JISTaP http://www.jistap.org
Journal of Information Science Theory and Practice

Research Paper

J. of infosci. theory and practice 3(1): 50-65, 2015
http://dx.doi.org/10.1633/JISTaP.2015.3.1.4

Study of US/EU National Innovation Policies Based on Nanotechnology Development, and Implications for Korea

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ABSTRACT

Recently US/EU governments are utilizing nanotechnology as a key catalyst to support national innovation policies with economic recovery goals. US/EU nano policies have been serving as a global model to various countries, including Korea. So the authors initially seek to understand US/EU national innovation policy interconnections, and then find the role of nanotechnology development within. To strengthen national policy coherence, nanotechnology development strategies are under evolution as an innovation catalyst for promoting commercialization. To strategically support nano commercialization, EHS (Environmental, Health, Safety) and informatics are invested as priority fields to strengthen social acceptance and sustainability of nano enabled products. The current study explores US/EU national innovation policies including nano commercialization, EHS, and Informatics. Then obtained results are utilized to analyze weaknesses of Korean innovation systems of connecting creative economy and nanotechnology development policies. Then ongoing improvements are summarized focusing on EHS and informatics, which are currently prominent issues in international nanotechnology development.

Keywords: nanotechnology, innovation, innovation policy, commercialization

Accepted date: March 18, 2015
Received date: November 10, 2014

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1. INTRODUCTION

Since the global economic crisis around 2008, international policies are refocusing on innovation sources such as revitalizing manufacturing. This new trend is motivated by steady economic growth via high-tech manufacturing even under economic crisis (McKinsey Global Institute, 2012; Pisano et al., 2009; The White House, 2011; NANoFutures, 2012). The US/EU find one national innovation source from manufacturing revitalization with the support of emerging technologies. Nanotechnology is especially regarded as a key catalyst to resolve high-priority social issues including national innovation, job creation, and economic impact (President's Council of Advisors on Science and Technology [PCAST], 2011 and 2012a; High-Level Group on Key Enabling Technologies, 2011). Following this trend, the main focus of nanotechnology development policy is shifting from the promotion of fundamental exploration to innovation/commercialization (PCAST, 2012b; National Nanotechnology Initiative, 2013; Communication from the Commission to the Council, 2004, 2005), to serve as innovation engines for sustainable economic growth. After the 2008 economic crisis, the implementation of capital intensive R&D investment is becoming difficult (Roco, 2013). Thus, the US/EU are undergoing renovation of national innovation ecosystems, securing sustainable development by maximizing horizontal-vertical policy coherence so that achievements of emerging technologies are quickly materialized to resolve top priority national agendas.

Additionally, there are past analyses finding that the fast-follower approach of Asian countries has been very successful in emerging technology development (NANoFutures, 2012; PCAST, 2011, 2012a; High-Level Group on Key Enabling Technologies, 2011)), and their scientific/technological achievements positively influenced the competitiveness of high-tech manufacturing industries (McKinsey Global Institute, 2012; Pisano et al., 2009; The White House, 2011). Even though the US/EU are still international leaders of emerging fundamental research, it was not sufficient to sustain global leadership. Upgraded policy was required to maintain leadership for both economic impact and high-tech capabilities. As an implementation methodology, the US/EU have been maximizing the coherence of national innovation strategy and emerging technology development policies. In particular, nanotechnology development implementation policy has evolved as an innovation catalyst to resolve national core issues. As a representative example, the US NNI (National Nanotechnology Initiative), which serves as one global reference model for nanotechnology development trend, now emphasizes nano based application/commercialization. The economic crisis around 2008 combined with threats by fast followers including China and Korea (National Nanotechnology Initiative, 2013; PCAST, 2010 & 2012c) accelerated the evolution of US nanotechnology development strategy as a national innovation engine. This is similar to the EU in that nanotechnology development direction has evolved to align coherence with national-level innovation policy, as well as a catalyst for innovation and commercialization (NANoFutures, 2012; High-Level Group on Key Enabling Technologies, 2011).

Throughout the current study, the authors discuss three major points as below. First, Korean nanotechnology application capabilities are suggested to be on a decreasing trend. Second, US/EU nanotechnology development policy alignment with national priority agendas has continued approximately over the decade, whereas Korea has initiated it recently compared with the US/EU. Third, the international nanotechnology development trend of supporting national commercialization is focused on key fields, including nano Environmental, Health, Safety (nanoEHS) and informatics. In the case of the US/EU, they have already initiated harvesting tangible results of nanoEHS whereas Korea is under development.

2. DEFINITIONS AND NANO-APPLICATION COMPETITIVENESS

The worldwide policy trend led by the US/EU is changing into actively exploiting emerging technologies to promote national innovation, economic growth, and job creation (The White House, 2011; NANoFutures, 2012). As a representative emerging technology, nanotechnology has attracted much attention as an innovation catalyst for national innovation. The declaration of the US nanotechnology development plan in 2000 fueled global nanotechnology development competition as a new general purpose technology to innovate existing/new industries. In the case of transforming general purpose technology into economic impact, it is important for securing sustainability in the innovation pipeline (Wiggins, 2012), which is also currently a key element in US/EU innovation policy. The importance of EHS/informatics is emphasized to secure sustainability by supporting safe/fast commercialization of nanotechnology. These trends are more easily understood along with concepts of innovation, innovation chains, and innovation systems that are summarized in the following section.

