2. Big data within my grasp
3. Communication environment with unlimited speed
4. Display that can be reshaped and resized freely
5. Tasting food with a smartphone
6. Cyborgs with human-like feelings
7. Drones that can fly without recharging
8. Electricity generated while walking
9. Batteries that can be worn like clothes
10. Technology for maintaining young skin
11. Mask pack that automatically applies make-up

Living together with the earth

Secure technologies for unlimited clean energy, fine dust removal, and economic water resource production that are highly efficient and unprecedented, using innovative and unique phenomena in nano-sized materials

12. Ultra-high efficiency next-generation solar power generation superior to thermal power generation
13. Fuel cells in preparation for blackouts
14. Cars that run on hydrogen
15. EVs that can travel from Seoul to Busan with five minutes of charging
16. Photosynthesis with artificial leaves
17. Energy-independent homes that do not need an electrical power supply
18. Reusing discarded water
19. Urban farming capable of self-sufficiency

Healthy and safe life

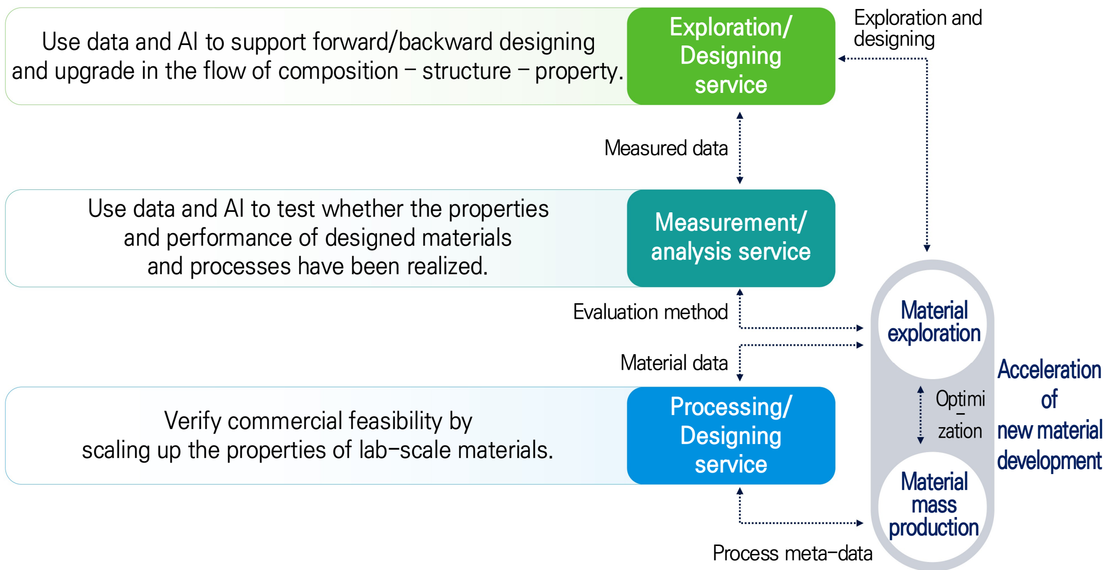
Secure technologies for convenient, accurate, and effective prevention/diagnosis/treatment, safety food, and disaster safety using fast transfer characteristics at the nanomaterial interface

20. Batteries with no risk of explosion
21. Preventive medicine for healthy life up to 100 years
22. Medication that can simultaneously offer diagnosis and treatment
23. Artificial organs with no rejection
24. Technology that allows looking into the body for treatment
25. Check health from anywhere at any time
26. AI system that warns about bad viruses
27. Clothes that block bacteria
28. Air purifiers that always keep the air inside the entire house clean
29. Meals that can be taken as a single pill even in space
30. Mic-robots that can quickly find victims at disaster sites

1.4. Establish and expand the nano/material data platform

▶ With the digital new deal as an opportunity, establish and operate a data platform for the entire cycle from nano/material exploration and design → synthesis/realization → mass production in order to promote efficient R&D.

Schematic of integrated nanomaterial data platform

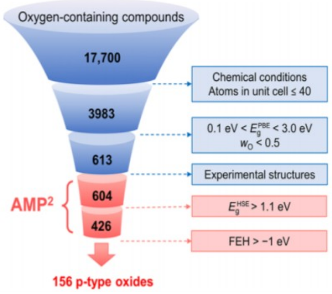


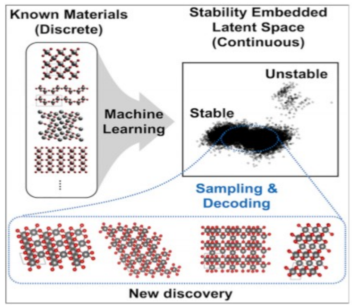
❯ Develop and operate nanomaterial exploration/design services

- Timely prediction and realization (forward design) of correlations among the use of data/AI, composition → structure → properties, and design and upgrade of nanomaterial composition with desired properties (reverse design).
  - Generate and collect specialized DB (components, synthesis conditions, etc.) by industry and sectors that use experimental and computational science-based nanomaterial to explore new materials and upgrade commercial materials.
  - Shorten development time by developing AI exploration and design models and providing services to analyze/predict correlations among composition/process/structure/properties.

Cases of accelerating new material exploration and designs using data

High speed data screening		Exploration of new material through reverse design
Exploration of candidates with p-type semiconductor properties (Chem. Mater. 2019)	Aluminum alloy design for additive manufacturing of space and aviation components	New VxOy material structure design, which is unavailable in the existing DB





Reduce material discovery time by 97%	Fundamental study published in Nature in 2017 which commercialized in two years	99.97% reduction in material discovery and design time

Establish and operate process/design service

- Properties of lab-designed nanomaterials are realized by a scale-up process for rapid verification of commercial feasibility (resolve lab-to-market gap).
  - Establishment of process recipes and verification of commercialization by developing and applying optimal process design solutions and using new research methodologies such as integrated computational engineering, combination experiments, and AI.

(Step 1) Lab-scale experimental verification	(Step 2) Scale-up process	(Step 3) Test bed verification
- Run computational science-based virtual process - Provide lab-scale process parameters	- Explore scale-up direction - Set optimal process conditions	- Optimize AI-based scale-up process - Test bed verification and prototyping

  - Provide corporate technical support* through process optimization modeling and testbed verification with the development of a process optimization solution utilizing simulation in virtual space.

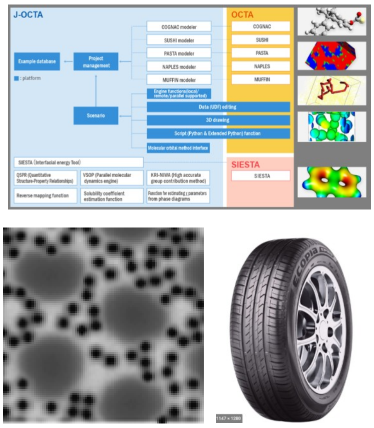
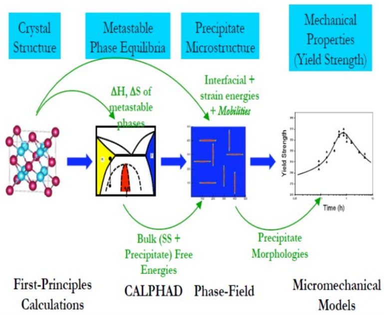
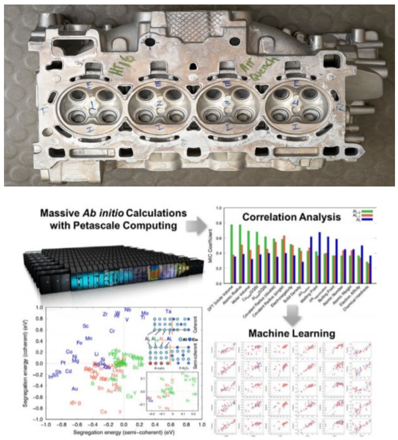
* Computational environment that enables modeling, analysis (structure, heat, fluid, limit analysis, etc.), process prediction, and analysis/assessment

Material innovation AI platform	Virtual engineering platform	Verification and commercialization
- Prediction of physical properties for virtual engineering analysis	- Process optimization (heat and flow analysis) - Component/module optimization (structural analysis)	- Test bed verification and prototyping - Corporate technical support

– **(Link to smart factories)** Material design → Process design and optimization → "Relay" of data and achievements of mass-produced (manufactured) commercial products.

※ Utilization of mid-term AI manufacturing platform (KAMP, Korea AI Manufacturing Platform)

Examples of process development using new research methods

Manufacturing eco-friendly, high-efficiency tires using material property prediction simulation SW platform (Bridgestone, Japan)	Development of automobile engine block manufacturing process using virtual aluminum casting platform (Ford, US)	Utilization of a new Al-Cu alloying method, development of aluminum alloy for automobile engines (OCNL, US)
		
Shortened research period (3 years), saved development cost ($300 million)	Shortened research period (25%), saved development cost ($100 million)	Successful in prototyping next-generation four-cylinder engine

Establish and operate measurement and analysis services

- Verification of whether actual properties and performance were realized through measurement and analysis technology on designed materials and processes using data and AI.
  – Integration and expansion of platforms by making protocols of high-level measurement and analysis skills that some researchers have acquired and possess as standard information items for sharing and using.

Examples of standard information items (protocol): Single-crystal X-ray diffraction analysis

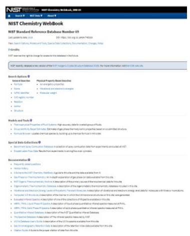
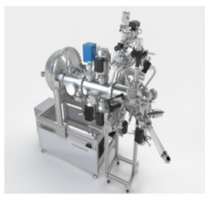
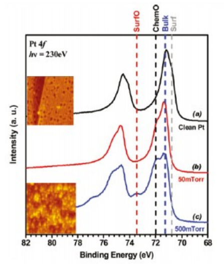
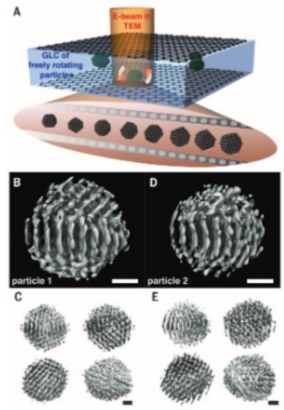
Standard information	Major group	Standard information	Major group
Measurement/ analysis conditions	Sample size/shape	Scope of measurement/ analysis	Inorganics
	Pre-treatment conditions		Organics
	Operating conditions		Organic/inorganic complexes
Data analysis	Program/formula used	Advantages/ disadvantages of analytical technique	Advantages/disadvantages
	Relevant articles/patents	Relevant facilities and experts	Equipment/system status
	Expert analysis skills		Name of institution/name of person/contact information

– Establish human* and physical networks by material, property, and applied field based on the measurement and analysis service platform to provide advice on bottleneck technologies and support the one-stop use of equipment.

