Chapter 4
Constructive Technology Assessment and Socio-Technical Scenarios

Arie Rip and Haico te Kulve

Since the 1980s, Rip has been instrumental in developing and applying an approach to broaden the scope of participants and considerations that go into technological developments—an approach known as Constructive Technology Assessment (CTA). A number of organizations have employed CTA, including the Rathenau Institute (formerly, the Netherlands Office of Technology Assessment). Since 2005, the Dutch national nanotechnology consortium, NanoNed, has included CTA as a program component under Rip's coordination. In this chapter, Rip and te Kulve suggest that because many nanotechnology applications remain little more than promises, studying their implications amounts to an exercise in "social science fiction." In light of this challenge, they develop socio-technical scenarios. Scenarios are a well-established foresight method that are gaining wide use in the study of nanotechnology (Türk, ch. 8; Kosal, ch. 13). Here, Rip and te Kulve identify complex and overlooked interactions that can be used to make scenarios more conceptually robust and pragmatically effective. In their description of two scenario construction frameworks, they offer a link between theory and practice. They suggest that CTA scenarios can serve as "useful fictions" for strategic purposes (Bünger, ch. 5) as well as for modulating ongoing socio-technical change. – Eds.

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Originally presented at the Center for Nanotechnology in Society at Arizona State University on 23 February 2007.

E. Fisher et al. (eds.), *The Yearbook of Nanotechnology in Society, Vol. 1*,

Introduction

Within the spectrum of methods and approaches of technology assessment, some are more appropriate to nanotechnology than others. The challenge is to assess technological developments and their embedding in society as these occur. Constructive Technology Assessment (Rip et al. 1995; Schot and Rip 1997) and Real-Time Technology Assessment (Guston and Sarewitz 2002) are the main candidates. There is quite a lot of overlap, but Constructive TA, which we will discuss in this chapter, explicitly attempts to use insights from studies of the dynamics of technological development.

For nanotechnology (actually, nanoscience and nanotechnologies), most of the envisioned applications are still in the realm of science fiction, in the sense that they are not there yet, and that it is not clear whether they will ever be realized. Their eventual impacts are even less clear—attempts to find out about them are then social science fiction. This doubly fictional character of nanotechnology requires the use of scenarios, in particular socio-technical scenarios which capture ongoing dynamics and develop implications for what might happen.

They can be used as input in interactive workshops with various relevant actors, and then support broader interactions, where actors probe each other's worlds, and reflexive articulation and learning might ensue. Such learning is not guaranteed, of course, but it is worthwhile to pursue it.

Thus, socio-technical scenarios are important for the reflexive change aim of Constructive Technology Assessment: to broaden technological development by including more aspects and more actors, and at an early stage, so as to (hopefully) realize better technology in a better society (Schot and Rip 1997). Depending on the technology, the sector and the existing embedment in society, this will take different forms.[1] It is a soft intervention, attempting to modulate ongoing socio-technological developments, at least by making them more reflexive.

In Constructive TA, socio-technical scenarios are not just creative exercises showing possible futures (which is one function of scenarios). They embody and further articulate emerging patterns in interactions, up to paths that actors tend to follow. The combination of understanding of dynamics ("theory"), and actual construction of socio-technical scenarios and their use, structures this chapter.

We start with discussing the general phenomenon of emerging irreversibilities in ongoing socio-technical developments, and how these constrain further thinking and action. In other words, futures are embedded in the present, and scenarios can be built drawing on such embedded or "endogenous" futures. The aim of Constructive TA to broaden technological development beyond what technology actors are doing already can be pursued in two ways. First, and following the concentric perspective of technology "enactors" we develop scenarios starting from a technological option or promising technological field, and broadening out concentrically. Second, we take a more distantiated perspective, where technological options are just one element in a larger, multi-level dynamic. We offer examples of both types of scenarios, the former applied to lab-in-a-cell analysis, the latter to nanotechnology in food packaging. In the concluding section we reflect on how far we have come.

Emerging Irreversibilities and Modulation of Socio-technical Developments

Emerging Irreversibilities and Endogenous Futures

While new (emerging) science and technology introduce novelties, and thus potentially breaking up existing orders to some extent, subsequent developments create new patterns, up to dominant designs and industry standards. In other words, irreversibilities emerge, which will be reinforced when actors invest in the paths that appear to emerge. "Emerging irreversibilities facilitate specific technological paths—make it easier to act and interact—and constrain others—make it more difficult to do something else" (Van Merkerk and Robinson 2006).

Emerging irreversibilities are a general feature of social life, and the sociological concept of "institutionalization" captures a large part of what happens. When technology is involved, irreversibilities are further solidified in configurations that work (Rip and Kemp 1998). The concept of 'configuration that works' applies to artefacts and systems, and includes (in principle) social linkages and alignments as well. A dominant design or industry standard would be an example, where the actual dominance, and thus the "working" of the design, depends on the adherence of relevant actors to it.

Paths and other stable patterns enabling and constraining actions and views will shape further development. Thus, they span up an "endogenous future": further developments are predicated on the pattern of the present situation. Not in a deterministic way: there are always choices and contingencies. Also, and important for the approach of Constructive TA, actors can use an understanding of these dynamics to act more productively, and in any case more reflexively.

The phenomenon as such of emerging and stabilizing socio-technical paths is now widely recognized. Actors anticipate them, up to attempts to create the "better" path, for example, in the struggle about an industry standard or a dominant design. The battle over consumer videorecording in the 1970s and 1980s is an example (Cusumano et al. 1997; Deuten 2003), and is remembered and referred to, for example, in the ongoing battle over advanced DVD standards.

The idea, and the practice, of roadmapping build on the recognition of emerging paths and the conviction that one can create such paths intentionally by coordinating actions. In micro-electronics there is a long history starting with SemaTech in the USA, and roadmapping is now globally coordinated by the International Semiconductor Technology Roadmap consortium. This is an example of a (strong) shaping of a path—as long as the strategic games based on mutual dependencies in the sector continue to be adhered to.

