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Technology Assessment as Part of the Co-Evolution of Nanotechnology and Society: the Thrust of the TA Program in NanoNed

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NanoNed is a consortium of Dutch research institutes working in nanoscience and nanotechnology (see Appendix 1 for an overview). It has obtained funding from two general R&D funding programmes (at the moment, there is no dedicated government funding of nanoscience and nanotechnology). On the initiative of the consortium leadership, a Technology Assessment (TA) component was included in the bids for funding. Arie Rip (University of Twente) was invited to lead the TA program. This paper indicates the thrust of the TA program, as it is now being implemented.

The original proposal of February 2003 (Appendix 2) focused on methodology, in particular Constructive Technology Assessment, and applications to domains of nanotechnology visible in within NanoNed. With first-round funding from Nano-Impulse, two PhD students have started working on Constructive TA of nanotechnology: (1) Expectations, agenda-building and CTA exercises using sociotechnical scenarios [Rutger van Merkerk, UU]. The theoretical question of “emerging irreversibilities” is combined with methodology development and actual CTA exercises. (2) Emerging alliances and networks between various actors [Douglas Robinson, UT]. The theoretical question of “emerging irreversibilities” is developed for the analysis of so-called nano-districts in Europe, and for sociotechnical scenarios to be used in CTA exercises.

There are other ongoing projects on nanotechnology with a policy and management focus, which overlap with the Constructive TA approach, for example: (3) Intermediary actors and activities in science & technology policy, in the case of nano-technology [Frank van der Most and Barend van der Meulen, UT, partly funded through the Innovation & Governance research programme of the University of Twente], (4) Governance of nanoscience and technology research centres and networks [Arie Rip, UT, and Philippe Larédo, Ecole des Ponts et Chaussées, partly funded through EU Networks of Excellence] and the emergence of “nanodistricts” [project coordinated by Vincent Mangematin, Grenoble].

While keeping the focus on Constructive Technology Assessment (CTA), in the second phase the proposal is deepened and broadened. This has become all the more important because of the sharp rise in interest in TA of nanotechnology over the last year. Coordination with what is done elsewhere is now also necessary, and this requires special effort. The order of magnitude of the budget is 1 million € over five years. The program is distributed over a number of Dutch universities. It is coordinated by Arie Rip (University of Twente), who also takes part in the meetings of the Flagship Captains of NanoNed. The two current PhD positions funded under the NanoImpulse Program will be integrated in the TA NanoNed program.

Intellectual framework of the program

The starting points of the original proposal were the importance of interaction with nanoscientists and technologists and with the development of nanotechnology (thus, CTA), and the need to develop approaches and methodologies that can address the doubly “fictional” character of TA of nanotechnology: many of the envisaged uses of nanotechnology are still science fiction, and the study of possible impacts is then social science fiction. Building blocks to address this challenge (CTA and controlled speculation with the help of sociotechnical scenarios) are in place.

What can be done now is to deepen and broaden the approach, using background studies in the sociology and economics (and political science) of technology development and its embedding in society, as well as experiences and experiments with new interactions between technology and society (e.g. responsible innovation, cf. below). Both can be discussed from the perspective of reflexive co-evolution of science, technology and society (see Appendix 3 for a brief presentation of the co-evolutionary perspective).

The intellectual framework uses three key phrases as entrance points: responsible innovation, governance of (new & emerging) science and technology, and ELSA (Ethical, Legal and Social Aspects). They will be discussed separately, for clarity and because they have their own intellectual and practical histories. But they are related, in any case because all three are instances of reflexive co-evolution.

responsible innovation

The phrase ‘responsible innovation’ refers to innovation activities in which social aspects, desirability and acceptability are taken into account. Innovation actors will be responsive and may be asked by societal actors to account for what they do. Such broader views of innovation have become more common (for example in the ‘Sustainable Care’ program of the chemical industry in the 1990s). While the phrase ‘responsible innovation’ occurred occasionally, it is now becoming more common, especially in nanotechnology. Examples are the USA Centre for Responsible Nanotechnology (with links to the Drexlerian “social world”), and the International Dialogue on Responsible Research and Development of Nanotechnology, recently started up by Mihael Roco (US National Nanotechnology Initiative). One reason could be the prospective element in the concept of responsibility, which suits the open-ended character of nanotechnology developments.

Other phrases are used as well, for example the idea of ‘license to develop’ (important when traditional regulation cannot cover all aspects of innovation). In biotechnology, the “fourth hurdle” (desirability of an innovation) is part of the discussion of acceptability. Corporate Social Responsibility now starts to include technology and innovation.

Responsible innovation is the responsibility of innovation actors, in interaction with various societal actors. They can be supported in their action and interaction through contributions from social scientists and humanities scholars, as well as by various mediators and facilitators. Constructive TA offers such support (it has been characterized as a Reflection and Articulation of Strategy Support System). “Real time” TA has been proposed by Sarewitz and Guston (now at Arizona State University). Further development of such approaches and methods is important, including ways of ‘public engagement’ as it is now called in the UK (see also the recent report of the Royal Society).

However, methods development should be embedded in understanding of innovation dynamics and the embedding of technology in society. One example of the necessary

background analysis is how Garud & Ahlstrom (1997) characterize different positions: enactors (insiders) vs. comparative selectors (outsiders) and their specific perspectives, and thus precarious interactions, as well as the possibility to improve on ‘bridging events’ and ‘nexusses’. Another example is the role of ‘third parties’ like insurance companies (see the recent report of Swiss Re on the risks of nanoparticles) and the strategic games, up to innovation races, that occur and shape thinking and action of innovation actors. These last considerations show that ‘responsible innovation’ is not just a matter of an innovation actor changing his (or her?) ways. Actors are part of larger patterns which drive (i.e. enable and constrain) them, in a sense govern them. The analysis of such patterns and articulation of such understanding with innovation actors is important to make actions more reflective, even if this may not be sufficient to change the patterns.

governance of (new & emerging) science and technology

In political science, as well as in the ideas and practices of government actors at all levels, the notion of ‘governance’ is increasingly important. It refers to the idea that governing is not a top-down activity, but carried by multi-actor (and often multi-level) arrangements. For example, so-called policy networks are not an instrument of government, but themselves doing governing, i.e. governance. The idea, and practice, of governance is particularly important for science and technology, where top-down steering can never be the last word. The additional challenge then comes from new & emerging science and technology, with their open-ended promises. At the level of the European Union, meetings and (small) funding programs address the issue of governance of science and technology. This also includes the role of old and new stakeholders, up to public engagement.

For the intellectual framework of the TA Program in NanoNed, an additional point is important: in the case of new and emerging science and technology, actors get involved and create patterns of interaction which enable and constrain further action. Thus, *de facto* governance arrangements. In Constructive TA, this is taken up in the mapping of expectations, alliances, and emerging networks so as to identify patterns shaping further development. The point can be taken further by inquiring into the functioning and value of such governance arrangements. One example is the overall diagnosis of Ulrich Beck, that our society is characterized by “organized irresponsibility”, and he uses aspects of science and technology in society to illustrate his diagnosis.

Reflexive co-evolution of science, technology and society (see Appendix 3) captures the general idea of governance as it emerges (thus, *de facto* governance) as well as shot through by attempts to do better, up to design of governance arrangements and interactions. A concrete application would be the phenomenon of hype-disappointment cycles which shape thinking and action of actors in different positions and at various levels, from scientists at the workbench to government officials articulating funding programs. How do such cycles work as governance arrangements, and can one do better? Quality control of promises (and expectations more generally) is one element, avoiding impasses derived from political and public disappointment after embracing new possibilities (cf. the concern of nanotechnologists how to not get in the same situation as GMO now) another.