2.1. Innovation, Innovation Systems, and Innovation Chains

The OECD 'Oslo Manual' (Organization for Economic Co-operation and Development, 2005) describes innovation as the "introduction of new products, new methods of production, new markets, development of new sources, creation of new market structure in an industry." The US report of "A Strategy for American Innovation" (The White House, 2009) defines innovation as "the development of new products, services, and processes." The US report then describes recent trends of innovation in high-tech/advanced-manufacturing sectors including nanotechnology, aerospace, life sciences, and energy, leading to job creation.

The OECD/EU often utilize the concept of the innovation system, which is important for understanding recent innovation policies including science and technology fields. The OECD document (1997) explains an innovation system as a "network of institutions in the public and private sectors whose interactions initiate, import, modify and diffuse new technologies." Work by Song (2009) summarized backgrounds of how innovation systems were suggested, with a methodology overcoming drawbacks of conventional R&D policies. The focus of conventional R&D policy was nationally investing in targeted science/technology fields that have high potential of rewards. It was believed that if emerging sciences/technologies are developed, then they will easily diffuse out to societal innovation/commercialization. However, it was the reality that few emerging technologies developed by existing R&D policies materialized into social innovation/commercialization. To overcome this broken connection between R&D results and innovation/commercialization, an improved policy system was required. Within the innovation system, the R&D field is one element of innovation policy that should be aligned/interconnected with other innovation policies including economy, social, and regulation ones, and so on, so that social innovation capabilities are maximized with sustainable growth.

Under innovation systems, an innovation chain is explained as "a process of matching technical possibilities to market opportunities," as the summarized diagram in Figure 2. (Foxon, 2004; International Energy Agency, 2009).

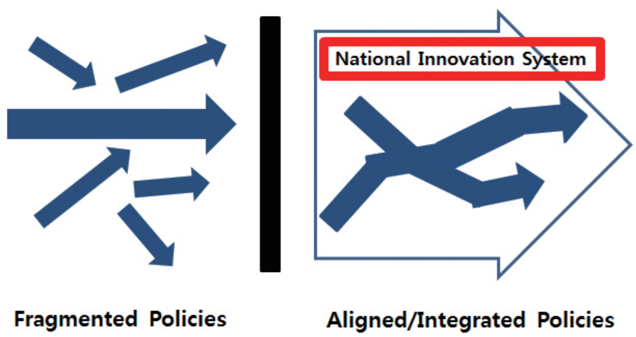

Fig. 1 Redrawing image of policy alignment/integration under a national innovation system (Song, 2009)

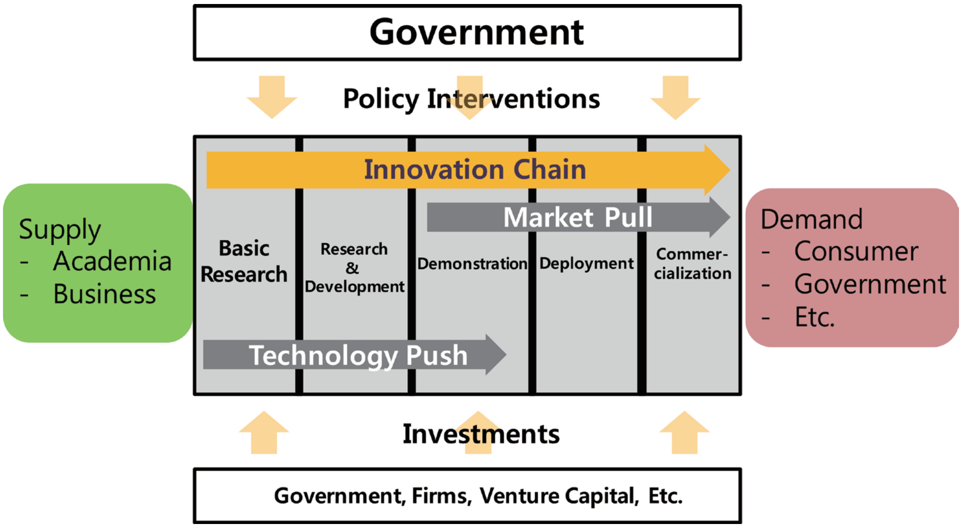

Fig. 2 Redrawing of innovation chain diagram (Foxon, 2004; International Energy Agency, 2009)

2.2. Competitiveness of Nano-Applications

Korean nanotechnology development policy has been maintaining the same framework of nanotechnology development policy over the decade, whereas global nano leaders such as the US have been significantly updating it. There would be no problem if Korea keeps its international nanotechnology capabilities well. However, several indicators show negative signs of stagnant/decreasing nanotechnology capabilities in innovation/commercialization that are central issues of the current global nano development trend. The US/EU are strengthening their nanotechnology commercialization capabilities for catalyzing national innovation with sustainability. Under these conditions, Korean nanotechnology development policy shows asymmetric achievements of fundamental and application capabilities based on the number of data. Lux research (2010) and the Korean Annual Nanotechnology Implementation Plan (National Science & Technology Council, 2013) reported that Korea is ranked in 3rd-4th position overall. However, if nanotechnology commercialization capabilities are separately considered, internationally Korea is ranked in 7th place (Cientifica, 2011). Recently Korean internal research reported that Korean nanotechnology competence compared to the global top (100%) decreased from 81.3% (2011) to 76.4% (2013) (Ministry of Trade Industry & Energy, 2013). Even though the number of research papers is expanding, the qualitative evaluation of nanotechnology commercialization capabilities is suggested to be on a decreasing trend.