* The team of measurement, analysis, and materials experts advises and presents guidelines for analyzing experimental data

– Develop new measurement and analysis technologies that go beyond the limits and enhance the accuracy of property verification through the integration of standards (KS, ASTM, ISO, etc.).

Successful cases of sharing and developing measurement/analysis technologies

Sharing of measurement/ analysis techniques		Development of new measurement/analysis technologies		
A part of Material Genome Initiative (MGI), operate material measurement/analysis information platform (NIST, US)		Identification of catalytic reaction mechanism based on electronic structure measurement technology under atmospheric pressure (JACS, 2011)		Observation of 3D structure of nanoparticles in liquid by TEM (Science, 2020)
			 	
Provide measurement/ analysis information	Standard material DB for chemicals	Atmospheric pressure photoelectron spectroscopy	Real-time redox measurements under atmospheric pressure	
Shortened research period (30%), saved development cost ($200 million)		Verification and application at different stages of process/design possible		Expanded areas of material properties exploration, accelerated development of new materials

2 Reinforce the competitiveness of innovative growth-led nano convergence industry

2.1. Secure leading nano convergence industrialization technology

▶ Develop leading nano-convergence industrialization technology that can actively respond to reorganization of global value chain for materials, components, and equipment, and changes in the structure of future industry.

Develop innovative nano-convergence products which can be linked to new future industries

- Conversion to technology development paradigm for reducing gaps and mismatch between supplier and buyer,* opening nano convergence market as a new promising industry sector with anticipation of new markets.

* Transition from development of unit technologies, such as existing nanomaterials and intermediates, to development of innovative nano convergence products in the form of core components or modules that can be directly mounted on finished products

– Buyers and suppliers for supply and expansion of nanotechnology to various industries, establish a collaboration model and create strategic businesses based on the model.

Nano convergence innovative product/technology development project – Promising new future industries

Nano convergence innovative product/technology development project (MOTIE): 2021-2025, a total of 178.2 billion won

Future car sector

Key components of future cars

- Rare earth metal-free high output, small steering motor
- 11 kW high-efficiency power conversion device
- Plate heater for EV batteries
- Power module driving stability heat dissipation part
- 5G electromagnetic wave shielding/absorbing part
- High safety anti-fog headlights
- Anti-pollution transparent lens for CID
- Realistic, high sensitivity crash pad

Display sector

Next-generation display components

- New flexible nano luminescent device
- Highly stretchable transparent nano electrode
- High performance substrate for touch-input equipment
- 3D freeform touch-input equipment for cars

New energy/environment sector

Carbon neutrality/ fine dust reduction

- High-efficiency, long-lasting secondary batteries
- Nano solid electrolyte secondary batteries
- Lithium metal secondary batteries
- Hydrogen electric vehicle fuel cell module
- Power-generating PAFC electrodes
- Renewable high-efficiency filter media
- Concentrator for ultra-low concentration VOC removal

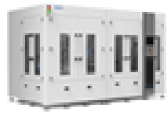
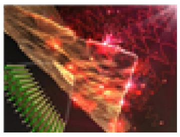
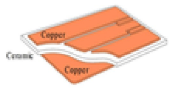
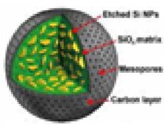
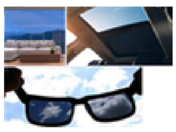
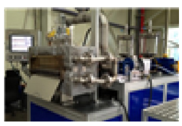
Bio/health sector

Real-time detection sensor

- New/mutated virus detection system
- Flexible/stretchable sensor for multi-monitoring
- Personally-tailored smart diagnostic machine and beauty care cosmetics

- Pursuing identification and planning for “nano convergence next advanced material/component/equipment products” that are expected to create new functions and markets by overcoming performance limitations based on future demand (new).
  - Proactively develop advanced nano convergence material, component, and equipment to anticipate and realize promising future products in new industries and lead the creation of new supply chains.

Next material/component/equipment advanced products/technologies(examples)

Applied industry	Future car sector		Advanced nano material (example)	Advanced nano component (example)	Advanced nano equipment (example)
	Current	2030			
Semiconductors/ display (including sensors)	• Si/compound semiconductors • Flexible (rollable, foldable) display • Micro LED display	• Advanced semiconductors for extreme performance • Highly stretchable display • Nano LED display	Highly stretchable electrode material for highly elastic displays 	Semiconductor devices for extreme environments (e.g. space) 	UV nano imprinter for nano LED 
Electricity/ electronics	• High frequency 5G communication	• Ultra-high frequency 6G communication	Ultra-high frequency electromagnetic  Shielding/ heat-dissipating materials 	High heat dissipation circuit board for 6G power semiconductors 	Atomic layer deposition (ALD) equipment for 6G power semiconductors 
Future cars	• High-capacity secondary battery • Level 2 partial autonomous vehicle	• Long-life, ultra-high capacity, high stability secondary batteries • Level 4 complete autonomous vehicle	Nano cathode material for long-life, ultra-high capacity, high stability secondary batteries 	Ultra-high sensitivity thermal imaging detection device that can operate in bad weather conditions 	Sputtering equipment for nano-coating secondary batteries 
Bio/ healthcare	• Skin diagnosis • Invasive diagnosis • High performance diagnostic system	• Skin regeneration • Non-invasive patch-type diagnosis • Real-time on-site diagnostic system	Nano neosome for improving skin wrinkles and elasticity  Attachable/ detachable bio electrodes 	CNT X-ray light source for digital testing equipment  Ultra-high-speed real-time infectious disease diagnostic system 	3D nanopatterning equipment for molecular sensing biodevices 
New energy/ environment	• Heat shielding film • Simple fine dust removing filters	• Smart color-changing insulating film • Eco-friendly, antibacterial/antiviral high-performance filters	Electrochromic transmittance adjusting smart film 	Antibacterial nanobubble generators 	Nanofiber composite material burn manufacturing equipment for high-performance filters 

2.2. Enhance support for the technology commercialization of NT companies

▶ Promote commercialization of nanotechnology by linking outstanding technology commercialization in the public sector, supporting the entire cycle of product development, verifying new performance, supporting regulatory response, etc.

Strengthen support for the commercialization of outstanding fundamental and original technology in the nanotechnology sector

- Operate close, full-cycle support projects, including BM development, additional R&D, and overcome other obstacles by integrating outstanding nano-based original research outcomes with the commercialization demand of a company.
  - Maximize synergy between public sector R&D capabilities and industrial demand for new product development.
  - Strengthen the function of the commercialization support platform, including BM development for each applied field, company-led autonomous and responsible commercialization, patent and market analysis, attracting investments, and technology consulting.

▶ (Tentative name) Promote of "Nano Convergence Technology Commercialization Support Project"

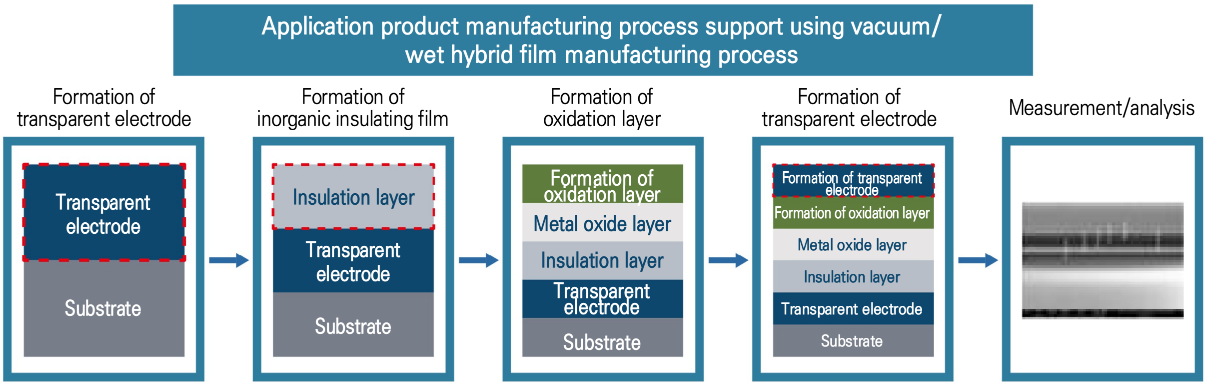
- Enhance opportunities and possibilities for commercialization by strengthening R&D* to demonstrate the efficacy of technologies led by government-funded research institutes(GFRI) and universities that hold laboratory original technologies and introduce many highly refined technologies.

* (Nano connect) Targeting nano application fields, including NT-IT, NT-BT, and NT-ET (pilot operation of eight projects in 2021)

Activate support for the manufacturing process, measurement, analysis, and demonstration of nano convergent products

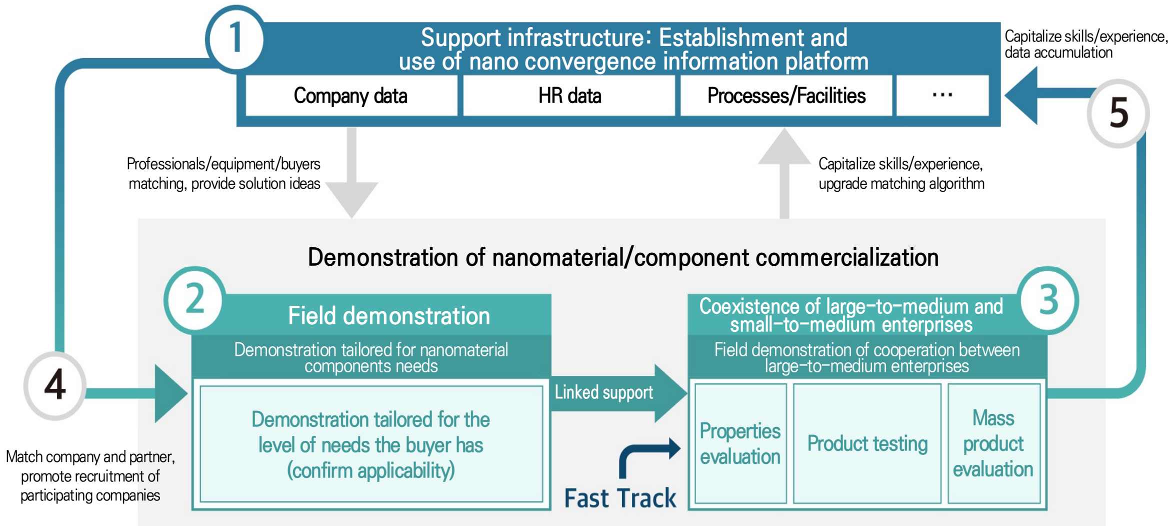
- Active support for companies in demand, including facilities, equipment, HR, and technologies owned by the national nano infrastructure.
  - Provide support from technology development to commercialization, including measurement/analysis (certification) and package manufacturing process combining unit processes for efficient production of finished products.