ELSA (Ethical, Legal and Social Aspects)

In the early 1990s, the Human Genome Program (in the USA) included studies of ethical, legal and social issues in its funding. Such a component is now a regular feature of genomics funding programmes all over the world, so much so that ELSI and ELSA have become acronyms which need not be spelled out. Nanotechnology programmes now also include

ELSA, sometimes on the initiative of the nanotechnologists themselves (and with money they could also have used to do nanotechnology). In the USA, the new law on the funding of nanotechnology specifies a range of ELSA studies and activities.¹ With the widespread occurrence of ELSA, the interest in economic and environmental aspects in addition to ethical, legal and social aspects is formulated as an addition to ELSA, and new acronyms are proposed like E³LSA.

As a phenomenon which occurs, the institutionalisation of ELSA is an example of an emerging governance arrangement for science and technology in society. At the same time, the actual studies and their results can support 'responsible innovation'. ELSA differs from impact studies in the traditional sense (e.g. environmental impact studies) because there is little or no impact yet that can be measured or estimated systematically. One lesson from the more sophisticated impact studies can be taken up, however: impacts are always co-produced, that is, result from a variety of actions and interactions, not just the force of the new scientific/technological option.

The three entrance points can be articulated further, theoretically (there is a lot of relevant literature) and practically (there are experiences and practices, and attempts at design and development). This can be an explicit further task of the TA Program.

A range of themes and projects

There are different ways of lumping & splitting themes and approaches so as to formulate possible projects for the TA Program in NanoNed. For example, relevant theories and concepts (from technology dynamics, governance theory, co-evolutionary theory) could be the focus of a PhD project, with nanotechnology as a research site. But they could also be used as an input to develop and improve methods for Constructive TA and other support for responsible innovation and reflexive co-evolution. And they could inform studies of specific issues, ranging from public-private interactions and the emergence of nano-districts to articulation of images and views of nanotechnology with a variety of actors.

The choice of areas within nanotechnology (that is, whatever falls under the umbrella term 'nanotechnology') can be made in terms of what is interesting for the research question in a particular project, but also the other way around: which area is interesting as such, either because it is important within NanoNed, or because it is drawing attention externally (the latter would be a reason to consider molecular manufacturing).

¹ *21st Century Nanotechnology R&D Act of 2003* (108th US Congress, First Session, S.189)

11 Program Activities of the National Nanotechnology Program.

#10: 'ensuring that ethical, legal, environmental, and other appropriate societal concerns, including the potential use of nanotechnology in enhancing human intelligence and in developing artificial intelligence which exceeds human capacity, are considered during the development of nanotechnology by –

(A) establishing a research program to identify ethical, legal, environmental and other appropriate societal concerns related to nanotechnology, and ensuring that the results of such research are widely disseminated;

(B) requiring that interdisciplinary nanotechnology research centers established under paragraph 4 include activities that address societal, ethical and environmental concerns;

(C) insofar as possible, integrating research on societal, ethical, and environmental concerns with nanotechnology research and development, and ensuring that advances in nanotechnology bring about improvements in quality of life for all Americans; and

(D) providing (..) for public input and outreach to be integrated into the Program by the convening of regular and ongoing public discussions, through mechanisms such as citizens' panels, consensus conferences, and educational events, as appropriate;

Some projects have been defined in a preliminary way, also based on the interests of the participating groups in Twente, Utrecht, Delft and Groningen.

[5] Processes of path emergence and path obsolescence, and strategic choices in micro- and nano-electronics, linked to broadening of foresight and roadmapping tools

[6] Analysis of practices and promises at the micro-, meso- and macro-level (the lab, programs and the mobilisation of funds and other resources, overall promises and priority setting) and their alignment – including the gap between promises for external consumption and what is actually achieved in the lab and taken up in products. Cf. also hype-disappointment cycle.

[7] Nanotechnology and sustainability: the difficult interaction between societal goals, promises of new scientific and technological options, and ongoing practices, and the possible role of approaches and tools like anticipatory life cycle analysis.

[8] The distance between ethical (and more generally, normative) aspects and ongoing work, studied for cases in bionanotechnology. Implications for governance arrangements.

[9] Mapping ongoing articulation of images and views of nanotechnology across a variety of actors, and the role of utopias and nightmare scenarios in shaping views and attitudes.

In addition to the themes set out here, which can be taken up in PhD or other projects, a number of smaller activities are envisaged which are an integral part of the TA Program in NanoNed. First and foremost, the possibility for nanotechnologists themselves to spend some time doing a TA study, supported by the TA Program (intellectually, sometimes also financially). Second, there are cross-cutting and synthetic themes which can be taken up in workshops and the writing of essays, within NanoNed or more broadly. Third, there will be activities for and/or supported by EU Networks of Excellence and other international collaborative ventures.

The TA Program takes up issues of general strategic discussion and public engagement and public debate, but does not position them as central to the Program. Other bodies are active there and collaboration is envisaged. This is particularly the case for the Dutch Rathenau Institute, with which the TA Program coordinates and occasionally collaborates.² Expertise of SMO (Stichting Maatschappij en Onderneming) and other bodies including STB-TNO may be taken up in joint ventures. There are also strong links with EU Networks of Excellence in nanotechnology (Nano2Life, Frontiers) and in science, technology and innovation policy (PRIME: Policies for Research and Innovation in the Move towards the European Research Area, coordinated by Philippe Larédo).

In general, the identification and exploitation of synergies will be important. At the research side, there will be opportunities for synergy with the Graduate Research School WTMC (*Wetenschap, Technologie en Moderne Cultuur*, Science, Technology and Modern Culture), including participation of TA NanoNed PhD students in the training program of WTMC. Synergy might occur with the NWO thematic area EMA (Ethical and Societal Aspects of research and innovation) which is now articulating its program. Internationally, there are many (and increasing) interactions with social scientists and humanities scholars interested in TA and social and ethical aspects of nanotechnology.

² One example is the booklet *Om het kleine te waarderen* (2004), on TA and societal discussion of nanotechnology, written by Rinie van Est, Ineke Malsch, and Arie Rip.

Appendix 1: Profile of the Dutch consortium NanoNed

Nanoned

Profile

NanoNed is eight leading Dutch R&D institutes that have formed a consortium to coordinate their activities and combine their strengths. Through this cooperation they achieve continuation and strengthening of excellence through a strong cooperation with industry and the European Union. The partners of NanoNed are:



- MESA+, University of Twente, Prof. David Reinhoudt
- DIMES, University of Delft, Prof. Hans Mooij
- BioMade/MSM+. University of Groningen, Prof. George Robillard
- TPD, Institute for Applied Science TNO, dr. Dick Schmidt
- University of Wageningen, Prof. Ernst Sudhölter
- Photonics Group, University of Amsterdam, Prof. Rob Zsom
- NSR/RIM, University of Nijmegen, Prof. Theo Rasing
- CNM, University of Eindhoven, Prof. Huub Saleminck
- Philips Electronics, Eindhoven

Chairman is Prof. David N. Reinhoudt. Industrial partners include DSM, Unilever, ASML, ASMI and Avantium.