The idea of endogenous futures predicated on existing and emerging irreversibilities is also the starting point for our scenario exercises. Such scenarios reconstruct ongoing and future paths, their rise and fall, and how they become a reference for actors' strategies. Compared with roadmapping exercises, they are open ended: there is no future socio-technological functionality and performance that must be realized and thus become the starting point to identify challenges.

Modulation of Concentric Perspectives of Enactors

To address the aim of Constructive TA, to modulate and broaden technological innovation, it is necessary to understand our primary "target group," i.e., those actors directly or indirectly involved in developing new technology. The first step is to recognize that "enactors" will work within a concentric perspective. For example, in the case of the development of new products, product managers often view the environment as concentric layers around the new product, starting with the business environment and ending with the wider society. Eventually, alignments with all layers need to be made, but the product manager often deals with them sequentially, starting first with clarifying functional aspects of the product, before addressing broader aspects (Deuten et al. 1997). The term "enactor" is adapted from Garud and Ahlstrom (1997). Their analysis can be developed to create a theory of actors and interaction dynamics around new and emerging technologies.

Enactors, i.e. technology developers and promoters, who try to realize (enact) new technology, construct scenarios of progress and identify obstacles to be overcome. They thus work and think in "enactment cycles" which emphasize positive aspects. This includes a tendency to disqualify opposition as irrational or misguided, or following their own agendas. "How otherwise can one explain that progress is opposed?"[2] Enactors will get irritated, because for them, explaining the promise of their technological option should be enough to convince consumers/citizens. For nanotechnology, enactors now also anticipate obstacles similar to the ones that occurred for GMO (Genetically Modified Organisms) in agriculture and food; compare Colvin (2003). But the structure of the situation remains the same, that of an enactment cycle.

While enactors identify with a technological option and products-to-be-developed, and see the world as waiting to receive this product—"the world" may well see alternatives and take a position of comparing and selecting. Thus, the other main position to be distinguished is the one of comparative selectors (not necessarily critics). There are professional comparative selectors (regulatory agencies like the US Food and Drug Administration) which use indicators, and develop calculations to compare the option with alternatives (e.g., versions of cost-benefit analysis). There are also citizens—consumers, etc., as amateur comparative selectors—which can range more freely because they are not tied to certain methods and to accountability. Spokespersons for consumers, citizens react and oppose (rather than just select); some NGOs become enactors for an alternative (as when Greenpeace Germany pushed for a better fridge—Greenfreeze).[3]

Enactors can, and sometimes must, interact with comparative selectors. Formally as with the US Food and Drug Administration, or informally as in marketing and in the recent interest in interactions between strategic management of firms and spokespersons for environment and civil society. And in a "domesticated" version in test-labs like Philips Home-Lab (Philips Research – Technologies) and the RFID (Radio-Frequency Identification Device) -filled shop (RFID Journal 2003) in which people are invited to try out the new products, services, and infrastructure.

The further step is to recognize that enactment cycles and comparative-selection cycles interfere anyway, and to identify (possible) interference locations and events *and what can happen there*. Garud and Ahlstrom (1997) speak of “bridging events” and identify some examples and their limitations. Bridging events may not only include “events,” but also *structural* interaction. Cowan (1987)’s analysis in terms of a consumption junction is one example.

For the soft intervention approach of Constructive TA, an important modality is to support and orchestrate bridging events. This is creating and orchestrating spaces where interactions occur, even if the interactions between citizens/consumers and technology developers and promoters will always be partial (because of their difference in perspective). There will be “probing of each other’s realities” (as Garud and Ahlstrom (1997) called it), with more or less contestation. In interactive workshops, this can be supported by socio-technical scenarios which show effects of (interfering) enactment and selection cycles, and give more substance to the interactions.

Concentric Scenarios and Interactive Workshops[4]

In the case of nanotechnologies, socio-technical scenarios are necessary to address their doubly fictional character, and they are important to support the interaction between enactors and selectors. In this section, we will focus on one bridging event, a strategy articulation workshop organized by Douglas K. R. Robinson (as part of his ongoing PhD research) for the European-Union Network of Excellence Frontiers, held in June 2006 in Amsterdam, the Netherlands. It was the first of a series of such workshops for Frontiers, looking at different areas including drug delivery and molecular machines. The June 2006 workshop focused on single-cell (on a chip) analysis.

Preparations for the Strategy Workshop: Mapping Ongoing Dynamics

In CTA terms, these workshops are insertions in the ongoing dynamics of the Network of Excellence, and thus also in the development of the area(s) focused on. Substantial interaction between actors in interactive scenario workshops has challenges of its own. The organizers of the workshop need to reach the actors, in particular the nanotechnology actors and those allied with them. Firstly, to get them to participate at all—so there must be something at stake for the prospective participants. Secondly, by linking up with their worlds – without completely instrumentalizing CTA. This also implies that we have to accept some of the limitations prevalent in the nano-world, in particular the concentric perspective.

To map the dynamics of development in single-cell (on a chip) analysis, we focused on existing and emerging technology platforms, and tools that might become integrated in such platforms.[5] Public R&D labs and firms can use integrated platforms to develop technological options and new devices and products. In the case of single-cell (on a chip) analysis, there are two broad areas of relevance: tools for analyzing dynamics of living cells and integrated microfluidic systems as MicroTAS or Lab-on-a-chip.

One challenge would be the development of an integrated cell-on-a-chip platform. This was recognized by enactors and motivated them to participate in the workshop. Robinson (and his co-organizers Tilo Propp and Arie Rip), in their research on these areas, had identified a number of possible innovation chains relevant to this challenge, as well as the present gaps in them. These were located on a multi-path map (see Fig. 4.1), with the innovation chain from R&D to tools and laboratory technological platforms, to integrated platforms, working devices and products and applications) as the vertical axis, and time as horizontal axis.

