STRATEGY FOR NEW INDUSTRY CREATION IN THE NANOTECHNOLOGY FIELD

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Abstract

Nanotechnology is expected to be a key technology in this century to bring new industries. For its commercialization, not only public research institutes must create fundamental technological seeds, but also existing industries (including SMEs) should design mechanism, which bridges a ‘valley of death’. For bridging efficiently, possible solutions are to make an arrangement of integration between basic research and applied research or between dissimilar fields, and to organize face-to-face meeting between researchers and industries. In this article, we review Japanese experiences: an introduction of technology road-mapping approach, an evaluation of economic impact of nanotechnology and a publicizing of its result, and a formulation of private consortium. We will also outline the current situation of national activities for commercialization of nanotechnology in Asia.

Introduction

One of leading core technology in the 21st century, nanotechnology is expected to bring breakthroughs to various industries such as, materials, electronics, machineries, bio-industries and pharmaceuticals. Nanotechnology treats nanoscale (10⁻¹⁰ m), which is same scale of atoms and molecules. As prior technologies handle micro-meters or larger scale, nanotechnology is a different order of magnitude not only in scales but also in innovation.

‘Breakthrough’ is a keyword to understand nanotechnology. In contrast to other forefront technologies, for instance, information technology or biotechnology, nanotechnology has potential to revamp entire basement technologies. It may create dramatic solution to technological challenges in industries or social life.

Nanotechnology as a tool for breakthrough puts a strong impact on both governments and industries. Multiple nations recognize implicit in nanotechnologies, and have developed tactical nanotechnology R&D strategies with consideration of their conditions. All over the world, not a few people believe that nanotechnology makes significant change in wide spectrum of fields. With such expectation, many government bodies put a nanotechnology into their national R&D strategy as a core subject matter.

From the point of view of industries, nanotechnology shows another face: it requires numerous challenges to commercialize. Since it belongs to the basic research, we must fill in the gap between research activities and business creation (so called ‘valley of death’). As we confirmed, the core value of nanotechnology is its potential to disruptive innovation. True nanotechnology must be an innovative one that operates materials in nanoscale and that brings innovation, which is only realized in nanoscale. True nanotechnology must be based on new science or phenomenon in order to achieve breakthrough rooted on nano-level phenomenon.

Therefore, creation of new industries based on nanotechnology requires following four conditions:

First, public research institutions should contribute to the entrenchment of technical seeds. Basic research or trans-disciplinary research is suited for public research organizations (Condition 1).

Second, industries should design a system, which promotes commercialization of nanotechnology. Since advanced technologies inescapably fall down to “valley of death”, it is desirable to prepare an arrangement of integration between basic research and applied research or between dissimilar fields, or an organization in which researchers and industries can exchange ideas in face-to-face meeting (Condition 2).

Third, these arrangements should involve inter-disciplinarily. Up-and-coming fields of nanotechnology applied are said to be inter-disciplinary and inter-technology: fusioning fields between electronics and bio/medical, electronics and chemicals, energies and bio-chemicals, and social securities and bio-chemicals. These fields are expected to be enormous markets (Condition 3).

Fourth, a public certification authority is needed to warrant safety of nanotechnology application. Nanotechnology will fall under severe attack on its safety and credibility from consumers when it progresses to its market diffusion phase. For its commercialization, its absolute safety must be assured. This assurance is a dead weight for private sector (Condition 4).

Japan has long been implementing policies and measures to fulfill these four conditions. Here, we review our three experiences: an introduction of technology road-mapping approach, an evaluation of economic impact of nanotechnology, and a formulation of private consortium. Then, we overview Asian nations’ activities: Taiwan province of China, Republic of Korea and Singapore.

Case study 1: National strategy on commercialization of nanotechnology in Japan

An adoption of road-mapping approach

Japan has actively produced technical seeds in nanotechnology and has been in forefront in this field. In early 2000s,
Japanese accounted almost 50% of world patent applications. Although this ratio is decreasing, it still keeps about 40%. It is obvious that Japan filed [Condition 1] above; Japan's challenge is how to meet [Condition 2–4], that is, how to achieve integration between private and public sectors and between different fields.

