Foresight

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Article information:

To cite this document:
Hsin-Ning Su Pei-Chun Lee Benjamin J.C. Yuan, (2010),"Foresight on Taiwan nanotechnology industry in 2020", Foresight, Vol. 12 Iss 5 pp. 58 - 79
Permanent link to this document:
http://dx.doi.org/10.1108/14636681011075713

Foresight on Taiwan nanotechnology industry in 2020

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The authors would like to thank the Science and Technology Policy Research and Information Center, National Applied Research Laboratories, for approving the research project and for funding; numerous nanotechnology experts who participated in this survey. The authors also gratefully acknowledge efforts from the research team and very helpful comments and suggestions given by Professor Tugrul U. Daim and anonymous referees.

Received: 7 December 2009
Revised: 6 March 2010
Accepted: 11 April 2010

Abstract

Purpose – *The purpose of this paper is to create a vision and obtain a consensus on Taiwan's nanotechnology industry in three dimensions (the 2007 situation, the R&D maturation time, and the 2020 scenario). It then seeks to foster a set of development strategies for Taiwan in 2020.*

Design/methodology/approach – *A Delphi-based foresight study together with an expert discussion meeting has been conducted to obtain a consensus for Taiwan nanotechnology in 2020.*

Findings – *The paper provides the results of the first Delphi-based survey on Taiwan nanotechnology development. The Nano Bio Medicine domain has greater maturity; the maturation time of most techniques will be 2010-2015; Nanocomposite Material Technique, Nano Optoelectronic and Optical Communication, and Nano Storage show relatively high competitiveness. Self-R&D and Technology introduced from overseas are the major development methods in 2020.*

Practical implications – *The paper is of interest to foresight practitioners and policy makers at the industrial and government levels in Taiwan.*

Originality/value – *The paper is the first publication to identify Taiwan's 2020 nanotechnology development by Delphi-based foresight investigation.*

Keywords *Delphi method, Technology led strategy, Taiwan*

Paper type *Research paper*

Introduction to Delphi-based technology foresight as a policy tool

One of crucial concerns of Sci-Tech investment for government is the type and the amount, and the areas into which resources have to be introduced. If there are multiple areas, before a proper investment can be made the capability to set priorities is crucial. A priority setting capability is the ability along a time horizon both to understand the development trends of technologies and to anticipate long-term social and economic needs. The combination of these will create a Sci-Tech forecast which is the fundamental determinant in formulating Sci-Tech policy. The fact that recent Sci-Tech development has become increasingly important in public policies suggests that the involvement of as many stakeholders as possible in a Sci-Tech forecasting process is desirable in order to have more democratic planning (Genus, 2006).

For this reason and in response to extensive global competition, democratic methods of Sci-Tech forecasting have been conducted in many countries to promote Sci-Tech developments. The Delphi based technology foresight is one method used to forecast the long-term future (20-30 years) of science, technology, the economy, and society with the aim of identifying areas of strategic research and emerging generic technology (Martin, 1995; Wechsler, 1978). It is based on ''structural surveys and makes use of the intuitive available information of the participants, who are mainly experts. Therefore, it delivers qualitative as well as quantitative results and has beneath its explorative, predictive even normative elements'' (UNIDO, 2003). Gupta and Clarke (1996) identified 463 papers between 1975-1994 which treat Delphi as the primary or secondary subject (Gupta and Clarke, 1996).

Delphi methodology was initiated by Rand Corporation of the USA in the 1950s (Landeta, 2006; Kaplan *et al.*, 1949), followed by Helmer-Hirschberg and Rescher (1960) and Dalkey (1969). Japan was the first country that started holistic Delphi-based foresight activities at the national level in the early 1970s (Kagaku Gijutsu Dōkō Kenkyū Sentā, 2005). These initial efforts were followed by the practices of European governments (Saritas *et al.*, 2007). Strategic decision making and prioritization have become inevitable for countries with limited resources. Owing to the intensifying global economics, Delphi based technology foresight has recently drawn global attention, particularly from those countries with limited resources who desire to upgrade their economic structures to a knowledge based economy.

Science and technology development, a fundamental factor of economic growth, are the result of complex relationships among actors in the system (OECD, 1997). Technology foresight can help policy making authorities understand how to improve complex networking relationships among actors and institutions in the innovation system; thus, technology development as well as long term economic growth can be expected (Martin and Johnston, 1999). As discussed by Anderson, possible advantages for technology foresight can be:

- forge new partnerships;
- identify generic technologies; and
- develop consensus on national priorities (Anderson, 1997).

Already a number of countries have conducted holistic technology foresight activities for the formulation of feasible science and technology policies. Some even conduct such activities on a regular basis, e.g. Japan and Korea, etc. (Havas, 2003; Saritas *et al.*, 2007; Yang *et al.*, 2004; Kagaku Gijutsu Dōkō Kenkyū Sentā, 2005; Schlossstein and Park, 2006; Czaplicka-Kolarz *et al.*, 2009; Mu *et al.*, 2008). Taiwan is geographically, culturally, and economically close to Japan and Korea, but has not yet conducted holistic national level technology foresight activity. So far such national holistic technology foresight activities has not been scheduled in Taiwan, even though it is stated in the latest Taiwanese ''White paper on Science and Technology'' that government should start technology foresight investigation to obtain democratic consensus on long-term technology and societal developments (National Science Council, 2007).

In 2007, a call for proposal for a ''Foresight Taiwan'' program was announced by the National Science Council to discover new ways by which science and technology could have a significant and lasting impact on Taiwan's economic growth in both near and long terms (*Foresight Taiwan*, 2008). The purposes anticipated in this Taiwan's program are quite similar to what technology foresight usually does, but the selection of techniques/projects to be funded relies on a panel's expert judges instead of a democratic consensuses obtained through regular technology foresight activities. Most important, the mechanism and operation of ''Foresight Taiwan'' are totally different from those of conventional technology foresight activities.

However, there is only one national level Delphi-based foresight activity initialized by the Taiwan government, i.e. ''2025 Taiwan Agricultural Technology Foresight'' which was planned by STPI (Science and Technology Policy Research and Information Center) and is now being investigated by the Taiwan Institute of Economic Research (TIER, 2010). It is very likely that the Taiwan government will conduct holistic technology foresight activities even though the schedule is still remains unknown.

In addition to above mentioned national-level foresight activities conducted by Taiwan government, there have been several relatively small-scaled Delphi surveys conducted in selected fields to obtain the development trends of future Taiwan industries, e.g. opto-electronics industry in 2010 (Chang *et al.*, 2002) and semiconductor industry in 2015 (Yuan *et al.*, 2006).

Conceptual framework

This study conducted a Delphi-based foresight investigation on Taiwan Nanotechnology Industry in 2020 in order not only to obtain a consensus on what Taiwan's nanotechnology

industry will be, but also to disseminate Delphi-based foresight activity. Hopefully a holistic technology foresight activity will be conducted in Taiwan in the near future.