The €275 million NanoNed national R&D initiative focuses on 11 Flagship programs, based on national strengths and economic relevance. Each Flagship is a vehicle for national cooperation between different partners including industry, and is lead by an independent scientific leader. The Flagships are:

- Advanced Nanoprobng (*Maan, Nijmegen*)
- Bottum-up Nano Electronics (*Hadley, Delft*)
- Chemistry and Physics of Individual Molecules (*Feringa, Groningen*)
- BioNanoSystems (*Meijberg, Groningen*)
- NanoElectronic Materials (*Blank, Twente*)
- *NanoFabrication (Huskens, Twente)*
- *NanoFluidics (van den Berg, Twente)*
- *NanoInstrumentation (Bastein, TNO)*
- *NanoPhotonics (Polman, Amsterdam)*
- *NanoSpintronics (Koopmans, Eindhoven)*
- Quantum Computation (*Grifoni, Delft*)

Together, this consortium effectively demonstrates Dutch strength and expertise in nanotechnology. All partners are devoted to developing a strong cooperation on the subject of nanotechnology in its various application areas, not only during the duration of this project, but also after its execution.

On January 1, 2003, the first phase of this proposal started with the Flagship programs shown above in italics. This first phase has an overall size of approximately €46 million.

As a part of this initiative, NanoNed initiated NanoLab NL, a national nanotechnology facility. NanoLab NL combines the existing facilities of Twente, Delft and Groningen, and carries out a targeted €110 million re-investment program in the coming 7 years, as part of the above-mentioned NanoNed initiative. The first €18 million phase of this program was begun on January 1, 2003.

NanoLab NL coordinates the use of the facilities, tariffs, investments and the cooperation with industry, with a special emphasis on Small and Medium-sized high-tech Enterprises.

The NanoNed partners

NanoNed will be executed by a consortium consisting of the main nanotechnology institutes of the Netherlands. Their individual role within the projects and infrastructure investments is defined through proven expertise, specialization and focus combined with strategic vision and ambition.

The consortium consists of:

- *BioMaDe/University of Groningen* - BioMaDe and the Materials Science Center (MSC+) of University of Groningen are specialized in working with "soft (bio)materials" on hard surfaces. This type of work demands a combination of equipment for molecular electronics and biological/organic analyses equipment.
- *Dimes/TU Delft* – The main strength of Dimes at the Technical University Delft (TU Delft) lies in fundamental research into nano electronics. They have a laboratory focused on realization and characterization of very small structures that is unique in the Netherlands. This expertise will be applied in such a way that they can operate on the absolute nano scale.
- *Mesa+/University of Twente* focuses on materials, technologies and systems of the information society. The institute has major, multidisciplinary programs, together forming two thirds of all the performed basic research at the university. Each program is oriented at the nanoscale as an enabling technology for progress. The institute has major infrastructural facilities dedicated to research programs.
- *Fotonica Group Amsterdam* – A cooperation in the Amsterdam region between the FOM-Institute for Atom- and Molecule Physics (AMOLF) and the Institute for Molecular Chemistry of the University of Amsterdam (UvA). AMOLF has strong expertise in the field of photonic nano-materials; IMC is specialized in organic bottom-up techniques. Recently AMOLF incorporated the Amsterdam nanoCenter, with the intention of developing new nano fabrication techniques.
- *NSR/RIM Institute, University of Nijmegen* – The NSR/RIM Institute is equipped for the “bottom-up“ approach of nanotechnology. There is a strong and efficient interaction between physics and chemistry in the field of manipulation of molecules. The institute has international renowned expertise in the organization of soft materials in external fields, scanning probe technology, supra molecular chemistry and NMR techniques.
- *TNO TPD* – To be able to realize nano devices and nano patterns on a production scale, current techniques must be adapted. This does not concern an improvement or refinement, but the use of truly different principles to reach stated goals. TNO TPD has a renowned

expertise center, in which it cooperates with the micro system industry. It uses this expertise to develop nanotechnology production techniques.

- *TU Eindhoven* – TU Eindhoven is strongly oriented on future technology, especially nano materials, design and devices related to the three research institutes (NRSC-C Catalysis, DPI Dutch Polymer Institute en Cobra/Photonics). These three research clusters combined their nanotechnology activities in 2001 in a center of Nano Materials (cNM), established as a common platform for research and education.
- *Wageningen University and Research Center* – has expertise in the field of agricultural basic material conversion, self-assembly, surfaces and the functioning of bio (macro) molecules. This knowledge and know how is a promising application area for nanotechnology. It will contribute to other possibilities for nanotechnology.

The NanoNed flagships

Within the NanoNed consortium, 11 large interdependent programs have been defined, based on national R&D strengths and industrial relevance. These so-called Flagships integrate top Dutch scientists in these fields with their respective groups into a truly national and multidisciplinary program. Each program is lead by an independent scientific leader, and has a size of, on average, 50 man-years of research capacity per year. Generic, technology-oriented, Flagships run together with more application-oriented programs, to create a nationwide and cohesive effort: NanoNed.

NanoFluidics

Scaling down the successful concept of microfluidics/Lab-on-a-Chip a few orders of magnitude towards the nanometer domain results in structural sizes close to the dimensions of large molecules. The aim of the Nanofluidics Flagship is to investigate, control and exploit new physico-chemical phenomena in structures with nanometer dimensions for use in high-throughput biomolecular characterization. Three main research areas can be distinguished:

- Nanofluidic physics and chemistry for biomolecular measurements
- (Bio)Chemical analysis using nanofluidic structures
- Technologies for nanofluidics: bottom-up and top-down

In the consortium, the aim is to combine the best knowledge in the areas of fluid-physics, biophysics, analytical- and single molecule chemistry with bottom-up and top-down nanofabrication.

It is expected that the expertise and knowledge generated in the Nanofluidics Flagship will find substantial applications in the related business areas of drugs discovery, screening, clinical diagnostics and new instrumentation, with an estimated world-wide turn-over of >10B\$/yr. A significant involvement of the Philips company underlines the strategic value of the Flagship in the diagnostics business area.

Nano Electronic Materials

For the next generation of nanoelectronic devices, new materials are needed. This holds for organic semiconductors and artificial materials with great potential in novel devices, materials that push the operating temperature of nanoelectronics devices to room temperature, new approaches in nanowires and crystals. Nowadays new technologies in deposition of complex materials as well as structuring techniques makes the applicability of those materials possible that were believed to be too complex to incorporate in semiconducting devices manufacturing. The search for novel materials intensified, starting with, among others, high K dielectric

alternatives for SiO₂ and the introduction of GMR-materials. In this flagship three topics are defined, each covering an area with high potentials:

- High mobility crystalline organic materials cover the increasing field of organic materials
- Novel materials for nanoscale devices deal with the new or enhanced functionalities of novel materials
- Semiconductor nanostructures and nanowires with electrical and opto-electrical functions cover the field of classical semiconductors, but now on nanoscale (quantum dots)

All research subjects in this flagship are categorized in three clusters, each covering the above-mentioned research areas. Both within and between the clusters there is a close cooperation. Generally speaking, the clusters are subdivided into preparation and growth studies, characterization, device concepts and theory. Again Philips is strongly involved with all clusters and the perspective is that the flagship will lead to novel materials with better or new functionalities (electrical, opto-electrical, magnetic) for future devices, like ultra fast logic or non-volatile memories.

Advanced NanoProbing

The objective of the flagship *Advanced Nanoprobng* is to advance and to develop truly novel scanning probe tools that will allow investigating and manipulating materials properties on a nanometer scale, which is of vital importance for the further development of Nano Science and Nano Technology. This includes the development of a new generation of probes and probing concepts, nanostructuring, development of essential spectroscopic methods like NMR, electron spectroscopy and optical techniques on a true nanometer scale as well as the development of molecular functionalized probes for medical and biological applications. The aim of this flagship is to develop “nano video cameras” that will allow real time study and manipulation of nanosized materials and systems under all practical conditions. This will require considerable developments both in experimental approaches and techniques, materials and theoretical understanding which can be realized by combining the strong existing expertise within the Netherlands into a closely collaborating network operating at the forefront of NanoProbe science and technology. The results will be beneficial for many of the Nanoned flagships, beneficial for Dutch industry, and will have potential commercial spin offs.

