Nanotechnology and business opportunities: scenarios as awareness instrument

W.H.C. Knol
Qeam
Vierde Binnenvestgracht 19 - 2311 NT - Leiden - the Netherlands
Erik.Knol@Qeam.com - www.Qeam.com

Presented paper published in the proceedings of
the 12th Annual International Conference 'High Technology Small Firms',
Enschede, the Netherlands, May 24 - 25, 2004, pp. 609 – 621[1]

ABSTRACT

For a few years now, nanotechnology has been recognised as a promising new growth innovator. This leads to a shift from the exploration of nanotechnology knowledge towards a phase of exploitation. The coming years this commercialisation of nanotechnology will be extended. Nanotechnology is a disruptive technology phenomenon, which leads to more difficulties in overseeing business opportunities. Additionally, the fact that high-tech small firms, especially those dealing with nanotechnology, are highly interested in developments in science and technology, begs the question how to stimulate the awareness for (new) business opportunities in nanotechnology within these firms. A promising strategy to stimulate learning and awareness of business opportunities in nanotechnology is the use of scenarios. These projections focused on uncertainty stretch the mental model of entrepreneurs and/or managers and have the ability to activate learning processes. This paper presents the (theoretical) fundaments of scenario usage in relation to the recognition of business opportunities in nanotechnology.

1. INTRODUCTION

Science and technology are seen as important determinants for survival and growth of companies, regions and nations (Schumpeter, 1934) and are related to new theories of economic development, technological change and industrial innovation (e.g. Dosi et al., 1990; Romer, 1990). In order to reach technology-based economic growth, it is not only necessary to invest capital, intellect and time in science and technology-related research and development (R&D), but also to execute processes related to diffusion, adoption and implementation of technology-based innovations. Additionally, disruptive technologies - as the counterpart of technologies with an incremental innovation effect - form important fundaments for growth innovations and related wealth creation (e.g. Kassicieh et al., 2002).

Nanotechnology is recognised as a promising new growth innovator for the decades to come (Wolde, 1998; Roco, 2001; Paull et al., 2003). It is mostly developed in knowledge intensive

[1] Citation suggestion: Knol, W.H.C. (2004), Nanotechnology and business opportunities: scenarios as awareness instrument. Proceedings of the 12th Annual International Conference 'High Technology Small Firms', Enschede, the Netherlands, May 24 - 25, 2004, pp. 609 – 621.

organisations (e.g. universities or company R&D laboratories) strongly focused on the science and technology part of nanotechnology. However, from a growth perspective it is important to facilitate the ability to exploit the innovative and added value of nanotechnology into applications. This means that nanotechnology knowledge generated in knowledge intensive organisations needs to be transformed and/or transferred in order to design, produce, sell, adopt and implement nanotechnology-based customer-oriented applications.

The innovation development process on (inter)organisational level from R&D to (high-tech) invention to market-ready applications is not linear, but a cyclic process with parallel and iterative loops (During, 1984; Kline and Rosenberg, 1986; Rothwell, 1992; Tidd et al., 2001). With respect to disruptive technologies like nanotechnology, Walsh (2004) presents an infrastructure model that points out the dynamics between technology-push side and market-pull side in the innovation development process. Nanotechnology as disruptive technology can lead to next generation (enhanced or new) applications, but also has the characteristics to create and facilitate next generation (initially unknown) markets. This gives additional dimensions and challenges to innovation processes concerning development and commercialisation of nanotechnology in an international market arena, especially for small nanotechnology firms. Scanning the environment for business opportunity related signals concerning market, technological, regulatory and other developments is essential in the innovation development process (Tidd et al., 2001). Although small technology firms in comparison with large firms are more responsive to commercialise disruptive technologies (Christensen, 1997; Kassicieh et al., 2002), small high-tech enterprises compared with large companies are inclined to the nature to have less (continuous) attention on business opportunities and strategies (Berry, 1996; Berry and Taggert, 1997; Oakey, 2003). The question is in what way it is possible to support small nanotechnology firms in signal scanning and processing in order to recognise business opportunities in a dynamic international market?

This paper presents scenario method as a business opportunity awareness instrument for small nanotechnology firms from a theoretical perspective. First, the paper describes the characteristics of nanotechnology and the dynamic international market. Next, small nanotechnology firms and their essential recognition of business opportunities are discussed. Scenarios are introduced as an instrument of organisational learning to enhance and extend business senses. Finally, a discussion focuses on the usage of scenarios to stimulate nanotechnology business awareness within small nanotechnology firms. The conclusion focuses on the outline presented and recommendations related to empirical validation of the concept and policy issues.