Delphi-based foresight activity is relatively new in Taiwan and requires dissemination. This study provides Delphi experience on Taiwan's nanotechnology in order to contribute to Taiwan's foresight experiences and to the formation of a foresight community. Figure 1 shows the conceptual framework of this study. The ''Delphi-based foresight'' is the core work conducted in this study with the introduction to the core work of:

1. Situation of current Taiwan nanotechnology development; and
2. Global foresight on nanotechnology.

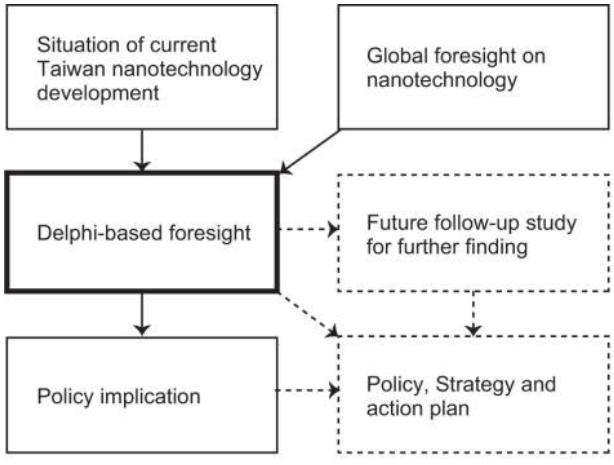
Finally policy implication can be generated for Taiwan's foresight community. ''Future follow up study for further finding'' are also suggested to obtain further findings and then contribute to transformation of Delphi results to a ''Policy, strategy and action plan''. The solid lines in Figure 1 represent what has been done in this study. The dashed lines indicates what can be done in the future

Nanotechnology in Taiwan

Nanotechnology is the development and utilization of devices and structures with a size range from 1 nm to 100 nm. In comparison to bulk and molecular scale structures, new physical and chemical properties occur with this scale. Interdisciplinary nanotechnology has been growing explosively in the past few years because nanotechnology can possibly be utilized in every conventional field if it is purposefully engineered.

The year 2001 is estimated to be near the beginning sector of the classical ''S'' development curve of nanotechnology, and 2006 is the first rising sector of the curve (Roco, 2001). As predicted by Lux Research, nanotechnology is approaching a phase change that will see it spread exponentially across manufactured goods within ten years. The $13 billion worth of products incorporating emerging nanotechnology in 2004 accounted for less than one-tenth of 1 percent of global manufacturing output. In 2014, this will rise to $2.6 trillion, 15 percent of manufacturing output (Lux, 2006). West Europe, Japan, and USA are the three major areas with the highest government funding, and these are each comparable to total government funding from other countries. These leading countries in fields of traditional science will always be present in the emerging revolution of nanotechnology. High government funding plus well developed science and industry infrastructure allow these countries to have

Figure 1 Conceptual framework



Source: Solid line: work in this study; dashed line: future work

significant nanotechnology patents (Huang *et al.*, 2004; Scheu *et al.*, 2006; Marinova and McAleer, 2003) and publications (Miranda Santo *et al.*, 2006; Tegart, 2002).

In order to develop Taiwan's competitiveness and to be part of this nanotechnology revolution, the Taiwan government started a six-year national program to develop nanotechnology. Accordingly, the National Science and Technology Program for Nanoscience and Nanotechnology was approved in June 2002 at the 5th Science and Technology Congress of the National Science Council. The program office consists of eight working groups including four execution groups and four R&D programs. The four R&D programs are:

1. Academic Excellence Research Program.
2. Nanotechnology Industrialization Program.
3. Core Facilities Program.
4. Education Program.

Industrial funding is 64 percent of the total funding, and indicates that Taiwan's National Science Program for Nanoscience and Nanotechnology is an industry driven program (NSTPNN, 2008, Su *et al.*, 2007).

To understand Taiwan's nanotechnology development, we have previously conducted surveys in 2002 and 2006. The results show that small and medium-sized enterprises have been the backbone of Taiwan's economic development. Nano material dominated Taiwan nanotechnology since 2002 (51.6 percent in 2002 and 53.3 percent in 2006) because of Taiwan's conventional industry. Most nano products are manufactured by introducing nano material to existing products. From 2002 to 2006, nano photonic has decreased from 16.1 percent to 4.7 percent, nano electronics has increased from 3.2 percent to 10 percent, and nano biotechnology from 9.7 percent to 16.7 percent. Also, R&D and manufacturing of nano material is the main focus and will continue to be the key point of Taiwan's nanotechnology development. Solving nanotechnology related problems such as nanotechnology manpower, consumer recognition, high product cost, limited technique, etc., with the aid from Taiwan government are essential (Luo *et al.*, 2002; Su *et al.*, 2007).

Technology foresight on nanotechnology

The scientific and technological importance of nanotechnology means that nanotechnology is being considered in national technology foresight conducted in several countries. For instance, the ''material'' area in Japan's 7th (2001) national technology foresight survey was upgraded to the ''material and nanotechnology'' area in Japan's 8th (2005) national technology foresight activity in order to cover ''nano'' related topics (Kagaku Gijutsu Dōkō Kenkyū Sentā, 2005). Also, three nanotechnology related topics are included in the ''new material'' technology foresight conducted by the Chinese Ministry of Science and Technology in 2002 (Yang *et al.*, 2004). Furthermore, some technology foresight activities make ''nanotechnology'' an independent area in their survey activities, e.g. the Danish nano-science and nano-technology foresight project was undertaken in 2004 by the Danish Ministry of Science, Technology and Innovation (Dannemand Andersen *et al.*, 2005), and the German Mini-Delphi study conducted in 1995 which has a nanotechnology subsection (Kuusi and Meyer, 2002).

All these foresight activities aim to promote national competitiveness in the global nanotechnology race, and no country can afford to be left behind. In addition to the above consensus on nanotechnology research topics, suggestions have also been investigated on: future nanotechnology research in many aspects (Bachmann *et al.*, 2001), how to bridge the gap between nanotechnology foresight research and market research (Malanowski and Zweck, 2007), and how to reduce the democratic deficit in institutional foresight program (Loveridge and Saritas, 2009). These provide a more detailed and practical way of allowing the results of nanotechnology foresight activities to be put into practice.

The Taiwan government has not announced a time schedule for holistic technology foresight activity. However, a Delphi survey, ''STPI Nanotechnology Survey'' (STPI, 2007), for creating a vision and fostering a set of development strategies for Taiwan's nanotechnology industry was carried out in 2006 by the Science and Technology Policy Research and Information Center (STPI). STPI was founded in 1974 as a science and technology unit supervised by Taiwan's National Science Council and was reorganized as a non-profit organization under the National Applied Research Laboratories in 2005.

This paper reports the results of this 2007 STPI Nanotechnology Survey. Because of the broad application of nanotechnology and in order to narrow the focus, this investigation selects Nano material, Nano electronic and semiconductor, and Nano biomedicine as the three subject areas that are relatively important in Taiwan. In comparison with the above-mentioned holistic, government supported, technology foresight activities (Havas, 2003; Saritas *et al.*, 2007; Yang *et al.*, 2004; Kagaku Gijutsu Dōkō Kenkyū Sentā, 2005; Schlossstein and Park, 2006; Czaplicka-Kolarz *et al.*, 2009; Mu *et al.*, 2008), the scale of this survey is smaller in terms expert participants and technology fields (STPI, 2007). The detailed mechanisms and results of STPI Nanotechnology Survey are as follows.