Quantitative analysis from authors utilizing the nano product inventory of the Woodrow Wilson Center (2013) suggests that Korean nanotechnology production is undergoing a stagnant phase whereas those of the US/EU are increasing. Korea was 2nd globally in nano product production in 2011 (National Science & Technology Council, 2011). However, the updated database of the Woodrow Wilson Center in 2013 shows that Korea is ranked 3rd after the US and Germany as shown in Fig. 3. It is beyond the focus of this article, but Fig. 4's trend shows that nano production in the US/EU is on an increasing trend whereas Asian countries are in a stagnant phase.

These observations motivate the study of US/EU national policy chain ranging innovation strategy, interconnection with nanotechnology, and the importance of nanoEHS/informatics within emerging technology commercialization ecosystems. The authors then compare these findings with the current status of Korean nanotechnology development policies, including nanoEHS/informatics.

The US/EU gauge that nanotechnology R&D achievements are already mature enough to serve as a catalyst for sustainable innovation/commercialization. The focus of nanotechnology development budgets have also shifted from fundamental research development to commercialization for resolving national issues such as revitalization of advanced manufacturing (High-Level Group on Key Enabling Technologies, 2011; PCAST, 2012b; National Nanotechnology Initiative, 2013; Communication from the Commission to the Council, 2005). The US/EU felt threatened by the rapid chasing of fast followers including Korea in emerging tech capabilities and economic growth. Thus an upgraded national innovation ecosystem was required (NANoFutures, 2012; PCAST, 2011) so that emerging tech development policy is supporting a national innovation system by catalyzing sustainable commercialization and resolving social issues. Such a focus was prepared from around 2006, and now nanotechnology development aims at supporting various areas including national innovation, revitalization of advanced manufacturing, commercialization of emerging technology, and regulation for safety. Within these, nanoEHS and informatics are invested in as priority fields to support revitalization of advanced manufacturing, and to provide a scientific/institutional safety basis so that innovative nanotechnologies resolving national issues are quickly/safely commercialized. The authors briefly summarize the current US/EU national innovation chain and the role of nanotechnology, including nanoEHS/informatics. For example, the US NNI has been renovating its nanotechnology investment portfolio from 2006 to now (National Nanotechnology Initiative 2004, 2007, 2011a, 2014) to strengthen nanoEHS, commercialization, and international policy harmonization. But Korea still uses the same investment portfolio since 2001, and its first time collecting and opening the nanoEHS budget to the public was in 2013 (National Science & Technology Council, 2013). Compared to the US/EU, Korean nanotechnology plans have relatively weak alignments ranging national innovation policy, nanotechnology development strategy, coherent interagency collaboration, commercialization, and securing safe usage.

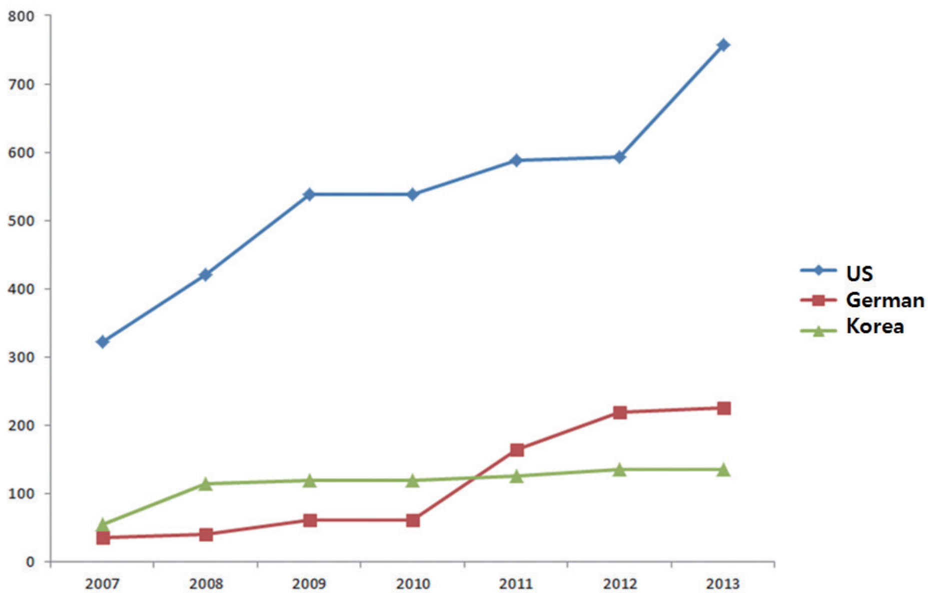

Fig. 3 Changes in numbers of products related to nanotechnology of US, Germany, and Korea