2. NANOTECHNOLOGY AND DYNAMIC INTERNATIONAL MARKET

2.1. Introduction of nanotechnology

Manipulating atoms arrangements is the basis of nanotechnology and ideas in this field were first communicated by physicist Feynman (1959). Nanotechnology is according to Roco (1999: 1) concerned with ‘development and utilisation of structures and devices with organisational features at the intermediate scale between individual molecules and about 100 nanometres where novel properties occur as compared to bulk materials’ (100 nanometres is 1/10.000 millimetre). These nanoscale structures and devices may have unique chemical, electrical, magnetic, optical or biological properties. It is a field at the junction of chemistry, physics, biology, computer science and engineering. Nanotechnology embeds nanoscience insight in order to fabricate new materials, structures or devices which exploits nanoscale properties. The table below gives more insight into which nanotechnology properties have a specific role in new or enhanced applications.

Properties and effects perceived on nanoscale	Example of (possible) applications
Higher surface to volume ratio - enhanced reactivity	Catalysis, solar cells and batteries
Lower percolation threshold	Conductivity of materials
Increased hardness with decreasing grain size	Hard coatings and thin protection layers
Narrower bandgap with decreasing grain size	Opto-electronics
Higher resistivity with decreasing grain size	Electronics
Increased wear resistance	Hard coatings and tools
Lower melting and sintering temperature	Processing of materials and low sintering materials
Improved transport kinetics	Batteries and hydrogen storage

Table 1: Properties and effects on nanoscale and related (possible) applications (Köhler et al., 2003)

2.2. Disruptive aspects of nanotechnology

The nature of nanotechnology is strongly multidisciplinary and Hullmann and Meyer (2003) show this via the range of scientific disciplines nanotechnology publications and nanotechnology patents covers. Some discipline examples for instance are material science, polymer science, electrical and electronic engineering, optics, biophysics, organic chemistry, or cell biology. They conclude that patent data suggests that the core activities of nanotechnology focus on electronics, instrumentation, and chemicals/pharmaceuticals. Besides this conclusion based on patent data, Bhat (2003) sees the following industries likely to be immediately affected by nanotechnology: aerospace, automotive, biotechnology, ceramics, chemicals, computing, defence, electronics, metals, materials, paper, plastics, renewable/sustainable energy, textiles and telecommunications.

Industry	Nanotechnology-based applications on the market
Automotive	Automobile General Motors GMC Safari nanocomposite step from Southern Clay. Advantages: stiff and light car parts. Antireflection coating on instruments of Audi cars and DaimlerChrysler trucks based on nanolayers on glass. Advantages: better antireflection.
Building materials	Duravit sinks and toilets using nanocoatings from Nanogate. Advantages: improved anti-stick properties.
Consumer electronics and instruments	Kodak EasyShare LS633 using nanoenhanced OLEDs. Advantages: brighter and less energy consuming displays. Germicidal nanocoating in Audio Service hearing aids from Germany's Institute of New Materials. Advantages: better non-stick properties of coating.
Cosmetics and body care	Nucelle sunscreen using titanium dioxide nanoparticles from Nanophase. Advantages: better absorption of UV-light. L'Oreal nanocapsules in cosmetics. Advantages: better skin moisturising properties.
Fashion	Maui Jim sunglasses with nanocoatings from Nanofilm. Advantages: better anti-reflection properties. Eddie Bauer khaki pants using molecular textile coatings from Nano-Tex. Advantages: for instance anti-wrinkle properties.
Medical equipment	Evidots (quantum dots) for medical imaging from Evident Technologies. Advantages: fluorescent biomarker with narrow, predictable emission band of light.
Sports	Babolat tennis rackets using nanotubes. Advantage: lighter but stronger rackets. Nanowax Derax ski wax from Nanogate. Advantages: hard and fast-gliding surface.

Table 2: Examples of nanotechnology-based applications (based on Lux Capital, 2003 and Qeam, 2004)

Nanotechnology as a cluster of new technologies undergoes typical patterns of scientific, technological and economic developments. First, nanoscience has lead to a strong scientific-push and resulted in a dramatic increase of scientific publications and patents on nanotechnology (Compañó and Hullmann, 2002; Hullman and Meyer, 2003; Marinova and McAleer, 2003; Roco, 2003). Additionally, the technology-pull has emerged in order to use and transform nanoscience knowledge into technologies. Lately, a premature market-pull era has been initiated which stimulates the use of nanotechnology in applications in order to create innovations. In this phase companies are actually producing and selling nanotechnology-based applications. Everyday life examples of nanotechnology-based applications on the market are given in the table 2. On the other hand Mazzola (2003) points out that many nanotechnology applications are still at concept level, requiring much more basic research before they can be incorporated into viable applications. Related to the typical sigmoidal curve of innovation diffusion (Rogers, 1995), nanotechnology is just about in the so-called 'take-off' phase.