Delphi methodology

STPI Nanotechnology Survey is based on the Delphi method which features an anonymous and democratic way of consensus creation by repeated surveys. Delphi method has been broadly applied in many fields for vision creation based on group consensuses. To adapt the Delphi method to different requirements, surveys would require slight modifications according to different research structures or investigated environments. However, the following three main characteristics of Delphi method remain unchanged after these slight modifications (Linstone and Turoff, 1975; Martino, 1983; Goodman, 1987; Hasson *et al.*, 2000):

1. *Anonymity*. Survey questionnaires are sent out and collected by mail (the most frequently used method) or the questionnaire is answered in a one-to-one interview. Experts participating in the survey are selected from different fields or regions, and the survey is conducted anonymously to ensure a higher response rate and to avoid the possibility of psychological interference from other experts.
2. *Iteration method with feedback control*. Experts' interaction can be obtained by providing previous experts opinions in the current survey. Both positive and negative opinions can be provided and usually it takes two to four rounds of surveys.
3. *Statistics of group responses*. Not only experts' opinions but also statistical analysis on collected responses of previous surveys can be provided to motivate experts to move toward convergent consensuses.

The study is divided into three steps along the time horizon:

1. Expert list creation.
2. Survey implementation.
3. Experts discussion meeting.

These are described below.

Figure 2 shows the detailed flow chart of the Delphi methodology used in this study.

Expert list creation. Experts in the relevant fields consistent with the nanotechnology to be investigated in this research are identified and screened and targets are clearly defined by the steering group. A list of 712 nanotechnology related experts was created from industry (162 experts) and universities and research institutes (550 experts). The percentages are shown in Table I, the distribution of experts in different nanotechnology fields is shown in Figure 3, and the detailed distribution of the 550 experts in research institute/university is shown in Figure 4. Of the university and research institutes, 34 each had three or more nanotechnology experts. The last category, ''Other universities'' had 8 percent of the experts (44) and these were from four research institutes, nine national universities and 19 private

Figure 2 Delphi survey research flow chart

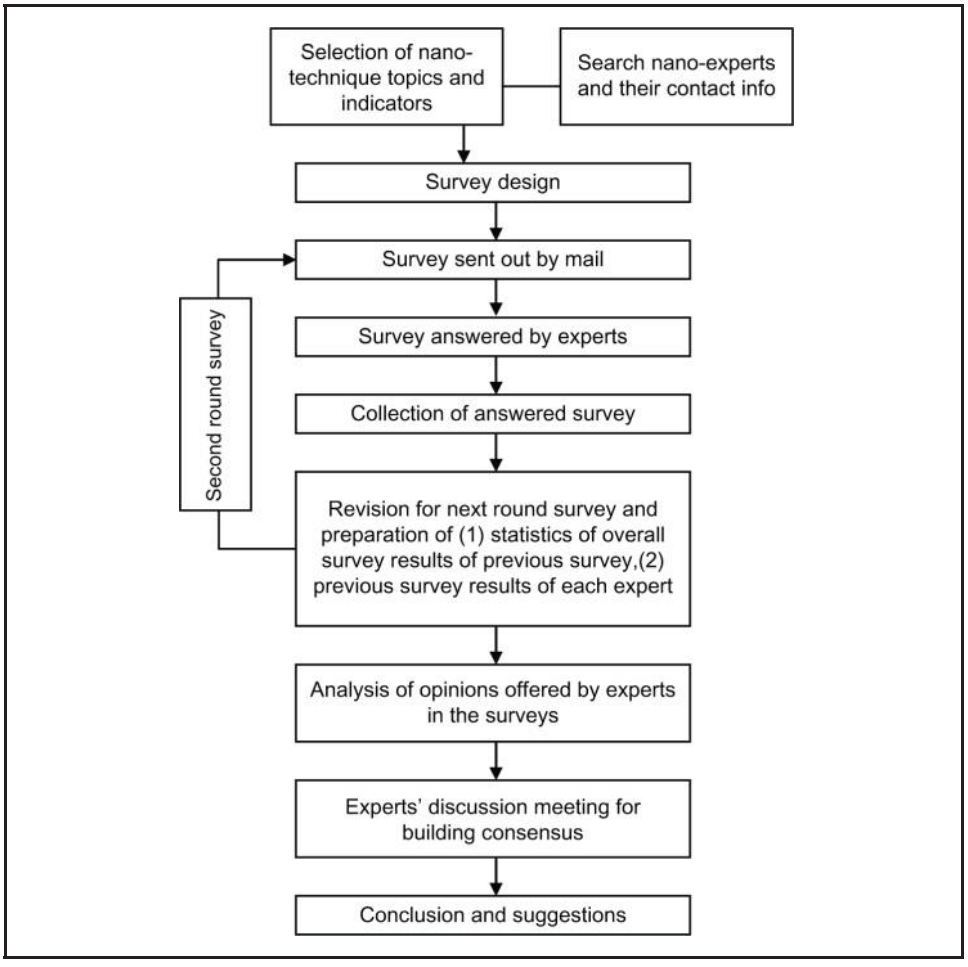


Table I Structure of experts participating in STPI Nanotechnology Survey

Sectors	*Number of experts*		*Percentage*
Industry	162		23
		115 for non-R&D	16
		47 for R&D	7
Academy and Research	550		77
Total	712		100

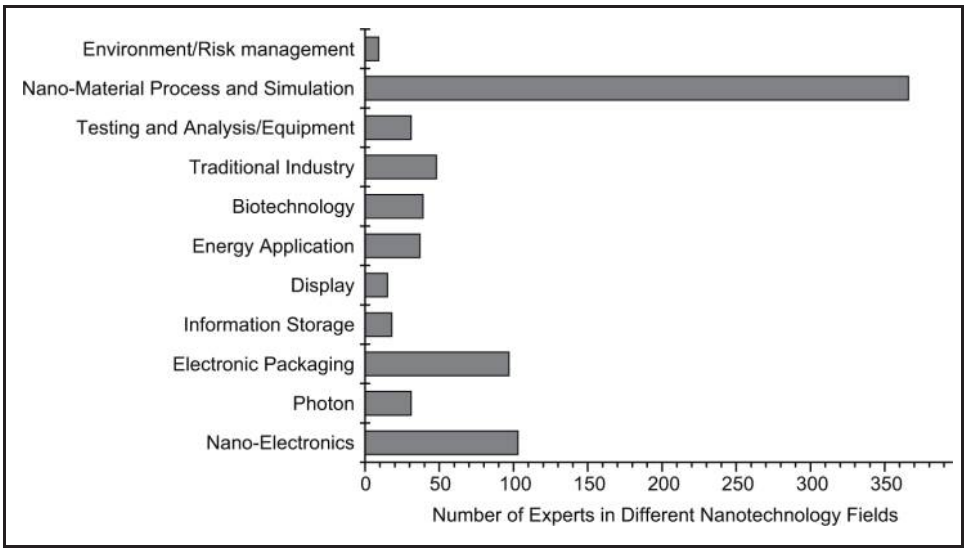
universities. There were a total of 66 research institutes or universities. Most of the expertise was in the nano material field and the two organizations with the largest number of experts were Industrial Technology Research Institute (ITRI) and National Taiwan University (NTU).