The multi-path maps served as support for the two aims of the workshop, first, to articulate challenges involved in designing a particular technology platform and the commercialization/application aspects of such a platform; and second, to articulate approaches and ways to deal with the identified challenges. In addition, socio-technical scenarios were created to show how actual developments could become entangled (making things easier or more difficult) and lead to one or another overall path.

Scenarios of Future Developments

Three scenarios were written up in advance of the workshop by the organizers and distributed to the participants in a pre-workshop report. During the workshop these

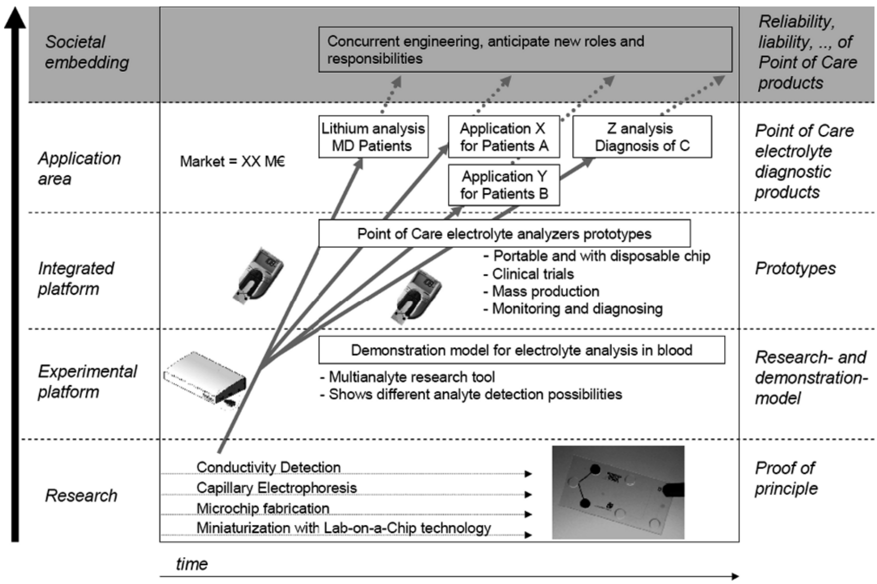

Fig. 4.1 Multi-path map of Point of Care electrolyte analyser

scenarios were mainly used to identify elements of dynamics to be taken into account in strategy articulation, for example, different design paradigms and polarization of visions. A key point was the limited malleability of the cell-on-a-chip field (and thus the difficulty for any particular enactor to make a difference). This, of course, was not new to the participants, but the scenarios articulate this "degree of difficultness" via sketching ongoing processes and (emerging) irreversibilities.

Scenario 1: Shifts and Lock-in into One Type of Application

[This scenario foregrounds dynamics such as the polarization of visions of different applications and subsequent lock-in of one of these visions, constraining the further development of the other vision.] Earlier research aimed at the development of a chip that can be used for analysis of cells, with application to point-of-care diagnostics, slows down because the promises are not achieved in the short term and support is withheld. Instead, new research lines are opened when pharmaceutical companies start to invest in this technology platform for drug screening applications, using arrays of cells that act as biosensors. A key factor stimulating pharmaceutical firms to invest in this type of technology are increased safety requirements on drugs and a general (political) trend to move away from animal testing. After a time, sunk investments in this new area of applications make it difficult to pursue the initial vision of single cell analysis (for point-of-care diagnostics or any other use). Although, as the scenario explains, "breaking out of this dominant path is possible, and is demonstrated by a number of small dedicated devices, but mobilising resources for a dedicated single cell analysis platform becomes too high a challenge" (Robinson 2006, 13).

Scenario 2: Precarious Links to Cell Biology Tests

[This scenario focuses instead on the dynamics of specific design paradigms and their impact on technological paths.] The promise of a cell analysis platform to enable the "measurement" of living cells in real time serves as a bridging opportunity between cell-on-a-chip research and cell biologists. Two different approaches towards the development of such a chip emerge. One approach emphasizes the development of a generic platform for cell-on-a-chip and a modular design. This approach turns out to work well for research but less for the commercialisation of a chip. A number of actors link up to establish a start up company named CellTron, linked to existing facilities and attempting to coordinate them, to develop lab-in-a-cell into a product family (large firms are not prepared to invest; they need a clear prospect of profitable applications). It explores various possibilities but finds it difficult to push particular applications when they emerge, and can survive only by further speculative investments.

The other approach is to focus on an application-specific platform. Spin-offs from universities and public labs try out possibilities, and some survive. A portable DNA testing device based on lab-in-a-cell is successful. Although profitable applications remain limited, it acts as a stimulus for other application-based research projects and start-ups exploiting them.

Scenario 3: Obliged to Remain in a Niche

[This scenario foregrounds the effect of overall promise and disappointment trends in nanotechnology.] In the research world, there is clear interest in improved understanding of sub-cellular mechanisms via cell-on-a-chip technology. But this is not enough to carry on, now that the general high expectations around nanotechnology are deflated. To survive and grow, cell-on-a-chip technology must link up with concrete promises (for example, drug delivery) and thus shift from the development of a platform for general research to applications. However, potential applications are difficult to identify. Since the relevance for general research remains clear, the field survives, but as a niche development. There is some support of funding agencies because of the articulated fundamental interests, and there are incidental applications developed by start-ups.

Use of Scenarios in the Strategy Workshop

The preparation of the scenarios was built on in-depth research, including knowledge of the technical field, of actor arrangements and entanglements. This is not only necessary to ensure accuracy and quality of scenarios (i.e. plausibility, not probability) but also to legitimate workshop organisers, when they intervene in the workshop process. This is important because intervention turns out to be necessary to move away from discussions about technical particulars and instead, focus on contestation and mutual articulation ("probing each other's worlds") related to the core questions.

Participants in the workshop recognized the dynamics embedded in the scenarios and saw the scenarios as "useful fictions," which could aid in strategy articulation. In retrospect, this can be seen as related to the concentric perspective, with the (enacted) technologies at the centre, which characterized the scenarios. Additional layers of complexity may be introduced. In the June 2006 workshop, the possibility to do so was explored, together with the participants, with the help of the "multi-path mapping" tool, by adding layers of societal embedding to the pre-circulated version (experimental platform, integrated platform, products, and application areas). This was continued after the workshop, because a spin-off company applied this tool to its own situation.