Although industries and applications are or will be (further) influenced by nanotechnology, Bhat (2003) argues that the mentioned multidisciplinary nature of nanotechnology makes it very difficult to pin down and prophesy the future impact in any specific sector appropriately. This is a major reason why nanotechnology is mostly seen as a disruptive technology. Kostoff et al. (2004) and Walsh (2004) suggest some literature related to the usage of terms such as disruptive technology and discontinuous innovation in different contexts. According to Brower and Christensen (1995) a technology is considered disruptive when its utilisation generates products with different performance attributes that may not have been valued by existing customers. In case of nanotechnology this means that it has the ability to introduce enhanced or new nanotechnology-enabled products, services or processes for existing or new markets. Disruptive technology - like nanotechnology - promises considerable opportunities for early and strong entry into existing and new markets, however they also involve a high risk of failure (Christensen, 1997; Walsh, 2004).

2.3. Dynamic international market

Besides the disruptive character of nanotechnology, the dynamic international market puts pressure on small nanotechnology firms' propositions. It could be stated that last decades markets became more international and dynamic. Important drivers for this globalisation process are greater participation in, and integration of, world trade, liberal government policies, changing corporate strategies, creation of global capital markets, capacities of information and communication technologies, increasing market homogeneity and global creation, use and sale of technology (Dodgson, 2000). A relatively faster obsolescence of modern technologies is related to the last-mentioned driver. All these 'inherent' global drivers influence a global market that could be characterised as high-velocity and hypercompetitive (D'Aveni, 1994, 1999; Harvey et al., 2001). In this dynamic environment Foster and Kaplan (2001) foresee a competitive role for those (networks of) companies who are able to master the Schumperian concepts of creative destruction.

Due to the fact that nanotechnology is an enabler for enhanced or new applications in a variety of industries, it is likely that a substantial part of small nanotechnology firms will be confronted directly or indirectly (via customers, partners, or suppliers of products and services) with the hypercompetitive aspects of the dynamic international business environment. This relates to the previously-mentioned nanotechnology diffusion take-off. Survey results of ENA (2004) indicate that a substantial part of the mainly European respondents expect that nanotechnology will have an impact in their business within a few years. Besides the fact that the survey report does not further discuss introduced terms such as nanotechnology, impact or business, its indication points out that nanotechnology firms or nanotechnology-focused application firms will be confronted with an even more dynamic business environment within a few years.

Next to the mentioned 'inherent' international market dynamics and the nanotechnology diffusion take-off, specific nanotechnology market related influences can be identified: societal discussions on nanotechnology, regulations and governmental funding programmes. Results of societal discussions on the ethical, legal and social implications of nanotechnology (e.g. Bainbridge, 2003; Mnyusiwalla et al., 2003; Roco, 2003; Est et al., 2004) could lead to certain boundary settings on some form of nanotechnology and/or nanotechnology-related production, usage or recycling processes. Therefore market segments within nanotechnology and nanotechnology-based applications markets do have a chance to be influenced by these discussions. Additionally, new regulations on nanotechnology and/or nanotechnology-based applications will mark business opportunities (e.g. Small Times, 2004). Furthermore, the market dynamics are directly and indirectly influenced by (supra)national governmental funding on nanotechnology R&D, diffusion and adoption programmes. Examples are the growing budgets of the U.S. National Nanotechnology Initiative and the EU Sixth Framework for nanotechnology research and development programmes (ENA, 2002).

Concluding, besides the disruptive character of nanotechnology, the increased dynamics of international markets puts intense pressure on the competitive capabilities and actions of small nanotechnology-focused firms. The next chapter will focus on these small nanotechnology firms.

3. SMALL NANOTECHNOLOGY FIRM BUSINESS OPPORTUNITY AWARENESS

3.1. Introduction of small nanotechnology firms

With respect to disruptive technologies like nanotechnology, research organisations (universities and laboratories of large companies) are not fully able to introduce flexibility with respect to science-based technology that needs to response to or create markets (e.g. Christensen, 1997; Kassicieh et al., 2002; Gerde and Mahto, 2004). That is why research organisations and large firms form the major two sources of new technology-based firms: the university spin-offs and the corporate spin-offs.

Small nanotechnology firms form important links between the science and technology domain of nanotechnology and the market domain. These entrepreneurial firms are more able to take advantage of disruptive technologies and redefine markets, whereas large firms will have serious problems with the introduction of disruptive technologies due to own market cannibalising and organisational inertia as a result of procedures and short-term focused incentives (Christensen, 1997; Kostof et al., 2004). The table below shows that a substantial part of the global nanotechnology actors are small enterprises (based on information of Cientifica, 2003).

Type of nanotechnology actor	Number of global actors
Large companies	117
Subsidiaries or joint ventures	83
Start-ups or small companies	462
Research institutes or universities	388
	total: 1050

Table 3: Number of nanotechnology actors as published in June 2003
(based on Cientifica, 2003)

3.2. Small nanotechnology firms and business opportunity awareness

Small nanotechnology companies have the entrepreneurial character to operate in a dynamic and uncertain nanotechnology business environment. This relates to a remark of Gelderen et al. (2000: 169): 'Without uncertainty, entrepreneurship would be unnecessary'. Audretsch et al. (2002) see entrepreneurship as a process that involves both perception and action: the perception of the business opportunity under influence of, for example, markets or technologies and the ability to act on that perception. Thus, in case of a small nanotechnology firm, the entrepreneurial team recognises or should recognise the commercial potential of a nanotechnology invention and organise the capital, talent, and other resources that turn it into a commercially viable innovation.