Survey implementation. The two major elements of the survey are:

1. nano techniques for the development of Taiwan's nanotechnology industry; and
2. indicators for evaluating these nano techniques.

Potential techniques and associated indicators were created by the steering group. The number of rounds for survey implementation is limited to two, in order to restrict as must as possible the ''bandwagon effect'' and the weariness of respondents (Scapolo and Miles, 2006). To maximize the response rate, respondents were fully informed about this study and reminders were provided. The first round survey, was submitted to 443 experts selected

Figure 3 Number of experts in different nanotechnology fields



from the list. A total of 83 survey results were collected (response rate 19 percent: 73 percent of the results from education and research sectors, 27 percent of the results from industry sector). These were analyzed for preparation of the second round survey.

In the second round survey, the number of technique topics was reduced to about half, as suggested by experts, in order to prevent survey complication, to increase response rate, and to sharpen the focus caused by too many technique topics. Thus, techniques with relatively lower competitiveness according to the results of the first round were removed. The second round survey and the first round results were submitted to the 83 experts who answered the first round survey. A total of 71 second round results were collected (86 percent response rate: 76 percent results from education and research sectors, 24 percent results from industry sector), analyzed, and provided as a reference for the following expert discussion.

Expert discussion meeting. The expert discussion meeting was conducted after the survey implementation. Of the experts who participated in the survey, 25 also joined this discussion in order to determine the proper nanotechnology development trend and strategy, based on the survey results. The description of current and future needs of Taiwan's nanotechnology development was developed in the meeting and can serves as an important reference for creating strategy. The discussion meeting strengthens the convergence of opinions, provides platforms for expert interaction, and converts numerical survey results to lexical suggestions regarding Taiwan's future nanotechnology.

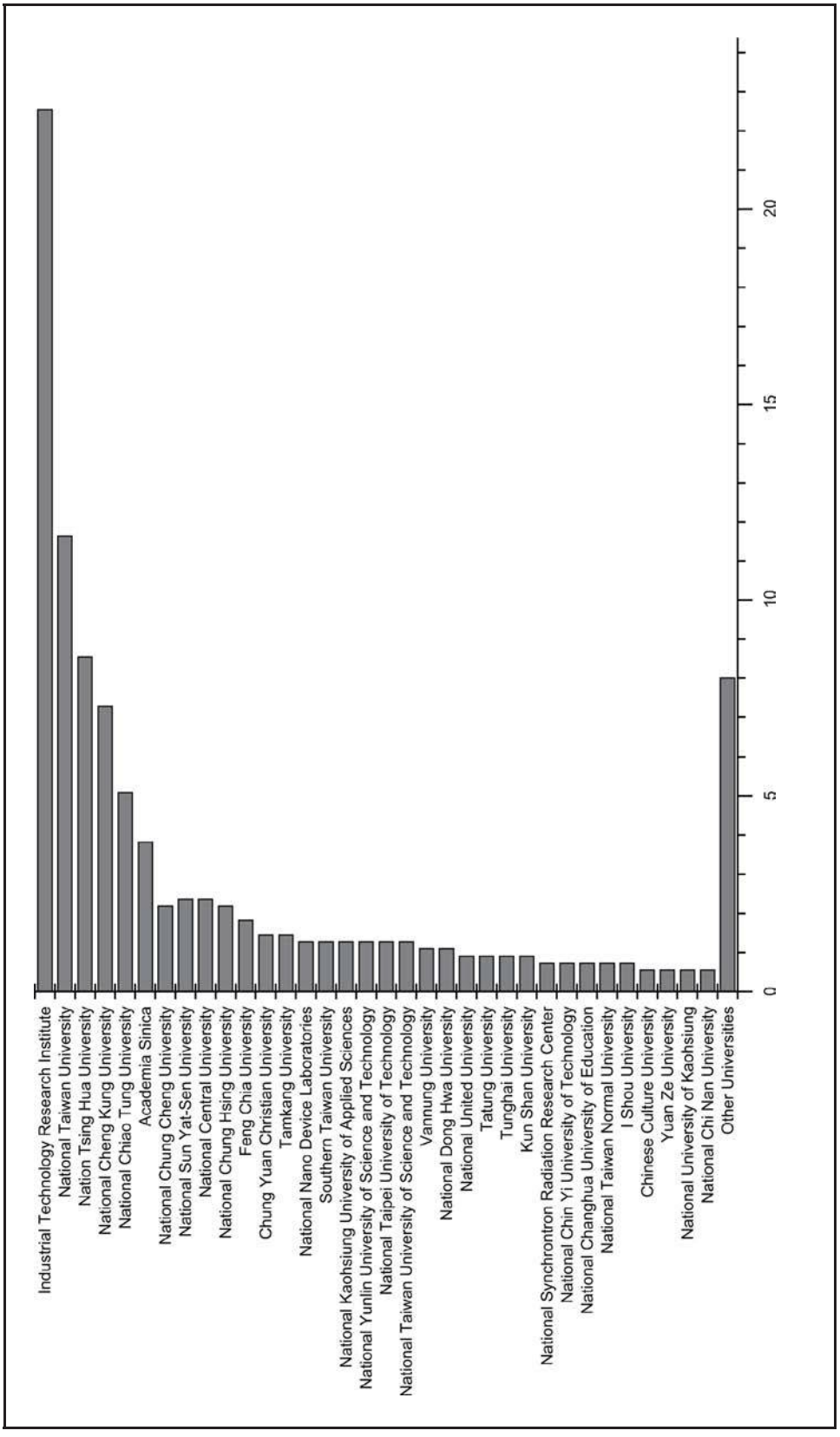
Survey design

In order to design an effective survey to understand Taiwan's nanotechnology development, nanotechnology technology foresight or Delphi survey reports/papers with nanotechnology topics as well as survey methods were collected from the literature and analyzed as the background information for this study (Kuusi and Meyer, 2002; Yang *et al.*, 2004; Dannemand Andersen *et al.*, 2005; Kagaku Gijutsu Dōkō Kenkyū Sentā, 2005; Mu *et al.*, 2008). The results served as references for creating the survey questionnaires.

There are three types of surveys (Van Zolingen and Klaassen, 2003; Nielsen and Thangadurai, 2007):

1. Classical Delphi;
2. Policy Delphi, and
3. Decision Delphi.

Figure 4 Percentages of experts in different organizations from academy and research sectors



The survey created in this study aims to facilitate future policy decision and therefore belongs to ''Policy Delphi''.