The concentric perspective is visible in the layered structure and direction of the arrows in Fig. 4.1. For the broader aims of Constructive TA, there is an uneasy trade-off between CTA agents accommodating to existing enactors' perspectives (so as to keep the enactors involved) and introducing incentives to broaden their perspectives (so as to induce some change). One way to do so is to include outsiders in the strategy articulation workshops. Once this is done, the concentric perspective itself is shown up as insufficient: there are other dynamics at play (e.g., regulation and societal debate), which have to be taken into account—by prudent enactors, who want to be successful, and by analysts (CTA agents) who want to understand the overall picture.

Evolving Multi-level Alignments as the Basis of Scenarios

An overall picture has to transcend the enactor perspective. Whatever interests and strategies the different actors may have, the key phenomenon is the introduction of novelty in an existing socio-technical order. This requires de-alignment of existing linkages and competencies and subsequent re-alignment (Abernathy and Clark 1985). In this way, a new socio-technical path may emerge. In the literature, technological interrelatedness, economies of scale, and sunk investments have been quoted to explain path dependency (cf. David 1985). What we want to add is multi-level dynamics.

Socio-technical paths become "doable,"[6] when there is alignment between three levels:

- Of ongoing work (and the practices this is embedded in), also across locations;
- Of the relevant institutions and networks that are directly involved, but also "third parties" who can provide or withhold credibility and legitimation (for example insurance companies, NGOs, and critical or activist groups);
- And of overall institutions, arrangements and authorities in our society (like patent law and patenting practices, but also issues of public/private collaboration).

There may be actors, like promise champions and institutional entrepreneurs, who attempt to align what happens at the different levels. Even so, eventual alignment will be an unintended outcome of interactions, rather than the direct result of dedicated alignment activities of one or a few actors. Alignment can also emerge because actors and activities accommodate to the same environmental constraints.

Basically, alignment refers to the eventual entanglement of actors and activities in such a way that they cannot move completely independently and there is some mutual accommodation, like parts fitting together, creating a configuration that works, cf. Rip and Kemp (1998). Alignment across levels is particularly important because it introduces vicarious stabilization: if actors or circumstances appear to move in other directions and might actually be able to do so on their own level, they will be constrained by the links to another level with its own dynamics, which makes it more difficult for them to effect change at the other level.

Based on these general considerations, we identify two entrance points for change (which we can observe and might want to stimulate). First, the role of actors who can work at two (or more) levels—linking-pin entrepreneurs. Second, spaces for interaction where actors can mutually position their activities and strategies in relation to possible and emerging paths. In general, alignment and the dynamics of stabilization and (attempts at) change can be mapped, and then form the basis to develop socio-technical scenarios; for example, in terms of strength of constraints and nature of emerging spaces for interaction.

In our recent work, we have added industry structure—or better: industry structure+—as an important pattern and an intermediary variable shaping paths and other outcomes. Industry structure+ broadens the traditional notion of industry structure where size and other "demographical" features of the distribution of firms in an industry, and the patterns of their relationships, are studied in industrial economics. First, it includes other actors than firms in a sector, for example NGOs. Second, it includes other instances and patterns that shape strategy and action of firms, for example, expectations as prospective structures (Van Lente & Rip, 1998). Concrete examples would be attempts at anticipatory coordination (as usual in the semi-conductor industry), endogenization of regulation via for example voluntary reporting or codes of conduct, and entrance and involvements of new actors such as regional authorities, NGOs and insurance companies.

For our analysis, as well as when building scenarios, we will use three levels, labelled as "micro," "meso," and "macro." This is a reduction of complexity, and the labels can be misinterpreted because of their common use and connotation. We use them as shorthand for the three levels specified when we discuss alignment, and characterize these levels in terms of activities and interactions, rather than scope. For example, when (central) government is labelled "macro," it refers to the nature of activities and to how government can be invoked as authority. Ongoing work in departments, and interactions of government actors would be counted as "micro."

With respect to (nano-)science one can distinguish between the level of: (micro) research activities, ongoing actions and interactions in labs; (meso) resource mobilization, acquisition and allocation of resources; (macro) discourse on and governance of socio-technical aspects of nanotechnology research, big debates on responsible innovation. Academic entrepreneurs are, often in their function as a group leader or director, responsible for the acquisition and allocation of resources for research, but also for the output of their group or institute. Typically, they act and move on all of the three levels of science.

The micro level can be considered as a protected space, relatively isolated from outside demands and concerns. As a general rule, scientists are not held accountable for pro-actively addressing societal concerns and demands such as responsible innovation and actively pursuing the uptake of their results in, for example, business enterprises. This rule would construct an argument for the continuation of the suggested gap. However, expectation pressures from governmental agencies and companies might result in either repairing or deepening the gap.

Multi-level Analysis of Socio-technical Developments of Nanoparticles

To give an example of multi-level analysis, we offer a sketch of the co-evolution of work on nanoparticles and concerns about their health, environment and safety aspects (Van Amerom and Rip 2007).

Multi-level dynamics are visible in the coupled evolution of nanoparticles (research, production, and use) and risks of nanotechnology. The repeated occurrences and acceptance of acronyms such as ELSA (Ethical, Legal, Social Aspects) and HES (Health, Environmental, Safety) in discourse on, and governance of, nanotechnology research and in the mobilization of resources, indicates emerging alignment between societal concerns and allocation of resources.[7]

Actors such as governmental agencies, industry and (academic) researchers are increasingly held accountable for addressing societal concerns—a new emerging rule within this multi-level process. Over time, the rules of the game might change into: you should not only (promise to) take HES and ELSA into account, but also incorporate them into your research and thus live up to your promises. Whether this will happen is another question, and one which might be pursued through the creation of scenarios of possible futures.