As Berry (1996) remarks the development of new technology does not in itself guarantee commercial success for enterprises like small nanotechnology firms. She identifies several constraints on the ability of new technology-based firms in general to fulfil their economic potential: weakness in management capacity, finance, sales and marketing. This could relate to the fact that research shows that technical entrepreneurs are not always focussed on growth or profit maximisation, but also substantially focused on aspects such as independence (Oakey, 2003). Berry (1996) and Oakey (2003) summarise that the presence of a diversified management team, in which technological (management) expertise is balanced with business (management) skills, is recognised as an important determinant of success in technology-based start-ups. These start-ups in their first entrepreneurial phase intensely focus on the transformation of science into technology (invention) and less on the transformation of technology into market-ready innovation. Of course this first transformation is essential for starting with the second transformation, but a parallel focus on both transformation areas could, in the end, lead in the end to an innovation that has more chance to fit into a market. As Oakey (2003) points out it is essential that the technical entrepreneur / entrepreneurial team shows willingness to create a learning organisation in which new influences and ideas are embraced. These influences and ideas for example relate to new products, new markets, new (innovation) processes or new organisational structures.

Small nanotechnology firms in general and those firms in a phase of science to technology transformation in specific need to have means to gain more business opportunity awareness in order to go through innovation development processes successfully. Awareness in relation to the mentioned entrepreneurial elements of perception and action needs to be seen from a learning perspective in order to define proper instruments to stimulate the business recognition. A promising instrument to stimulate (new) business awareness for small nanotechnology firms is the usage of scenario methods. Scenario methods can stimulate learning processes and create fundaments for broader externally oriented scopes.

4. SCENARIOS AS AN INSTRUMENT TO STIMULATE BUSINESS AWARENESS

4.1. Scenarios for strategy and learning

The first application of the term scenario in an economic and managerial context comes from Kahn and Wiener (1967). Scenarios, in contrast to forecasting methods, leave room for uncertainties by presenting various fundamental future perspectives in a qualitative way. With regard to the application of scenarios in recent decades, Bood and Postma (1998) distinguish two generations. The first generation of scenarios is mainly a tool for the evaluation and identification of future opportunities for organisations. The second generation of scenarios makes managers aware of environmental uncertainties, broaden the mental models of the managers, and activate and speed up the processes of organisational learning (see table 4).

Bood and Postma (1998), Stroeken and Knol (1999) and Knol and Stroeken (2001) give an overview of aspects related to learning processes and mechanisms of scenarios to stretch mental models of the entrepreneur / entrepreneurial team within (small and medium-sized) enterprises.

Original functions of the first-generation scenarios
- Evaluation and selection of strategies - Integration of various kinds of future-oriented data - Exploration of the future and identification of future possibilities
The second-generation scenarios: more recently added functions
- Making managers aware of environmental uncertainties - Stretching of managers' mental models - Triggering and accelerating processes of organisational learning

Table 4: Two generations of scenarios (Bood and Postma, 1998)

Scenarios are a tool in the process of strategic thinking of entrepreneurs and managers (Millet, 1988; Van der Heijden, 1996; Bood and Postma, 1998; Postma and Liebl, 2004) and reduce three shortcomings of the learning cycle at the strategic level. The time span between experience, activity and implications is reduced by simulating and communicating specific uncertain situations that can occur in reality in a brief period of time. In this way scenarios stretch the mental models of the people involved, so that the degree of cognitive inertia is reduced. Moreover, scenarios stimulate creativity and are a way to promote the internal communication of ideas, so that the variations in mental models of the people involved can become more balanced. This provides collective insight into the opportunities and threats that accompany particular uncertainties.

The creation and construction of scenarios is a practical matter and many methods are listed in the literature (e.g. Mercer, 1995; Van der Heijden, 1996; Gausemeier et al., 1998; Cairns et al., 2004; Postma and Liebl, 2004). The development process of scenarios often involves an iterative process in which entrepreneurs or managers should be involved during the entire process (Mercer, 1995; Bood and Postma, 1998). Mercer (1995) indicates that the simpler a scenario and the simpler the process to construct scenarios, the stronger the scenarios are at broadening the mental models of the people involved. Furthermore he notes that convincing entrepreneurs or managers to use the constructed scenarios is the hardest part of the scenario planning process.

Scenarios are mainly focused on uncertainties of known elements to form causal and consistent combinations of projections. But Postma and Liebl (2004) argue that a projection of inconsistent, non-causal and unknown elements needs to be embedded in scenario methods in cases in which environmental turbulence is very high. In these cases it is important that scenario methods embed possibilities to focus on things we know we know, things we know we don't know and things we don't kno w we don't know. As a result, Postma and Liebl (2004) suggest that a scenario method alternatively based on so-called wild cards is useful, especially in case of assessments related to risks and opportunities of innovations. This additional approach not only introduces the standard 'what if ...' questions, but also focuses on unusual events triggered via 'what must happen, so that ...' questions.