Single Molecule Chemistry, Physics and Biology

The aim of this flagship program is to deliver both the molecular components as well as the fundamental insight into the molecular properties essential for the development of the nanotechnology-toolbox. This includes probing of single molecule phenomena and the design, study and control of functions at the molecular level, when the molecules are assembled at interfaces, in arrays or in multifunctional (supra-) molecular components. The expertise in the consortium provides the opportunity to investigate synthetic-, semi-synthetic and biological single molecule systems. The flagship program is based on three core activities which will combine the strength of the participating groups and will address some of the most challenging issues in nanotechnology:

- Single molecule function and detection
- Organization, recognition and addressing of single molecules at interfaces for data storage, sensing and delivery
- (Bio-) synthetic molecular motors

The emphasis throughout this program will be on *function, from single molecule to material and device*.

NanoSpintronics

The central goal of the flagship NanoSpintronics is the development of novel concepts for manipulation, transport and storage of “spins” (the tiny magnetic movements by electrons), and their implementation in nanoscale electronic devices and systems. Research themes represent main application areas, covering magnetic memories (MRAM), magnetic sensors, hybrid semiconductor devices based on spin-injection into semiconductors, as well as devices based on novel (quantum) spin effects in nanowires and nanodots. These issues, although specifically selected on the basis of their relevance for the information society, involve a number of highly challenging scientific quests. The program aims at the realization of an intense network combining complementary expertise available within the Netherlands. Such a collaboration will be a requisite to maintain the forefront position of the Dutch scientific community in this field, and for its transfer to a competitive infrastructure for the Dutch industry.

NanoInstrumentation

NanoInstrumentation will focus on two steps of device fabrication that require high resolution: “definition” or “lithography” and “inspection and repair”. The latter is of interest since a production technology is only viable if the products can be calibrated. The challenge for this flagship is to contribute to the solution of the instrumentation problems that limit the production of devices in the sub-20 nm regime.

Four clusters are described in these areas:

- The cluster EUV Lithography focuses on the practical resolution limit that can be achieved using Extreme UV lithography (EUV, $\lambda \approx 13$ nm); the ultimate limit that can be expected is of the order of the wavelength itself (typically 10 nm). Image enhancement and resist image control are the crucial research subjects in this cluster.
- In the cluster 2-20 nm-Lithography (represented by developments in EBID, IBID and EBL) the challenge is to have more control over the physical and chemical effects that currently put limits on resolution. More specifically the behavior of secondary electrons with respect to resist or precursors is a crucial topic;
- To enable the lithographic techniques mentioned above, the Metrology stages cluster focuses on fast positioning and measuring in 3D space with (sub)-nanometer accuracy;
- Current inspection and repair techniques suffer from limited extensibility towards higher resolution. Either their resolution is limited or their yield is limited at high resolution. The Inspection and Quality Control cluster is aimed at investigating three techniques that overcome this deadlock: Photo-electron Emission Microscopy (PEEM), massive parallel e-beam inspection, and scatterometry. The ultimate goal of this method is wafer inspection with 10 nm resolution in 5 minutes.

Bottom-up Nano-Electronics

In bottom-up nano-electronics, electrical components such as transistors, memory elements, light-emitting diodes, lasers, and sensors are fabricated by chemical synthesis and then assembled into circuits. This has tremendous potential for making circuits more cheaply than is now possible. Electronic components can be made in large numbers with practically atomic precision using chemical synthesis. This flagship will address some important fundamental issues concerning the coupling of atoms, molecules or nanocrystals to macroscopic leads. Transistors based on carbon nanotubes, polyiso-cyanide nanowires, semiconducting nanowires, monolayers of fullerenes, and conjugated polymers will be investigated. Self-assembly techniques will be used to incorporate the nanoscale devices into circuits. The first applications are likely to be sensors for medicine and the chemical industry. Eventually, bottom-up techniques will be used in mass-market microelectronics.

BioNanoSystems

In order to realize the full potential of molecular nanotechnology it is necessary to develop the ability to control nanosystems from the macroscopic world in such a way that they will perform a predetermined task at the desired time. Within the flagship BioNanoSystems this challenge met by aiming to develop and fully characterize nanosystems that are responsive to macroscopic signals. These signals as a consequence have a predetermined effect on, or in the direct environment of the nanosystem. The focus will be on three types of systems with future commercial potential:

- Addressable delivery systems
- Controllable assemblies
- Functional surfaces

Applications of this technology can be found, among others, in the areas of medicine, food, catalysis, data storage and diagnostics.

Quantum Computing

The objective of this flagship is the development of electronic circuits based on nanodevices, to be used as building blocks for quantum computers. Its focus is on semiconducting and superconducting nanosystems, where the electron spin and clockwise/anti-clockwise circulating persistent currents are used as fundamental logic units. Qubits will be fabricated using advanced nano-lithographic techniques, as well as novel epitaxial techniques aimed at producing high-purity materials. The nano-circuits, as well as the quantum algorithms used for the operations, are optimized with respect to fault tolerance, decoherence and probability leakage. Fast electronics will be developed for read-out and storage of quantum information. The parallel nature of quantum logic yields an enormous potential for applications. However, to scale few-gates quantum logic circuits to practical computers will remain a challenge for many years.

NanoFabrication

This strongly interdisciplinary consortium targets the development of strategies for the preparation of nanostructures in the 5-100 nm resolution range that is currently inaccessible with existing lithographic and micromachining technologies. It will focus on the development of generic methods that are applicable in a wide range of materials and on various substrates. Such strategies will allow the development of new efficient technologies for industrial nanofabrication processes with sub-100 nm resolution. The strength of the consortium is that it will bring together expertise in top-down as well as bottom-up methodologies for nanostructure preparation. The main emphasis of the consortium will therefore be to combine these methodologies in novel patterning strategies. The focus will be on three main lines of research, each represented in a cluster. The aim of the first cluster is to realize fabrication techniques for large-scale periodic structures (gratings, arrays etc.), applicable in data storage, bio-filters, photonic structures, quantum dot arrays and test structures for wafer steppers and mastering equipment. The second focuses in particular on the combination of top-down and bottom-up approaches to explore the governing principles of surface patterning and functionalization for new areas of application. In the third cluster the aim is on the fabrication of arbitrary patterns by the use of optical technologies (top-down) and self-assembly strategies (bottom-up). The nanopatterned structures accessed in this project find application in high-density data storage, (bio)sensors, and photonic and electronic devices.

NanoPhotonics

The NanoPhotonics Flagship addresses photonic materials and devices based on nanotechnology. Novel nanotechnological methods allow a further miniaturization of optical devices. In addition, nanotechnology allows to develop new functional materials with well

designed properties. In the Netherlands, eight research institutes with a high reputation in photonics have joint their activities in this program. Together, these institutes focus within NanoPhotonics on three themes:

- Nanoscale energy transfer- memories/switches
- Innovative light/laser sources and concepts
- Photonic signal processing

This focused research effort will lead to new knowledge, concepts and intellectual property (patents), novel materials or material combinations, new fabrication technologies and methods and prototype optical devices.