The implication of this brief analysis is that socio-technical paths, specifically of nano-particle R&D and product development, will occur in a world in which HES considerations have become forceful, and thus have to be taken into account (a further element of alignment). The force of HES (up to the use of just the acronym) is itself the outcome of what one could call an emerging and stabilized path, now at the meso/macro levels.

This was not always the case. When the issue of health and environmental risks of nanoparticles was raised, and further highlighted by the ETC Group (2003), the immediate response was negation (in all senses of the word), and fury about the ETC proposal for a moratorium on nanoparticles. In a news feature article in *Nature*, it was noted that "the debate is clearly gathering pace," while "some researchers... feel that they don't need to join in the argument. 'They don't really see what the hoop-la is about.' " (Brumfiel 2003, 247).

Inputs from toxicologists and epidemiologists (and scientists like Colvin) introduced some moderation, but the gut reaction remained. It was not legitimate to seriously discuss such risks, because that would only enlarge a possible roadblock. By the time the Royal Society (and Royal Academy of Engineering) Report appeared in July 2004, with its message to be cautious with introduction of nanoparticles in the environment because of the knowledge gaps about health and environmental impacts, it had become more difficult to just claim that nanoparticles were no cause for concern. The balance shifted, irreversibly, with the appearance of re-insurer Swiss Re's report in April 2004. Discussing (and researching) risks of nanoparticles then became fully legitimate. One irony, played upon by the ETC Group and Swiss Re alike, was "size matters": if the small size is what gives nanoparticles their interesting properties, these same size-dependent properties can also create harm.

The immediate effects were double: more risk research is done, and regulatory agencies start moving (one question is whether existing regulation can be used to address the issues of nanotechnology). That creates a focus, almost a lock-in, on HES issues, and backgrounding of broader questions about the actual use of nanotubes, and nanoparticles in general. This narrow focus is now coming in for criticism.

In parallel, firms started to have second thoughts about flagging nano for their products. If something untoward would happen under the label nanotechnology, that might then also reflect on their products, even if there was no cause for concern. Some firms stepped out of the nanotube business altogether, others proceeded,

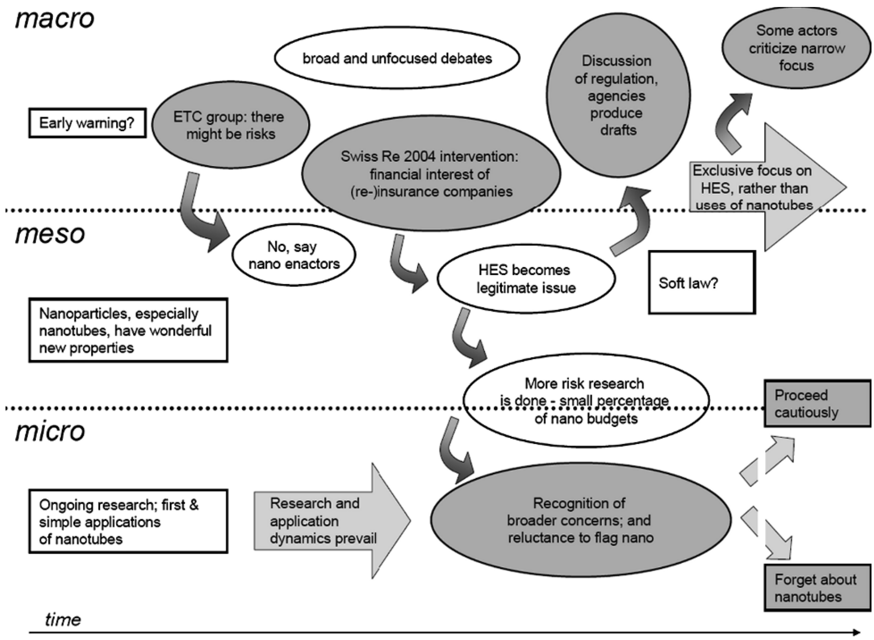

Fig. 4.2 Multi-level dynamics of socio-technical developments of nanoparticles

but more prudently. In the UK, this has led to a de facto alliance between firms and the regulatory agency DEFRA (Department for Environment, Food and Rural Affairs), where DEFRA is experimenting with voluntary reporting ("soft law"). In other countries, regulatory authorities are still considering what to do, or, as in the USA, need to show that they do something because of criticisms levelled at them. The multi-level dynamics are visualised in Fig. 4.2.

The right hand side of the diagram can be extended into the future by creating scenarios based on what becomes the dominant direction for each of the forks that are visible.

Multi-Level Dynamics in a Sector: The Case of Nanotechnology and Food Packaging

The concentric (enactor) perspective can be circumvented, or at least reduced, through analyzing dynamics in sectors, foregrounding evolving activities and evolving actor relations related to (nano) science and technology in a sector, instead of a particular emerging technological path. Here we will focus on the food sector, and within that sector, on food packaging. To prepare multi-level scenarios, context and background analysis are important. Therefore, we will introduce nanotechnologies in the food packaging sector, after which we sketch three scenarios as a preparation for a Constructive Technology Assessment workshop.

Development of Nanotechnologies for Food Packaging Applications

Expectations are that the food sector will see a major rise in nanotechnology enabled products, but the magnitude of this development is contested. Market estimates range from 20.4 billion US dollars in 2010 (market study in 2004) to 5.8 billion US dollars in 2012 (market study in 2006).[8] Concerns of consumer acceptance are voiced, as well as possible environmental and health risks associated with the application of nanotechnologies for food, which may act as a barrier for large scale commercialization, cf. Kuzma and Verhage (2006). As a journalist attending a nanotechnology and food conference in 2006 noted: "The food industry is hooked on nano-tech's promises, but it is also very nervous" (Renton 2006).

Food packaging is expected to be one of the first areas in the food sector to witness the application of nanotechnologies. Novel nanomaterials are expected to contribute to improve the shelf life of food products, which is a key function of food packaging. For example via the development of better oxygen barriers, active antimicrobial surfaces, and sensors integrated in packaging which can detect microbiological and biochemical changes (ElAmin 2005).