Research scopes in this study

Forecast time point. The year of 2020 is set as the target time point for investigating Taiwan's future nanotechnology development.

The time horizon for technology forecast by the Delphi method can be as long as 20 years. But as the forecast becomes longer, the converging of a consensus by experts will be much harder or may even create unavoidable imprecision. Particularly for well-defined techniques with specific industrial purposes, industrialization times should not be too far in the future so that their industrialization situations can be more precisely forecast. Since the purpose is forecasting industrialization situations of some well-defined nano techniques, the target time to be forecast is set at the year of 2020.

Focused period in technology life cycle. Focus on technology development and industrialization.

This study aims to search for nanotechnology with potential niches in Taiwan on the basis of current nano-related projects in National Science and Technology Program for Nanoscience and Nanotechnology (NSTPNN, 2008) and to understand the opportunities in the context of market size, industrial competitiveness and sustainability.

Studied techniques. While nanotechnology covers most fields in science and technology, three nano related fields with strong support from Taiwan's conventional industries are selected:

1. nano material;
2. nano electronic and semiconductor; and
3. nano bio medicine.

The three fields are further divided into 13 sub fields containing 75 technique topics, 26 in Nano Material, 24 in Nano Electronic and Semiconductor, and 25 in Nano Bio Medicine, as shown in Tables II-IV.

Indicators. There is no good standard indicator for evaluating development of nanotechnology. However, we reviewed the literature and integrated our past experiences to generate logical indicators which cover the current situation, the maturation time, and the future scenarios. Hence, the three major criteria to be investigated are shown below and in Table V:

1. *2007 situation*. The current degree of maturity and the human resource availability of Taiwan's nanotechnology are obtained, as a starting basis for future scenario projection.
2. *R&D maturation time*. The expected time for mature R&D for shaping theh nanotechnology S-curve in Taiwan is investigated.
3. *2020 scenario*. The expected future of nanotechnology in Taiwan is investigated in terms of technology industrialization, preferential development strategy, and obstacles or bottlenecks, in order to realize how to stimulate Taiwan's nanotechnology value chain.

Survey processing and result statistics

Since the Delphi-based method was selected in this study, a two-step survey process was used in order to obtain converged opinions from experts. A first round survey was sent out to experts and the results collected. Then basic statistics of these results were analyzed and items listed in Tables II-IV were revised based on expert opinions. Subsequently, a second round survey with a reduced number of techniques together with the first round results was sent out to the same group of experts who answered the first round survey. Finally the second round results were collected and analyzed.

Table II Nano material-related techniques in the first survey

Nano material	
Nano powder manufacturing	Nano metal colloidal particle Nano metallic particle coating material and device development Polymeric nano powder manufacturing and packaging Synthesis, coating, surface processing of carbon nano capsule
Nano template manufacturing	Highly homogeneous nano template manufacturing One-dimensional nano material orientation technique Growth control of co-axial nano tube Polymer and carbon template manufacturing Synthesis of polymer and carbon template for energy storage application
Self-assembly of nano structure	Self-assembled nano structure on ceramic substrate surface Self-assembled nano structure for photo-electronic device Self-assembled nano catalyst electrode Self-assembled nano catalyst electrode material Self-assembled three-dimensional photonic material Optical communication application of self-assembled polymeric and supra-molecule
Nano composite	Nano micro-porosity composite material Polymeric nano composite material manufacturing Nano structural surface device Polymeric optical display substrate material Polymeric optical display thin film process
Nano structural and manufacturing simulation	Nano structural simulation Nano polymer Nano organic and inorganic composite material Nano device property Nano manufacturing simulation Formation of nano ball, tube, multiple thin film Formation of addressing nano structure

Table III Nano electronic and semiconductor-related techniques in the first survey

Nano electronic and semiconductor	
Nano electronics	Nano carbon tube electronic device Spintronic device Quantum device SiGe-HBT/OE Nano inertial sensor
Nano optoelectronics and optical communication	Photon crystal Design simulation Structural manufacturing Active and passive device Nano optics Nano coating Epitaxy and measurement QD photonic device EO material Self-assembled quantum dots Quantum dot infrared detector
Nano storage	Near-field recording Optical write and magnetic read Disc mastering (Mastering) Super-RENS 3D storage
Nano display material and device	Integrated flexible TFT LCD substrate Thick film field emission display Rollable display

Table IV Nano bio medicine-related techniques in the first survey

	Nano bio medicine
Nano biomedical analysis	Scanning probe microscopic system and detection technique Manufacturing of probe for scanning probe microscopy Synthesis and detection of fluorescent nano particle Synthesis and detection of metallic nano particle Synthesis and detection of magnetic nano particle Technique for linking bio molecule and nano particle Electron microscopic examination on biological object
Nano biomedical measurement	Nano wire biosensor Biochip manufacturing and inspection Optical lithography and imaging Microfluidic system manufacturing and inspection Protein chip-related technique Magnetic nano particle image-sensing technique
Nano biomedical material	Synthesis of nano porous material Microscopy biomimetic material High strength and stable nano powder manufacturing Nano particle dispersion Antibacterial TiO_2 nano particle technique Biodegradable nano particle manufacturing
Nano biomedicine	Nano capsule manufacturing Nano-particle labeling and therapy Synthesis of catalytic nano material Nano powder toxicity detection Detection of drug delivery Technique for reducing medical particle size

Table V Indicators designed for the survey

2007 situation: (specify degree of 1 ~5)	Degree of maturity Degree of sufficiency of professional personnel
R&D maturation time (select one time period)	2007 ~ 2010 2010 ~ 2015 2015 ~ 2020 2020 ~
2020 scenario	Technology industrialization: (specify degree of 1 ~5) Degree of difficulty for technology development Degree of technology competitiveness Degree of sufficiency of R&D platform Degree of industrial application Preferential development strategy (select one of the items below): Self-R&D Technology introduced from overseas OEM Strategic alliance Obstacles or bottle-necks (select one of the items below): Manufacturing apparatus Manufacturing technique Economies of scale Government policy Market demand Professional personnel

Note: For 2007 situation and 2020 scenario-technology industrialization, scale of 1 ~ 5, 1-very low; 2-low, 3-medium, 4-high, 5-very high, is specified. For questions of R&D mature time, 2020 scenario-preferential development strategy, and 2020 scenario-obstacle or bottle-neck, the best answers have to be checked by survey participants

Since this survey covers very broad nanotechnology subfields and experts might not provide confident answers for every technique, experts are also asked to provide information on their professional level (1 ~ 5) for each technique. Different subjective weights corresponding to different professional levels are used in the statistical calculation so the final results obtained by this study can reflect the experts' self-assessment of their expertise. The weight for level 5 is 100 percent, level 4 is 75 percent, level 3 is 50 percent, and survey answers associated with level of professionalism equal or below 2 are ignored.

The average standard deviation for the first round survey is 1.09, and second round survey is 0.74, suggesting the expected Delphi effect of opinion convergence is observed in this study. The final analytical results for Nano Material, Nano Electronic and Semiconductor, Nano Bio Medicine are shown in Tables VI-VIII, and also obstacles or bottlenecks are shown in Table IX.