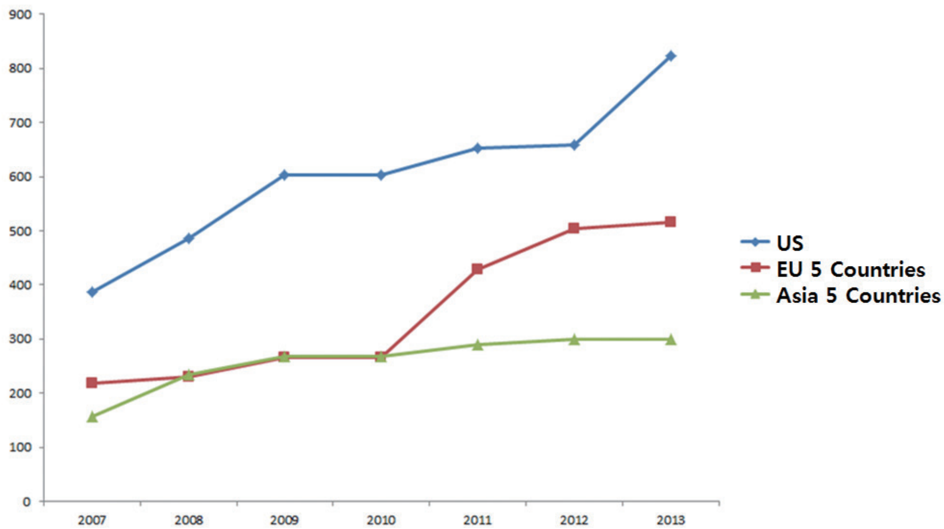

Fig. 4 Changes in numbers of products related to nanotechnology of US and EU (Germany, UK, Denmark, Switzerland, France), and Asia (Korea, China, Japan, Taiwan, Singapore)

3. US INNOVATION POLICIES INCLUDING NANOTECHNOLOGY

3.1. American Innovation

The White House announced "A Strategy for American Innovation" in 2011 to integrate national growth resources for high quality job creation and economic growth, therefore securing sustainable national prosperity. This innovation policy is implemented based on the America COMPETES Acts of 2010 (US Public Law 111-358, 2010) that was enacted to overcome the economic recession/financial crisis around 2008. Within this innovation strategy, US government is implementing advanced manufacturing partnerships (AMP) (PCAST 2011, 2012a, 2012b) and updated nanotechnology development policy (National Nanotechnology Initiative, 2014) so that emerging technologies can serve as key elements for the revival of US manufacturing that finally innovates in the US.

3.2. Advanced Manufacturing

Advanced manufacturing partnership (AMP) (PCAST, 2011, 2012a), aiming at a manufacturing revival by exploiting emerging technologies, have been implemented based on the America COMPETES Acts of 2010, as well as US innovation strategy in 2011. AMP is supported with the development of nanotechnology, especially the Nanotechnology Signature Initiative.

The US was a world manufacturing leader, and it played a key role in securing global economic leadership. Now the United States government is seriously recognizing its loss of international manufacturing competitiveness, and plans to recover it by revitalizing advanced manufacturing with the support of emerging technologies. The AMP report summarized top priority technologies required for the renaissance of US advanced manufacturing as follows: advanced sensing, nano manufacturing, IT, nano materials, and energy efficient technology (PCAST, 2012b). At the request of the Obama administration, NNI has been developing specialized nano programs to maximize policy coherence with upper strategies of national innovation and AMP. As a result, NNI developed 5 Nanotechnology Signature Initiative (NSI) programs that serve as key catalysts for creating a national innovation and advanced manufacturing renaissance. The 5 core technologies of AMP and the 5 Nanotechnology Signature

Table 1. Comparison of 5 Core Tech of AMP and 5 Nanotechnology Signature Initiative (NSI) Programs of NNI

5 Core Technologies of AMP	5 NSI Programs
Nanomanufacturing	Sustainable Nanomanufacturing
Information Technology	Nanoelectronics for 2020 and Beyond
Energy Efficient Manufacturing	Nanotechnology for Solar Energy Collection and Conversion
Nanoscale Materials	Nanotechnology Knowledge Infrastructure
Advanced Sensing and Measurement Technologies	Nanotechnology for Sensor and Sensors for Nanotechnology

Initiative programs of NNI have strong relations and it would be reasonable to see them as complementary programs as summarized in Table 1. Recently NNI announced a totally reformed NNI implementation strategy that will be summarized in the following section.

3.3. National Nanotechnology Initiative

From an early period the US government recognized the importance of nanotechnology, and announced the NNI (National Nanotechnology Initiative) in January 2000 which fueled international nanotechnology development competition. In December 2003, the Bush administration established the Nanotechnology Research and Development Promotion Act as a legal basis for the promotion of NNI. The vision of NNI is to understand and control matter at the nano scale leading to a revolution in technology and industry that benefits society. During FY 2001-2012, the US government invested $15.6 billion into NNI as a top priority national investment field in science and technology. Now, NNI is implemented as a strategic key catalyst for realizing a national innovation and manufacturing revival. The initial draft of the American COMPETES Reauthorization Act 2010, the legal basis of US innovation strategy and AMP, included the revision of the 21st Century Nanotechnology Research and Development Act (PL 108-153), but was mostly erased in the final version. Instead, administration documents including US innovation strategy, AMP, and PCAST evaluation (The White House, 2011; PCAST, 2011; PCAST, 2010, 2012c) have requested that NNI find fast-growing and promising areas so that the United States can find breakthroughs by close interagency collaboration, with joint R&D. Accelerating the growth of these selected areas supporting nanotechnology, the US aims for economic recovery, job creation, securing national energy production, and so on. In response to these, the NNI developed 5 Nanotechnology Signature Initiative (NSI) programs between 2010 and now (three programs in 2010, and two programs in 2012). NSI's five focus areas include advanced manufacturing revival, escaping from fossil energy, new semiconductor industry development, big data, and promotion of safe commercialization. The implementation of NSI aims at resolving national critical issues, and foresees visual results within 10 years as summarized in Table 2.