At first glance, embedment of nano-enabled food packaging seems relatively straightforward compared to the application of nanotechnologies in food such as, for example, nutraceuticals. Still further downstream more controversial issues might appear such as the transfer of food safety responsibility from actors to packaging sensors, or divides between rich and poor related to purchases of high quality food, cf. ETC (2004). In addition to the challenge of anticipating possible issues further downstream—aligning discussions on risks and benefits of nanotechnologies with research and product development activities—nanotechnology enactors face the challenge of mobilizing and co-ordinating activities of multiple actors in the food packaging sector.

The food packaging sector can be understood as an intersection of the food and packaging chain, including suppliers of raw materials, suppliers of packaging materials (convertors), food companies, and retailers. In addition to firms and knowledge institutes, also NGOs and regulatory agencies play an important role through, for example, articulation of concerns and regulations of health and environmental aspects of packaging, cf. Sonneveld (2000), Prisma & Partners and MinacNed (2006).

Worldwide, the food packaging industry structure+ has evolved with respect to the exploration and exploitation of nanotechnologies. New alliances to develop nano-enabled food packaging technologies have emerged in the US, UK, and Nordic Countries (Wolfe 2005; Joseph and Morrison 2006; ElAmin 2007) and a few packaging technologies that make use of nanotechnologies have already appeared on the market (Joseph and Morrison 2006). Food safety authorities in the US, UK, and Europe are currently examining nanotechnologies and their regulation.

Within Europe, the international research program SUSTAINPACK stands out both in size and ambition. SUSTAINPACK aims to develop nano-enabled fibre-based packaging as the future industry standard for packaging purposes, building on expectations of nanotechnologies and debates on sustainable packaging materials. Such a program is a space for interaction, and playing ground for exploring nanotechnologies in food packaging. Another example of a new space (plus some linking-pin entrepreneurial activity) is the Dutch quasi-branch organisation MinacNed. MinacNed is an association of companies and research institutes active in micro or nanotechnology and aims to strengthen economic activities in this area. As one of its activities, it initiated the development of a roadmap of applications for food (including packaging).

Alliances to exploit the potential of nanotechnologies exist, but are still very much emerging according to specialized consultancies such as Pira International (Moore 2006). Enactors, voicing expectations of nano-enabled packaging technologies reducing (associated costs of) food wastage due to improved shelf life, or the development and adoption of more sustainable packaging materials, face scepticism related to embedment of these technologies. For example, nano packaging is expected to be linked with a high price tag and therefore met with reluctance by firms and consumers. Uncertainties about future regulation and return on investments, coordination challenges across the chain, and fears of negative consumer perceptions may act as further entry barriers, cf. the MinacNed roadmap (Prisma & Partners and MinacNed 2006, 18).

Taking into account the described developments in nano-enabled food packaging, what could be future developments in terms of alignments between actors and activities?

Scenarios of Future Developments

This brief mapping of the situation can be detailed further, but it is sufficient to characterize the present situation and its multi-actor, multi-level dynamics, and to develop three scenarios differing in how alignment emerges between levels. The time horizon of the scenarios is the coming five to ten years.

At the moment, research in the application of nanotechnologies, such as the development of nanocomposites to improve paper-based packaging materials, occurs in a few relatively isolated places such as universities and incumbent firms. Although interactions between other companies and research institutes occur and new networks are expected to develop, they are not very substantial yet. Firms supplying packages take into account the strong requirement of low costs of materials from their customers, the fillers, with the retailers in the background, and do not consider using materials exceeding a certain price per kilogram material. Due to sunk costs, convertors may not easily change production technology, and will consider the extent to which it is possible to adapt existing machinery to the use of new materials. Until uncertainties about benefits, risks, and regulatory issues of new materials and components are reduced, companies are hesitant to allocate resources to R&D developments. With exception of incumbent firms and research institutes, virtually no other actors in the packaging sector are yet active in the exploitation of nanotechnologies for packaging. Figure 4.3 visualizes our mapping, and uses the characterization of the starting situation we just gave to outline three scenarios.

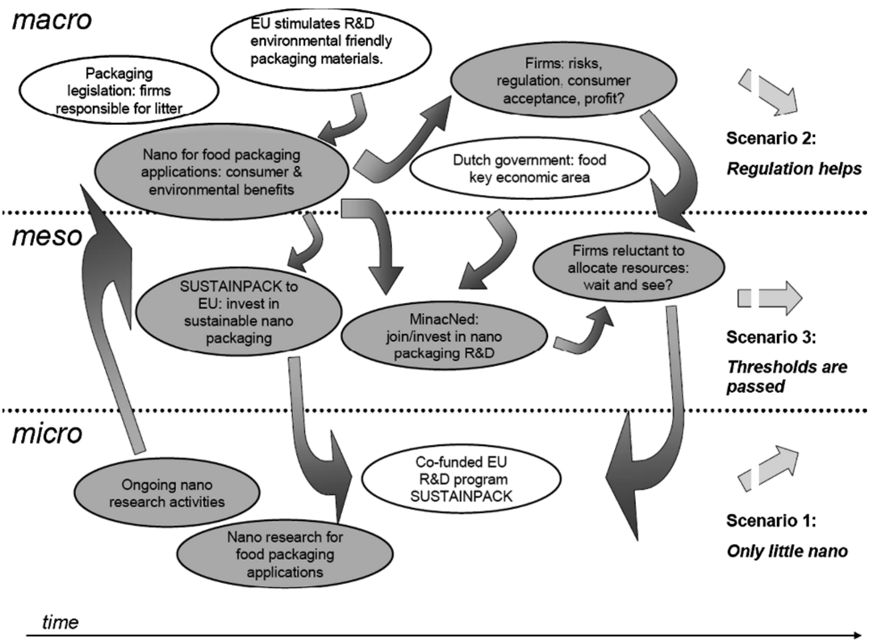

Fig. 4.3 Multi-level dynamics of socio-technical developments of nano food packaging