Japan has established industry-government-university collaboration research epicenters and has conducted qualified technology talent education in graduate schools with close industry-university cooperation. This policy followed the U.S. and European experience. These two giants took successful approach to integrate knowledge in different fields and to stimulate cross-sector open innovation; they exploited selected industry-university hub institutions. Moreover, they supported universities to endeavor to exercise technical professionalism.

In addition, Japan has been taking a unique ‘road-mapping approach’. In the process of nanotechnology commercialization, it is necessary to communicate frequently and to achieve a consensus among various stakeholders. Roadmap supports understanding R&D processes and goals. Roadmap also upholds ethical and social debate in nanotechnology. Common recognition of directions of R&D is indispensable for the substantial discussion.

Nevertheless there is no unified definition under the general recognition; technology roadmap must satisfy three requirements: punctuality, numerical targets, and certain extent consensus. Firstly, the map should show the process of technology development in chronological order. Secondly, it should have clear goals in number. Thirdly, it should obtain stakeholders’ approval to some extent. The third requirement is an important factor for the roadmap to be effective. The following Japanese cases illustrate effective consensus building.

In 2005, the Ministry of Economy, Trade and Industry of Japan published the first roadmap of nanotechnology R&D in the world (Figure 1). This technology map clearly specified that it is designed for public understanding of the R&D concept, subject matters and expecting outcomes through the map itself and its drawing process. The concept of the map is (i) to grasp technology and its drawing process. The concept of the map is (i) to grasp technology and market dynamism, (ii) to select excellent future technology seeds, which should be targeted by both industries and the government, (iii) to maintain a policy debate mechanism to plan national R&D projects, (iv) to integrate different technologies, different academic fields, and different industry sections for corresponding to highly specialized technology and for supplying diversified market or social demands, and (v) to concentrate all industry, government and university efforts.

After 2005, Japan has already drawn several national roadmaps in nanotechnology under the collaboration with scholars, professionals in industries and government staffs. For example, Mitsubishi Research Institute, Inc., one of the largest private Tokyo-based think-tank, assisted couples of roadmap making (including unpublished maps).

The procedure of national technology roadmaps making takes the following steps; the New Energy and Industrial Technology Development Organization (NEDO) arranges a working group, which consists of members from universities, industries or government agencies, such as the Ministry of Economy, Trade and Industry (METI), the National Institute of Advanced Industrial Science and Technology (AIST), and NEDO. The working group drafts a roadmap considering diverse opinions of those who are doing...
the actual work. Then, the draft map is authorized by a deliberation council (i.e., the Research and Development Subcommittee, Industrial Science Technology Policy Committee, Industrial Structures Council), which is publicly held by METI and consists of technical professionals in various fields: information technology, life science, energy science, chemistry, and production engineering.

As we see above, Japan’s standard procedure of national road mapping deeply depends on human dedication based on consensus with people in widely different field. Therefore, deliberation by technical professionals and authorization by the public council is essential for the drawing process.

In addition to these national roadmaps, the academia or industry associations compose their own technology roadmaps. A typical roadmap is the ‘Technology Forecast’ by the National Institute of Science and Technology Policy (NISTEP), a government-operated academic agency for policy studies. Composition of the forecast takes the ‘Delphi’ approach, which conducts several repeat questionnaire surveys to the same, numerous professionals. This approach is known to be an effective measure to predict uncertain matters, for example, a prediction of a nanotechnology application market.

Another example of private roadmaps is a material technology roadmap made by the Materials Process Technology Center (Sokeizai Center). Sokeizai Center established a special committee to take direction of the map, drafted it in the subcommittee, and finally, the committee again deliberates the draft. Same as these national or private roadmaps, its drafting process is considerate of concerned parties’ conviction.