Support for package manufacturing process and measurement/analysis (example)



- Activation of business creation through product demonstration support, such as developing customized product technology according to the needs of each client, verification, and recognition of reliability and suitability for mass production.

Demonstration support based on demand in the nano convergence field

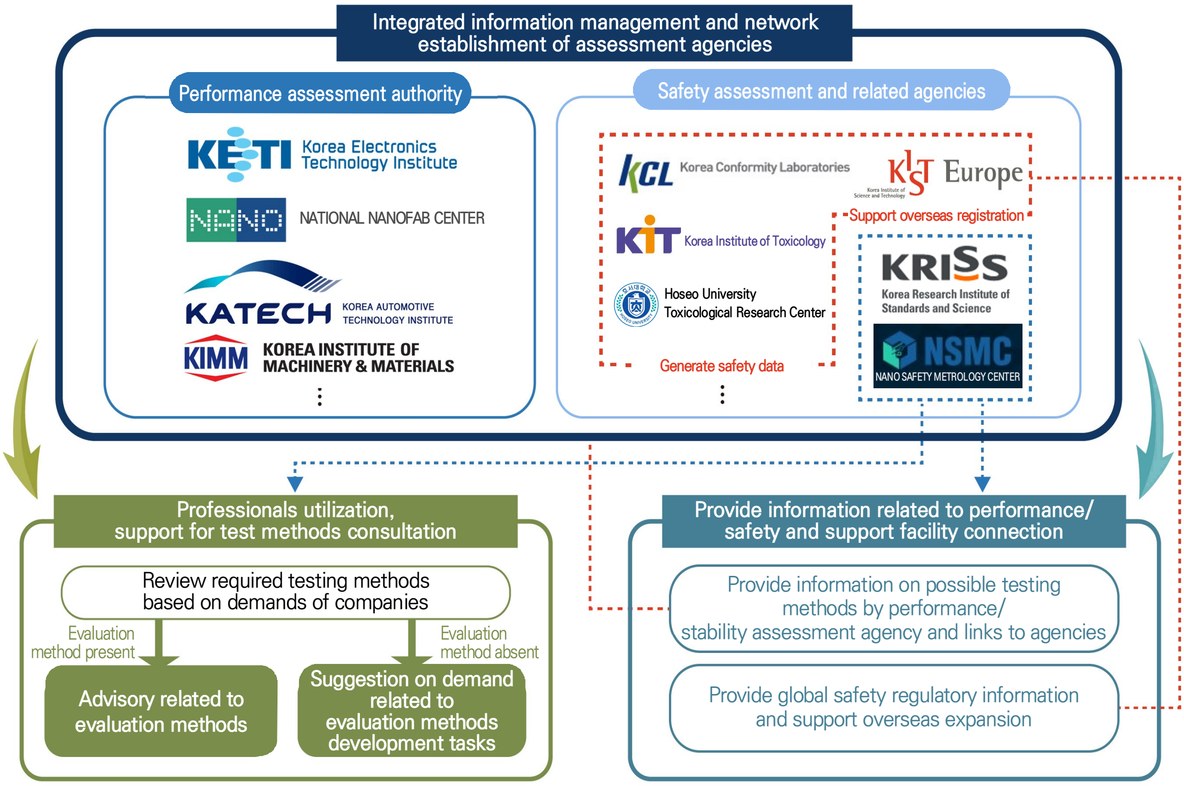


Support performance evaluation and regulatory responses for the commercialization facilitation of nano-products

- Develop performance/safety evaluation methods for nano products and operate corporate support system to promote the entry of nano SMEs into South Korean and overseas markets and provide global regulatory response support.
  - Support development and dissemination of publicly trusted performance evaluation methods* that can be commonly used.

* Develop and disseminate at least 30 unobtained performance/safety evaluation technologies by 2025.
※ Pursue approximately 9 new/on-going projects each year (each project: 2–3 years and 400 million won/year).

Corporate support for nano performance/safety evaluation



2.3. Promote the creation of an innovative ecosystem for the nano-convergence industry

▶ In order to facilitate the creation of a nano-convergence industry ecosystem, operate an innovation consortium that is linked with promising future industries, and nano-convergence integrated information.

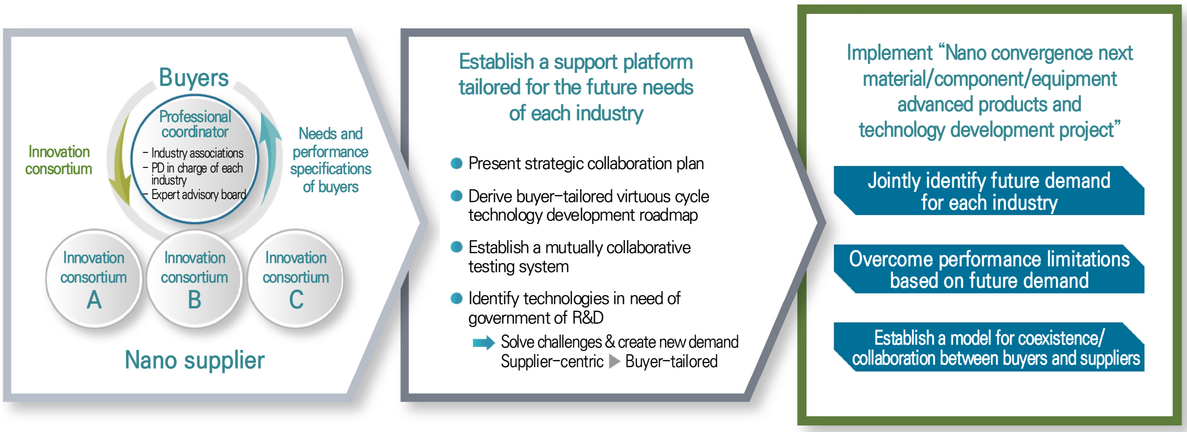
Organize and operate an innovation consortium to discover promising future products on a regular basis

- Present a technology development roadmap to solve technical difficulties and allow buyers and suppliers of nanotechnology to jointly identify the demands of new and promising future industries.*

* (1) Semiconductors (including sensors), (2) displays, (3) future cars, (4) bio/healthcare, (5) energy, and (6) environment (Green New Deal)

※ Implementation of new "nano convergence industry ecosystem promotion project"

Implementation of nano convergence innovation consortium (example)



Create an effective integrated information system to support companies

- Provide user-centric integrated nano information system, effective technology/policy,* and production and processing of industry information** through a mutual linkage between relevant organizations.

* (Technology policy information) Overseas R&D and policy trends, trend analysis, major issues, etc.

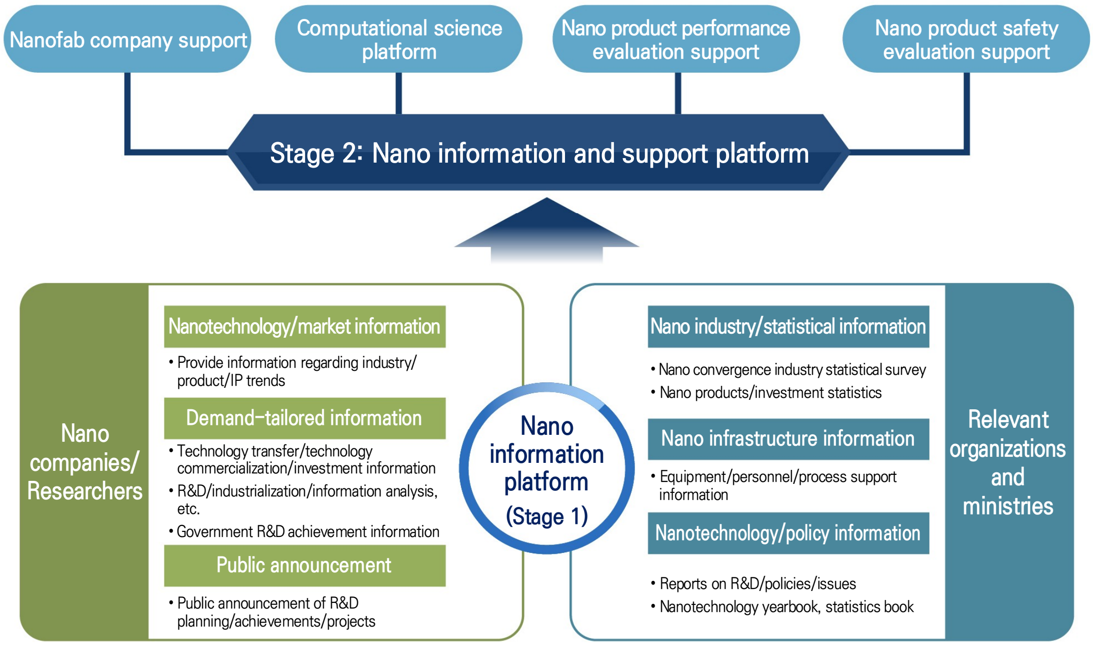
** (Industry information) New technologies, product market, infrastructure information, statistics, corporate achievements, etc.

- Integrate and provide distributed technology/policy and industry information with priority and gradually expand support services, including nanofab company support, research data platform, etc.

- Establish and operate a collaborative business system (Nano-BizMate) such as technology commercialization curator* pool and provide customer-tailored professional information.

* (Technology commercialization curator) Government-funded researchers, professors, retirees of over 20 years of corporate experience, technology valuation experts, technology commercialization (technology manager/technology evaluator/technology instructor) experts, etc.