The NSI budget was not classified as a 8 Program Component Area of NNI up to the FY 2014 NNI supplement report (National Nanotechnology Initiative, 2013; National Nanotechnology Initiative 2010, 2011b, 2012), but only gathered a total amount of investment. The Nanotechnology Signature Initiative investment budget in 2104 was $343 million, which is an increase of 11.4% compared to 2013. 5 NSI and investment budget information are summarized in Table 3 below. The two recently started NSI projects of "Nanotechnology for Sensor and Sensors for Nanotechnology" and "Nanotechnology Knowledge Infrastructure" directly supports AMP in two fields of nano-informatics and nanoEHS. The development of nanoEHS aims at promoting an institutionalization basis for safe commercialization. Also, the importance of information science for gathering/storage/retrieval/classification/manipulation is emphasized as emerging technologies (nano/bio/information/cognition) are converging, and their applications are promoted for high-tech manufacturing (Roco, 2013; Materials Genome Initiative, 2014).

Table 2. 5 Nanotechnology Signature Initiative (NSI) Programs and Major Goals

Starting Year	NSI Program	Goal
2010	Sustainable Nanomanufacturing	Support establishing large-scale and sustainable nano-based manufacturing system contributing to the recovery of global leadership of US manufacturing
2010	Nanoelectronics for 2020 and Beyond	Support new technologies and manufacturing systems of semiconductor industries that significantly contribute to securing US global economic leadership for decades, and continue into 21st century
2010	Nanotechnology for Solar Energy Collection and Conversion	Develop solar energy as a strong candidate for the development of alternative energy sources to overcome the dependence on conventional fossil fuel, with environmentally friendly and economically valuable results
2012	Nanotechnology Knowledge Infrastructure	Establish a national nano system supporting S&T information (big-data) and life-cycle based nano safety
2012	Nanotechnology for Sensor and Sensors for Nanotechnology	Acquire nano-based measurement and monitoring technology for the promotion of both safety and commercialization

Table 3. Summary of 2012~2014 NSI Budget (Unit: Million $)

NSI Programs	2012, Actual	2013, Estimated	2014, Proposed
Sustainable Nanomanufacturing	56	72	60
Nanoelectronics for 2020 and Beyond	92	87	80
Solar Energy Collection and Conversion	88	82	102
Nanotechnology Knowledge Infrastructure	2	2	23
Nanotechnology for Sensors	55	65	78
Total	**294**	**308**	**343**

In summary, the NNI is undergoing evolution for the support of critical national issues including the revival of advanced manufacturing that the US lost to Asian competitors including Korea. US governments have selected key nano fields including nanoEHS/informatics for advanced manufacturing revival, and the success of current US policy activities will return to Korea as an economic threat due to its heavy reliance on high-tech manufacturing industries.

3.4. NanoEHS/Informatics within National Innovation Policies

The US NSI program supports key technology fields, including nanoEHS and informatics, that have high potential for realizing national innovation/commercialization. The commercialization of an emerging technology such as nanotechnology has immeasurable potential in both positive and negative sides. The benefits of emerging technology could be maximized with proactive prevention of its hazards to humans and the environment. In the case of the US, nanoEHS capability is already mature and materialized as regulations of FIFRA banned the importing of Korean nano silver products to the US around 2006. Actually the US government has been growing its nanoEHS fields since the enactment of its nanotechnology promotion act (PL 108-153) up to now. The NNI has been strategically strengthening nanoEHS around 2006 by specifying the nanoEHS field as Program Component Area 7 along with a sharp increase of budget, preparing/updating nanoEHS federal strategic development plans from 2006 to 2011 (National Nanotechnology Initiative 2006, 2008, 2011c), and institutionalizing nano safety as a regulation of FIFRA/TSCA. Such regulation capabilities of nanotechnology are now supporting national innovations of manufacturing.

Informatics is an important element of supporting advanced manufacturing revival. Informatics has the potential of minimizing time periods required for new material development toward commercialization, integrating intelligent manufacturing processes, and exploiting existing information for various purposes. The NNI launched its NKI program under NSI as of 2012 for stimulating nano informatics, for multiple reasons.

4. EU INNOVATION POLICIES INCLUDING NANOTECHNOLOGY

Similar to the US, the European Commission (EC) also realized the value of nanotechnology from early on and incubated nanotechnology as a key catalyst for resolving national economic and social issues. The importance of nanotechnology in EU policy can be found from past European Commission reports (Commission of European Communities, 2004), and in the recent trend of utilizing nanotechnology for realizing European innovation that is included in the European 2020 Strategy as Key Enabling Technology (KET) (High-Level Group on Key Enabling Technologies, 2011).

The document "concerning nanotechnology opinion on the strategy of the European Union (12/05/2004)" (Commission of European Communities, 2004) proposed safe, integrated, and responsible development of nanotechnology. This trend is one setting the pace of European innovation policy so that the EU dominates global nano science/technology and responds to future needs regarding environment, health, and possible social issues.

