Paper 3 : Roadmapping as TA-Tool: Pre-requisites and potential benefits for assessing Nanotechnology

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I. ABSTRACT

Phenomenologically, nanotechnology (NT) can be characterized by the early stage of the development of most nanotechniques and by its diversity. Although a lot of nanotechniques are rather research projects than technology, it is expected that nanotechnology will have a deep influence on almost all fields of social life10. On the other hand, a few nanotechniques are already in the production phase and some are even on the market. Therefore, policy-makers as well as decision-makers in the industry are right now forced to come up with decisions concerning research investments but also with decisions about regulations. To build up fundamental knowledge for these decisions to rely on, the special character of NT makes it necessary to extend the viability of foresight methods within technology assessment activities.

In this contribution the authors propose roadmapping (RM) as an appropriate method to build up strategic knowledge for enabling politicians and governmental institutions as well as research institutions to deal with the challenges of NT. First of all, the characteristics of NT with respect to technology assessment are discussed. Here, the focus will be on the diversity of the field of investigation and the early stage of development of most nanotechniques. Against the background of this analysis it is briefly summarized what kind of questions concerning societal implications have to be addressed and what sort of decisions have to be made in the near future.

Furthermore, the strengths and problems of the method of RM are discussed in terms of using the method as a business management tool. This discussion also includes the use of RM for strategic planning in research policy and concentrates on the differences between industrial organizations and governmental administrations with respect to the RM process. .As the result of this analysis, the pre-requisites necessary for a successful RM process are presented. Together with this analysis, further benefits of the RM process beyond structuring the field of nanoscience and NT are also reflected. Especially the question of how the RM process has to be designed to guarantee commitment from the participants, is addressed. Finally, the limits of RM as a tool for technology assessment (TA) are discussed and the integration by including other methods is proposed.

II. CHARACTERISTICS OF NANOTECHNOLOGY

From nanotechnology (NT) it is expected that it will have a deep influence on almost all fields of social life [NST Report, BMBF04, Cordis04]. This widely accepted estimation calls for technology assessment (TA) to verify or weaken that estimation and to find out which changes in which social and environmental fields are the most effective and the

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[10] NSTC-Report "Nanotechnology: Shaping the World Atom by Atom", http://itri.loyola.edu/nano/IWGN.Public.Brochure

most realistic ones. Confronted with the challenge to perform TA of NT we remark, that established tools for TA are not sufficient. The characteristics of NT described in the following require new approaches.

I. Diversity of Nanotechnology

The main characteristic of NT is its diversity. The reason for that is how NT is defined, which is in terms of size. “Nanotechnology is made up of areas of technology where dimensions and tolerances in the range of 0.1 nm to 100 nm play a critical role.” (Glossary of the Nanoforum, [Nanoforum04])
Even though in many definitions other aspects are included like new functionalities which are generated by the small size of the objects or by the structure of the material under investigation. In common use, only the size which is in the nm-scale is used to characterize what NT is. In addition to that, it is also common, that the structure characterizes the device as NT, must be generated by a controlled process. More about the problems of the definition of NT including an elaborated definition could be found in G. Schmidt et al. 2003 [Schmidt03].
Since NT is mainly defined in terms of size, this leads to the fact that a huge variety of different techniques, research topics, methods of structuring material, and manipulate surfaces are summarized under the term of NT. Herein we find such different things like anti-reflexive coatings, nanoparticles mixed in fluids or solids in order to alter their material properties or displays made from carbon nanotubes. Furthermore, due to the ongoing miniaturization in microelectronics, characteristic length scales of the electronic components will soon fall below 100nm. Right know, the German State Secretary Dudenhausen calls the whole electronic industry NT[11].
It is obvious that these heterogeneous techniques can not be analyzed and assessed as a whole. It is necessary to make a choice.

II. Nanotechnology as Enabling Technology

Another problem is the fact that NT is predominantly an enabling technology. This means that NT is only one component of a bigger system, which may give the product the crucial functionality. So, there will be many very different products for very different purposes containing the same NT. For every context of use, NT has to be assessed separately.