Scenario 1: Only Little Nano

Research institutes recognize this situation but are not pro-active in trying to change this as they diagnosed this situation as an impasse and not up to them to break through this impasse. They are focused on scientifically-interesting high tech solutions to packaging issues—with nanotechnology as its most recent hype. Research institutes start to pro-actively anticipate fashionable ideas on valorization of research, international economic competition, and the knowledge economy. More concretely, the acquisition of funding for research projects, reproducing the quest for the most advanced material solution to packaging problems such as barrier properties and mechanical strengths, will no longer be viable. Researchers in packaging start to co-operate with polymer scientists to analyze properties of materials known to improve barrier properties and ways to synthesize and integrate these in a relatively inexpensive way in existing foil making machinery. Rather than focusing on the realization of long term promises of nanotechnology, researchers increasingly orient themselves to short term pragmatic challenges of firms. Both big and small incumbents diagnose these research projects as promising and fit their interests, i.e. their considerations of costs and adaptability of machinery, and are willing to co-operate and invest. Support by funding and governmental agencies, taking into account the broader discourse on innovation, as well as the chance of success due to the involvement of companies, help to tip the balance in the formation of new collaborations. By focusing on short term valorization of knowledge by actors in the packaging sector, entry barriers for nanotechnology developments are de facto increased as there are fewer resources left for long term research into nanotechnologies. As a result, work on materialization of long term nanotechnology promises is fragmented. Big promises of nano-enabled food packaging move to the background along with discussions on broader socio-technical aspects of nano food packaging.

Scenario 2: Regulation Helps

With broader debates on environmental issues such as, for example, climate change in general, and HES of nanoparticles and packaging legislation in particular, discourse on nanotechnologies and packaging increasingly focuses on environmental aspects. Political parties such as, for example, the ChristenUnie in the Netherlands, advocate a precautionary approach, up to a moratorium. At the same time food regulators such as the Food and Consumer Product Safety Authority in the Netherlands press on with their activities and engage in various discussions with assessment experts, researchers, companies, but also NGOs and consumer organizations. Although discussion on risks, especially toxicology of nanotechnologies, are ongoing and no clear policies are developed, the sheer existence and visibility of these discussions cast a shadow on R&D developments and emerging alliances between actors to develop nanotechnologies for packaging. The emerging nano food packaging sector experiences a bifurcation. SMEs and start ups anticipate further controversies and regulatory barriers, and exit the field. These companies start to align themselves with other research activities and discourses that focus on biodegradable packaging materials that do not carry the perceived hazards of nanoparticles. They find strong allies in the form of retailers who follow the example of Wal-Mart who require the use of biodegradable packaging by their suppliers. Whereas the smaller and new firms exit the field, the incumbents welcome regulation and proceed cautiously with the development of nano food packaging products. They expect that regulation will shield them from protests from consumers and the added value of novel and improved functions of packaging materials will convince retailers. Discourse of nano in food packaging is focused on health, environment and safety risks and the development of nano packaging sets through, but cautiously.

Scenario 3: Thresholds are Passed

Nanotechnology research entrepreneurs recognize the entry barriers as they are perceived by some firms. Although additional funding for research is promised by governmental agencies, firms are still reluctant to participate because of their concerns about risks of nanoparticles and consumer perceptions. This poses a problem for research entrepreneurs because they consider the involvement of firms essential: both for ensuring additional funding and developing legitimacy for nanotechnology activities. Therefore they persuade critical consumer organizations as well as risk research institutes to participate in a research and development network through arguing that they can make a difference in future technologies. Subsequently, firms are willing to enter, anticipating that these new allies will legitimize new developments.

The research entrepreneurs are also successful in mobilizing additional funds from governmental agencies, and a broad platform for the development of nanotechnologies for food packaging is ready to take off. The food packaging industry structure+ further evolves when first research results are published. Promising results about improved barrier properties of paper and plastics-based materials encourage pharmaceutical companies to join the further development of nano packaging. Although new relationships between food and health had already been anticipated and discussed, they now materialize in the form of collaborations in the development of new packaging materials. Over time, several thresholds are passed in the development of nanotechnologies for food packaging applications, softening entry barriers, forging relationships, and substantial interactions between an increasingly heterogeneous assembly of actors. Although broader socio-technical considerations such as risks of nanoparticles and consumer acceptance are taken up, it is often of a prudent nature, to ensure the development and stabilization of the research network.

Use of Multi-level Scenarios

These scenarios can be used to explore further questions, for example whether and how ethical, legal, and social issues (ELSA) will be taken up at an early stage. This was one of the points raised in the multi-level mapping of the risk landscape around nanoparticles, where health, environmental, and safety risks are getting almost exclusive attention. In the food packaging scenarios, ELSA will not be necessary in the first scenario (there is no nano in food packaging), it will be reduced to immediate risk considerations in the second scenario (where regulation has reduced uncertainties), and might occur in the third scenario, especially because wider uses are becoming visible.

The scenarios have not been used yet in workshops or other interactive settings. There has to be something at stake for relevant actors before they are prepared to invest in participating in a workshop. At the moment, there is too little at stake, concretely, to organize a scenario workshop. If we want to insert ourselves in ongoing dynamics, we have to find another way.

Conclusions

We have shown how to create socio-technical scenarios that are of high quality because of detailed research into the technologies, sector, relevant actors, and the use of insights in technology dynamics and societal embedding, and of societal dynamics more generally. The scenarios are relevant to various actors, so they can be taken up as starting point for interactions ("probing each other's worlds"), which lead to more reflexivity about what can and should be done, and eventually to other strategies and actions. For the scenarios we have presented here, it is too early to trace such impacts (if that is possible at all).

We took up the doubly-fictional nature of nanotechnology character by locating the promises in contexts, tracing their dynamics, and more importantly, developing the fictions from claims of enactors and counter-claims of competing enactors or concerned and critical groups, into complete worlds—socio-technical scenarios—that can checked as to their plausibility and further evolution.

