Postprint: Foresight and Strategic Deployment Analysis of Nanotechnology Development in Major Countries

Authors: Zhang Chaoxing, Bian Wenyue, Wang Haiming, Xing Ying, Leng Fuhai

Date: 2017-10-21T00:00:00+00:00

Abstract

This article investigates and analyzes 35 nanotechnology strategic plans and reports released by major countries worldwide in recent years, including China. First, it examines the commonalities in national nanotechnology development prospects or deployments from perspectives including investment intensity, research personnel, R&D priorities, platform construction, and education. Second, acknowledging the differing national contexts, it analyzes the similarities and differences in the overall direction and goal achievement of these prospects/deployments, with particular focus on the distinctive features and priorities of nanotechnology strategic deployments in the United States, Japan, South Korea, Germany, the European Union, Australia, and China. Finally, through comprehensive excavation and analysis of nanotechnology development prospects/deployments, the research directions covered in the 35 reports are comparatively analyzed across seven domains: biology, environment, energy, devices and manufacturing, measurement, instrumentation, and standards and safety. The analysis reveals that countries place considerable emphasis on nanobiology research, a field frequently addressed in national nanotechnology strategic plans, whereas research strategies related to nanotechnology standards and safety are mentioned in relatively few national strategic plans.

Full Text

Preamble

This paper investigates and analyzes 35 nanoscience and technology strategic plans and reports published in recent years by major countries worldwide, including China. First, we examine the common characteristics of these national nanotechnology development plans from perspectives including investment scale,

research personnel, R&D priorities, platform construction, and education. Second, given the different national circumstances, we analyze the similarities and differences in the overall direction and implementation goals of these plans, focusing on the unique features and emphases of the United States, Japan, South Korea, Germany, the European Union, Australia, and China. Finally, through in-depth mining and analysis of these nanotechnology development plans, we compare the research directions mentioned in the 35 reports across seven domains: biology, environment, energy, devices and manufacturing, measurement, instruments and equipment, and standards and safety. Our analysis reveals that nanobiology is a research area receiving considerable attention across countries, frequently mentioned in national nanotechnology strategic plans, while research strategies related to nanotechnology standards and safety are mentioned in relatively few national plans.

Keywords: nanoscience and technology plans, strategic goals and deployment, planned research areas, differences/commonalities, major countries

Nanotechnology is a strategic frontier technology with broad application prospects. In 2001, the United States took the lead in formulating the National Nanotechnology Initiative, followed by the United Kingdom, Germany, Russia, the European Union, China, Japan, South Korea, India, Australia, and others, which subsequently developed their own national or regional nanotechnology development plans. Entering the second decade of the 21st century, countries have carried out new foresight exercises or deployments.

Common Characteristics of Nanotechnology Plans in Major Countries

In recent years, nanoscience and technology have developed rapidly, and national R&D plans for nanotechnology have undergone significant changes. Through content and comparative analysis of the 35 nanotechnology development plans or foresight reports obtained (Table 1), we found that despite different national conditions, these plans share certain common features: (1) **Enhanced confidence and increased investment in nanotechnology.** For example, South Korea' s "4th Comprehensive Nanotechnology Development Plan" increases government R&D investment in nanotechnology from 531.3 billion won in 2014 to 880 billion won in 2025, raising its share of total government R&D investment from 3% to 4%. The number of core researchers and related enterprises has also increased substantially—South Korea' s core research talent in nanotechnology grew from 1,100 in 2001 to 8,548 in 2014 [1]. (2) **Nanotechnology is designated as a key technology for national economic development and solving critical problems**, particularly in energy storage and conversion and targeted therapy in biomedicine [2]. (3) **R&D focus has shifted from single nanomaterial preparation and function control to application and commercialization**, marking a new stage in nanotechnology research. For instance, the U.S. nanocellulose commercialization project identifies "nanocellulose as an enzyme immobilization carrier and its application in antimicrobial packaging" and "nanocellulose materials for food preservation" as investment directions for commercialization [3]. (4) **Public R&D platforms and industrial parks promote industry-academia-research collaboration and integration with other fields**, significantly shortening the time from "proposal" to "industrialization." In China, there is the National Center for Nanoscience and Technology in Beijing—an international academic hub—and Suzhou has built the large-scale industry-government-university collaborative innovation center, the Suzhou Nanotechnology Collaborative Innovation Center. Japan also launched the "Nanotechnology Platform Program" led by the Ministry of Education, Culture, Sports, Science and Technology in 2012. (5) **EHS (environment, health, safety) and ELSI (ethical, legal, social implications) research and the development of international standards and norms (ISO, IEC) are promoted** to facilitate societal acceptance of nanotechnology-enabled industries. (6) **Basic and higher education in nanotechnology is emphasized.** South Korea has completed English-language higher education textbooks based on nanotechnology, and universities in the United States and South Korea offer undergraduate courses incorporating nanotechnology. The United States and Taiwan, China have also intensified textbook revision and teacher training programs to build a K12 science education system based on nanoscience and technology [4].