A drafting process of designing roadmap may bring opportunity for creating new industry. Optoelectronics Industry and Technology Development Association, which has broad experience in drawing technology roadmap, succeeded to satisfy four of two conditions of new industry creation through roadmap drafting. Like Sokeizai Center, the association organizes a committee and subcommittees, then many professionals and person concerned deliberate in the committee. Since the committees are from various fields and sectors, a mechanism of exchanging ideas in face-to-face meeting [Condition 2] is achieved. Furthermore, the deliberation is inter-disciplinary [Condition 3]. Its optoelectronics technology roadmap composition is highly regarded by interested parties.

As we mentioned above, consensus building is a key factor to design effective technology roadmaps. Drafting process of Japanese cases apparent care for formality; they form committees of professionals concerned, propose tentative map, and then authorize it with a consensus of the committees. This is an efficient approach to achieve both designing maps and building consensus.

However, this formal approach is inappropriate to discuss innovative matters or things that bring new value. An arbitrary and conservative choice is inevitable in the consequent process; (i) to clarify the times for targeting, (ii) to set a technical specification, (iii) to choose adequate technologies, (iv) to draft a tentative proposal, then (v) to review the draft and to build a consensus. In the process, to ensure better objectivity, sufficient information should be gathered and discussions should be done with data. Also, in-depth open discussion by interested professionals is desirable especially in the early phase of drafting.

**An evaluation of economic impact of nanotechnology**

A core value of nanotechnology is to bring breakthroughs with utilizing nanoscale undiscovered phenomena. In other words, nanotechnology holds ‘innovativeness’ or ‘disruptivity’ to the extent. Therefore, nanotechnology is expected to overcome technological challenges in industries or social life.

Public understanding of this potential will lead broad collection of attention and participation to the road mapping. As an evaluation of economic impact of nanotechnology supports potential recognition, Japan evaluated it long time ago. Japan has focused on market size prediction from industry sector’s viewpoint. In 2001, the Mitsubishi Research Institute published first estimation of the nanotechnology applied market, in which share of nanotechnology would reach at USD 240 billion in 2010. Followed by various other estimation, Mitsubishi’s estimation is said to be “pessimistic scenario” (Figure 2). This may be interpreted as our market prediction promoted an entry of newcomers and stimulated nanotechnology business field.

Nanotechnology gives breakthrough to a brick wall of prior technologies, therefore, it is not easy to start its applied market or to predict the start. Even today, market-leading nanotechnologies are micro-technologies in the strict sense of the word. People concerned have expected micro-technology to create a market while reserving nanotechnology’s future.

A Delphi survey of chief technology officers (CTOs) conducted in 2001 jointly by Nikkei Newspaper and Mitsubishi Research Institute revealed CTOs’ attitude toward nanotechnology and micro-technology. The result showed that CTOs forecasted among 11 hot technological subject matters, five subjects such as photonics crystals, molecular electronics, next generation memories, quantum communications and quantum computers, and brain devices, might remain in pre-market phase in 2010. Contrastingly, they evaluated that two micro-technology applied market, the drug delivery system and micro-machines, would reach at about USD 100 billion in 2010. Next generation electronics market was expected to start from 2010s. Nano-materials market was anticipated to grow constantly. But quantum communications and quantum computers markets, brain devices markets and markets of the bottom-up approach to nano manufacturing were forecasted not to become large to any substantial extent even in 2015.

Nevertheless those forecasts are pessimistic, some of nanotechnology applied industries have a potential to be an extraordinary large market due to the
drastic improvement of quantum electronics or the utilization of self-assembly. We must note that most of CTOs knew the difficulty in R&D and they were tending to forecast so cautiously that the actual market size is larger than the prediction.