Concept of nanotechnology integrated information and support platform



Create a nano-convergence cluster to maximize integration synergy between industry, academia, and research

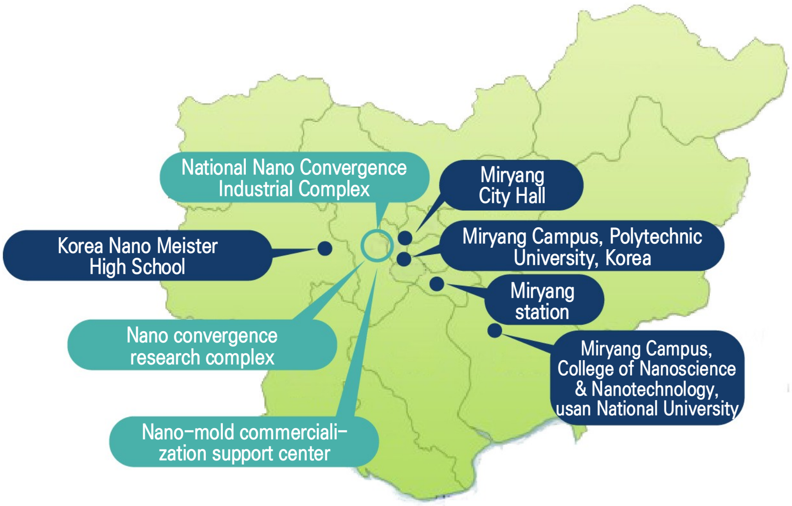
- Maximize industrial synergistic effect by concentrating nano companies, buyers, universities, and research institutes in close proximity of the National Nano Convergence Industrial Complex (Miryang).*

* Creation of the Miryang National Nano Convergence Industrial Complex (~2023): Parts of Bubuk-myeon, Miryang (1,650,000㎡)

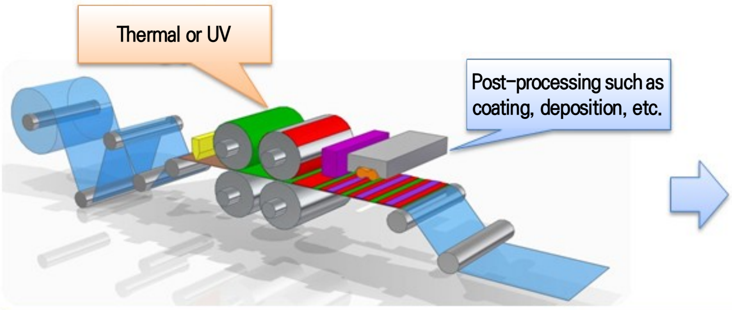
※ (Cluster panel) MOTIE, South Gyeongsang Province, Miryang (sponsor organization), Materials Research Institute (managing organization), Gyeongnam TP, etc.

- Established a nano-mold-based commercialization support center (Aug. 2019) to support prototyping of nano-patterned cylindrical mold application products (functional films, sensors, filters, etc.) and HR development.

Overview of Miryang National Nano Convergence Industrial Complex



Nano-mold-based Commercialization Support Center



Create patterns on film through nano-patterned cylindrical mold-based roll imprint process equipment (continuous process)

Production of the final product

3 Enhance the function of nanofab infrastructure

3.1. Enhance the support system for nanofab infrastructure

▶ Support research and development nationwide by operating a supporting system for each region and a linkage-supporting system between other regions based on the expansion of institution participation in nano-infrastructure.

Create infrastructure for Korea Nanotechnology Coordinated Infrastructure (KNCI)

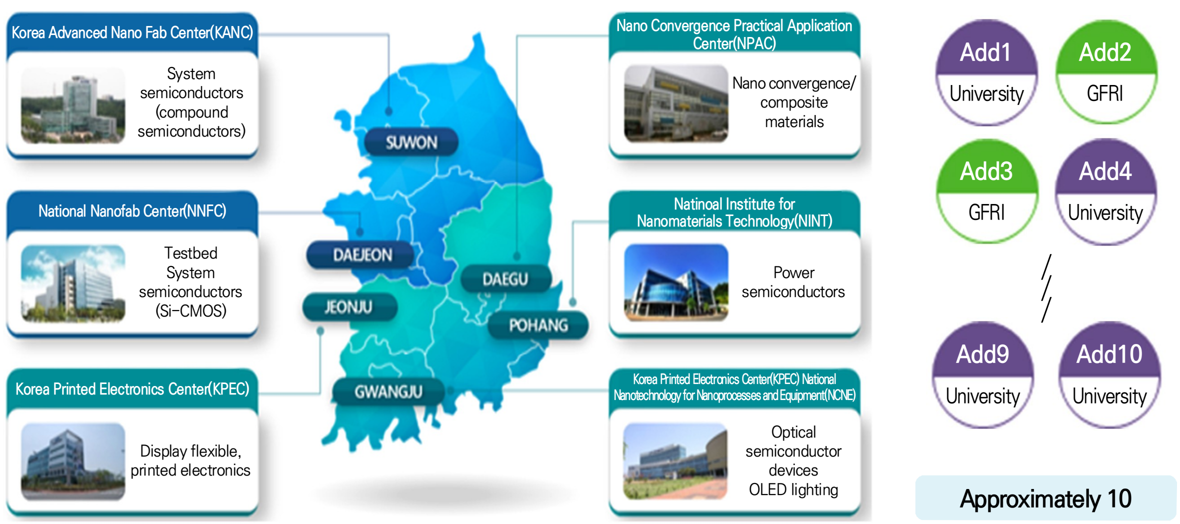
- Expand organizations participating in national nano infrastructure to efficiently support major R&D strategies, such as self-reliance of material, components, and equipment technologies and system semiconductor technology innovations.
  - In addition to the current national nano infrastructure, universities and GFRIs (government- funded research institutes) with facilities and equipment for the nano sector and research capabilities are also included.*

  * 2~3 institutions will be added every year to the national nano infrastructure for approximately 10 institutions by 2025

- For institutions newly participating in national nano infrastructure, nano infrastructure upgrade will be supported to strengthen education, research, and service capabilities in the nanotechnology sector.
  - Provide support* prioritizing the improvement of nano-process services and existing equipment or areas that can contribute to HR development in the nanotechnology sector within the region.

  * Plan to support three institutions in 2021 through the “Nano Infrastructure Upgrade Project”

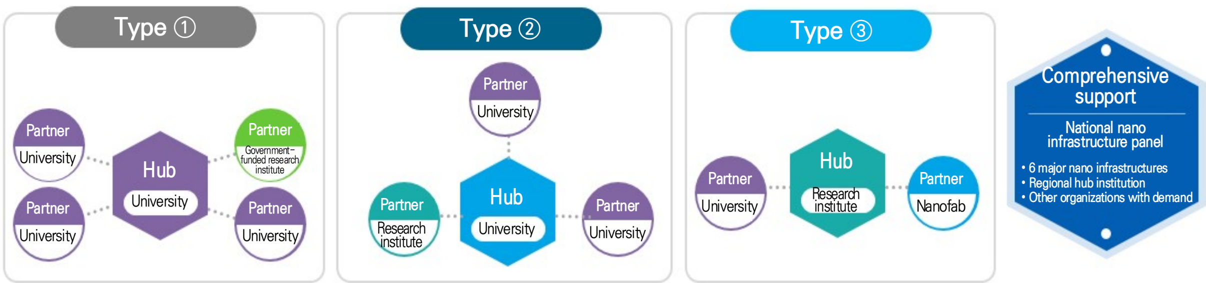
Creation of infrastructure for Korea Nanotechnology Coordinated Infrastructure (KNCI)



Construct a regional nano-infrastructure support system

- Establish and operate a regional nano infrastructure support system capable of responding to continuous education, research, and industry demand related to nano semiconductors within a region.
  - Among institutions with infrastructure within the region, institutions with comprehensive competencies such as education and research capability, process/testing and analysis capability, and facility and equipment establishment status will be designated as the regional hub.
  - Establish a system for linkage and cooperation between partner institutions with infrastructure and the hub institution.

- Organizational and functional reform of the national nano infrastructure panel for comprehensive support of the regional system.

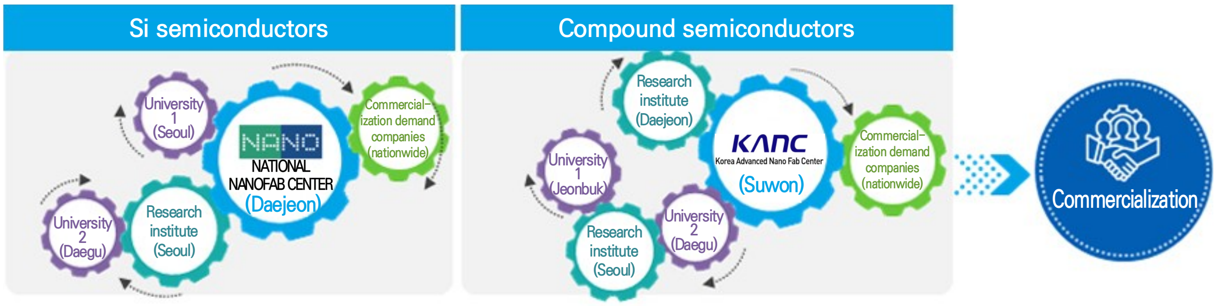


Establish a cooperative system for nano-infrastructure by each specialized field

- Support technology development through a linkage and cooperation system without dividing the demand for advanced research and commercialization into regions, which is difficult to be met with only nano infrastructure within the region.
  - Mutually link specialized fields of each infrastructure institution for each development stage to support seamless development through universities, GFRIs (basic and original) → public nanofab (commercialization).

Linkage and cooperation system between institutions in different regions

- **(Necessity)** When the specialized field or facility level of the infrastructure within a region does not meet the demand for research and industry, it is necessary to provide linkage and cooperation support with institutions in other regions capable of meeting such demand.
- **(Linkage system)** Combine universities, research labs, and nanofabs with strengths in specialized fields (e.g., Si semiconductor, compound semiconductor, etc.) to establish an integrated support system with "R&D + Process technology + Equipment."
  - (Cooperation by development stage) Basic research by universities → Applied research by research labs → Scale-up for nanofabs



NNCI support system (Case of the US)

(Overview) The National Nanotechnology Coordinated Infrastructure (NNCI) is a government network organization established to support SMEs and institutions to utilize user-centric nano infrastructure

- When the facilities and infrastructure required for nano R&D were concentrated in research-oriented universities or national research institutes, the NSF was implemented as a follow-up to NNIN in 2015 for maximizing the utilization of SMEs or small academic institutions (funding of $16 million per year).

(Composition) The NNCI network consists of 16 sites in 17 states in the US, along with 29 universities and partner organizations

National Nanotechnology Coordinated Infrastructure

(Function) Facilities in each NNCI site support academic research and product/process development by IAR (industry-academia-research) and are accessible to students and professionals from the US and worldwide

- All facilities of NNCI support technology innovations and commercialization based on accumulated technological capabilities for existing or new companies.
  - (Examples) The research areas of the SINGH Center for Nanotechnology (U. Penn) are nano-photonics, mechanics, microfluidics, nanomaterials, biological applications, and microsystems

(Goals) 1) Provide public access to equipment and expertise in the US through state-of-the-art nano manufacturing and characterization facilities, 2) provide resources for supporting education and outreach, and 3) provide program resource support for education on the social and ethical implications (SEI) of nanotechnology

(Achievement) More than 13,000 users, including 200+ educational institutions, 900+ SMEs, 50+ government and non-profit organizations, and 46 foreign organizations, have participated in the NNCI program (trained more than 5,000 users over three years)

3.2. Enhance supporting function for nanofab infrastructure

▶ While focusing on responding to urgent issues such as semiconductor testbeds and development of next-generation semiconductors, enhance process-supporting capabilities, and improve technology commercialization achievements by strengthening development capabilities in specialized fields for each nano-infrastructure.