If one would like to estimate the toxicity of a compound material which includes nanoparticles it is not enough to investigate the toxicity of the nanoparticles themselves. It has to be known under which conditions this material will be used. Will a human get in contact with this material? Are the particles tightly bound to the matrix? Are the particles soluble in other media, for instance when it gets in contact with acid rain? If this compound material is to be used for brake shoes, what kind of processes will happen while the material is exposed to heat caused by friction? What kind will the abrasion be like? Which path will it take and what will it do there?

[11] "Nanoelectronis is the engine of innovation for almost all branches. Even today in Germany, there are 70.000 employments within the chip manufacturing and suppliers industry, dependent on nanoelectronics. The market for electronic devices in Germany counts up to a value of about 20 billion Euro.“(English U.F.)
Wolf-Dieter Dudenhausen at the 25th Nov. 2003, Source: Pressemitteilung 219/03 of the BMBF

III. Early Stage of Development

A third characteristic aspect of NT that is also linked to the diversity of the topic is the diversity of stages of development NT could be found in. For some simple applications like the improvement of the rubber mixture for tires nanoparticles have been used for several years. Yet, most concepts of products like drug delivery systems are far from application, others like nano-assembler are pure science fiction. But most of the concepts assigned to NT are pure science, ideas of applications are rare, at times even don't exist.

The early stage of development of most techniques within NT touches an old dilemma of TA. From emerging technologies little is known about the technique and its interaction with environment, society and the human body.. Statements about future effects are not well-founded. On the other hand, if a technique is fully developed, has been on the market for a long time, and is well established so that society is imbued with this technique, then a lot of the consequences of the use of the technique are well known. But then, it is too late to prevent perils accompanied by the use of the technique. To overcome this dilemma TA needs to be embedded already in the development process as it is pursued by the concept of Constructive Technology Assessment [Ripe95].

As mentioned above, prerequisite of TA is the knowledge of the context of use. But due to the early stage of development the ideas of applications of most of the concepts assigned to NT are fuzzy and not deliberate. One of the main objective for introducing the method of RM in TA is to find out to which application nanoscience could lead to; or the other way round, to analyse if pretended applications are realistic and if the kind of nanoscience in mind is suitable for the realization of that application.

To start with some reliable reflections on consequences of certain scientific activities it is necessary to know what kind of products or applications could emerge in the near future from that scientific activity. How can we find out about which application could be the result of which scientific and engineering activity? To answer this question it is not enough to identify possible products which could be produced, but also in which time frame its realization will be possible.

IV. Debate About Nanotechnolog

A fourth characteristic of NT is the existence of a debate about NT even though almost no products are on the market and the impact on the public is marginal. The outcome of these debates can influence significantly the development of the concerning technology. This could be seen from other debates about new technology, like the debate about nuclear energy, stem cell research or gene manipulated organism (GMO).

Therefore, the third task for TA is to follow and analyse the debate on NT, the argumentation used, as well as its dynamics. The/Our (goal) objective should be to deliver arguments which could rationalize this debate and contribute to an agreed upon compromise between the involved parties.

V. How to Deal With these Characteristics?

The only way to deal with the diversity is to monitor all the developments in order to become alert for a sudden acceleration of the development and for concentration of activities in a special field of NT. The task of TA is first of all to give an overview about the most important R&D activities, secondly to structure them and finally to monitor the progress. Meanwhile, a number of studies with that purpose already do exist. However, one of them should be mentioned: it was performed by the Office of Technology Assessment at the German Parliament (TAB) and concluded in November 2003 [Paschen04].

It will be necessary to concentrate on some R&D fields in which the largest impact is estimated. Here it is necessary to connect research activities with possible applications. This is exactly which the RM approach is designed for. As the questions above imply the pre-requisite to start with the assessment of a new technology is to know the context of use. Therefore, it is necessary to have an idea of possible products in order to know in which context they will be used.