NanoNed activities

Dutch national programs and foundations for science and technology have several agreements with comparable programs and foundations in the most important countries in nano- and microtechnology, such as the U.S., Japan, Canada, Germany, France, etc. Joint research proposals are effective means to foster international cooperation. The Netherlands contingent organized a very successful MicroMachine Summit (Japan Micro Machine Center) in Maastricht in 2002 and the renowned Commercialization of Micro/nanoSystems (COMS), September 7-11 2003 in Amsterdam. This prestigious Gordon-style conference, started in the U.S. in 1994, is the leading platform to address issues like market development, business strategies, capital formation for start-up firms, and relevant technology-market platforms. The conference is frequented by more than 300 leaders in business (60 %), academia (15 %), venture capital and consultants (15%) and officials and policy-makers (10%).

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Appendix 2: NanoNed proposal, 12 February 2003

Technology Assessment of NanoTechnology

1. Approach

Summary: The focus is on processes (of co-evolution of nanotechnology and society) and how to improve them. Three main components:

- 1. mapping and analysing ongoing dynamics of technological development, the actors and networks involved, and the further (and possibly conflictual) embedding in society, with particular attention to emerging patterns*
- 2. articulating, on that basis, socio-technical scenarios about further developments and possible impacts, and stimulating reflection.*
- 3. search for early signals about impact (as such, and in terms of concerns that can be articulated).*

Nanotechnology is at an early stage of development. Promises about new technological options abound, but little definitive can be said about their eventual realization, let alone impacts on society. Thus, an impact assessment of nanotechnology would be speculation; one could call it science fiction (about future nanotechnology) combined with social science fiction (about the world in which future nanotechnology would have impacts). Still, it is important to create visions of possible futures, so as to stimulate reflection and broaden the scope of strategic choices about nanotechnology and more generally.

Within the range of approaches to technology assessment, one can see future visioning as one extreme. The other extreme is how firms and R&D institutions compare existing technological options in order to select the promising ones. In other words, an attempt to pick the winners, even if the question which will in the end be the winners is still open. Within the range of approaches between these two extremes, new methodologies have been developed and piloted over the last ten years, under the label of Constructive Technology Assessment. This approach is called 'constructive' because it attempts to contribute to the actual construction of new technologies and how these get more or less embedded in society, rather than wait for this to happen and only then try to map possible impacts. It is this approach which will be followed in the project. Other methodologies and techniques, and contributions from further disciplines, will be included when appropriate.

The approach of Constructive Technology Assessment has been pioneered by Rip and his group at the University of Twente, and is now attracting attention worldwide.

A. Rip, Th. Misa, J.W. Schot (eds.), *Managing Technology in Society. The Approach of Constructive Technology Assessment* (London: Pinter Publishers, 1995).

Johan Schot and Arie Rip, 'The Past and Future of Constructive Technology Assessment,' *Technological Forecasting and Social Change*, 54 (1997) 251-268.

Arie Rip, 'Assessing the Impacts of Innovation: New Developments in Technology Assessment,' in *OECD Proceedings, Social Sciences and Innovation*, Paris: OECD, 2001, pp. 197-213.

Arie Rip, *Challenges for Technology Foresight/Assessment and Governance*, Enschede: University of Twente, 2002. A report commissioned by the Commission of the European Union, contributing to the STRATA program area 'Sustainability: R&D policy, the precautionary principle and new governance models'.

The overall perspective is one of co-evolution of technological developments and societal changes, in which patterns emerge (including preferred technological paths and so-called dominant designs) which will shape further co-evolution. Concretely, the approach combines

- mapping and analysing ongoing dynamics of technological development, the actors and networks involved, and the further (and possibly conflictual) embedding in society, with particular attention to emerging patterns
- articulating, on that basis, socio-technical scenarios about further developments and possible impacts, and stimulating reflection more broadly..

There is an element of speculation, but it is controlled speculation. It will help technologists and other relevant actors to reflect on their strategies and choices, making these more socially robust. Compared with customary technological roadmapping, this analysis is broader, and builds on analysis of ongoing dynamics rather than reasoning back from goals to be achieved in x years, and identification of what needs to be done to overcome barriers. The 2002 conference on Nanotechnology Business Roadmap for Industry in Chicago indicated the importance of focusing on dynamics. The scenarios which are developed in this project are open-ended, and serve to identify 'forks' in the development so that key choices can be made.

Nanotechnology is still at an early stage, which implies that it lives on promises rather than actual performances. In addition, the promises of nanotechnology have to be realized through their uptake in other products and services (from better analysis to sunscreens to drug delivery). Its impact depends on what happens there, and is in that sense co-produced, even if one might consider that is nanotechnology which has made the difference. (Thus, the well-known problem of attribution of impacts to earlier actions.)

The analysis must therefore focus on expectations and how these evolve and set an agenda, and on the parallel emergence of alliances and networks and how these support particular directions of development. In the NanoNed programme itself one sees such agenda building and links with other researchers and with a variety of interested firms. The combination of evolving agendas and emergent structures, and the irreversibilities that arise, sets the patterns for further developments. Constructive TA reconstructs these dynamics and extrapolates them in socio-technical scenarios.

This approach to assessment of a technology at an early stage can build on a number of relevant methodologies and some pilots (including SocRobust, an EU-FP5 project recently concluded), as well on recent advances in relevant disciplines, in particular innovation studies, sociology of technology, and industrial economics. It also raises challenges for these disciplines, viz. to analyze processes in real time rather than in retrospect, and to do so in interdisciplinary collaborations. There are examples already, but for technologies at a later stage, like fuel-cell technologies.

Avadikyan et al. (2003) emphasize, in their analysis, how networks of firms, laboratories and policy-makers create 'collective visions' (or at least, shared agendas) and allow sharing of knowledge, aspects usually neglected by economists. Studies by sociologists of technology show how such networks themselves emerge because of expectations about the new technology and attempts to learn about its potential.

Schaeffer, Gerrit Jan, *Fuel Cells for the Future. A Contribution to Technology Forecasting from a Technology Dynamics Perspective*, PhD Thesis, University of Twente, 1998

Hoogma, Remco, *Exploiting Technological Niches. Strategies for Experimental Introduction of Electric Vehicles*. PhD Thesis, University of Twente, 2000.
A. Avadikyan, P. Cohendet, J.-A. Heraud (eds.), *The Economic Dynamics of Fuel Cell Technologies* (Berlin: Springer Verlag, forthcoming 2003)

Clearly, TA studies of nanotechnology can learn from the analysis of what happened with fuel-cell technologies, provided one takes into account the even more open-ended nature of developments in nanotechnology.

The other dimension on which we can learn from what happened with other technologies is about their possibly conflictual embedding in society. While it is too early to expect actual conflicts about nanotechnology, concerns are being articulated, for example about uncontrolled spread of nano-particles. What happened and is happening in this respect with biotechnology and genomics can be taken as a learning experience, even if the technologies are different. Genomics stimulation programmes now have an ELSA component: Ethical, Legal and Social Aspects of the new technology. To include TA studies in the NanoNed program is a similar pro-active response to possible societal concerns (the US National Nanotechnology Initiative responds to recent concerns by saying they are working on them already). In nanotechnology, however, it will be more difficult than in genomics to identify such aspects directly, because nanotechnology's impacts will depend on how various technological options are taken up in sectors closer to eventual users.

What is possible, and this is the third main component of the project:

- search for early signals about impact (as such, and in terms of concerns that can be articulated).

The challenge is the assessment of the significance of the signals. Customary quality checks cannot be used (the impacts are not yet there) while, as case studies of early warning show, early signals start out as tentative, often diffuse and not yet convincing. Still, there might be something in them. To address this dilemma, two approaches will be used. First, insight in the dynamics of early warning. In particular, recent work in risk assessment has shown the role that 'story lines', say of escape of a new device from its confinement, play in the articulation and assessment of concerns (and not only because novels are written with such a plot). Second, the possibility of quality control of the process of interaction and articulation, rather than the signals themselves. This idea is now pursued more widely, and a few interesting experiments with interactive TA can be a further input into understanding the quality of the processes and improving them.