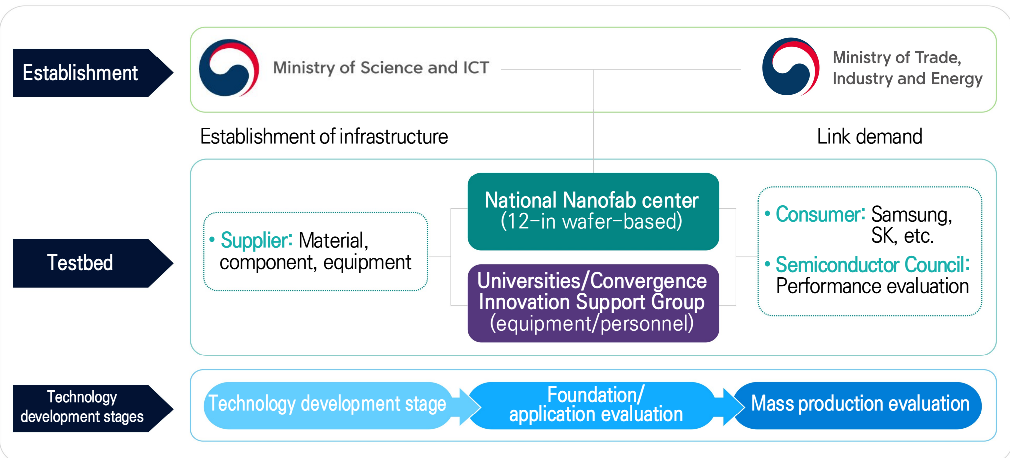
Enhance support for material, component, and equipment semiconductor testbeds

- Construct public testbed (12-inch) for materials, components, and equipment at mass production level for self-reliance of semiconductor backend industries (material, component, and equipment) and support testing and performance evaluation.
- Strengthen the effectiveness of the testbed through an organic linkage and cooperation system.
  - MoU between MSIT and MOTIE smoothly connects testbed demonstration results to the utilization by users (large corporations).

Support for development of semiconductor material, component, and equipment

- **(Equipment)** Ten 12-inch key equipment such as ArF immersion scanner, thin film deposition, and measurement and analysis equipment
- **(Services)** Photoresist evaluation, 40nm class semiconductor material evaluation, fabrication of pattern wafer for evaluation use, etc.
- **(MoU)** Cooperation for strengthening industrial competitiveness of semiconductor materials, components, and equipment and building a healthy ecosystem (Participating organization: MSIT, MOTIE, National Nanofab Center, Convergence Innovation Support Group, and Korea Semiconductor Industry Association)

Cooperation system for self-reliance of semiconductor material/component/equipment



Reinforce support for next-generation system semiconductor development

- For smooth support of the development of next-generation system semiconductors, upgrade nanofab facilities and equipment related to Si compound systems and power semiconductors, and establish an R&D support system.
  - Link pre- and post-processing for (Si) NNFC (FEOL) → KANC (BEOL) (8 inches).
  - (Compound) Upgrade and use of KANC's compound semiconductor processing equipment (4/6 inches).

  ※ Upgrade and use of National Institute for Nanomaterials Technology's power semiconductor (Si compound combined) process equipment

- Promote association between basic and original research by universities and GFRIs (government-funded research institutes) and support processing procedure for nanofab.
  - Support for association to develop various types of new devices by universities and GFRIs (≤ 6 inches), large-diameter wafer integration, and performance evaluation by public nanofabs (8 inches).

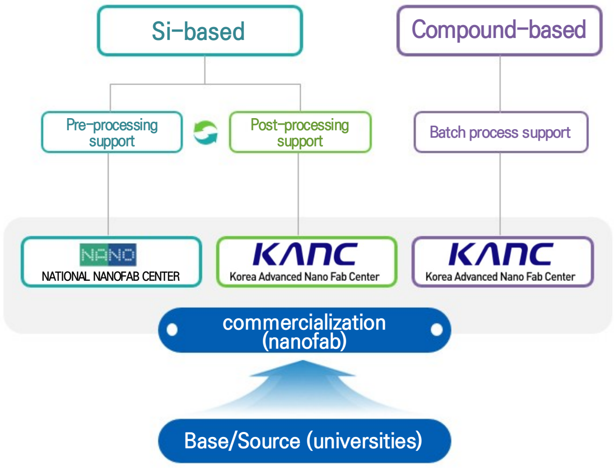
  ※ Including support for facilitation of research projects by the Next Generation Intelligence Semiconductor Foundation

- Operate a cooperation system consisting of project groups, corporations, and public fabs (MoU) to strengthen the semiconductor industry ecosystem in South Korea and to achieve shared growth for the success of next-generation semiconductor technology development.

Support for development of next-generation semiconductors

- **(Establishment)** 8 inch Si semiconductor 90nm full-processing (FEOL), 130nm post-processing (BEOL)
  - Establish 4 inch compound semiconductor 250nm system semiconductor fabrication supporting system.
- **(Service details)** Prototyping convergence devices (Si-based), including system semiconductor new devices and IoT sensors
  - Small scale production of multiple products based on GaN and InGaAs (InP), development of ultra-high-speed electronic devices (compound-based).
- **(MoU)** Cooperation to establish and expand the next-generation intelligent semiconductor ecosystem (participating organizations: project groups, three sponsors, four user corporations, 4 developers, nano infrastructure association, semiconductor association)

Next-generation semiconductor testbed support and cooperation system



Shared growth collaboration

- **(Project group)** Management of national R&D projects
- **(Sponsor)** Collaborate with a corporation with demand, test design outcome, and provide foundry support.
- **(User corporation)** Share requirements with the developer, support joint research for innovative product development and activate shared growth ecosystem.
- **(Developer)** Development of world class technology, active use of technology and HR in applied industries
- **(Partners)** Integration/prototyping, analysis/evaluation, design/testing, etc.

Enhance process capabilities and technology commercialization of nano-infrastructure

① Enhanced process capabilities through university/GFRI-nanofab joint research

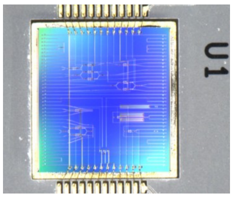
- Implement scaled-up joint research between university, GFRI (government-funded research institutes), and nanofab by utilizing laboratory original technology from university/GFRI and large-diameter process technology from nanofab.

※ Convergence research on mid-to-long term original technology and multi-product/low- quantity/high-difficulty products that are difficult to handle for large corporations

- When projects are implemented through matching between organizations and identifying joint projects by university/GFRI and nanofab, the government makes a matching investment for stable project execution.
- Link and apply accumulated capabilities for process services and develop technology for technology transfer and business start-up.

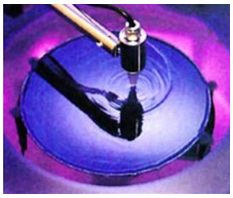
Promising technology from joint research between universities, GFRIs (government-funded research institutes), and nanofabs (examples)

Large-diameter, new material-based quantum information science core device



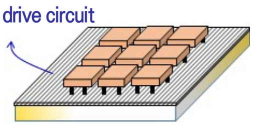
- Need GFRI and nanofab to jointly acquire large-diameter, new material-based quantum information science core device fabrication technology
- Secure globally-leading technology in the quantum communication sector by acquiring wafer growth technology and device processing technology

Exploration of core materials and process development for next-generation semiconductors



- Need to conduct researches for exploration of candidate materials using new material design and synthesis, which is difficult to do for large corporations in South Korea
- (Example) Precursor development by the Korea Research Institute of Chemical Technology and material company → equipment support from the Korea Institute of Machinery and Materials → nano infrastructure performance evaluation

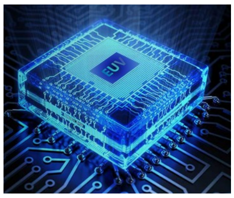
Development of new devices for PIM AI semiconductors



BEOL-based PIM device and integratable unit cell IP

- Need to secure memory foundry research infrastructure to meet various R&D needs
- Secure PIM super-gap core leading technology by providing an environment for PIM AI semiconductor development

EUV-related material development platform for next-generation devices



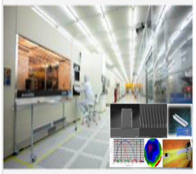
- Need to develop various materials, such as blank masks, reflective film, and PR, for the development of next-generation EUV
- Equip nano infrastructure with EUV light source and measuring equipment for exploration of materials together with GFRIs (government-funded research institutes) and universities

② Encourage technology commercialization in specialized fields for each nano infrastructure

- Support commercialization technologies optimized for major sectors, available equipment, and development capabilities.
- Achieve practical industrialization results by converging “corporate commercialization needs + specialty of researchers + process technology of nano infrastructure.”

Major sectors and support capability for each nano infrastructure

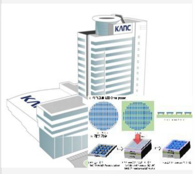
NNFC (Daejeon)



[Si-CMOS]

- Photoelectric transformation device for object recognition
- Flexible hybrid device
- Modular nano biosensors

KANC (Suwon)



[Compound devices]

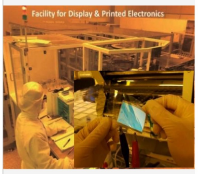
- GaN nano LED device for Q-NED displays
- Micro LED devices
- 5G/6G GaAs BiFet (MEMT + HBT)

NINT (Pohang)

[Power semiconductors]

- Core standard process for SiC power
- International certification of semiconductor neutron test
- Commercialization of 5G wide bandgap semiconductors

Jeonbuk NCNT



[Display]

- Transparent display device backplane batch process
- Micro OLED display
- Form-fitting flexible/stretchable electronic parts

Gwangju NCNT

[Optical device/ OLED : lighting]

- Optical simiconductors for ultra-high-speed, large-capacity optical communication
- Flexible, large-area OLED panel platform
- MEMS/NEMS technology-applied convergence sensors

NPAC (Daegu)

[Nano convergence composite materials]

- Comprehensive performance evaluation platform for light-emitting devices for next-generation displays
- Integrated-device heat dissipating material evaluation platform
- Ceramic-based carbonized/ oxidized/nitrified product precision machining technology

3.3. Create innovation in nanofab infrastructure and mid-to long-term development strategies

▶ Enhance the service of infrastructure through continuous maintenance when replacing old facilities and equipment, improvement of user convenience, and prepare for the future by making a mid-to long-term strategy.