4.2. Construction of scenarios

In case of small nanotechnology firms and business awareness, it is necessary to construct a method that creates scenarios that can stimulate business opportunity awareness. The table below gives an appropriate method that is based on the concepts of Cairns et al. (2004).

Scenario method step	Output	Participants other than facilitation team
Step 1: project set-up	Key business focus, key business problem and organisational knowledge gap.	Entrepreneurial team / management team of small nanotechnology firm.
Step 2: interviews and analysis	Interview overview with issues related to business focus and business problems.	Interviewees – full range of firm's decision makers related to the context of key business problems.
Step 3: scenario agenda workshop	Overview of critical uncertainties, related triggering wild-card options and scenario agenda.	Scenario team as an extract of the entrepreneurial team / management team.
Step 4: scenario workshop	Scenario story-lines based on impact/unpredictability matrix, including wild-card analysis, representation of cause/effect and implications for organisation.	Full group of entrepreneurial team / management team of small nanotechnology firm

Table 5: Scenario method steps (based on Cairns et al., 2004)

In the case of nanotechnology it is advisable to construct scenarios that are influenced by a broad range of elements that originate from science, technology, market, political, legal, and ethical domains. Key factors need to be identified in a variety of segments: developments in nanoscience and nanotechnology, general developments in nanotechnology-influenced industries and markets, specific developments in industries related to alliances, mergers, intellectual property (patent) aspects, (supra)national government (innovation and subsidy) policies on nanotechnology, legal aspects related to nanotechnology and nanotechnology-based applications, societal discussions on implications of nanotechnology, etc. Within the scenario method these key factors need to be analysed and organised with the aid of 'what if ...' questions in order to create an overview of uncertainties with the relatively highest impact (see figure below). The two uncertainties with the highest impacts form the basis to construct four scenarios. These four scenarios are based on more-or-less known elements. Next, with respect to a vision on the unknown elements (or elements that are not in the scope) wild-cards on the basis of the 'what must happen, so that ...' questions are discussed.

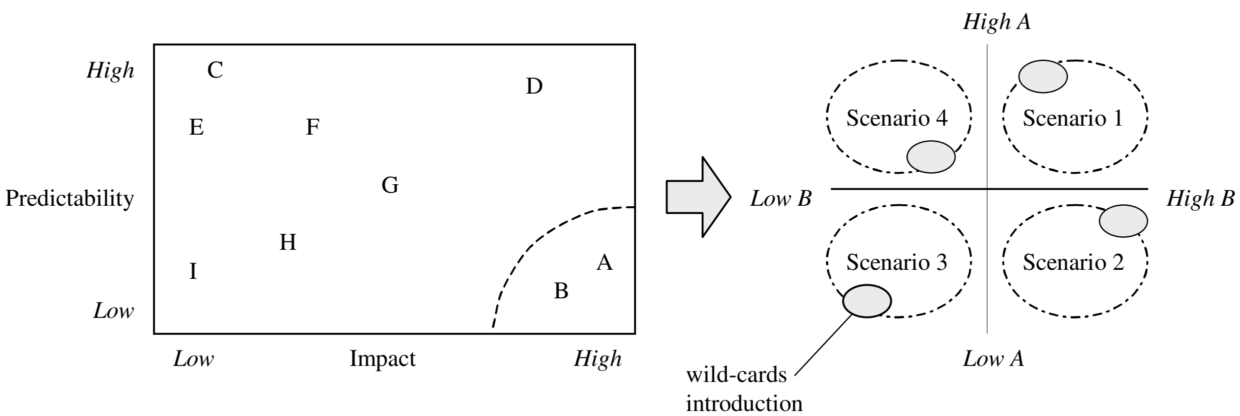

Figure 1: Scenario construction (adapted from Postma and Liebl, 2004)

4.3. Example: questions related to a fictive small producer of carbon nanotubes

In order to explain the above-mentioned concept some 'what if ... ' questions and 'what must happen, so that ...' questions that could relate to a fictive small producer of carbon nanotubes are worked out (see table 6). This paper does not discuss the whole scenario development process of this fictive case.

Carbon nanotubes can be described as graphite sheets rolled to form a tube-like structure with a diameter of a few nanometres and possess relatively advanced properties in fields like strength-to-weight ratio, weight density, heat transmission or current conductivity. These particles are used or will be used in industries like electronics and chips manufacturing, automotive, aerospace or biomedicine (Mamalis et al., 2004). Due to the fact that carbon nanotubes can be used in a variety of applications in several industries, international market dynamics - as mentioned earlier - are present in the context of small manufacturers of carbon nanotubes. Additionally, up-scaling of production processes and introduction of new production processes could lead to severe disturbances in market penetration strategies due to lower prices, more purified batches or specialised products. Moreover, it is likely that substitutes of carbon nanotubes could have substantial disruptive impact in certain industries. An example of a substitute is a new class of nanowire materials based on transition metal chalcogenide-halides (Mo6, 2004). For more readings on carbon nanotubes see Köhler et al. (2003) and Mamalis et al. (2004).