Another motivation for the RM approach is to strengthen the technical feasibility of a certain concept of a product and by doing so to prevent that the reflection on social implications are put aside as pure speculations. A detailed discussion of the changing environment for TA and the future role that RM could play as a precursor or a part of a TA process, could be found in Fleischer et al. [Fleischer04].

III. THE ROADMAPPING CONCEPT

RM describes the process of roadmap development. Lately, the term RM has become more common than the term roadmap because the first one focuses on the processing character of the roadmap development rather than on the result..
There are several different types of roadmaps and therefore different concepts of the RM process. They differ in respect to the topic (product, technique, science, political issues) but also in respect to the participating institutions (companies, consortia of enterprises, research laboratories, government departments). The following list by Kostoff et al. presents a good classification of the variety of RM concepts[12] [Kostoff01]:

1. product roadmaps (e.g., Motorola, Intel, and others)
2. technology roadmaps (e.g., aerospace, aluminum, etc.)
3. industry roadmaps (e.g., SIA's International Technology Roadmap for Semiconductors);
4. cross-industry roadmaps (e.g., Industry Canada initiative)
5. science/research roadmaps (e.g., science mapping)
6. project/issue roadmaps (e.g., for project administration)

The first four types of roadmaps can be basically distinguished by the extent of the involved institutions from one company to a whole industry of a country. Usually, they

[12] For another classification which is more oriented on the structure of the roadmapping process rather than on classification by the institutions which perform the roadmapping see [Phaal01].

are all technology roadmaps[13], that is a "technology planning process to help identifying, selecting, and developing technology alternatives to satisfy a set of product needs" in order to make the appropriate technology investment decisions [Garcia97]. Science and research roadmaps[14] differ from the four business roadmap concepts (because) they are performed by governmental research institutes, are therefore not embedded in the economic system and have not to cope with economical constrains.
The last classification point, that is project or issue oriented RM, is characterised by the fact, that the RM process is used to address an issue like waste management or energy and water supply. It is intended to identify issues and their consequences for project planning and budgeting [Garcia97].

In the next two sections, we will concentrate on two types of RM, corporate RM and industry RM. In contrast to these concepts, we will discuss at the end of this chapter science RM within governmental research institutes.
We will start with corporate RM for several reasons. First of all, corporate RM is the origin of RM [Probert03] and is the most concrete concept. So, its easier to grasp the idea of this concept. Secondly, the steps are clearly visible and are more easily translated too the concepts of RM, and finally, it has a stronger emphasis on communication. This inherent communicative issue is one aspect the application of RM is promising for TA purposes. For TA it is not sufficient to know how to deal with a certain technology but to involve the concerned people in the discussion and the decision process. Furthermore, it is necessary to communicate the results of the TA-process. On the other hand, the RM process allows easily to include peoples from different parties, social groups, and other stakeholders and to meet thereby the legitimacy problem of TA.

1. Corporate Roadmapping

Developments like shortening of product cycles, increasing complexity of the products, and increasing technological efforts for the development of new products as well as for cost reduction of the production process[15] forced companies to improve the efficiency of the R&D investment.

There are some market developments that forced companies to make more efficient R&D investment decisions. These are for example shortening of product cycles, increasing complexity of products which leads to increasing technological effort for the development of the product and for the building up of the production facilities [Australia01, Groenveld97]. To make the right R&D investment decision has become a crucial issue for the survival of a company. The right investment decision not only means establish the appropriate facility to produce the intended product but it also means to find a product which will be demanded on the market in the future. The main purpose of the RM process is to combine market demand with technology development.

[13] In literature, the more general expression roadmap is often used synonym for the expression technology roadmap.
[14] Even thought science roadmap is some times also used synonym with technology roadmap in this paper it is only used for roadmapping activity in the field of science and research.
[15] This is especially thru for consumer electronics or automobile industry where the products are very complex and the investments for a new product are tremendous.