The European Action Plan 2005-2009 (24/09/2004) (Communication from the Commission to the Council, 2005) regarding nano science/technology development states 8 core areas as listed below to promote safe and responsible development of nanotechnology. The European Commission monitors the progress of this investment portfolio and the collaboration/participation of member countries from the early stages of nanotechnology development.

- Research, Development and Innovation
- Infrastructure
- Interdisciplinary Human Resources
- Industrial Innovation
- Integrating the Societal Dimension
- Public EHS and Consumer Protection
- International Cooperation
- Implementing a Coherent/Visible Strategy at European-Level

4.1. EC Framework Program (FP) 7

The EU has been developing nanotechnology in its Framework Program (FP) as Nanoscience, Nanotechnology, Materials, and New Production Technologies (NMP). Horizon 202 (2014-2020) is under implementation as post FP7. The FP7 Cooperation program, budget, and related configuration are summarized in Fig. 5.

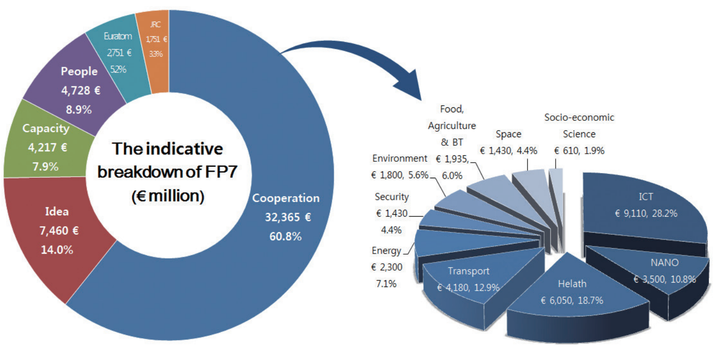

Fig. 5 FP7 Cooperation program, part of the budget and related configuration

The FP program is composed of four parts, 1) Cooperation, 2) Idea, 3) Capacity, and 4) Human Resources (People). The nanotechnology development program is involved under the cooperation part that has the largest investment budget under FP. Under the cooperation part, Nanoscience, Nanotechnology, Materials, and New Production technology (NMP) research and development support integrated development of nanotechnology. The implementation of NMP aims at strengthening the competitiveness of the EU industry and leading existing resource-intensive industries toward a knowledge-based economy. Nanotechnology is regarded as a key technology supporting high value-added production and knowledge-based industries (including the development of new technologies bringing SME competitiveness). NMP budgets through FP7 (2007-2013) and main four investment areas are summarized as below in Table 4.

1) Nanoscience and Nanotechnology (NanoScience and Nanotechnology): Nano-scale research and development of nanotechnology in development
2) Advanced Materials (Materials): NT and BT materials for new products
3) New Production (New Production): Conditions for continuous innovation and technical/institutional/human resource utilization, nanotechnology, and safety (EHS)
4) Industrial production technology integration (Integration of technologies for industrial Production): Through the use of new technologies and new materials promoting industrial development in Europe

The European Union regards advanced technology, especially nanotechnology, as a key R&D area for exploring 1) fundamentals, 2) application/commercialization, and 3) innovation. A more detailed diagram for these 3 major contribution areas of nanotechnology is summarized as below in Table 5.

Table 4. 2007~2013 NMP Budget Summary (Unit: Million Euro)

Year (FP7)	2007	2008	2009	2010	2011	2012	2013
NMP	372	390	421	413	461	511	615
NMP/ Total R&D	6.8%	6.4%	6.2%	5.5%	5.4%	5.0%	5.7%
NMP budget increase rate		4.8%	7.9%	-1.9%	11.6%	10.8%	20.4%

Table 5. Nanotechnology Contribution to Fundamentals / Visualization / Application

NT: the 3 Main Axis			Remark
Nanotechnology	Enabling Program Components	Next Gen. nanomaterials -devices & systems	Non application specific Research (TRL 1-4), Fundamental
		Safe development & application	
		Societal dimension	
		Synthesis and manufacturing	
		Capacity enhancing Techniques	
	Cross KET application focus areas	Nano enabled surfaces	Application specific R&D&I with NT support (TRL 5-8), Application
		Nanostructures and Composites	
	Nanotechnology Innovation Showcase	Nanomedicine	Application uniquely enabled by NT (TRL 5-8), Innovation
		Environmental technologies	

4.2. Horizon 2020

Horizon 2020 is an integrated program of the existing Framework Program (FP), the Competitiveness & Innovation Programme (CIP), and the European Institute for Technology (EIT) to simplify the program operation and accessibility of participating institutes/researchers. The EU plans to invest approximately 40% of its entire R&D budgets through the Horizon 2020 program. Horizon 2020 is the new European growth and job creation program aiming for the recovery of Europe from economic crisis. Europe stresses that investing in R&D is a solution to overcome the current economic crisis, and plans to allocate an R&D budget up to 3% of GDP by 2020. Horizon 2020 is investing in 3 main component areas of "Excellent Science," "Industrial Leadership," and "Societal Challenges."