In general, TA of new technologies faces the problem that the technology, let alone the impacts, are not yet there (so controlled speculation is necessary). In addition, the technology that is the object of a TA study may well change along the way, as such and as to intended functionalities; or it may be left because other options appear to be more attractive. Rather than taking these considerations as messages of despair, we see them as challenges. One concrete implication is that TA studies cannot be a one-off matter, and that feedback to relevant actors and take up in choices is often a more important result than the findings of the study as such.

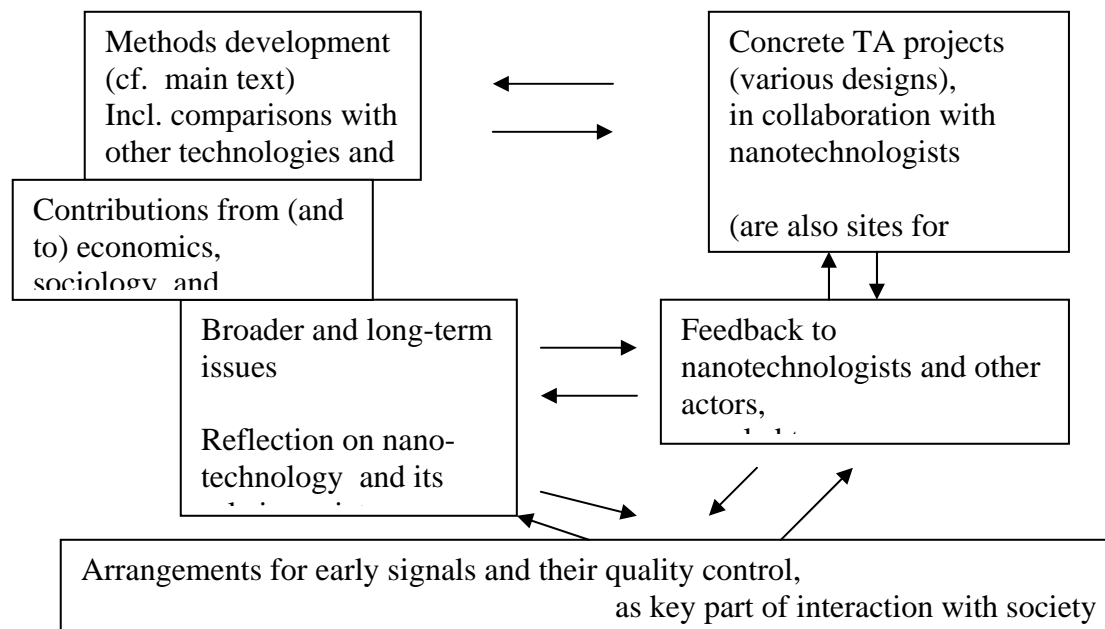
A broader implication is that TA is not (just) about a particular technology and its potential impacts, but about the co-evolution of technologies and society and the emerging patterns that can be traced in the co-evolution. Such patterns then shape further actions and choices, and in that sense, are predictors for what may happen. But the issue is not just about predictability and thus better management (broadly speaking), but also about reflection. What does it mean

when you can manipulate and control materials at the nano-scale –which will enable changes which the nanotechnologist herself cannot foresee, let alone control?

Such TA studies require inputs from technology studies and innovation studies (interdisciplinary domains which include contributions from sociologists and philosophers), but also evolutionary economics and industrial economics, industrial ecology and political science. They also, and importantly, require inputs from technologists themselves. The latter, and the productive interaction of technologists and social scientists, will be an explicit part of the design of the project.

2. Goals and activities

Overview:



Activities comprise:

- Separate studies (by junior and senior science & technology scholars etc)
- Methodology development
- Dedicated TA studies (with particular emphasis on scenarios and emergent networks and structures)
- *Begleitforschung* of ongoing nanotechnology research and interaction with researchers and other actors
- Nanotechnologists adding TA and reflection on nanotechnology to their work
- Special meetings and projects (cf. feedback and articulation of strategies)
- Collaboration with TA nanotechnology projects elsewhere, and with scholars doing relevant work in sociology and economics of technology
- Participation in the fast-moving world of nanotechnology
- Link with interactive communication projects about nanotechnology, but no own contribution

These activities will be done by the Dutch TA NanoTech Network, the core members of which are University of Twente, University of Utrecht, Technical University of Delft, and Technical University of Eindhoven, with contributions from other universities and STB-TNO, and from relevant individuals. The TANT Network will be led by Arie Rip (University of Twente).

The TANT Network already has collaborative links with relevant groups, individuals and networks in Europe and outside Europe, and will expand and intensify such links. Examples are the European Network on Social Impact of Nanotechnology (ENSIN), the COST Nanoscience and –Technology Advisory Group (NanoSTAG) with its interest in ELSA studies of NanoTech, and the Technology Scenarios Programme at Risø National Laboratory in Denmark. Interesting developments in the USA, in the wake of the National Nanotechnology Initiative include attempts at interactive TA from CSPO at Columbia University, and the more philosophically oriented projects at the University of South Carolina and their ‘NanoTalk’ discussion forum.

Because of the increasing interest in nanotechnology, such TA-type initiatives, groups and networks proliferate. It is essential to work in a coordinated manner, and for the Dutch TANT efforts select topics and approaches which will make a difference, rather than reiterate what is being done elsewhere. The dynamics of nanotechnology development and its embedment in society are a global phenomenon, even if uptake of nanotechnology will always start locally. Articulation of strategies will take the specifics of the Dutch situation (and to some extent the European situation, e.g. for the issue of selective concentration) into account.

Some of the activities will be part of the regular work of the groups participating in the TANT Network, or get additional support. The NanoNed funds will be used for three purposes:

1. To employ researchers (often with an economics or sociology background) on dedicated projects. We expect to have three PhD students and one post-doc employed throughout the period of six years.
2. To support nanotechnologists in doing small projects (and other activities) adding a TA-component to their work. We expect interest with PhD students, and we shall develop special guidance for such projects.
3. To support non-research activities of which strengthen and expand the TA component of NanoNed, and enhance reflection across NanoNed as a whole. These activities will include general inputs from economics, sociology and philosophy, offered by internationally known scholars.

The actual projects will be designed as selections from the items in the general approach, and the opportunities and needs of the research and emerging networks in NanoNed.

We will link up with work that is being done already, for example a Constructive TA study of lab-on-a-chip and technological options linked to advances in nanofluidics; and a study of informal and formal scenarios (“fictive worlds”) of actors, combined with the construction of integrative socio-technical scenarios by the analyst. We can also profit from collaborations that have been set up internationally with evolutionary and industrial economists, and with sociologists and policy analysts working on expectations about new technologies. There are opportunities to develop new approaches in innovation studies and industrial economics.

Appendix 3

Excerpts from *Arie Rip, A co-evolutionary perspective on ELSI, CTA and other attempts at re-contextualisation of science and technology in society* (paper for EASST Conference, York, August 2002)

In this paper, reflexive co-evolution is used to understand how the historically grown separation between promotion and control is bridged (but not overcome) with the help of (C)TA, ELSI, Foresight, and in fact science and technology policy more generally, seen as the articulation and instrumentation of science-society interfaces. As I will argue below, these could become a *nexus* at the level of society: “bridging the gap” as an emerging pattern, but also as a goal of reflexive actors. And reflexivity can be enhanced by analysis of the patterns, for example by STS scholars.