Improve facilities, equipments and service of nano-infrastructure

- Continue to maintain and replace old equipment for expanded nano infrastructure.
  - Prioritize and support institutions and equipment subject to replacement and/or new support through annual analysis of the current status of available equipment in nano infrastructure equipment.
  - Implement and operate equipment engineering for maintenance and management of high- quality equipment.

- Open nano infrastructure service equipment and expand usage time.
  - Expand open cases in stages for general equipment, excluding expensive and specialized equipment.
  - Expand equipment usage time for each institution in consideration of equipment usage demand.

  ※ Enhance the effectiveness of service expansion (equipment number and time) by strengthening equipment training for users

- Accumulate, process, and utilize research data related to the process, measurement, and analysis according to the use of nano infrastructure equipment to reduce fab service time and improve quality.

  ※ Incorporate research data platform to expand the use throughout all nanomaterial sectors

- Enhance the quality of equipment operation and fab services by utilizing highly experienced retirees from the semiconductor industry.

- Strengthen support for emerging, female, and local researchers and utilization of nanofab facilities belonging to SMEs.

Prepare a strategy to enhance nano-infrastructure for a globally leading country

- Comprehensively analyze infrastructure status, IAR (industry-academia-research) needs, and outstanding overseas cases to develop a "national nano infrastructure development strategy" suitable for South Korea (2024).
  - Investigate and analyze existing infrastructure achievements and limitations, specific needs of IAR, functions of research facilities belonging to private companies, the scope of use of public research, mutual linkage plans, etc.
  - Analyze overseas cases with similar functions, such as IMEC, TSRI, Albany, Leti, Fraunhofer, etc.

  ※ Derive a strategy for establishing a Korean version of nano research centers based on the results of a comprehensive analysis of current South Korean and international status.

4 Expand the foundation for nanotechnology innovation

4.1. Enhance the nurturing of nanotechnology professionals

▶ By training next-generation core researchers and demand-responsive industrial experts in nanotechnology, contribute to enhancement of nano-R&D and nano-convergence industries.

Train R&D professionals in nanotechnology

- Develop nanotechnology professionals using the national nano infrastructure.
  - Develop nanotechnology professionals with integrated practical skills by utilizing public university facilities and the six national nano infrastructures* by region and industry.

  * NNFC (Daejeon), KANC (Suwon), NINT (Pohang), Jeonbuk and Gwangju NCNT (Jeonju), and NCPAC (Daegu).

  - Implement tailored education courses for basic-application-advanced stages and employment-linked advanced curriculum for nanodevice processes and measurement/analysis technology.

Supporting nanotechnology professionals using the national nano infrastructure

- **(Project goals)** Develop nanotechnology professionals with integrated practical skills at national level by utilizing public university facilities and the six national nano infrastructures specialized by region and industry.
- **(Project period)** 2020–2025 (six years)
- **(Project details)** Conduct applied practical training specific to characteristics of each region and industry by utilizing public university facilities and the six national nano infrastructures tailored by region and industry.
  - Goal of developing 6,390 nanotechnology specialists needed in nano convergence industry through customized convergence education based on basic-application- advanced curriculum

- Development of system semiconductor convergence professionals.
  - Develop master's and doctoral level system semiconductor convergence professionals by establishing a system semiconductor convergence development center with universities, corporations, and research laboratories.
  - Support integrated curriculum including major courses on utilization of promising system semiconductors, such as AI and IoT, semiconductor devices/circuits/design, and HW/SW integration.

Development of system semiconductor convergence professionals

- **(Project goals)** Development of convergence professionals in promising system semiconductor sectors for opening future markets for semiconductor technologies and strengthening industrial competitiveness.
- **(Project period)** 2020–2026 (seven years), support each center for six years
  ※ Pre-selected for 20 years: AI (Seoul National University and others), IoT (Sungkyunkwan University and other), and bio (POSTECH and others)
- **(Project details)** Establish basic/intensive/convergence curriculum to develop expertise in promising system semiconductor fields and comprehensive skills in semiconductor devices/circuits/design and HW/SW integration.
  - Simultaneously implement project-based learning (PBL) curriculum by identifying industry-academia-linked project topics that consider the needs of participating companies and changes in technology.

Train professionals for industrialization support

- Develop nano convergence technology professionals targeting specialized high schools.
  - Target specialized high schools for developing and supplying field professionals suitable for cutting-edge nano businesses using regional and national nanotechnology infrastructure facilities.
  - Conduct student-led practical training to reflect the demands of field professionals linked to locally specialized industries and for acquiring operating skills for advanced nano equipment.

- Development of employment-linked nano professionals.
  - Support the development of professionals tailored for industrial fieldwork and the creation of practical jobs through internship training using advanced equipment of nano infrastructure institutions for prospective science and engineering college graduates and unemployed graduates.
  - Conduct practical training for equipment and specialized device fabrication training linked to nano convergence technology sectors (semiconductors, advanced sensors, etc.) that are the key parts of the 4th industrial revolution.

- Newly establish and conduct education for nanotechnology qualification system that reflects industrial demand and work level.
  - Establishment of a private or national testing function and technology certification that can verify the knowledge level of nanotechnology professionals and guarantee the level of quality of human resource in the field.
  - Conduct prior theoretical and practical education for applicants of nanotechnology certification system (students from Korea Nano Meister High School, specialized high schools, university students, and people who are currently employed).

4.2. Expand international cooperation for open innovation

▶ With accumulated technical and industrial capabilities, and international cooperation experience, promote changes and innovation for the transition from a "participating country" to a "leading country."

Lead international cooperation in nano science and technology

- Pursue international joint research considering the level and characteristics of nanotechnology by country.
  - **(Nanotechnology-leading countries)** Develop new technologies in the nanotechnology field through technical collaboration with leading countries, possessing technological capabilities, accelerators, and large-scale nano infrastructure.

Direction of collaboration with leading countries

Country	Collaboration status	Future direction of expansion
US	▪ Technology development for nanomaterials, nano-bio, etc. ▪ (Channels) [South Korea] Government /(Local) IAR - Korea-US Nano Forum	▪ Collaborative R&D for key nanotechnologies ▪ (Expected effect) Technological collaboration and shared experiences with nanotechnology powerhouses
EU	▪ IAR (industry-academia-research) collaborative international R&D - Robots, lightweight construction materialcarbon, bio, renewable energy, manufacturing technology, etc. ▪ (Channels) [South Korea] Government agencies and IAR (industry-academia-research) [Local] Government agencies and European R&D network	▪ Joint development of commercialization technology, overseas expansion ▪ (Expected effect) Increase international market share, acquire advanced technology

  - **(Expansion of ODA collaboration)** As a leader in nanotechnology, secure global leadership through nanotechnology R&D collaboration with developing countries such as New Southern/New Northern/ASEAN countries.
  - **(Preparation for inter-Korean cooperation)** Implement phased collaborative projects* such as holding joint events and academic exchanges for nanotechnology sectors between South Korea and North Korea to provide an opportunity for joint advancement toward peace and prosperity.

* Establish mid- to long-term plans and prepare collaboration strategies considering the conditions of inter-Korean cooperation.

Direction of collaboration with North Korea and developing countries

Country	Collaboration status	Future direction of expansion
New Southern/ New Northern countries and others	▪ Nanotechnology collaboration with ASEAN and Eastern European countries (technology development, infrastructure establishment) ▪ (Channels) [South Korea] IAR [Local] Government agencies	▪ Collaborative research, including the establishment of nano policies ▪ (Expected effect) Entry into new markets and sharing experiences with nanotechnology powerhouses
North Korea	▪ Some academic exchanges between the South Korea and the North Korea ▪ (Channels) [South Korea] Researchers [Local] Researchers	▪ Academic conferences, technology development, HR development, infrastructure establishment, etc. ▪ (Expected effect) A new market and shared experiences with nanotechnology powerhouses

Support global expansion of companies using South Korean and overseas hubs

- **(South Korean hubs)** Support the operation of global business development programs through nano associations, Korea Carbon and Nano Industry Association, and KOTRA.
  - Customized support for global expansion of nano companies, market entry by country and product.

- **(Overseas hubs)** Utilize overseas' local supporting organizations (KIC, KOTRA, etc.) as overseas local hubs for nano companies to expand their roles.
  - Operate localization supporting programs* such as R&D and production/sale of nano products that suit local demand by linking wiht overseas hubs such as KIC and KOTRA.

  * Support R&D, cooperation between companies, and personnel hiring suitable for local conditions.

- **(Inter-Korean cooperation)** Identify a cooperation model* for the next generation of joint economic development by combining the technological and economic power of South Korea with the human and material resources of North Korea.

  * Develop and expand in stages starting from identification of a cooperation model with consideration for inter-Korean cooperation conditions.

Expand cooperation by strengthening international cooperation platform

- **(South Korea)** Operate Nano Korea Innovation program, continue to implement and strengthen cooperation with existing partners (Korea-US, Korea-EU, etc.).
  - Prepare plans to utilize the achievements of Nano Korea that served as a hub for IAR (industry-academia-research) networks, develop and operate programs in preparation for the post-COVID-19 era.
  - Expand exchanges with leading countries in nanotechnology while continuing to strengthen academic exchange and cooperation, such as Korea-US Nano Forum and Korea-EU nano workshops.

- **(Overseas)** Pursue practical exchange and cooperation, such as corporate participation, expansion of buyer consulting, and joint product development at overseas events.

- Strengthen the global network of South Korea at exhibitions, such as Techconnect (the US), Nanotech (Japan), CHInano (China), and RUSNANO (Russia).
- Strengthen global competitiveness of companies and establish collaborative relationships, including global collaborative research, inter-company exchanges, and product integration cooperation.

International collaboration strategies for nanotechnology

International collaboration and global expansion strategies by major region

- The US and Europe
  - **(Direction of collaboration)** International collaboration, market creation, acquisition of advanced technologies, formation of a global community
  - **(Current status)** Acquisition of cutting-edge technologies by supporting international collaborative research with foreign R&D institutions and enhancement of industrial competitiveness through global market entry
  - **(Promising sectors)** Renewable energy, bio, AI, big data, non-memory semiconductors, etc.