In particular, Horizon 2020 research and development was established by analyzing existing economic/social changes, therefore enables promoting innovation in broad areas including environment, climate change, aging society, and so on. These major goals are achieved by collaboration of industry-academia-public institutions and integrated/coherent policies covering R&D-education-innovation system. The Nanotechnology (NMP) in Horizon 2020 acts in the 'leadership in Enabling and Industrial Technology (LEIT)' section. Nanotechnology is a key enabling technology (KET) to recover the competitiveness of European industries, and focuses on crossing the valley of death for societal challenges. Nanotechnology serves as a key catalyst technology supporting these major goals by developing five major components as follows: 1) the next generation nano-materials, nano-devices and nano-systems, 2) safe development and applications of Nanotechnologies, 3) the social dimension of Nanotechnology, 4) Efficient synthesis and Manufacturing of Nanomaterials, Components, and Systems, and 5) Capacity enhancing techniques, measuring methods and Equipment.

In order to provide the solutions for societal challenges, European Commission started European Economic Recovery Plan (Commission of European Communities, 2008) that includes 3 PPP(public-private partnership) programs of Factories of the Future(FoF), Energy efficient Building(EeB), and Green Car(GC).

4.3. NanoEHS/Informatics within National Innovation Policies

Similar to the US, the EC also regards nanotechnology as a national innovation catalyst. Therefore the nano enabled commercialization promotion policy is paired with the development of nanoEHS throughout the European Action Plan 2005-2009, FP 7, and Horizon 2020. For example, the FP7 program covers activities from fundamental research to commercialization of technologies (innovation) of nanotechnologies in DG Research and development (RTD). NanoEHS was one of the key parts in 3) New production as well as The NanoSafety Cluster (NSC) initiative that was organized in 2009 to maximize synergies between the FP6 and FP7 projects, addressing all aspects of Nanosafety. Horizon 2020 (Post-FP7) was started in 2014 and set to run until 2020, and Nanotechnology as NMP is located under 'Industrial Leadership' and 'Leadership in Enabling and Industrial technologies (LEIT),' and focuses on the level of technological readiness (TRL) 3/4 - 8. Nanotechnolgy is one of the 6 key enabling technologies (KETs) driving competitiveness and growth opportunities, contributing to solving societal challenges with safe development/applications. Like the US regulation of FIFRA/TSCA, the EC also established REACH regulation that proactively monitors potential hazards of nanomaterials. In both the US/EU cases, their recent nanotechnology development direction is highly aligned with national innovation strategies of promoting nano enabled commercialization paired with nanoEHS. The EC has been collecting ongoing nanoEHS programs and budgets that are spread out over FP6-7 under the program of the nanosafety cluster since 2009. The EC supported 13 nanoEHS programs with a budget of 31 million euro under FP6, and 34 programs with 106 million euro under FP7. Their annual reports summarizing nanoEHS programs each year are available from the project home page (http://www.nanosafetycluster.eu/).

Nano policy elements of EU are not clearly separate such as in the US NNI program, but are integrated in the national program of Horizon 2020. The importance/interconnection of advanced manufacturing, nanotechnology, informatics for smart/fast production, and nanoEHS for safe commercialization are already fused in plans such as Factory of the Future (http://ec.europa.eu/research/participants/portal/desktop/en/

opportunities/fp7/calls/fp7-2013-nmp-ict-fof.html) in FP7 and Horizon 2020 (http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/calls/h2020-fof-2014.html#tab2).

5. KOREAN INNOVATION POLICIES INCLUDING NANOTECHNOLOGY

The mainstream of US/EU nanotechnology development policies are focused on application/commercialization goals that finally support national innovation policy. But Korean nanotechnological achievements are still weighted on fundamental/basic areas (Bae et al., 2013), and application/commercialization capacities show negative signs as described in Fig. 3. Below, the authors summarize limitations of Korean nano policies, and contrast the progress of US/EU policies to suggest possible future improvements for Korean nano policies.

5.1. Presidential Election Pledge

As a reminder, the main focus of global nanotechnology development trends is shifting from fundamental exploration to innovation/commercialization. Also, US/EU nanotechnology development policies are horizontally and vertically interconnected with neighboring policies to catalyze national innovation and commercialization. The Korean government also understands the importance of nanotechnology, and President Park Geun-Hye highlighted nanotechnology as an important supporter for creative economic policy (Park, 2012).

5.2. National Comprehensive Development Plan for Nanotechnology (NCDPN)

Since 2001, the South Korea government has been implementing the National Comprehensive Development Plan for Nanotechnology (NCDPN), revising it every five years. The first NCDPN (2001-2005) was planned to complete constructing major infrastructures within 5 years, and to achieve 10 world-top class technologies within 10 years. The second phase of NCDPN (2006-2010) was aimed at 3 major goals of becoming one of the top 3 nano competitive countries, preempting emerging markets by fusing with existing IT·BT·ET, and realizing the goal of a safe/prosperous country by 2015. The 3rd phase of NCDPN (2010-2020) was established to realize 4 major goals of achieving 30 top world-level practical skills, building infrastructure for research/education, creating nanotechnology based industries, and strengthening social/ethical responsibilities (National Nanotechnology Policy Center, 2012).

Through phases 1-2 of NCDPN, South Korea achieved building bases for nano R&D and industrialization. The implementation of the 3rd NCDPN achieved a significant increase of nano R&D budgets responding to social/market demand, and challenged making 30 core technologies for promoting nano commercialization. In particular, interagency collaboration was emphasized to respond to nanotechnology pre-occupation by the US/EC/Japan, support green growth, and create a new growth engine for society.