Distinctive Features and Priorities of Nanotechnology Plans in Major Countries

The overall direction and implementation goals of these plans vary across countries, each with its own characteristics and priorities.

(1) United States. As a leader in nanotechnology innovation strategy, the U.S. nanotechnology strategy and research goals are more specific. In recent years, the National Nanotechnology Initiative (NNI) has developed mission-oriented research plans on carbon nanotubes [5], nanocellulose commercialization [3], and sustainable water utilization through nanotechnology [6]. Simultaneously, its strategic plans are committed to solving major challenge problems through multidisciplinary integration, such as the "Nanotechnology-Inspired Grand Challenge for Future Computing" issued by the White House Office of Science and Technology Policy in 2015 [7].

(2) Japan. Japan aims to systematize nanotechnology to promote problem-oriented research. In December 2013, the Japan Science and Technology Agency (JST) published the "2013 Comparative Report on R&D in Major Countries," which identified three priority directions for Japan's future nanotechnology: bio-nano, green nano, and nanoelectronics. The goal is to leverage existing achievements in nanotechnology "sophistication" and "integration" to further systematize nanotechnologies that can address societal needs and promote problem-oriented research [4].

(3) South Korea. While continuing to emphasize strategic basic research in nanotechnology, South Korea stresses promoting nanotechnology industrialization to achieve national strategic technology goals [1]. In April 2016, the National Science and Technology Council of South Korea announced the "4th Comprehensive Nanotechnology Development Plan (2016–2020)," jointly formulated by ten ministries including the Ministry of Science, ICT and Future Planning, Ministry of Education, and Ministry of Environment. Over the next five years, the plan will focus on promoting innovation-led nanotechnology industrialization, conducting strategic basic research in nanotechnology, systematizing government investment in the field, strengthening nanotechnology innovation infrastructure, ensuring nanotechnology safety management systems, and building innovation support information systems to facilitate the realization of five major national strategic technology goals: emerging industries integrating information technology, future development drivers, clean and convenient environments, health and longevity, and a safe and secure society.

(4) Germany. Germany has focused its research priorities on the effective translation of existing research results to enhance the competitiveness of German enterprises [8]. In September 2016, the German Federal Cabinet adopted the "Nanotechnology Action Plan 2020" proposed by the Federal Ministry of Education and Research, defining cooperation among federal government departments in nanotechnology for 2016–2020. The plan targets nanotechnology toward priority areas of Germany' s high-tech strategy (including digital economy and society, sustainable economy and energy, intelligent transportation, etc.), aiming to further leverage the opportunities and potential of nanotechnology, enhance German enterprise competitiveness through effective translation of research results, and ensure nanotechnology' s contribution to sustainable development through safety research on nanomaterials.

(5) European Union. Recent EU nanotechnology strategic plans have focused on graphene R&D and application, particularly in the energy sector [9]. In October 2014, the Flagship European Research Area Network (FLAG-ERA) issued a joint transnational call for graphene as an emerging future technology, with research themes involving its applications in nanofluidics and energy. In February 2015, the EU "Graphene Flagship" proposed a 10-year roadmap for graphene science and technology, identifying 11 scientific and technological tasks including energy conversion and storage, and providing an R&D timeline [10].

(6) Australia. Australia aims to use nanotechnology to solve major challenge problems. In 2012, the Australian Academy of Sciences released the "National Nanotechnology Research Strategy" [11], proposing that to achieve nanotechnology-driven economic development, nanotechnology R&D opportunities must be aligned with the country' s major challenges. Through multidisciplinary research at critical scale using nanotechnology, solutions to these major problems can be found. Key challenges where nanotechnology can play a role include improving community health, providing drinking water, environmental remediation, developing clean energy, defending national security, and revitalizing Australian manufacturing.