Patterns emerge through de-alignment and re-alignment, and institutionalization (i.e. stabilized expectations).

Modulation of co-evolution, over and above simple variation and selection, can occur through more or less institutionalized activities and patterns in the co-evolution. In particular, as Van den Belt and Rip (1987) have shown, institutionalized links, a *nexus*, between variation and selection have emerged. An interesting example is the test lab: a protected space, protected against immediate selection pressures, but simulating them in the conditions of the test – as it were a micro-cosm substituting for the real world. Test labs were first established in the German synthetic dye industry in the last decades of the 19th century to recreate conditions of the selection environment (then, the dyers’ shops). A test lab is an arrangement which enables anticipation and feedback to the technology developers. Test labs, and more generally, tests of performance and further effects (including risks), help developers to be prepared for later selection pressures. Such enlightened self-interest, however, has also societal effect: there is some pre-selection.³

(...)

Many more realignments are necessary to achieve success, so the actor, or better, actor-network, must accordingly be more complex. In fact, there are now conscious attempts to guide and improve the introduction of new technologies into society through special initiatives, as for an Electronic Superhighway, or platforms as for telework. I have used the term ‘alignment macro-actor’ to describe such efforts, and argued that such macro-actors can be set up (“constructed”) if the emergent networks promise insufficient re-alignment (Rip 1995, p. 426). An interesting recent example is the California Fuel Cell Partnership where fuel cell producers, many of the main car manufacturers, oil companies, and various government forces have joined forces to articulate technological options and try out their introduction (spurred on by the California zero-emission standards).⁴

³ The ELSI/ELSA studies of genomics, which which I opened this paper, can be seen as a “test” through studies. Rather than exposing society to new technologies in a trial-and-error manner (cf. Krohn and Weyer 1994), a kind of test-lab is created by doing ELSA studies about possible effects and their assessment: “trial” by studies. And so perhaps little critical pre-selection, only legitimacy effects (which is also a selective effect).

⁴ I draw on the analysis of this case in Van Lente, Hekkert et al. (2002).

While these examples refer to attempts, initiated by technology actors and/or government agencies, to improve the introduction of a new technology, and thus modify selection, the idea of re-alignment and possible ‘alignment macro-actors’ is also applicable to situations where there is criticism and so-called new stakeholders raise their voice. This can lead to contestation, but increasingly such voices from the selection environment are listened to, and more recently, incorporated in the techno-economic network – to anticipate better on the selection environment and/or to make it harmless. In fact, for the same reason a platform promoting tele-work (in which I participated at the time) included old stakeholders, spokespersons for trade unions and professional workers’ leagues.

Micro-institutionalization of specific patterns and nexuses merges into macro-institutionalization of larger and longer-term patterns.

At a macro-level, co-evolution of science, technology and society can lead, and has in fact led, to stable patterns or regimes (sometimes including explicit governance arrangements). This is, for example, how Nowotny et al (2001) locate the academic-disciplinary “Mode 1” of knowledge production. We can see this as a protected space at the macro-level, for science-as-we-knew-it (Rip 2002c). As I noted before, the present time then sees a punctuation of the earlier equilibrium, and many new varieties of doing science are appearing.

For technology, the situation is more complex, because technology was much less separable from society than science was. In fact, the distinction between technology variation and societal selection which carried part of my argument about an evolutionary approach being applicable, is actually predicated on the existence of a historically evolved regime where technology development is separate from uptake and use (Rip and Kemp 1998). Then, variation and selection are institutionally separated – and have to be bridged again in anticipations, experiments, and interactions.

Historically, the separation was part of the industrial revolution. In a further step, during the 19th century, engineers and other technology actors were given a mandate to develop new technologies and confront society with them, as long as this could be presented as progress (Van Lente 1993). This was complemented by the emergence of the idea of ‘technology’ in general, symbolically linked to ideals of progress (Smith and Marx 1994; Rip and Kemp 1998). The mandate and its symbolic justification offered a macro-protected space. It was maintained until the 1960s (when Harold Wilson, the UK Prime Minister, could still proclaim the “white-hot technological revolution”), but then started to break down.

The existence of the mandate, and the macro-protected space for technological developments, however, had allowed the establishment of institutions and divisions of labour which could not simply be turned back. While shifts do occur, and there are contestations, the overall pattern of a gap between promotion and control and attendant division of labour between promoters and critical selectors remains strong (including the cultural repertoire component, cf. Rip and Talma 1998). Clearly, modulation from the selection side, other than market reactions or plain refusal at a late stage, is not easy. The rhetoric of the evolutionary metaphor, where selection is all-powerful, breaks down in the face of the actual patterns in co-evolution.

Let me be more specific. In our modern societies there is an asymmetry between “impactors” (those at the source of impacts of technology) and “impactees”. This can be a difference in power, but is always a difference in timing. Initiators of technological development know more, and have invested more, at an early stage, and impactees and spokespersons for society have to wait and in a sense, follow their lead. Collingridge (1980) has identified the

knowledge & (public) control dilemma which follows from this situation. The problem is visible already within the “innovation journey” (Van de Ven 1999) as a flexibility dilemma (Verganti 1999): one has to foreclose options at a moment when not enough is known. In fact, there are assessments going on all the time, and the challenge is to improve on them, for example by including more aspects and perspectives at an early stage (as Constructive TA proposes, see Rip et al 1995, Schot and Rip 1997), or by identifying *loci* where the process of emerging irreversibilities is accelerated and focus interventions for improvement on those *loci* (Rip and Schot 2002).

The asymmetry has another component: technology developers are insiders and do not necessarily know very much about the outside. Adoption and diffusion, however, is up to “outsiders”, with other interests and expectations. The story of nuclear energy since the 1960s is one of a struggle between insiders and outsiders. At a much smaller scale, the same storyline is visible in the development of cochlear implants for deaf people (Garud and Ahlstrom 1997), especially when it turned out – unexpectedly for the insiders -- that the deaf community was negative about taking deaf people out of their own culture by providing them with implants. Garud and Ahlstrom (1997) suggest technology developers are working in an ‘enactment frame’, and look at the world as a challenge (and sometimes a barrier) to be overcome.⁵ While from the outside in, actors are selective from their own backgrounds.

The asymmetry gives rise to a division of TA labour where insiders articulate ‘promotion’ and outsiders ‘control’. A similar division of labour, at one remove is visible in how governments and their agencies handle technology in society. Government technology policy most often focuses on promotion of (selected) technologies, as when stimulating the electronic superhighway. The main question for such technology policy is to “pick the winners”, now at the level of the society. On the other hand, other agencies of the same government are occupied with reducing the human and social costs of the introduction of new technology, for example through safety and environmental regulation. This dichotomy between promotion and control of new technology is thus part of the *de facto* constitution of modern industrialised societies, and is reflected not only in the division of labour between government agencies, but also in cultural and political views, as in the assumption that there will be proponents and opponents to a new technology (Rip and Talma 1998).

One implication is that the interest (and effort) spent on technology assessment, public awareness, participation, may remain fragmented when focussing on problem solving (like resolution of conflicts, legitimation problems, new agenda building). For example, to find out how consensus conferences can be organized better, it is not enough to evaluate a number of cases and identify so-called best practice. Consensus conferences are part of larger co-evolutionary processes, and their effect depends on how they fit in the process (and sometimes stretch it). Callon et al. (2001) locate consensus conferences, and ‘hybrid forums’ more generally, as instances of a new “*démocratie technique*”.