Discussion

Survey result

As shown in 2007 situation in Tables VI-VIII, in ''Nano material'' domain, the subdomains of both nano powder manufacturing and nanocomposite material technique have higher degrees of maturity and of personnel sufficiency. In ''Nano electronic and semiconductor'' domain, the subdomain of nano optoelectronic and optical communication has a higher degree of maturity and of personnel sufficiency. Generally, the ''Nano bio medicine'' domain has a higher maturity and personnel sufficiency than the other two domains, and the subdomain of nano electronics has the lowest overall degree of maturity.

For R&D maturation time in Tables VI-VIII, Most answers fall in the period 2010-2015 for both ''Nano material'' and also ''Nano electronic and semiconductor'' domains, but most answers fall into the period of 2007-2010 for ''Nano bio medicine'' domain. Insignificant number of experts expected the maturation time will be after 2015.

It is noteworthy that the expected maturation time for Nano bio medicine is before that of Nano electronic and semiconductor in Taiwan as Taiwan has an existing strong semiconductor industry. This indicates that Bio medicine related nanotechnology is expected to emerge in Taiwan and should be mature earlier than other technologies. This expectation is consistent with the ''Six key emerging industries'' newly proposed by the Taiwan government, where medical therapy and biotechnology are two of the six key emerging industries in Taiwan (*Executive Yuan*, 2010).

For 2020 scenario – technology industrialization, most of answers fall between 2 to 4, but the difficulty for technology development is 4.4 for CNT electronic device, revealing the difficulty of CNT development. The degree of industrial application is 4.2 for Epitaxy technique and measurement and 4.1 for disk mastering. This suggests Taiwan's leading role in optoelectronic and storage industries in 2020. Also, the subdomains of Nanocomposite material technique, Nano optoelectronic and Optical communication, and Nano storage show relatively high degrees of technology competitiveness in 2020.

For 2020 scenario – preferential technology development method, most answers indicate either self-R&D or technology introduced from overseas. A very high proportion of self-R&D is observed in the survey results, but as suggested by the expert meeting held for this study, this might be because most of survey participants are doing research in academia even though technical introduction from overseas is quite common in Taiwan's industry. In addition, strategic alliances are also critical for the future of Taiwan. Very low numbers support OEM since Taiwan has long been an OEM oriented country and this needs to change to a self-R&D or brand building society in order to transition to a knowledge-based society by 2020.

As shown in Table IX, the major obstacles and bottlenecks that Taiwan is going to face in 2020 are: ''Manufacturing technique and market demand for nano material'' domain; ''Manufacturing technique for nano electronic and semiconductor domain''; and ''Economies of scale and professional personnel for nano bio medicine''. Government policy seems not to be too critical for the future of Taiwan in 2020.

Table VI Foresight for Taiwan nanotechnology in 2020 – second round survey results – nano material

		Nanotechnology domain													
		2007 situation		*R&D mature time*				*2020 scenario*							
									Technology industrialization				*Preferential technology development method*		
Sub-domain	*Investigated technique*	*A*[a]	*B*[a]	*C (%)*	*D (%)*	*E (%)*	*F (%)*	*G*[a]	*H*[a]	*I*[a]	*J*[a]	*K (%)*	*L (%)*	*M (%)*	*N (%)*
Nano material															
Nano powder manufacturing	Metallic nano particle coating material and device	3.7	3.3	63	37	0	0	2.9	3.3	3.4	3.7	42	31	11	16
	Polymeric nano powder manufacturing and packaging	3.6	3.5	29	68	4	0	2.8	3.4	3.2	3.8	42	30	16	12
Nano template manufacturing	Highly homogeneous nano template manufacturing	3.1	2.9	4	80	12	4	3.4	3.1	2.9	3.2	45	45	3	8
	Polymeric carbon template manufacturing	3.0	2.7	4	88	4	4	3.1	3.2	2.8	3.3	38	45	8	10
	Synthesis of polymeric carbon template and energy storage	2.4	2.3	4	64	24	8	3.6	3.1	2.9	3.1	34	53	3	11
Self-assembled nano structure technique	Self-assembled nano structure on ceramic substrate surface	2.5	2.3	7	71	21	0	3.5	2.7	2.5	2.5	28	57	11	4
	Self-assembled polymeric and supramolecular materials for optical communication application	2.2	2.5	4	57	32	7	3.6	2.5	2.4	2.3	32	46	8	14
Nanocomposite material technique	Polymeric nanocomposite material manufacturing technique	3.7	3.6	56	41	4	0	2.9	3.6	3.4	3.8	47	30	9	15
	Polymeric optical display substrate material	2.9	3.3	22	74	4	0	3.1	3.6	3.4	3.8	41	33	8	18
	Polymeric optical display thin film application process	3.2	3.2	59	33	7	0	3.1	3.7	3.4	4.1	40	33	8	19
Nano structural behavior and process simulation	Nano polymer	3.2	3.4	16	76	8	0	2.8	3.3	3.3	3.3	40	40	2	17
	Nano organic-inorganic composite	2.9	2.9	15	69	15	0	2.7	3.0	3.0	3.5	45	31	0	24
	Nano ball, tube, multi-layered thin film	3.2	2.8	12	69	15	4	3.0	2.9	2.9	2.8	29	49	0	22

Notes: [a] 1~5, 1 = very low; 2 = low, 3 = medium; 4 = high, 5 = very high. A = Degree of maturity; B = Degree of sufficiency of professional personnel; C = 2007 ~ 2010; D = 2010 ~ 2015; E = 2015 ~ 2020; F = 2020 ~ ; G = Degree of difficulty for technology development; H = Degree of technology competitiveness; I = Degree of sufficiency of R&D platform; J = Degree of industrial application; K = Self-R&D; L = Technology introduced from overseas; M = OEM; N = Strategic alliance

Table VII Foresight for Taiwan nanotechnology in 2020 – second round survey results – nano electronic and semiconductor

		Nanotechnology domain													
		2007 situation		*R&D mature time*				*2020 scenario*							
									Technology industrialization			*Preferential technology development method*			
Subdomain	*Investigated technique*	*A*[a]	*B*[a]	*C (%)*	*D (%)*	*E (%)*	*F (%)*	*G*[a]	*H*[a]	*I*[a]	*J*[a]	*K (%)*	*L (%)*	*M (%)*	*N (%)*
Nano electronic and semiconductor															
Nano electronics	CNT electronic device	2.2	2.5	4	46	19	31	4.4	2.6	2.6	2.4	30	41	9	20
	Quantum device technique	2.3	2.5	4	48	12	36	4.0	2.9	2.6	2.5	21	48	10	21
	SiGe-HBT/OE	2.4	2.4	20	40	20	20	3.6	3.0	2.7	2.4	34	39	11	16
Nano optoelectronic and optical communication	Active and passive device	3.5	3.4	42	46	0	13	3.3	3.3	2.9	3.9	48	23	10	20
	Nano coating	4.0	3.5	72	12	8	8	2.8	3.9	3.9	3.9	45	14	25	16
	Epitaxy technique and measurement	3.8	3.5	60	20	12	8	3.3	3.8	3.8	4.2	36	30	16	18
	QD photonic device	3.4	2.9	13	63	17	8	3.6	3.0	3.2	3.4	37	35	14	14
Nano storage	Optic write/magnetic read technique	3.2	3.0	56	40	0	4	3.0	3.7	3.9	3.8	44	31	10	15
	Disc mastering	3.9	3.2	64	32	0	4	2.9	4.0	3.7	4.1	50	30	10	10
	Super-RENS	2.9	2.3	8	80	8	4	3.3	3.4	3.0	3.5	25	48	13	15
Nano display material and device technique	Integrated flexible TFT-LCD substrate	2.9	3.0	20	68	8	4	3.5	3.4	3.4	3.2	53	25	10	13