(7) China. China formulated its nanotechnology development plan early. In 2001, the Ministry of Science and Technology, National Development and Reform Commission, Ministry of Education, Chinese Academy of Sciences, and National Natural Science Foundation of China jointly issued the "National Nanotechnology Development Outline" [12]. During the 10th Five-Year Plan period, various ministries provided large-scale funding for nanoscience and technology through national programs such as the "973 Program," "863 Program," "Key Technologies Support Program," major and key projects from the National Natural Science Foundation, the Ministry of Education' s Revitalization Plan, the National Development and Reform Commission' s industrialization demonstration projects, and major scientific engineering projects. In early 2006, the State Council issued the "National Medium- and Long-Term Program for Science and Technology Development (2006–2020)," which included nanomaterials and devices in its priority development areas [13]. In 2016, the Ministry of Science and Technology released the "13th Five-Year National Science and Technology Innovation Plan" [14], which included specific provisions for nanoscience and technology in sections on "Major International Science and Technology Programs,""New Generation Information Technology," and "Materials Technology." For example, the new materials technology direction included research on nanomaterials and devices. In the same year, the National Development and Reform Commission released the "13th Five-Year Strategic Emerging Industries Development Plan" [15], which mentioned nanomaterials and technologies in information, manufacturing, and new energy fields, such as forward-looking deployment of cutting-edge new materials R&D involving breakthroughs in graphene industrialization application technology and expanding the application scope of nanomaterials in optoelectronics, new energy, biomedicine, and other fields.

Comparison of Research Directions in Major Countries' Nanotechnology Plans

The key research directions in nanoscience and technology development plans or deployments of major countries show both differences and commonalities. This paper compares the research directions mentioned in these 35 reports across seven domains: biology, environment, energy, devices and manufacturing, measurement, instruments and equipment, and standards and safety (Table 2).

(1) Biology. The UK emphasizes the industrialization of bionanotechnology, such as establishing nanofiber production platforms and nanofactory design. China focuses on the biological applications of carbon nanomaterials and the development of biomedical materials with immune response. Australia emphasizes research on human bionic nanodevices. India hopes to develop pest-resistant plant varieties using nanoparticles. Russia, Germany, South Korea, and the EU consider nano-implant materials as important research directions. The United States, Russia, Australia, Japan, and India have listed targeted delivery of nanodrugs as a key support direction. The United States, Japan, and Germany attach great importance to applications in medical imaging.

(2) Environment. The EU and Germany regard CO capture and utilization as important research directions. The UK pays more attention to research on the environmental toxicity of nanomaterials. Japan includes radioactive substance removal technology as one of its strategic directions. South Korea emphasizes research on atmospheric purification nanocatalysts. China focuses more on R&D of extreme environment materials. Additionally, the United States, Russia, the UK, Australia, and Japan attach great importance to nanomaterial water treatment technologies.

(3) Energy. In the field of nanoscale energy storage materials, the United States emphasizes R&D of lithium battery solid polymer electrolytes and thermally self-charging batteries. In nanoscale power generation materials, it focuses on porous solid oxide fuel cell electrolytes and photovoltaic power generation enhancement materials. The EU emphasizes flexible batteries, lightweight electrical storage, hydrogen storage systems, and new renewable energy including osmotic power generation. Russia emphasizes solar cells, heavy-duty ceramic magnets, and alternative energy materials. The UK focuses on perovskite battery modularization. Japan emphasizes high-temperature superconducting power transmission. South Korea mainly deploys flexible electrodes, smart windows, and thermal insulation components. Australia emphasizes safe power batteries and solar cells. China emphasizes thermoelectric materials and long-endurance power batteries.

(4) Devices and Manufacturing. The United States, Russia, and the EU all list nanosensor R&D as a strategic direction. Both the United States and China emphasize chip R&D. The EU and China include flexible smart devices and non-volatile memory in their research directions. The United States emphasizes soft matter manufacturing technology. Russia emphasizes memristor-based electronic components. The EU emphasizes R&D of integrated circuits, plasmonic optical switches, and transistors based on graphene. China emphasizes extremely low-power devices and circuits, 3D printing, and silicon-based terahertz technology.

(5) Measurement. The United States focuses on heterogeneous material characterization. The EU emphasizes selective single-molecule detection. Russia emphasizes atomic-resolution material surface imaging systems. China will focus on developing characterization and measurement technologies with ultimate resolution capabilities.

(6) Instruments and Equipment. Both the EU and South Korea have strategic deployments in flexible displays. The United States, Germany, the EU, South Korea, and Australia emphasize functional detectors/sensors (such as molecular detectors, photodetectors, and sensor detectors). The EU emphasizes R&D of devices utilizing terahertz technology. Germany emphasizes hazardous substance detection and rescue personnel protection equipment. Russia emphasizes nanorobotics research. China considers nanogreen printing and nano-etching as important research directions.

(7) Standards and Safety. The United States emphasizes graphene regulation and its effects on genes. Germany emphasizes necessary protective measures when applying nanotechnology and innovative research on food materials. South Korea proposes research on infectious biological substance detection and monitoring. China places more emphasis on important standards and detection technologies for nanotechnology applications. Strategic deployments in the nanotechnology standards and safety domain by the United States, Germany, South Korea, and China all involve biosafety technology research on nanomaterials.