'What if ...' questions
- What if our biggest two customers won't re-order the usual yearly amount of carbon nanotubes grams? - What if the acceleration rate of the innovation development processes on industry or application specific carbon nanotubes of our (known and unknown) competitors is substantial higher? - What if newly invented and patented production processes of our (known or unknown) competitors have the potential to decrease the production costs per weight unit of general carbon nanotubes substantially? - What if our known or unknown competitors have the ability to upscale carbon nanotubes production in short-term due to heavy investments of venture capitalists and/or local governments? - What if toxicological research shows that specific types of carbon nanotubes create significant health risks after inhalation in human lungs? - What if the public opinion on carbon nanotubes in general becomes significantly negative?
'What must happen, so that ...' questions
- What alliances need to be formed by enterprises (e.g. known and unknown competitors, partners, suppliers, customers), so that our carbon nanotubes business opportunities in the European and Asian pharmaceutical research market will be minimised? - What carbon nanotubes substitutes need to be invented, patented and marketed by enterprises (e.g. known and unknown competitors, partners, suppliers, customers), so that our market positions in developing industries like display electronics and composites will be undermined? - What contexts must be applied, so that legal restrictions minimise our future carbon nanotubes business opportunities in the tires segment within the automotive industry? - What ethical debate needs to be introduced, so that the chance of exploiting carbon nanotubes business opportunities in industries like aerospace, electronics and health will be minimised? - What must happen, so that the coming EU seventh framework programmes doesn't focus anymore on subsidising research and development on carbon nanotubes?

Table 6: Examples of scenario construction questions related to a fictive carbon nanotube manufacturer start-up

Based on entrepreneurial team discussion related to the given questions as shown in table 6 it is possible to identify uncertainties with relative high impacts and to introduce unusual events to broaden the scope from known uncertainties to unknown elements. This will lead to more triggering scenarios on business opportunities (and threats) and to stretched mental models.

4.4. Discussion

Activities with small nanotechnology firms' entrepreneurial team / management team in order to discuss the two types of questions mentioned and to formulate uncertainty-based scenarios, stimulates the awareness on business opportunities in a dynamic international market and technology context and stretches mental models of people involved on the essence to balance science and technology aspects and business opportunity aspects. A broader range of signals via a broader and/or more overlapping set of mental models feeds the small nanotechnology firms' innovation development process in order to be better equipped to successfully explore *and* exploit nanotechnology.

Besides the presented concept of scenarios several other instruments are available to support high-tech small firms with their strategic business planning. Forecasting is an available instrument, but due to the disruptive character of nanotechnology this instrument is less feasible to deal with fundamental uncertainties. Roadmapping is also a useful tool to match the technology and science domain with a firms' business domain, but with respect to new business awareness this instrument is more appropriate if this awareness is already transformed in concrete product-market focuses with needed science, technology, and project management and business management competencies. To scan future technology developments based on experts' opinions delphi -method is appropriate. It is less feasible to stimulate awareness on business aspects and chances. Although the above-mentioned instruments are not (fully) able to fulfil the role of scenarios methods, it could be interesting in what way complementary approaches make small nanotechnology firms more successful in nanotechnology commercialisation. For instance, scenario method forms an instrument that could be complementary with roadmapping. Based on the stretched mental models due to scenarios technology roadmapping aspects like market discussions could be much broader and more divers.

5. Conclusion

Small nanotechnology firms in general and those firms in a phase of science to technology transformation in specific need to have means to gain more business opportunity awareness in order to go through the innovation development processes successfully. To influence this awareness, scenarios as supporting instrument are introduced in this paper. According to theoretical insights signals related to external business influences are essential to feed the innovation development process. Theory also suggests that mental models of a technical oriented entrepreneurial team have the chance to be more biased to explore aspects in the science and technology domain and pay less attention on business (management) aspects. Scenario method form an approach to stretch mental models in order to be more balanced as a company on exploration and exploitation of nanotechnology and therefore better mentally equipped to innovate successfully with disruptive nanotechnology in a dynamic international business environment.

Future research should focus on deepening the theoretical base and the generation of a concrete methodology to actually support small nanotechnology firms with business opportunity awareness via scenarios. Cases need to be initiated and monitored in order to evaluate and test the presented theoretically-based concept with empirical data.

Moreover, it is interesting and perhaps necessary to use the given concepts in this paper to refine practical methodologies to assist small nanotechnology firms with their business opportunity awareness to make or keep them market driven and competitive. Additionally, from a policy point of view it is advisable to analyse in what way practical scenario methods for small nanotechnology companies could be embedded in a policy instrument package focused on the stimulation of balanced commercialisation of nanotechnology.