An economic analysis conducted by AIST and Mitsubishi Research Institute estimated nanotechnology’s impact on (i) natural resource and energy industry (ii) transportation and automobile industry, (iii) ICT industry, (iv) home electronics industry, (v) medical and bio industry, (vi) space and ocean development, (vii) environmental issues, (viii) food supply, and (ix) overpopulation. Focused on innovativity of nanotechnology, we defined the ‘innovative factor’ calculated by expected value divided by current value. We interpreted innovative factors more than 10 as true nanotechnology.

The result clearly illustrates an impact of nanotechnology. Natural resource and energy industry indicated the highest value in the innovative factor. Nanotechnology makes it possible to cut marginal resource and energy consumption. This has strong impact on Japan, a country lack of natural resources. The analysis also reveals transportation and automobile industry will be 10 times in their market size when nanotechnology is applied completely. Consumer product field such as ICT industry or home electronics industry shows diversified effect of nanotechnology.

The survey and analysis contributed to receive attention to nanotechnology from people in its applicable fields, such as electronics, medical industries, energy industries or machinery industries. Utilizing its ultra-fine processing technology, nanotechnology only commercializes through these fields. For example, two native-Japanese technologies, carbon nanotube and photocatalyst nanoparticle was commercialized in a medical industry and in electronics industry.

A formulation of private consortium
In this article, we repeatedly confirmed the importance of a mechanism connecting industries and basic research institutions and of entrants from various fields who understand the impact of nanotechnology. Such a mechanism should be open to small and medium enterprises (SMEs) because in order to strengthen national industry’s competitiveness the participation from SMEs is essential. In Japan, a private consortium built this mechanism: Nanotechnology Business Creation Initiative (NBCI).

NBCI purposed to bridge between academia and industry or large firms and SMEs. In its charter, NBCI mentions the importance of bridging:  
*“For commercialization of nanotechnology, it is required to move beyond existing fields or organizations since nanotechnology is so innovative and highly generalized that a single technology seed creates multiple new products in diversified fields and that a combination of multiple technology creates new products. In order to gain a competitive edge in the global market using nanotechnology, new combinations of market players should be achieved; for example, it needs trans-field fusions or vertical integrations between different size of firms or traditional industrial classifications. Instead of consumer products, an advanced research device market for universities and research institutions would be a large market; nevertheless it remains in the early stage because of a lack of a market analysis, an industry-university cooperation, and strategic alliance between companies. This means the necessity of creation of new business model with integrating different players, and of close industry-university collaboration for desterilizing technical seeds in research labs. To be more precise, we should propose a national project, which aims at incubation or promotion of research and development for commercialization, with conveying to research institute market needs or benchmarks of commercialization. We should prepare efficient incubation mechanism or consultation function for commercialization. Recognizing centrality of practical realization of*
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nanotechnology and awakening the necessity of activities beyond organization borders, we voluntary members from industries establish Nanotechnology Business Creation Initiative."

To enhance matching up business opportunities, NBCI provides an information exchange service in latest technology, an idea exchange opportunities between entrepreneurs, investors and researchers, a researchers-technicians networking events. Also, NBCI suggests national R&D strategy, supports ventures, assists standardization, and enlightens the public. NBCI formed the following committees for these activities; ‘Business Committee’ plans to conduct networking and incubation with SMEs and public research organizations, to hold a matching event and a business negotiation with companies that have clear demands, ‘Nanotechnology Committee’ discusses on the prospects of nanotechnology for the future, and ‘Social Acceptance and Standardization Committee’ delivers information to subscribers on nanotechnology’s environment, health and safety (EHS), for instance, issues in discussion at OECD/WPMN, or on standard settings, for example, situations in ISO/TC229. Moreover, NBCI published a technology roadmap as a fruit of collective wisdom of members. The map designed in the standard process: forming a committee, then predicting a hot technology and products in demand, and deliberating subsidiary elemental technologies in the committee. In detail, the committee firstly illustrates social structure in the future, then forecasts products in demand under such a society, next enumerates technical elements for them, finally projects an approach to develop these elemental technologies.