For that reason, RM could be seen as a pivotal point for the shift from technology push to market demands driven R&D strategies.

A quotation by Bray from Sandia Laboratories points this out: "Roadmapping is driven by a need, not a solution" [Bray97]. A further characteristic aspect of RM is the time issue. At the end of the RM process not only the hurdles which have to be overcome to realize a product are identified but also the time which is needed to overcome them is estimated. This helps to monitor and correct the development process. A further important aspect of RM is the identification of alternative development paths. From these the cheapest and most promising could be chosen. The monitoring process permits to realize if preconditions are changing which could lead the fact, that other development paths will become easier to pursuit. This is the reason why RM is not only the development of the roadmap, it will be continued until the product is realized or in general, the goal is reached.

One can conclude: RM is designed to provide the management with information about consumer demands and its development in the future, about the technological skills and the potential for development of the own corporation as well as in the whole sector, about financial constrains, chains of distribution and about the interconnectedness of all of these parameters. Finally, it gives an answer to the question of how to coordinate and combine the R&D activities within time[16]. "Roadmapping is a complicated process, requiring the simultaneous consideration of markets/products, technology and the interaction between them over time." [Groenveld, 97].

Starting point for the corporate RM process is the analysis of the technological skills and the core competencies of the own company. This analysis encompasses the analysis of what could be developed with these skills in the near and the far future and which kind of investments would be necessary to extend these skills to produce new products[17]. Accompanying the portfolio analysis, an analysis of the market is crucial for the RM process. Starting from the actual market demands future consumer needs will be estimated. At that point the visionary aspect of RM comes into play. The RM team has to crate a vision of a product for example by identifying sets of functionalities which could be delivered by new technologies and which will satisfy the identified consumer needs. This vision of the new products is the starting point for back casting. Starting from that product vision the developments of demanded technical abilities to realise the product vision will be traced back to the actual situation.

During this activity the specific technological developments required to realize the envisioned product will be analysed and evaluated in respect to the efforts which are necessary for its realisation. Thereby possible roadblocks and alternative technical options will be identified which could deliver the demanded functionality of the product. In fig. 1 this circular character of the RM process is visualized. It is an iterative process. This fore and back casting is done several times and with every new circle the vision of the product gets more concrete and the path how to realize the products gets more and more clear. It shows that RM is used for both retrospective and prospective studies in time.

[16] In contrast to a project plan roadmapping encompasses a wider time horizon. It is not only constrained to the next product but it should be charged for the next family of products for the next five to ten years. In that respect an important contribution to roadmapping are foresight activities.

[17] This portfolio analysis comprises the analysis product variety as well as a SWOT analysis to have a basis for strategic investment decisions.

To avoid confusion it should be mentioned that RM is a kind of meta method. It includes detailed planning techniques known from technology management practices like SWOT-, portfolio - analysis, Boston square, Quality Function Deployment and Innovation Matrix [Baker95, Groenveld97].

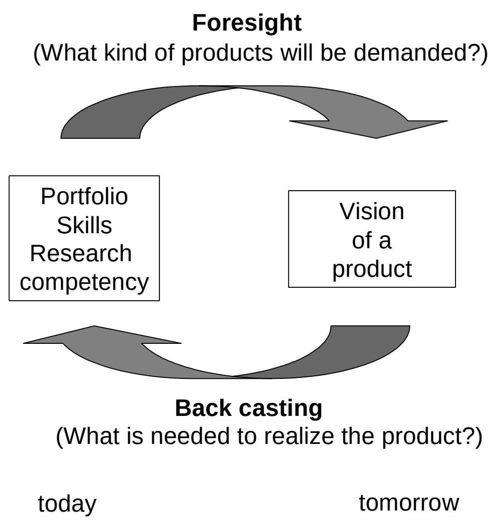

Fig.1
Cyclic and iterative character of roadmapping

Essential for the success of the RM process is that this analysis of the portfolio and the market as well as the creation of a vision of a new product is not performed by a small group of one department, lets say the management department but that all departments are involved in the process. Therefore, a cross functional team has to be established to ensure that for example the knowledge of the sales department about the consumer preferences will be included in the RM process as well as the knowledge from the production department, the research department, people from the administration of the company, the PR-department, and so on.