Notes: [a] 1~5, 1 = very low; 2 = low, 3 = medium; 4 = high, 5 = very high. A = Degree of maturity; B = Degree of sufficiency of professional personnel; C = 2007 ~ 2010; D = 2010 ~ 2015; E = 2015 ~ 2020; F = 2020 ~ ; G = Degree of difficulty for technology development; H = Degree of technology competitiveness; I = Degree of sufficiency of R&D platform; J = Degree of industrial application; K = Self-R&D; L = Technology introduced from overseas; M = OEM; N = Strategic alliance

Table VIII Foresight for Taiwan nanotechnology in 2020 – second round survey results – nano bio medicine

		Nanotechnology domain													
		2007 situation		*R&D mature time*				*2020 scenario*							
									Technology industrialization			*Preferential technology development method*			
Subdomain	*Investigated technique*	*A*[a]	*B*[a]	*C (%)*	*D (%)*	*E (%)*	*F (%)*	*G*[a]	*H*[a]	*I*[a]	*J*[a]	*K (%)*	*L (%)*	*M (%)*	*N (%)*
Nano bio medicine															
Nano biomedical analysis	Preparation and detection of fluorescent nano particle	3.4	3.2	63	26	7	4	2.8	3.8	3.5	3.6	50	26	4	20
	Preparation and detection of metallic nano particle	3.5	3.1	67	15	15	4	2.7	3.4	3.2	3.5	44	29	6	21
	Technique for linking bio molecular and nano particle	3.3	3.2	56	30	11	4	3.5	3.6	3.2	3.5	43	27	6	24
Nano biomedical measurement	Nano wire biomedical sensor	3.2	2.9	31	52	10	7	3.3	3.2	3.1	3.1	40	35	6	19
	Bio chip manufacturing and diagnosis	3.7	3.7	62	24	7	7	3.0	3.3	3.3	3.7	48	27	12	13
	Protein chip	3.3	3.7	59	24	10	7	2.9	3.3	3.1	3.7	38	34	6	23
Nano biomedical material	Synthesis of nano porous material	3.2	3.4	55	35	6	3	3.0	3.3	3.3	3.4	41	43	2	13
	Nano particle distribution technique	3.7	3.1	68	26	3	3	3.0	3.5	3.3	3.5	50	31	4	15
	Antibacterial TiO_2 nano particle technique	3.9	3.6	84	13	3	0	2.7	3.7	3.4	4.3	50	29	4	17
Nano biomedicine	Nano capsule manufacturing	3.2	3.0	63	26	0	11	3.0	3.3	3.3	3.3	44	25	13	19
	Synthesis of catalytic nano material	3.5	3.1	67	11	15	7	3.0	3.4	3.3	3.4	51	32	2	15
	Miniaturizing medical particle	3.6	3.5	63	26	11	0	3.0	3.4	3.2	3.5	51	29	4	16

Notes: [a] 1~5, 1 = very low; 2 = low, 3 = medium; 4 = high, 5 = very high. A = Degree of maturity; B = Degree of sufficiency of professional personnel; C = 2007 ~ 2010; D = 2010 ~ 2015; E = 2015 ~ 2020; F = 2020 ~ ; G = Degree of difficulty for technology development; H = Degree of technology competitiveness; I = Degree of sufficiency of R&D platform; J = Degree of industrial application; K = Self-R&D; L = Technology introduced from overseas; M = OEM; N = Strategic alliance

Table IX Obstacles or bottle-necks that Taiwan is going to face in 2020

Nanotechnology domain	*Subdomain*	*Manufacturing apparatus*		*Manufacturing technique*		*Economies of scale*		*Government policy*		*Market demand*		*Professional personnel*	
		Percentage	*Average percentage*	*Percentage*	*Average percentage*	*Percentage*	*Average percentage*	*Percentage*	*Average percentage*	*Percentage*	*Average percentage*	*Percentage*	*Average percentage*
Nano material	Nano powder manufacturing	8	7	23	24	32	21	10	6	23	26	5	15
	Nano template manufacturing	14		35		14		4		28		5	
	Self-assembled nano structure technique	6		32		15		3		28		16	
	Nanocomposite material technique	3		18		29		8		29		13	
	Nano structural behavior and process simulation	5		12		16		7		22		38	
Nano electronic and semiconductor	Nano electronics	16	13	36	35	7	11	7	7	8	7	26	27
	Nano optoelectronic and optical communication	13		35		10		7		6		28	
	Nano storage	10		37		12		5		7		29	
	Nano display material and device technique	13		32		13		10		8		24	
Nano bio medicine	Nano biomedical analysis	4	5	21	23	24	24	16	11	9	11	26	26
	Nano biomedical measurement	6		22		26		9		9		27	
	Nano biomedical material	4		28		19		8		16		25	
	Nano biomedicine	6		20		26		9		11		28	

Experts' discussion meeting

A total of 25 experts who participated in the survey joined an expert discussion meeting in order to identify a proper nanotechnology development trends and strategies. Experts provided opinions on the three nanotechnology domains as references for creating strategy.

1. *Nano material*:
   - Material is an important basis for fundamental research. According to statistical results, Taiwan tends to have both Self-R&D and Technology introduced from overseas and lacks of Strategic alliances. This might lead to a negative effect on overall development.
   - Nano material is the field with a relatively higher maturity and better opportunities for industrialization and commercialization.
   - Nanocomposite is the field that generates better outcomes and in the future it is desirable to integrate flexible electronics techniques.
   - In general, the degree of maturity and the sufficiency of professional personnel should be prior to industrial application. The results show that Nano electronic and semiconductor and Nano bio medicine have higher degrees of maturity and of sufficiency of professional personnel, suggesting strong tendencies for technology introduction from overseas.
   - The development of critical material and its related nanotechnology are important for the material industry and for the development of upstream material. Downstream material application should be smoothly integrated to form a sustainable value chain.
2. *Nano electronic and semiconductor*:
   - The advance of Taiwan's electronic and semiconductor industry is due to the advantage of Taiwan nanotechnology. The results show higher competitiveness for Nano optoelectronic and optical communication and Nano storage in 2020, suggesting these two important subdomains are emerging and appropriate for larger resource inputs.
   - The integration of nanotechnology and flexible electronics will be an emerging field and will be a critical focus for Taiwan's technology development. A proper strategy to accelerate the integration will be desirable.
   - Self-R&D and techniques introduced from overseas are two major development methods, but optoelectronic research requires much higher R&D cost. The results which show less favorable methods of OEM and Strategic alliance might occur because survey participants are mainly from academia. OEM and strategic alliances are, so far, two major development methods from an industrial perspective.
3. *Nano bio medicine*:
   - Nano bio medicine is the field in which Taiwan has a stronger development basis in the short-term.
   - This study focuses on material, nano particle, synthesis, manufacturing, and distribution; so, it is reasonable to have a high degree of maturity with a short-term focus. However, if drugs for medication or invasive diagnosis related techniques are considered in this study, the time consuming human risk assessment on drugs and detection devices should be included. This is also a suggestion for the future of Taiwan's biomedical development.