Type	The US	Germany	England /Switzerland
Collaboration status	■ (Content) Nanotechnology development [nanomaterials, nano-bio] ■ (Channels) - (South Korean) Government agencies - (Local) IAR	■ (Content) IAR collaborative international technology development [robotics, light-weight construction materialcarbon] ■ (Channels) - (South Korean) Government agencies - (Local) Government agencies	■ (Content) IAR collaborative international technology [bio, renewable energy, manufacturing technology] ■ (Channels) - (South Korean) IAR - (Local) Government agencies
Promising sectors	Nanomaterials, nanodevices	Semiconductors, energy, autonomous driving, aerospace	Bio, smart materials, manufacturing technology
Future collaborative activities	■ (Type) Collaborative research ■ (Content) Core nanotechnology development ■ (Expected effect) Technological collaboration and nanotechnology experiences	■ (Type) Collaborative research ■ (Content) R&D ■ (Expected effect) Increased international market share, acquisition of advanced technological capabilities	■ (Type) Collaborative research ■ (Content) Commercialization technology development ■ (Expected effect) Increased international market share, acquisition of smart factory technology

Type	France/Netherlands	Sweden/Norway	Czech/Poland	Russia/Belarus
Collaboration status	■ (Content) International collaboration for industrial technology [bio, smart grid] ■ (Channels) - (South Korean) Government agencies - (Local) European R&D network	■ (Content) IAR collaborative international technology development [bio, materials] ■ (Channels) - (South Korean) IAR - (Local) Government agencies	■ (Content) Enhanced industrial competitiveness through acquisition of advanced technologies and global market expansion [non-memory semiconductors, autonomous driving] ■ (Channels) - (South Korean) IAR - (Local) Government agencies	■ (Content) International collaboration for industrial technology [bio-health, renewable energy] ■ (Channels) - (South Korean) Government agencies - (Local) European R&D network
Promising sectors	Digital health, autonomous driving, nanotechnology, untact technology	Biology, quantum materials	EV/HEV, aerospace	Renewable energy, autonomous driving, big data

Type	France/Netherlands	Sweden/Norway	Czech/Poland	Russia/Belarus
Future collaborative activities	■ (Type) Global expansion ■ (Content) Commercialization technology development ■ (Expected effect) Increased international market share, acquisition of advanced technological capabilities	■ (Type) Collaborative research ■ (Content) Commercialization technology development ■ (Expected effect) Increased international market share, acquisition of advanced technological capabilities	■ (Type) Global expansion ■ (Content) Commercialization technology development ■ (Expected effect) Enhanced industrial competitiveness, acquisition of intellectual property	■ (Type) Global expansion ■ (Content) Commercialization technology development ■ (Expected effect) Increased international market share, acquisition of advanced technological capabilities

- Asia

Type	China	Japan	India	Australia
Collaboration status	■ (Content) Strengthen competitiveness in science and technology [BT, renewable energy, aerospace] ■ (Channels) - (South Korean) Government agencies - (Local) Government agencies	■ (Content) Nanotechnology development [nanomaterials, nano-bio] ■ (Channels) - (South Korean) Government agencies - (Local) IAR	■ (Content) Collaborative technology development [bio-health, digital conversion] ■ (Channels) - (South Korean) Government agencies - (Local) IAR	■ (Content) Identification of new technologies [eco-friendly energy] ■ (Channels) - (South Korean) Government agencies - (Local) Government agencies
Promising sectors	Autonomous driving, energy, EV/HEV	Nanomaterials, nanodevices	Digital health, Hydrogen electric vehicle	Eco-friendly energy
Future collaborative activities	■ (Type) Collaborative research ■ (Content) R&D ■ (Expected effect) Acquisition of advanced technologies	■ (Type) Collaborative research ■ (Content) Core nanotechnology development ■ (Expected effect) Technological collaboration and sharing experiences with nanotechnology powerhouse ■ (Considerations) Need to implement new collaborative nanotechnology businesses	■ (Type) Collaborative research ■ (Content) Commercialization technology development ■ (Expected effect) Enhanced industrial competitiveness, acquisition of intellectual property	■ (Type) Collaborative research ■ (Content) Commercialization research development ■ (Expected effect) Enhanced industrial competitiveness

ODA collaboration

- **(Direction of collaboration)** Support nanoscience and technology R&D needs and prepare strategies for mutual development.
- **(Current status)** As latecomers, prepare the foundation for mutual market entry and strengthen global collaboration using the knowledge, experience, and other resources related to technology innovation of both countries according to market expansion for products with application of new technology.
- **(Promising sectors)** Healthcare, eco-friendly energy, and renewable energy

Type	New Southern /New Northern countries
Collaboration status	■ (Content) Collaboration with ASEAN and Eastern European countries for nanotechnology (technology development, infrastructure establishment) ■ (Channels) (South Korean) IAR (industry-academia-research) /(Local) Government agencies
Promising sectors	Healthcare, eco-friendly energy, renewable energy
Future collaborative activities	■ (Type) Collaborative research ■ (Content) Establishment of nanotechnology development policies ■ (Expected effect) Creation of new markets and sharing experiences with nanotechnology powerhouses ■ (Considerations) Need to pursue new businesses for nanotechnology collaboration

Inter-Korean collaboration

- **(Direction of collaboration)** Implement collaborative projects in multiple stages, mutual development towards peace and prosperity.

Type	South Korea and North Korea (new)
Collaboration status	▪ (Content) Some academic exchange ▪ (Channels) (South Korean) Researchers /(Local) Researchers
Promising sectors	Nanotechnology research, nanotechnology education, nano infrastructure establishment
Future collaborative activities	▪ (Type) Collaborative research ▪ (Content) Implement in stages with collaboration in nanotechnology as a pilot project among science and technology collaboration projects (academic conferences, technology development, HR development, infrastructure establishment, etc.) ▪ (Expected effect) Entry into new markets and sharing experiences with nanotechnology powerhouses ▪ (Consideration) Sanctions against North Korea, international situation, agreements/treaties, etc.

4.3. Lead nano-safety and standardization around the world

▶ Strengthen establishment of a nanosafety management system and secure international competitiveness in national health and nano-industry with the increased public interest in nano-product safety.

Lead the development and standardization of nanosafety evaluation techniques

- Pursue international collaboration and develop safety evaluation technology for new nanomaterials and products, including microplastics, fine dust, advanced materials, bio-nano materials, etc.

Current status of international collaboration for nano safety

- **(US)** As a joint effort between KRISS (South Korea) and NIST (US), developing international standard for measurement of photocatalytic activity of nanomaterials and measurement techniques for cytotoxicity due to photocatalytic activity of nanomaterials.
- **(EU)** Participating in six nano safety-related EU Horizon 2020 projects (PATROLS, ACEnano, Gov4Nano, NanoSolveIT, NanoHarmony, and SUNShINE).
- **(International standards)** Active participation in OECD WPMN and ISO/TC229·TC113, revision of international standard guidelines

- Acquisition, dissemination, and standardization of the latest nanosafety evaluation technologies through continued updates and development of evaluation methods for the physicochemical properties and toxicity of nanomaterials.
  ※ Also carry out the development of exposure and risk evaluation technologies for environmental receptors (human/ecosystem).

Establish foundation for nanosafety management

- Strengthen links between nanomaterial and product safety-related DBs belonging to different departments and establish collaboration system with overseas nanomaterial and product safety-related DBs.
  - Support the design and manufacture of nanomaterials and products with low (no) risk by linking accumulated nano safety-related data to nanomaterial research data and biology DBs.

- Select representative nano products and apply full-cycle* evaluation technique, control banding technique (risk/exposure/hazard evaluation on all targets, including workplaces, consumers, and environment), grade research safety management.
  ※ (Current) Existing research focusing on the risk of and exposure to nanomaterials concentrated mostly on biological/simulation experiments using nanomaterials ⇨ Limited to manufacturing and usage among manufacturing-production-usage-disposal
  ※ (Future) Comprehensive full-cycle risk evaluation, from the "production" of consumer nano products to the "disposal" according to the usage

- Conduct research on a classification system, procedures, and implementation plans related to safety certification in accordance with the increased need for public certification for the safety of nanomaterials and products.

4.4. Enhance national awareness on nanotechnology

> ▶ **Through nanotechnology-related education for experience and enhanced development and promotion of related contents, expand infrastructure of nanotechnology, enhance understandings of cutting-edge technologies, and promote safe use of products.**

Operate regional nanotechnology education programs for experience for primary, middle, and high school students and educators

- Enhance growth potential for future talents by allowing regular students and science teachers to approach nanotechnology with a sense of familiarity while gaining interest and acquiring basic knowledge.
- Operate nano STEM programs through affiliated nano-infrastructure in each region and operate experience-based education such as lectures on nanotechnology research trends and curriculum for primary, middle, and high school teachers.
  * Open online education for theoretical education and support both theoretical and practical education.

Directions for operating educational programs

- **(Direction of education for primary, middle, and high school students)** Establish an educational network using national nano infrastructure facilities and universities, provide an experience-based program (2–3 periods according to free semester system) that allows primary, middle, and high school students to easily access science.
- **(Direction of education for science teachers)** Introduce various methods, such as scientific cases that can arouse interest in primary, middle, and high school students, through on-site lectures on nanotechnology for primary, middle, and high school teachers, along with the latest research trends and tips for gaining admission to nano major.

Reinforce expansion of achievements through systematic management of promotional activities

- Strengthen long-term public experience activities, such as organizing and disseminating new nanotechnology achievements, by closely linking existing distributed promotional projects.*

* Nano Korea, Nano Young Challenge, Nano Convergence Conference, "15 Minutes: Time to Change the World," etc.

Develop and disseminate interactive and citizen-based promotional content

- Transform the diffusion of nanotechnology information and results, which have been provided unidirectionally from the viewpoint of technology suppliers, to an interactive type that focuses on the needs of citizens.
  - Produce and widely distribute experience-based promotional content about nanotechnology using highly recognized channels, such as science YouTube channels and podcasts.

Development and dissemination of interactive and citizen-based promotional contents

Science Cookie X Gwacheon National Science Museum Video of special Feynman exhibition

People Behind the Science Move special program

- **(Direction of promotion)** Strengthen nanotechnology promotion through content production and diffusion using media with high recognition and active opinion-sharing.
  - Maximize experience enhancement activities through joint programming and broadcasting of nano contents, along with science YouTube channels and podcasts with a subscriber base above a certain level.

Reorganize laws and policies regarding nanotechnology promotion

- Revision of the Act on the Promotion of Nanotechnology to account for changes in the environment and advances in nanotechnology that have occurred over 20 years since its enactment.

– Identify and reorganize issues* essential for implementing nanotechnology policies and meet South Korean and international technological and industrial development trends through IAR (industry–academia–research) opinion–gathering.

* Issues related to nanotechnology R&D innovation and commercialization support, taking a leading position in nanosafety research and international standards, and designation of nanotechnology policy centers for sustained policy support

- Prepare policies and systems* that can lead the solutions to rapidly changing external environments and global megatrends (the 4th industrial revolution, COVID–19, etc.).