One can also look at the variety of attempts at Foresight, TA, ELSI/ELSA, but also the interest in “governance” of science (in Europe and elsewhere), as instances of reflexive co-evolution in a period of punctuated equilibrium. Viewed in this way, they can be assessed together, and the question can be raised whether they add up to a new pattern, perhaps a new *de facto* constitution. A re-contextualization which bridges the gap by introducing a new layer, a “trading zone” (to use a concept from Peter Galison taken up by Nowotny et al. 2001)?

⁵ This then leads to a concentric approach to product development: get the product right, then the market and regulation, and only then we will start worrying about public acceptability. Deuten et al. (1997) have mapped this phenomenon for biotechnology products. The ‘enactment frame’ itself evolves, as they have shown in a narrative analysis of one of the cases (Deuten and Rip 2000).

Nowotny explicitly warns against the danger of thinking in terms of additional layers; science itself is being (or must be) overhauled.

“Rather than merely adding to a supposedly hard scientific core an ever increasing number of outer layers – consisting of [regulatives for relevance, ethical concerns, societal acceptance of outcomes] – science has to reorganise itself in accordance with the fluid and dynamical structure under which it already operates.” (Nowotny 2002, at p. 28)

This is a vision of a reflexive actor, and if taken up by others, might create a shift. For the moment, I would already be content with a better ‘trading zone’, a *nexus* at the macro-level.

Bridging the gap

All sorts of instruments and actions, existing and emerging *nexusses*, divisions of labour in a regime, are bridging the gap, even if precariously. As distantiated analysts, we do not mind how successful the bridging is (and in which direction it goes). As reflexive actors, bridging the gap is also a normative question, and we want to evaluate what is happening and diagnose what the dynamics are so as (hopefully) be able to do better.

Let me start with a summary check of what the various “instrumentations” of the interface, as they have developed over time, have to offer in terms of bridging the gap (more details in Rip 2002d).

<i>instrumentation of interface</i>	+/-	<i>Nature of bridging</i>
“picking the winners”	±	Initiated at the variation side, selection in own terms, with some anticipation on societal aspects.
strategic niche management, societal experiments	+	Joint effort from variation and selection sides
Medical and Health Care TA/ environmental impact assessment	+	Bridging from the selection side.
OTA / Policy analysis style	-	No bridging, because OTA was doing policy support for US congress. Other parties may use results for bridging.
Public debate & Agenda Building	±	Bridging from the selection side, still rare. Could occur through credibility pressure, depending on circumstances.
Participatory TA, hybrid fora, interactive TA	±	Bridging sometimes possible, sometimes not. Depends also on composition of the forum.
Constructive TA	+	Introduces “selectors” in the development at the variation side. If well done, bridges by definition – but may revert to enlightened probe & learn from the variation side.
ELSI/ELSA	+	Started out as just add-on, but now institutionalized and interacting with genomics researchers
Science & Technology Foresight	±	sometimes interactive, but often exercises producing a report only

Obviously, one cannot evaluate instruments without considering the context in which they are used. An example, including an interesting suggestion about the dynamics, is offered by foresight exercises. FORMAKIN (2001) has shown that the effect of a foresight exercise (with its key function being improvement of distributed coordination) will depend on the (social) configuration of the domain. For example, in a close-knit configuration, foresight is not needed because coordination occurs already, while in a loose-knit configuration there is insufficient incentive to produce coordination (as a collective good). In-between configurations will profit from foresight exercises.

Many of the “instrumentations” of the interface can (and must) profit from this broader view by positioning themselves (and optimizing their approaches) as part of anticipatory intelligence produced as well as taken up in context (which are themselves distributed, cf. Kuhlmann et al. 1999). One must then understand the dynamics of contexts + instrumentations.

Underlying dynamics and emerging patterns

While actual futures cannot be predicted, the occurrence of socio-technical dynamics and emerging irreversibilities implies that there is an *endogenous future*. Embedded in the present are preferred directions which imply that a trajectory will be followed (Dosi 1982). Even if paths are created while “walking” (Garud and Karnoe 2001), emerging paths can be mapped, and the way they emerge can be analysed (prospective technology analysis) – and this can be fed back to actors. In some cases, such activities have become institutionalised as “technological roadmapping”, for example in the integrated-circuit industry. The predictions based on Moore’s Law are a guideline, and thus become self-fulfilling.

Basically, what happens is that scenarios are created in which impacts can be (speculatively) identified and assessed – a kind of social science fiction. Actors always work with partial and diffuse versions of such scenarios to orient themselves – and others. A social-science supported TA might improve the quality of their scenarios. A structural problem is that actors tend to project a linear future, defined by their intentions, and use this projection as a road map – only to be corrected by circumstances. Mapping tools which force actors to consider the non-linearity of evolution, and accept the complexity, can be developed to make them more effective (if they are prepared to accept such social-science based support).

Especially at an early stage, expectation dynamics are important. For example, promises are inflated, and have to be inflated in order to get a hearing – so will almost inevitably lead to disappointments (unless one can make people forget by pushing new promises). The general idea of expectation dynamics was originally set out by Van Lente (1993) and Van Lente and Rip (1998), and has been used to analyse a number of cases, including ICT (Konrad 2002).

In the domain of genetics and genomics, many examples of the importance of expectation dynamics can be found, as in the construction of markets and products of gene therapy in the USA (Martin 2001), and the “selling” of the Icelandic genomic data (Fortun 2001). “Geno-hype” (Fleising 2001) is everywhere, and leads to “geno-hope” as well as the emergence of paths and path dependencies.

Here and in general, quality control of promises and expectations is an important challenge. It has to address content, but cannot be done in terms of its eventual “truth” – which is itself at issue (and never unequivocal because of self-fulfilling and self-negating “prophecy” effects – a general sociological phenomenon! (Merton 1948)). The way to go is to focus on the quality of the process of promises and requirements and the eventual outcomes; this is more important than a debate on the probability of certain predictions.

The same point can be made about early warnings and the quality of the expectations and counter-expectations involved. With reference to the precautionary principle, I already identified the need to articulate and check the ‘threat scenarios’ involved in the warning. Similarly, one can think of methods to articulate ‘promise’ scenarios and check the quality of how the scenario was made.

Already at the early stage of “hype” and “hope”, actors start moving, taking positions, building alliances – this is how networks and industry structures emerge. For our question of analysis of dynamics of irreversibilisation, this is an important process. It has been studied by a few industrial economists, evolutionary economists and network economists (e.g. Håkansson and Snehota 1995), while actor-network theory, with its interest in “warm”, that is, fluid situations, and how they cool off, offers additional intellectual resources (Callon 1998). There are striking differences: The growth of biotechnology was carried by small R&D firms, allied to venture capital and/or big firms in the agrofood and pharmaceutical sectors. Genomics is already linked to genetic counseling, but also, at one remove, to life and health insurance companies; and to pharmaceutical and agricultural companies. For nanotechnology one sees only a few small companies producing prototypes. It is not quite clear what effects these different structures (and their dynamics) will have on further co-evolution. Thus, a challenge can be defined for disciplines like industrial economics and regional economics.

Differences between technologies in terms of patterns in co-evolution, while recognized for what they are, have rarely been studied systematically. One interesting entrance point is the difference between technologies offering a general promise (nuclear in the 1950s and 1960s, genomics now)⁶ and technologies like ICT delivering services more or less immediately. The promise-requirement cycles are different, and doing ELSA-type studies seems only relevant for the former type. In other words, ELSA-type studies must be understood as part of such general promise dynamics, adding some reflection.

⁶ This general promise often has the form of an upstream solution for downstream (future) problems, and can thus remain general. In the domain of ICT, the Electronic Superhighway had a similar general status, and did not really lead to articulation and implementation (Konrad 2002).