Scenarios about future development of nanotechnology in society are not just imagined futures: they are rooted in historical and contemporary developments. In other words, they build on the endogenous future shaped through present irreversibilities and alignments. This is very clear in the concentric scenarios focusing on present and emerging socio-technical paths. In the multi-level scenarios, the scope is broader, but one can still see strengthening of, and shifts in, alignments and further lock-ins leading to trajectories, for example, how risks of nanoparticles are handled.

The CTA approach was further specified in terms of enactors ("insiders") and comparative selectors ("outsiders") and their interactions. CTA workshops were positioned as intentional bridging events, and in fact, their design and organisation builds on diagnosis of ongoing dynamics in those terms.

We have seen that concentric socio-technical scenarios are appreciated by enactors. This derives from their own tendency to think in terms of scenarios (and opportunities and blockages). We expect that political and civil society actors in a comparative-selector position will appreciate the multi-level scenarios, because their role there is constitutive rather than contributory.

We have also argued that concentric scenarios need to be further contextualized, and include multi-level dynamics. If fully-fledged multi-level scenarios could be created, we would see how the present diagrams are actually selections, geared to the perspective of a particular kind of actor (in our diagrams, that of enactors). In other words, concentric scenarios are not just a ploy to accommodate enactors in order to broaden their views and actions—a necessary evil, as it were. Multi-level scenarios do not identify with a particular type of actor, but provide the backdrop to actor-specific scenarios. They are the scenarios related to CTA agents, who have no axes to grind other than promoting reflexivity (Schot and Rip 1997). They are broader, and in that sense better. But their broadness also makes them less relevant to actors, unless a translation and specification is made. Our suggestion that political and civil society actors would appreciate multi-level scenarios must therefore be modified: also for them, selection and specification are necessary.

The CTA approach combines analysis and action: from tracing dynamics and articulating them, to modulating co-evolution, at least making it more reflexive. Socio-technical scenarios are thus not just tools, supporting one or another type of actor in reflection and articulation of strategies. They are created (or co-created) by CTA agents as part of insertions in ongoing dynamics, unavoidably so. We referred to this occasionally when we discussed scenario workshops.

Further reflection on CTA as soft intervention is in order. If we are right in our diagnosis of endogenous futures, and use it to create socio-technical scenarios, we are actually creating a paradoxical situation, where we say to actors that they are part of a pattern and being shaped by it (cf. paths)—and then enjoin them to take action, perhaps changing the pattern. In each concrete case, actors may recognize how their choices and actions are being shaped (softly determined) by socio-technical factors and patterns, while at the same time they will act, and attempt to act better based on their understanding of such factors and patterns—up to undermining them.

This point about actors being part of a pattern that is reproduced, and then profiting from insight in the pattern to do something different occurs explicitly as soon as there are stabilized anticipations. The well-known Gartner Group hype-disappointment cycle (mainly applied to information and communication technologies) is a case in point.[9] Including its "paradoxical" use: there is an existing pattern (up to master curves), and The Gartner Group is willing to advise firm X about when and how to follow the cycle, or step out. Determinism and voluntarism in one: things *will* go this way, but if you understand it (and hire Gartner Group as consultant) you can escape from it by acting. Similarly, one could say: emerging irreversibilities and path dependencies will occur, but if you understand them, thanks to Constructive TA, you can escape them . . ..

Such paradoxes have to be kept in mind, but socio-technical scenarios and scenario workshops can do useful things. They contribute to reflexive co-evolution of science, technology, and society. This need not, by itself, lead to a better technology in a better society. But it will definitely make the co-evolutionary processes more reflexive and create openings for responsible innovation.

Notes

1. The notion of an "early stage" is relative: one might see electric vehicles as being at a late stage of technological development: starting in the late 19th century, surviving in niche applications, now getting new leases on life. But their actual embedding and broader uptake requires further socio-technical innovations, and is therefore in an early stage. This is how social experiments with electric vehicles have been studied (Hoogma 2000; Hoogma et al. 2002).
2. For an extreme example of this argument, see Bond (2005) who argues that it would be unethical to stop the development of nanotechnologies because of their potential to "enabling the blind to see and the deaf to hear."
3. Pressure to substitute fluorochlorocarbons as coolants were ineffective until Greenpeace Germany and an ailing refrigerator company in former East Germany got together and created a technical alternative, Greenfreeze, which shifted the balance of forces, at least in Europe (Verheul and Vergragt 1995). Van de Poel (1998, 2003) has shown more generally that it is important to have a technological alternative, a configuration that actually works, to effect regime change.
4. The authors acknowledge contributions from Douglas K.R. Robinson in drafting this section, and his willingness to let us use documents from and data on the workshop before his own writing-up of them.
5. The emergence of platforms is a general innovation dynamic, and of particular importance for nanotechnologies (Robinson et al. 2007).
6. Cf. Fujimura's (1987) analysis of doability. She shows how research becomes doable because of alignment (and the work of aligning) across levels: activities in the lab, the institute, the wider world, especially sponsors of research.
7. Whether the requirements for ELSA, as in the US National Nanotechnology Initiative, also lead to the integration of ELSA in research activities (in the technical sciences) is not clear. The few studies that have been carried out show that isolation from the outside world is still the main

goal—and functional for pursuing the research without interference. See for example the studies by Erik Fisher in Colorado, who has developed and experimented with the concept of midstream modulation (Fisher et al. 2006). So there is no three-level alignment (yet), an alignment which would create strong stabilization, almost a lock-in.

8. See: http://www.hkc22.com/Nanofood.html and http://www.cientifica.com/www/summarys/Nano4-FoodBrochure.pdf; accessed on 12-01-2007.
9. The hype-disappointment cycle is a folk-theory, because widely recognised, used to draw out implications, and not an object of systematic research. It is a relatively innocent folk theory, though, because actors can easily recognize its limitations and define their actions taking the limitations into account. See further Rip (2006).

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