Case study 2: National strategy on commercialization of nanotechnology in the Taiwan province of China

Taiwan province of China stated “National Nanoscience & Nanotechnology Program” to foster nanotechnology R&D and its commercialization. During the first phase of the program (2003–2008), with the participation of 10 departments and agencies, the government invested TWD 17.7 billion: 63% of the budget was for nanotechnology industrialization, 20% was for basic research in universities or research institutes, 15% was for core facilities, and 2% was for education. In the ongoing second phase (2009–2014), 8 departments and agencies participated and TWD 22.6 billion has been provided. TWD 16 billion (70% of the total budget) is for nanotechnology industry; the break down is for a device and equipment development 26%, electronics and optoelectronics development 23%, energy and environment field development 14%, bio-medical and agricultural development 14%, and other traditional field development 23%. TWD 4.5 billion (20%) is for advanced research. Rest TWD 2.3 billion (10%) is for strategic projects; the budget is made up of 45% budget for nanoMark system and industrial promotion, 25% for environmental protection and safety actions, 25% for education, and 5% for standardization.

Taiwan government also launched TWD 24 billion funds as a part of national nanotechnology development plan. According to the estimation, 90% of the fund is used up by Industrial Technology Research Institution (ITRI), a leading applied research organization in Taiwan province of China, and rest 10% is by universities for basic research. You might be aware that in Taiwan province of China an applied research hub in nanotechnology is ITRI, which promotes industrialization of technology in science parks, verifies nanotechnology applied products, holds certificate exam, conducts surveys for industrial development and transfers technology to the private sector. Especially, ITRI bridges between Taiwanese firms and patent holders in abroad in patent licensing.

Statistics demonstrates contribution of ITRI and other public research organizations for Taiwanese nanotechnology industry to strengthen its competitiveness. In payroll number, nanotechnology industry is with a staff of more than 41, 6% is with 21 to 40 operated, and rest 84% is with less than 20 staffs. For SMEs, sufficient investment and staffs are difficult to obtain, nevertheless, they contribute greatly their own funds in ration to total R&D investment. Public research organizations have supported SMEs to conduct efficient R&D.

Typical activity for enhancement of nanotechnology commercialization is the nanoMark certification, which officially approves containment of nanomaterials. As nanomaterials are expensive, consumers often distrust nanomaterials applied products whether they truly contain nanomaterials or, if so, whether they are in state of functional. Responded to consumer associations’ request, a nanomaterial certificate system, nanoMark, started from 2004. The nanoMark certificate various products, for instance construction materials; except cosmetics and foods, although in the certification process toxicity is examined. According to the report in Taiwan Nano Exhibition, Indonesia, Thailand and Iran are interested in the nanoMark certification.

In the Taiwan province of China, a private non-profit organization, Taiwan Nanotechnology Industry Development Association (TANIDA), connects industries, universities and basic research institutions to promote commercialization of nanotechnology and development of whole nanotechnology applied industries. TANIDA, established in 2004 by 57 members from industries, universities and public research organizations, plans nanotechnology industrialization strategy, proposes national R&D investment to the government, supports standard setting which contributes nanotechnology development, enlightens public about nanotechnology, provides inter-field exchanging, holds symposiums and arranges study tours. TANIDA also contributed to the nanoMark; its subsidiary committee, “Nanotechnology Standard Setting Committee” designed examination process of nanomaterial based products.
Case study 3: National strategy on commercialization of nanotechnology in the Republic of Korea

The Republic of Korea focuses on nanotechnology (especially on its commercialization) as their national science and technology strategy. Roh Moo-Hyun Administration declared nanotechnology as one of six important fields in the National Science and Technology Basic Plan (2002–2006). Lee Myung-Bak Administration modified the Basic Plan (“577 Initiative (2008–2012)”) and put “Green Growth Korea” as a core term. This meant national nanotechnology R&D shifted to be pro-commercialization.