REFERENCES

Audretsch, D.B., Bozeman, B., Combs, K.L., Feldman, M., Link, A.N., Siegel, D.S., Stephan, P., Tassey, G. and Wessner, Ch. (2002), The economics of science and technology, *Journal of Technology Transfer*, Vol. 27, pp. 155 - 203.

Bainbridge, W.S. (2002), Public attitudes toward nanotechnology, *Journal of Nanoparticle Research*, Vol. 4, pp. 561 - 570.

Berry, M.M.J. (1996), Technical entrepeneurship, strategic awareness and corporate transformation in small high-tech firms, *Technovation*, Vol. 16, 9, pp. 487 - 498.

Berry, M.M.J. and Taggart, J.H. (1998), Combining technology and corporate strategy in small high tech firms, *Research Policy*, Vol. 26, pp. 883 - 895.

Bhat, J.S.A. (2003), Concerns of new technology based industries - The case of nanotechnology, *Technovation* - article in press.

Bood, R.P. and Postma, T.J.B.M. (1998), *Scenario analysis as a strategic management tool*, Research report SOM 9805, University of Groningen, Groningen.

Brower, J.L. and Christensen, C.M. (1995), Disruptive technologies: Catching the wave, *Harvard Business Review*, Vol. 73(1), pp. 43 - 53.

Cairns, G., Wright, G., Bradflield, R., Van der Heijden, K. and Burt, G. (2004), Exploring e-government futures through the application of scenario planning, *Technological Forecasting & Social Change*, Vol. 71, pp. 217 - 238.

Cientifica (2003), *The nanotechnology opportunity report - Edition 2,* Research report June 2003, Cientifica, Las Rosas.

Christensen, C.M. (1997), *The innovator's dilemma: When new technologies cause great firms to fail,* Harvard Business School Press, Boston, MA.

Compañó, R. and Hullmann, A. (2002), Forecasting the development of nanotechnology with the help of science and technology indicators, *Nanotechnology*, Vol. 13, pp. 243 - 247

D'Aveni, R.A. (1994), *Hypercompetition: managing the dynamics of strategic maneuvering*, Free Press, New York.

D'Aveni, R.A. (1999), Strategic supremacy through disruption and dominance, *MIT Sloan Management Review*, Vol. 40(3), pp. 127 - 135.

Dodgson, M. (2000), *The management of technological innovation: An international and strategic approach*, Oxford University Press, Oxford.

Dosi, G., Pavitt, K. and Soete, L. (1990), *The economics of technical change and international trade*, Harverster Wheatsheaf, Hertfordshire.

During, W.E. (1984), *Innovatieproblematiek in kleine industriële bedrijven*, Van Gorkum, Assen.

ENA (2002), *It's ours to lose: An analysis of EU nanotechnology funding and the sixth framework programmehe*, Research report, European NanoBusiness Association, Brussels.

ENA (2004), *The 2004 European nanobusiness survey: 'Use it or lose it'*, Research report, European NanoBusiness Association, Brussels.

Est, R. van, Malsch, I. and Rip, A. (2004), *Om het kleine te waarderen... Een schets naar nanotechnologie: publiek debat, toepassingsgebieden en maatschappelijke aandachtspunten*, Working document 93, Rathenau Instituut, the Hague.

Feynman, R. P. (1959), *There' s plenty of room tathe bottom*, Caltech, http://www.its.caltech.edu/~feynman/plenty.html.

Foster, R. and Kaplan, S. (2001), *Creative destruction: Why companies that are built to last underperform the market – and how to successfully transform them*, Currency, New York.

Gausemeier, J., Fink, A. and Schalke, O. (1998), Scenario management: An approach to develop future potentials, *Technological Forecasting & Social Change*, Vol. 59, pp. 111 - 130.

Gelderen, M. van, Frese, M. and Thurik, R. (2001), Strategies, uncertainty and performance of small business startups, *Small Business Economics*, Vol. 15, pp. 165 - 181.

Gerde, V.W. and Mahto, R.V. (2004), Disruptive technology and interdependence: The relationships of BioMEMS technology and pharmaceutical firms, *Journal of High Technology Management Research*, Vol. 15, pp. 73-89.

Harvey, M., Novicevic, M. and Kiessling, T. (2001), Hypercompetition and the future of global management in the twenty-first century, *Thunderbird International Business Review*, Vol. 43 (5), pp. 599 - 616.

Heijden, K. van der (1996), *The art of strategic converstation*, Wiley, Chichester.

Hullmann, A. and Meyer, M. (2003), Publications and patents in nanotechnology: an overview of previous studies and the state of the art, *Scientometrics*, Vol. 58(3), pp. 507 - 527.

Kahn, H. and Wiener, A.J. (1967) *The year 2000: A framework for speculation on the next thirty-three years*, MacMillan, New York.

Kassicieh, S.K., Kirchoff, B.A., Walsh, S.T. and McWhorter, P.J. (2002), The role of small firms in the transfer of disruptive technologies, *Technovation*, Vol. 22, pp. 667 - 674.