Lesson learned for foresight practitioner

Deriving expert consensuses by Delphi-survey is possible without providing extra information about what the future society or technology will be. Experts draw the picture of the future in their minds. However, it is more reasonable to provide basic information about future global and local societal directions, as the demand-pull side. Based on these, experts

can more easily forecast technology development by answering survey questionnaires. The clearer the future scenario provided, the easier it is to obtain expert consensuses by Delphi-survey.

According to several experts' opinions the survey covered too broad a range and even exceeded their expertise. For some the questionnaires were too large to be completed; so, the questionnaires' design has to be optimized again in the future to make them more suitable and acceptable to the selected experts. This will not only lead to more precise technology forecasting but also increase the response rate.

Manually dealing with survey processing and results statistics is costly and time-consuming. A foresight web site would be more effective, and would act as an online platform for:

- survey answers;
- survey result analysis; and
- discussion for survey participants.

The discussion forum would clarify questions, resolve any problems, and also obtain group consensus. The web site can be integrated with existing Sci-Tech Policy related systems, e.g. ''Sci-Tech Policy and Management Information Platform'' or ''Sci-The Project Evaluation Platform'' or ''Government Research Bulletin'' which already operate under National Science Council of Taiwan, in order to create a more effective process for Taiwan's national innovation system. Steinert (2009) has conceptually proposed an online Delphi approach as an effective and efficient explorative research tool (Steinert, 2009).

In addition to the above suggestions to foresight practitioners, disseminating Delphi-based foresight activities is also important as a tool for consensus building in Taiwan. The Delphi methodology is quite new for national level consensus building in Taiwan. Time and more resources may be required to foster a sound environment where the participation of experts in foresight activities can be more encouraged.

Policy implications and future study

These findings have important implications for resource allocations for Taiwan's nanotechnology development. This investigation provides a clearer vision for resource allocations and can create future economic opportunities for Taiwan. Nanotechnology is globally recognized as a high-priority emerging technology that brings dramatic benefits, but systematically obtaining objective information which can serve as a reference for policy making is not a simple task. This study does provide systematic and structured insight on selected nanotechnology subdomains to strategically develop. Taiwan's government, industry, and academy need to receive this message regarding Taiwan's nanotechnology development, so that resources for Sci-Tech development can be more efficiently allocated. Thus competitiveness and economic performance can be improved.

The second key policy implication is the need to conduct a national-scaled, holistic technology foresight on a regular basis. In contrast to instant policy intervention decided on the basis of both short-term scenarios and expert panel meetings, a systematic Delphi-based forecast which provides a long-term Taiwan scenario is important. A holistic Delphi based technology foresight activity on a regular basis would systematically update Taiwan's future scenarios and serve as a reference for Sci-Tech policy making.

We are still far from having enough knowledge about how foresight results can be fed into the policy decision process in Taiwan. However, a policy workshop or personal interviews with policy makers can be conducted to explore policy makers' reactions to foresight results. Some follow up studies are also possible in order to enhance these Delphi finding through further inquiry (Engels and Powell Kennedy, 2007) and to offer a useful way of developing policies and strategies and of transforming them into actions (Saritas and Oner, 2004).

Conclusion

Taiwan's technology policy formation process usually relies on expert panel meetings, and is similar to that for the formation of the ''National Science and Technology Program for Nanoscience and Nanotechnology.'' However, the latest ''White Paper on Science and Technology'' of Taiwan (National Applied Research Laboratories, 2007) proposes that the government should start Delphi-based technology foresight investigation to obtain democratic consensus on long-term technology and societal development. Taiwan should revise its conventional science and technology policy formation mechanism, even though it has been a bit late compared to China, Japan, Korea and many other countries.

Actually no holistic Delphi-based technology foresight activity has yet been conducted by the Taiwan government. Hence, a foresight process should be conducted in order to define the allocation of limited resources and to promote strategically Taiwan's technology competitiveness. In addition to a policy formation mechanism and to technology development, what also must be noticed and improved are several societal concerns which are easily missed:

- manpower building;
- social environment; and
- innovation management, etc.

Owing to Taiwan's limited economies of scale, nanotechnology focused on smaller scale and wider application fits well with the characteristics of Taiwanese industry and academia. The development of industrial technology in Taiwan is usually based on the existing technology of other advanced countries. Technology introduced from overseas and from strategic alliances are still two critical mechanisms for technology development.

Taiwan has its own industrial characteristics. The development of future nanotechnology should be based on conventional industries, i.e. new technology is an extension of old technology, without generating gaps between new fields and old fields. A correct selection of new technologies based on conventional fields is essential for developing Taiwan's new technology and industries. Further, the interdisciplinary integration of technologies from different fields helps maintain high competitiveness in nanotechnology. In addition, professional human resources are essential for nanotechnology development that leads to economic growth. Education and training are essential for building professional human resources, and are ways of increasing the potential of nanotechnology development.

The wider development of upstream nanotechnology industry in Taiwan is expected, even if downstream development is not yet mature. This easily leads to the phenomenon of a good product without a proper market. In addition to resource inputs to upstream industry, the development of new downstream products and technologies are also important for sustaining a complete value chain in Taiwan. There are many organizations playing different roles in creating Taiwan's nanotechnology value chain. A lot of interactions are established among industry, government and academia. The Industrial Technology Research Institute (ITRI) has been one of the core organizations that is directly in touch with industry and serves as a key technical center for industry. ITRI is expected to continue playing a crucial actor in the industrialization of Taiwan's nanotechnology in 2020.

In addition to nanotechnology foresight conducted in this study, Taiwan government it is very likely to conduct holistic technology foresight activities even though the schedule is remains unknown. This study conducted a Delphi-based foresight activity on Taiwan Nanotechnology Industry in 2020 in order not only to obtain a consensus on what Taiwan's nanotechnology industry will be, but also to disseminate Delphi-based foresight activities. Hopefully a holistic technology foresight activity will be conducted in Taiwan in the near future. Delphi-based foresight activity is relatively new in Taiwan and requires dissemination. This study provides Delphi experience on Taiwan's nanotechnology in order to contribute to Taiwan's foresight experience and to the possible future formation of a foresight community in Taiwan.

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