In respect to the technological investment management the RM process helps to break down the challenge to manageable tasks and also helps to coordinate R&D activities. For that purpose, the time dimension of the roadmap is crucial. Only if the tasks are assigned to certain time frames the coordination of the diverse development activities will be able to perform. The time schedule of the tasks enables monitoring progress by tracing and evaluating the development. This is done by identifying Key Success Factors to measure the impact of the foresight, enable quantifying progress towards the strategic goal, and to measure the impact and effectiveness of the R&D activities [Barker95].

To build up a technological investment plan is not the only purpose of the RM process. Others are the enhancement of cross functional communication within the company. The RM process helps to create a common vision of the future challenges the company is faced with and of the linked developments which it has to undergo to meet the objectives. In contrast to a project plan, the vision for future products, or new families of products, created during the RM process has a wider scope. It is a visualisation of the strategic goals concerning developments within the next five to ten years.

The graphical representation of the roadmap has also several purposes. It helps to disseminate the outcome and to communicate these upcoming strategic goals within the whole company.

It helps to

- structure the investigation,
- foster informed discussion,

- express extensive and complex information into small space, and
- aiding the process of checking for consistency of the data

There are several ways to visualise the result of the RM process. The most common is the generic format [Farruk03, Bucher02].

The benefits of the RM process beyond the technical investment planning could be summarized as such: “Roadmapping stimulates organizational learning”. [Groenveld97].

2. Industry Roadmapping

In contrast to the corporate RM process where the participants are the different departments of the corporation the participants of industrial RM are different companies which contribute to a complex product. A well known example is the SIA-roadmap. There, a huge consortium from the electronic industry is established to map out the challenges the semiconductor industry is faced with, if they will continue the miniaturisation as moors law describes it. The challenges are too big to be managed by one company. Every involved company is specialized in one field and has to develop special technical solutions as contribution to the overall development process. While in the corporate RM process the participants are not independent actors but are committed to the allover goal of the company, the commitment of the participant in the industrial RM process has other sources. They hope to profit from the process by exchanging and sharing information about upcoming problems and their possible solutions. Critical for the commitment is, that an industrial RM initiative has to be performed on a pre-competitive level, where all the parties that participate in the process do not gain unfair competitive advantage [McCarthy03]. Because it is not clear how to balance the effort a participant has to deliver to the roadmap with the benefit the participant gains from the participation in the RM process industry roadmaps are at the beginning often subsidized by the government[18].

3. Roadmapping as TA-Tool

This question of the commitment within an industrial RM initiative is interesting for the application of the RM concept for the use of TA. If it is intended for example to use the RM approach to find promising research topics for the future, it is necessary to gain and hold the participation of the research institutes. For them it must be clear visible why they should participate in the RM process. As mentioned above the benefit for the participants of an industrial RM process is the gain of knowledge about the future development process and the specific needs they have to full fill, if they would like to contribute to the whole development process.

[18] For example this was the case fort he SIA-Roadmap by funding the SEMATECH organisation in 1987 [McCarthy03].

Transferred to the application of RM within the field of science and research it has to be ask, what are the benefit for the research institutes if they participate in the RM process. Due to the inherent interdisciplinary character of NT a RM initiatives provide some benefit for the participating institutes. They are forced to extent their knowledge beyond their disciplinary expertise. During the RM process they profit from the knowledge of the other participants. They could share their knowledge which is focused on the specific topic of the roadmap.