Kline, S.J. and Rosenberg, W. (1986), An overview of innovation, in Landau, R. and Rosenberg, N. (eds.), *The positive sum strategy: Harnessing technology for economic growth*, National Academy Press, Washington, D.C., pp. 275 - 305.

Knol, W.H.C. and Stroeken, J.H.M. (2001), The diffusion and adoption of information technology in small- and medium-sized enterprises though IT scenarios, *Technology Analysis & Strategic Management*, Vol. 13(2), pp. 227 - 246.

Köhler, Th., Mietke, S., Ilgner, J. and Werner, M. (2003), Nanotechnology - Market & trends, *Vakuum in Forschung und Praxis*, Vol. 15(6), pp. 292 - 297.

Kostoff, R.N., Boylan, R. and Simons, G.R. (2004), Disruptive technology roadmaps, *Technological Forecasting & Social change*, 71, pp. 141 - 159.

Lux Capital (2003), *The nanotech report 2003*, Research Report, Lux Capital, New York.

Mamalis, A.G., Vogtländer, L.O.G. and Markopoulos, A. (2004), Nanotechnology and nanostructured materials: Trends in carbon nanotubes, *Precision Engineering*, Vol. 28, pp. 16 - 30.

Marinova, D. and McAleer, M. (2003), Nanotechnology strength indicators: International rankings based on US patents, *Nanotechnology*, Vol. 14, pp. 1 - 7.

Mazzola, L. (2003), Commercializing nanotechnology, *Nature Biotechnology*, Vol. 21(10), pp. 1137 - 1143.

Mercer, D. (1995), Scenarios made easy, *Long Range Planning*, Vol. 28(4), pp. 81 - 86.

Millet, S.M. (1988), How scenarios trigger strategic thinking, *Long Range Planning*, Vol. 21(5), pp. 61 - 68.

Mo6 (2004), Information on a new class of nanowire materials based on transition metal chalcogenide-halides, April 2004, website of Mo6, www.mo6.com.

Mnyusiwalla, A., Daar, A.S., Singer, P.A. (2003), ‘Mind the gap’: Science and ethics in nanotechnology, *Nanotechnology*, Vol. 14, pp. 9 - 13.

Oakey, R.P. (2003), Technical entreprenenurship in high technology small firms: some observations on the implications for management, *Technovation*, Vol. 23, pp. 679 - 688.

Paull, R., Wolfe, J., Hébert, P. and Sinkula, M. (2003), Investing in nanotechnology, *Nature Biotechnology*, Vol. 21(10), pp. 1144 - 1147.

Postma, T.J.B.M. and Liebl, F. (2004), How to improve scenario analysis as a strategic management tool, *Technological Forecasting & Social Change* - article in press.

Qeam (2004), Overview of nanotechnology applied in everyday life applications, April 2004, website of Qeam, www.Qeam.com.

Roco, M.C. (1999), Nanoparticles and nanotechnology research, *Journal of Nanoparticle Research*, Vol. 1, pp. 1 - 6.

Roco, M.C. (2001), International strategy for nanotechnology research and development, *Journal of Nanoparticle Research*, Vol. 3, pp. 353 - 360.

Roco, M.C. (2002), Coherence and divergence of megatrends in science and engineering, *Journal of Nanoparticle Research*, Vol. 4, pp. 9 - 19.

Roco, M.C. (2003), Broader societal issues of nanotechnology, *Journal of Nanoparticle Research*, Vol. 5, pp. 181 - 189.

Rogers, E.M. (1995), *Diffusion of innovations*, The Free Press, New York.

Romer, P. (1990), Endogenous technological change, *Journal of Political Economy*, Vol. 98, pp. 71 - 102.

Rothwell, R. (1992), Successful industrial innovation: Critical success factors for the 1990s, *R&D Management*, Vol. 22(3), pp. 221 - 239.

Schumpeter, J.A. (1934), *The theory of economic development*, Harvard University Press, Cambridge MA.

Small Times (2004), *Regulation on Europe’s agenda while labs, business collaborate*, April 2004, article by G. Oger on website of Small Times, www.smalltimes.com.

Stroeken, J.H.M. and Knol, W.H.C. (1999), IT scenarios for small and medium-sized enterprises, Paper presented on the 3rd international conference 'Technology Policy and Innovation' in Austin, U.S.A, August 30 - September 2.

Tidd, J., Bessant, J. and Pavitt, K. (2001), *Management Innovation: Integrating technological, market and organizational change*, Second edition, John Wiley & Sons Ltd. Chichester.

Walsh, S.T. (2004), Roadmapping a disruptive technology: A case study; the emerging microsystems and top-down nanosystems industry, *Technological Forecasting & Social Change*, Vol. 71, pp. 161 - 185.

Wolde, A. ten (1998) (eds.), *Nanotechnology: Towards a molecular construction kit*, Report of SST, the Hague.