Up to now the Korean government has successively incubated the competitiveness of nanotechnology by implementing NCDPN. Recently the Korean government is beginning to reconsider the importance of promoting nano/convergence technologies as a breakthrough for innovation and economic growth. Superficially, Korea has been following global nanotechnology development trends well, but related data and indicators show negative signs of stagnation/decrease in Korean nanotechnology competitiveness and commercialization capabilities. Recently there have been discussions for the necessity of reforming the nanotechnology development policy framework to support nano/convergence based industries in a seminar held by the National Party (Kim, E.-D., 2013) and in research (Bae, 2013).

5.3. NanoEHS/Informatics within National Innovation Policies

The US/EU have been strengthening their national innovation chains of utilizing nanotechnology by renovating nanotechnology development for the realization of national innovation strategies, executing them by manipulating R&D budgets, and preparing a legal basis for sustainable application. Compared to the US/EU, Korean nanotechnology development is argued to have weak points as described below.

Korean nanotechnology policy has maintained the same investment portfolio since 2001 by fixing it as 3 components (R&D, infra, and education), but has been adopting international core issues of nanotechnology development including innovation and nanoEHS. However, investment budgets for key issues including nanoEHS were rarely monitored, and therefore it is difficult to evaluate progress (National Nanotechnology Policy Center, 2012). The US has been collecting nanoEHS budgets from 2006, and the EU has been managing nanoEHS budgets and programs under the name of the nanosafety cluster since 2009. In the case of Korea, the importance of nanoEHS has been emphasized from the 3rd phase NCDPN by planning for raising nanoEHS budgets up to 7% over all. However, it is very recent that the nano EHS investment amount was officially monitored, only since the 2013 Korean Nanotechnology Annual Implementation Report (National Science & Technology Council, 2013). Even still, national nano related budget assessment had showed approximately 2x differences depending on the source (collection from agencies participating in NCDPN, and the National Science & Technology Information Service under National Science & Technology Council), and this issue is improved since the 2014 Korean Nanotechnology Annual Implementation Report (National Science & Technology Council, 2014). In the case of the '1st national comprehensive nano safety plan (2012-2016)' (National Science & Technology Council (2011) led by the Ministry of Environment, this interagency collaboration plan is encountering difficulties in finding clear connections with the Korean Nanotechnology Promotion Act or NCDPN, meaning a weak national level of policy alignment. Also, Korea still does not have a developed legal tool supporting sustainable usage of nano e-material/products such as FIFRA, TSCA, and REACH in the US/EU cases.

Compared to the US/EU situations, Korean development of nanoEHS in R&D and legal tools is not clearly aligned for contributing nano based commercialization that finally supports a national innovation chain. Now the Korean government is putting prime importance on creative economy policy, but the nanotechnology policy design contributing to national innovation with economic growth is still questionable in various aspects such as controlling nano investment portfolios, supporting targeted technology fields including nano commercialization/nanoEHS, and synchronizing them with national innovation through interagency collaboration. In the case of informatics, it is too early to discuss whether national innovation policy clearly covers nano informatics for advanced manufacturing. Overall, Korean interpolicy connections of utilizing nano for national innovation need further development when compared with the US/EU.

Recently the Korean national assembly held a single forum sharing the issues of Korean nano policies described above, and discussed the necessity of revising its nanotechnology development promotion act (Kim, E.-D., 2013), including strengthening national nanosafety fields that support national innovation. The current nanotechnology promotion act and NCDPN require strengthening nanoEHS more systematically. On the continuation of this forum, a nanotechnology development promotion act revision bill was proposed (Kim E.-D. et al., 2014b) for first including nanoEHS elements.

6. CONCLUSION

Stimulated by the rapid chasing of Asian followers including Korea, the US/EU changed the focus of their nanotechnology development policies from fundamental exploration to application/commercialization. US/EU nanotechnology policies and legislative/administrative activities have been aligned with national visions over the last decade to maximize national capabilities for national innovation and societal challenges. These US/EU trends are reflected in 2014 NNI strategy and EU KET policy goals that support advanced manufacturing revival.

Compared to the US/EU, Korean nano policies show limitations for supporting nanotechnology commercialization and national innovation. The authors have investigated these weaknesses throughout previous original research (Bae S.-H. et al., 2013) and the support seminar held in the National Party (Kim E.-D., 2013) with the policy report of nanotechnology promotion act amendment direction (Kim, E.-D., 2014). These works discuss the necessity of promoting interagency collaboration with the required amendment direction of the Nanotechnology Development Promotion Act. Based on these activities, National Party member Kim Eul-Dong currently a proposed nanotechnology promotion act amendment bill (Kim, E.-D., 2014b). The main purpose of the amendment bill is strengthening nano commercialization and EHS/informatics to further support the Korean policy of creative economy. Initiated by this law revision, additional national efforts should be continued to reinforce a national innovation ecosystem by promoting nano commercialization with EHS/informatics.

US/EU policies have been focusing on advanced manufacturing revival with the support of nanotechnology commercialization capabilities as a counterattack against fast-followers, and Korea currently shows negative signs of decreasing commercialization capabilities and social acceptance of nano applications. If Korea does not react to US/EU nano policies of strengthening advanced manufacturing, then its consequences might return to us as an economic threat due to the heavy reliance of high-tech manufacturing industries.

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