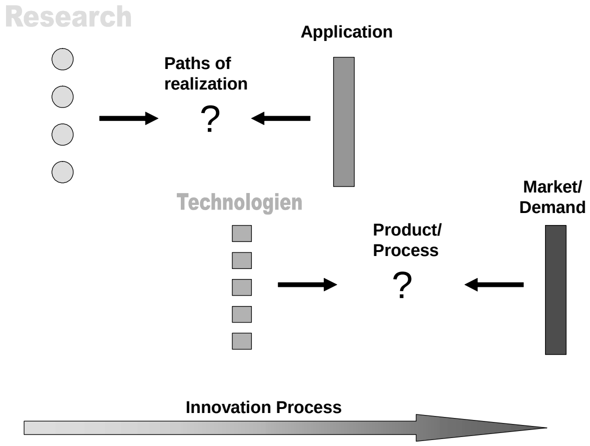

Fig.2
While raodmapping used as classical R&D management tool combines technologies with market, in the field of science it combines research with possible applications.

Together they could identify key problems and how they could to overcome in an mutual effort.

What kind of barriers could prevent co-operation. Researchers could be afraid, that their concept will be taken up from others, that they will loose the leadership in that field. At the beginning it might be not clear, what kind of knowledge could be delivered from the other participant. The process of discussion could be seen as time wasting activity. The different disciplinary languages which are used within the different scientific communities could reduce the efficiency of the communication process.
For TA purposes the RM concept enables to extend the group of participants by people from other contexts like consumer organisations, or other groups could be concerned be the technique which development is under investigation by the RM process.
A further aspect of RM which is interesting for TA purposes is the above mentioned aim of RM to foster informed discussion and create a shared vision of the up coming challenges among the involved people.
The differences between the use of RM within industry and the use within scientific field we have discussed concerned the procedure of the process. Another very important difference is the topic. While in industry the market is the relevant issue on which the technological development is focused on in the field of science the research activities are too fare from the market to do so. This is especially true for the most research activities within NT. There it is first necessary to identify possible applications the considered research activity could contribute. This difference is visualized in fig.2.
There are two approaches how to combine research activities with a possible application.

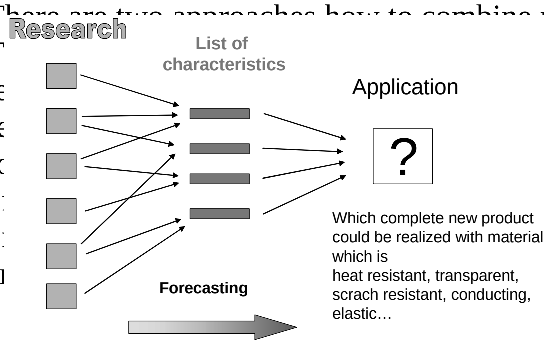

Fig.3
Schematic chart of the question: To which application the actual research activities could lead to?

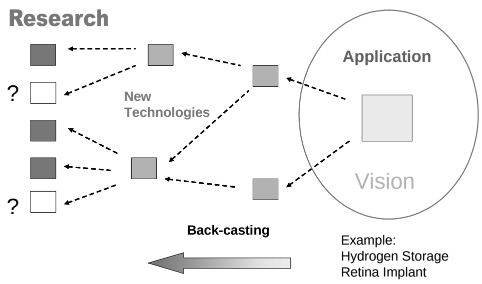

Fig.4
Schematic chart of the question: What kind of research is necessary to realize a certain application?

of problems has to be solved before the application could be realized. This is labelled as back-casting approach.

At the end of this article some benefits of the RM concept for the use for TA of NT should be summarised:

1. The RM concept allows the combination of research activities with possible applications which is a pre-requisite for TA. Especially within NT, there are a lot of research activities where possible applications are not clear or seem not to be realistic.
2. The inherent interdisciplinary character of NT fits very well to the design of the RM process, which tend to include all perspectives a certain topic generates.
3. The aim of RM to foster informed discussion and to come up with a shared vision of the future challenges is suitable to the communicative and meditative aspect of TA.

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Wolf-Dieter Dudenhausen (German State Secretary) at the 25th Nov. 2003,

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