* (Example) Standardization of registration, evaluation, and certification standards to assure the safety of nanomaterials and products

- (Composition of public–private cooperation system) Secure the driving force of pan–ministerial implementation of nanotechnology development plans by organizing "Nanotechnology Development Council"* with joint participation by government ministries and private sectors.

* The Nanotechnology Development Council will be a consultative body with participation by nano–related major government ministries, universities, GFRIs (government–funded research institutes), nano infrastructure organizations, private associations, groups, associations, and corporations.

PART

VI

Implementation Measures

VI Implementation Measures

1 Investment plan (estimated)

For execution of the 5th KNI, approximately 12.7 trillion won will be invested over the next 10 years (2021–2030), an investment of approximately 5.6 trillion won for five years (2021–2025) until the next plan is established

- Approximately 10.3 trillion won for R&D, 1.11 trillion won for infrastructure, and 1.23 trillion won for HR development.

※ (Calculation criteria) Calculated by applying the annual average rate of increase (5.0%) of the proposed expanded investment size (2020 → 2024) based on the annual investment size of the existing nanotechnology implementation plan

Nanotechnology-related government investment plan (estimated)

(Unit: 100 million won)

division	2021	2022	2023	2024	2025	2026~2030	Sum
Total investment	10,068	10,572	11,100	11,655	12,238	71,005	126,638
R&D	8,211	8,622	9,053	9,505	9,981	57,907	103,279
Infrastructure	883	927	973	1,022	1,073	6,226	11,104
HR development	974	1,023	1,074	1,128	1,184	6,872	12,255

※ The investment plan may change based on discussion with the budgeting authorities

2 Implementation management

Establishment of the implementation plan and outcome management

- To strengthen the effectiveness of KNI, nanotechnology implementation departments and research institutions will participate in establishing implementation plans for each year according to strategies and projects.
  - Each strategy verifies the previous year's performance for projects in the 5th KNI, and the findings are reflected in the implementation plan for the current year.

- Implement selection, sharing, and diffusion of outstanding achievements through annual nano events.
  - (Nano Korea) A venue for global exchange and collaboration for academic and industrial achievements.
  - (Nano Convergence Conference) An annual event for selecting, sharing, congratulating, and encouraging outstanding technological and industrial achievements.

The 5th Korea Nanotechnology Initiative(2021-2030)

Leading the Global Future

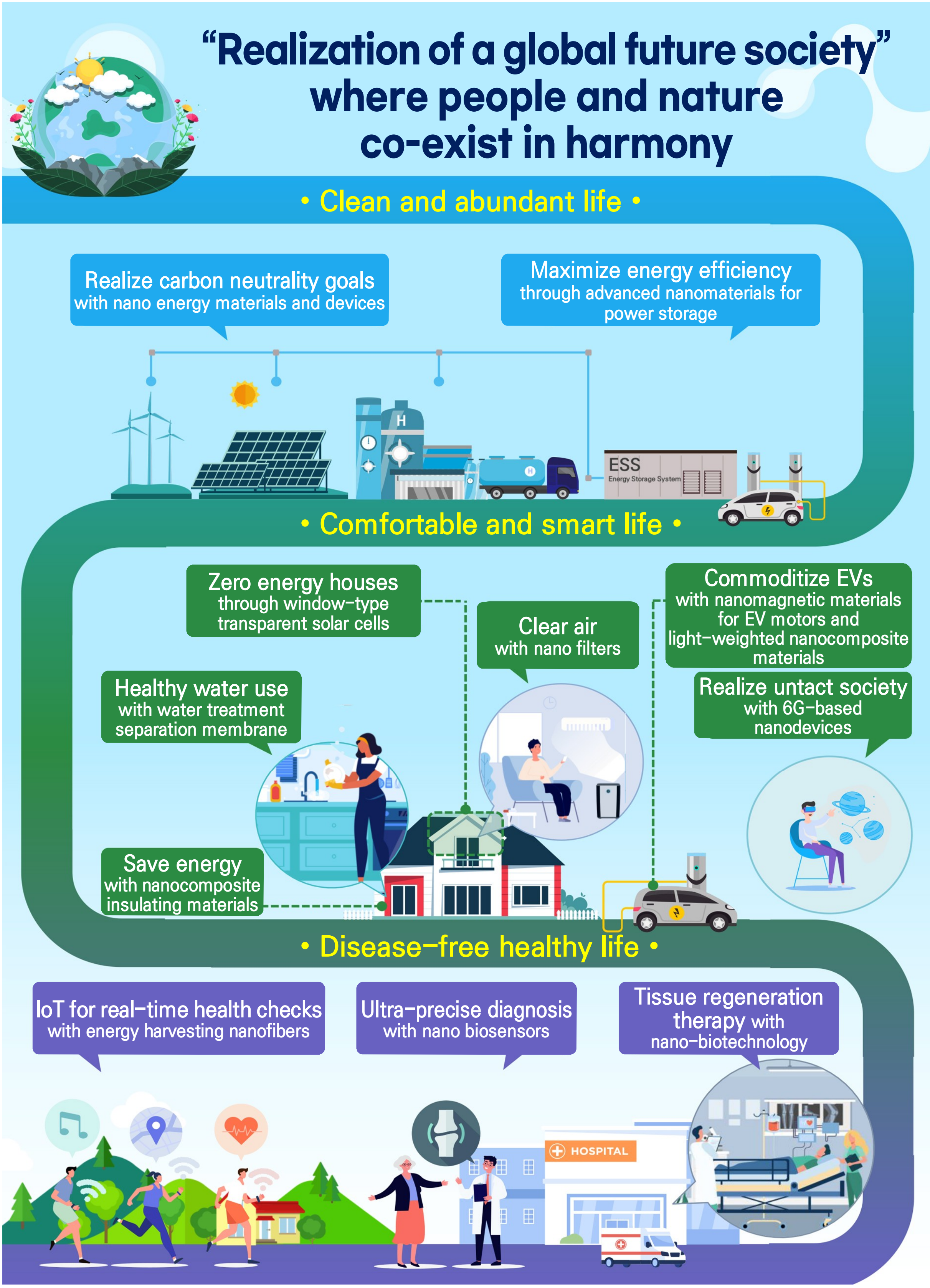
NANO 2030

PART

Ⅶ

Expected Effect

Expected Effect



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Leading the Global Future

NANO 2030

PART

VIII

Ministries in Charge of Key Projects

VIII Ministries in Charge of Key Projects

	Four major strategies and key projects	Ministries in charge
Strategy 1. Reinforce creative/challenging and globally-leading nano research		
1-1. Expand investment in nano-fundamental and original research		
①	Expand investment size of fundamental research in nanotechnology sectors	MSIT, MOE
②	Develop original technology in advance in order to accommodate future demand	MSIT
③	Secure key technologies to create a supply chain of material, component, and equipment	MSIT, MOTIE
④	Develop professional research committees in the nanotechnology field	MSIT
1-2. Promote nano-based R&D that can resolve future issues		
①	Promote invention of nano-electronic device technologies, which is essential in the untact era	MSIT, MOE, MOTIE, MOHW, MFDS, ME, MAFRA
②	Promote the development of nano-biotechnologies to be ready for pandemic and aging society	
③	Promote technology development of nano-green energy source for sustainable future	
1-3. Enhance the strategy for investment in nanotechnology		
①	Establish the 4th National Nanotechnology Roadmap to enhance nanotechnology strategy	MSIT, MOTIE
②	Reconstruction of the nanotechnology classification system	
③	Strengthen the analysis of nanotechnology information and statistics	
1-4. Establish and expand the nano/material data platform		
①	Develop and operate nanomaterial exploration/design services	MSIT, MOTIE
②	Establish and operate process/design service	
③	Establish and operate measurement and analysis services	
Strategy 2. Reinforce the competitiveness of innovative growth-led nano convergence industry		
2-1. Secure leading nano convergence industrialization technology		
①	Develop innovative nano-convergence products which can be linked to new future industries	MOTIE
②	Develop next advanced nano convergence materials, component, and equipment	MOTIE, MSIT
2-2. Enhance support for the technology commercialization of NT companies		
①	Strengthen support for the commercialization of outstanding base and original technology in the nanotechnology sector	MOTIE, MSIT, MSS
②	Activate support for the manufacturing process, measurement, analysis, and demonstration of nano convergent products	
③	Support performance evaluation and regulatory responses for the commercialization facilitation of nano-products	
2-3. Promote the creation of an innovative ecosystem for the nano-convergence industry		
①	Organize and operate an innovation consortium to discover promising future products on a regular basis	MOTIE, MSIT, MSS
②	Create an effective integrated information system to support companies	
③	Create a nano-convergence cluster to maximize integration synergy between industry, academia, and research	

Four major strategies and key projects		Ministries in charge
Strategy 3. Enhance the function of nanofab infrastructure		
3-1. Enhance the support system for nanofab infrastructure		
①	Create infrastructure for Korea Nanotechnology Coordinated Infrastructure (KNCI)	MSIT, MOTIE
②	Construct a regional nano-infrastructure support system	
③	Establish a cooperative system for nano-infrastructure by each specialized field	
3-2. Enhance supporting function for nanofab infrastructure		
①	Enhance support for material, component, device semiconductor testbeds	MSIT, MOTIE
②	Reinforce support for next-generation system semiconductor development	
③	Enhance process capabilities and technology commercialization of nano-infrastructure	
3-3. Create innovation in nanofab infrastructure and mid-to long-term development strategies		
①	Improve facilities, equipments, and service of nano-infrastructure	MSIT, MOTIE
②	Prepare a strategy to enhance nano-infrastructure for a globally leading country	
Strategy 4. Expand the foundation for nanotechnology innovation		
4-1. Enhance the nurturing of nanotechnology professionals		
1	Train R&D professionals in nanotechnology	MSIT
2	Train professionals for industrialization support	MSIT, MOTIE
4-2. Expand international cooperation for open innovation		
①	Lead international cooperation in nano science and technology	MSIT, MOTIE
②	Support global expansion of companies using South Korean and overseas hubs	
③	Expand cooperation by strengthening international cooperation platform	
4-3. Lead nano-safety and standardization around the world		
①	Lead the development and standardization of nanosafety evaluation techniques	MSIT, MOTIE, ME
②	Establish foundation for nanosafety management	
4-4. Enhance national awareness on nanotechnology		
①	Operate regional nanotechnology education programs for experience for primary, middle and high school students and educators	MSIT
②	Reinforce expansion of achievements through systematic management of promotional activities	MSIT, MOTIE
③	Develop and disseminate interactive and citizen-based promotional content	MSIT
④	Reorganize laws and policies regarding nanotechnology promotion	MSIT

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Ministry of Science and ICT

KIMS Korea Institute of Materials Science

NNPC National Nanotechnology Policy Center