The Republic of Korea has launched several initiatives on nanotechnology development; they are said to be for catching up with nanotechnology advanced countries, such as the U.S. or Japan. Under the Korea National Nanotechnology Initiative Process (established in 2001), Republic of Korea government issued the Nanotechnology R&D Master Plan. Since development of nanotechnology is quick, the Plan has been modified three times: the first Master Plan (2001–2010), the second Master Plan (2006–2015) and the third Master Plan (2011–2020).

Under the first Master Plan, Republic of Korea Ministry of Science and Technology (current Ministry of Education, Science and Technology: MEST) invested USD 1,238 million in 10 years to nanotechnology R&D programs. Some part of investment is used for establishment of nanotechnology R&D infrastructures, like research centers.

The Republic of Korea has six hub nanotechnology institutions: National Nano Fabrication Center (NNFC), Korea Advanced Nano Fab Center (KANC), National Center for Nanomaterials Technology (NCNT), Korea Printed Electronics Center (KPEC; former National Nano Printed Electronics Center, NNPEC), National Center for Nanoprocess and Equipment (NCNE), and USN/RFID Cluster (former u-IT Cluster Center). USN/RFID had been governed by Ministry of Knowledge Economy (MKE), now it is a private organization, while other five institutions are under the government control; MEST supervise NNFC and KANC, and MKE governs NCNT, KPEC, and NCNE. Expenses of incorporation is USD 274 million for NNFC, USD 160 million for KANC, USD 120 million for NCNT, less than USD 75 million each for rest institutions. These institutions work with universities or public research organizations; for example, NCNT forms a consortium with 136 organizations and cooperates with 18 universities and public research organizations. These six hubs play an important role in nanotechnology industrialization in the Republic of Korea.

Case study 4: National strategy on commercialization of nanotechnology in Singapore

Singapore from early 1990s have issued science technology five years basic plans to respond the prediction that Singapore economy would shift from a labor-intensive industry, through a capital-intensive industry, to innovative knowledge economy where intellectual properties are core assets.

The latest five years basic plan, Science & Technology Plan 2010 (2005–2010), set forth an enhancement of applied researches in nanotechnology which supply demands of various industrial clusters: electronics, chemical, food, the precision machinery, transportation machinery, environmental engineering service, and ICT. The Plan also indicates nanotechnology is fundamental to these clusters.

Under the Plan, Fusionopolis was established in 2008 as a new research hub. This center aims to promote fusion of scientific theories and engineering, and their commercialization. It equips the most advanced research facilities or devices for fabrication of CMOS and MEMS, and for fabrication and characterization of nanomaterials, such as thin-film, polymeric semiconductor, III-V composite semiconductor.

Although in Singapore no nanotechnology cluster generated, a couple of consortiums for nanotechnology R&D, like Singapore Bioimaging Consortium (SBIC), are active with financial aids by The Agency for Science, Technology and Research (A*STAR). As their members are from different universities or research institutions, these consortiums inevitably stimulate networking among researchers from different organizations.

A*STAR itself contributes directly to the commercialization. A*STAR Research Institute, a subsidiary research section of A*STAR, plays a key role in nanotechnology industrialization in Singapore. The institute has conducted more than 250 research projects with private companies (including foreign companies). More than 30 spin offs have launched their business from 2001. Moreover, some universities uniquely struggle to industrialize; for example, Nanyang Technological University holds nanotechnology commercialization promotion agency, NanoFrontier.

Conclusion

As the next center of economy and R&D, and a core of economic growth in this century, Asian countries have worked on innovation through nanotechnology commercialization. We already overviewed that each Asian country tries to enhance it in their distinctive way. While they compete with each other, many countries seek cooperation with others: for instance, Asian Nano Forum and Asian Productivity Organization. Asian Nano Forum (established in 2004), consists of 15 Asian countries, hosts international conferences and working groups on policy, R&D or commercialization of nanotechnology. Asian Productivity Organization, consists of nine Asian countries, convene study meetings for exchanging information and discussion on commercialization. We must note that such cooperation is important to enhance commercialization of nanotechnology.