Summary and Outlook

Nanoscience and technology not only benefit the economy but also play a significant role in addressing major challenges such as sustainable energy, clean water, and healthcare. Nanotechnology continues to flourish, and an increasing number of countries are deploying nanoscience and technology development plans suited to their national conditions to maximize opportunities for enhancing national competitiveness. It is hoped that relevant departments in China will, while actively promoting basic research in nanoscience, strengthen the integration, focus, and utilization of existing achievements, identify and support with emphasis the commercialization and industrialization of nanotechnologies where China has advantages, making them a booster for China' s industrial transformation, upgrading, and innovation-driven development.

This article is adapted from the "Nanotechnology Research Frontier Analysis Report."

References

1. 제 4 기나노기술종합발전계획대한민국나노혁신 2025(안). [2016-09-17]. http://www.nstc.go.kr/c3/sub3_1_view.jsp?regIdx=792&keyWord=&keyField=&nowPage=1
2. A call featuring two important topics, representing more than €100 million EU investment, will open on 15 October. [2016-10-15]. https://ec.europa.eu/digital-agenda/en/news/electronics-eu100-million-bugdet-call-open-15-october
3. Cellulose Nanomaterials–A Path Towards Commercialization. NNI Workshop Report. http://www.fpl.fs.fed.us/documnts/pdf2014/usforestservice_nih_2014_cellulose_nano_w
4. 科学技術振興機構. 研究開発の俯瞰報告書が 2013. [2014-06-17]. http://www.jst.go.jp/crds/pdf/2013/FR/CRDS FY2013-FR-01.pdf
5. A Nanotechnology-Inspired Grand Challenge for Future Computing. [2016-10-08]. https://obamawhitehouse.archives.gov/blog/2015/10/15/nanotechnology-inspired-grand-challenge-future-computing

6. Working Together to Build a Sustainable Water Future. [2016-09-05]. https://www.whitehouse.gov/the-press-office/2016/03/22/fact-sheet-working-together-build-sustainable-water-future

7. A Nanotechnology-Inspired Grand Challenge for Future Computing. [2016-10-08]. https://obamawhitehouse.archives.gov/blog/2015/10/15/nanotechnology-inspired-grand-challenge-future-computing

8. Bundesministerin für Bildung und Forschung. Aktionsplan Nanotechnologie 2020. [2016-11-17]. https://www.bmbf.de/pub/Aktionsplan_Nanotechnologie.pdf

9. Research funding organisations in Europe launch their funding instruments in support of the Flagship initiatives on Graphene and Human Brain. [2016-11-10]. http://www.flagera.eu/extra-files/FLAG-ERA_Press%20release_27102014.pdf

10. Graphene flagship. The European roadmap for graphene science and technology. [2016-03-13]. http://graphene-flagship.eu/?news=the-european-roadmap-for-graphene-science-and-technology

11. National Nanotechnology Strategy. [2015-09-17]. http://www.science.org.au/policy/documents/nanotech research-strategy.pdf

12. 国家纳米科技发展纲要 (2001—2010 年). 中国基础科学, 2001, (10): 30-34.

13. 国家中长期科学和技术发展规划纲要 (2006—2020 年). [2006-02-09]. http://www.most.gov.cn/mostinfo/xinxifenlei/gjkjgh/200811/t20081129_65774.htm

14. 科技部. "十三五"国家科技创新规划. [2016-11-10]. http://www.most.gov.cn/mostinfo/xinxifenlei/gjkjgh/201608

15. 国务院. "十三五"国家战略性新兴产业发展规划. 中国战略新兴产业, 2017, (1): 57-81.

16. 中国科学院. 中国科学院"十三五"发展规划纲要. [2016-11-17]. http://www.cas.cn/yw/201609/W020160902357072

17. 中国科学院. 前沿科学"十三五"规划. 中国科学院院刊, 2016, 31(Z2): 63-68.

18. 国家自然科学基金委员会. 国家自然科学基金委重大研究计划"纳米制造的基础研究"2009 年度项目指南. [2016-10-08]. http://www.nsfc.gov.cn/publish/portal0/tab251/info24441.htm

19. 国家自然科学基金委员会. 国家自然科学基金"十三五"发展规划. [2016-11-23]. http://www.china.com.cn/zhibo/zhuanti/ch-xinwen/2016-06/14/content_38662624.htm

---

Zhang Chaoxing is a Research Associate at the Institutes of Science and Development, Chinese Academy of Sciences. His research focuses on information analysis. E-mail: zhangchaoxing@casipm.ac.cn.

Leng Fuhai is a male Professor at the Institutes of Science and Development, Chinese Academy of Sciences, and received his Ph.D. degree from the University of Chinese Academy of Sciences. His research focuses on information analysis. E-mail: lengfuhai@casipm.ac.cn