SKEP ERA-net : Scientific Knowledge for Environmental Protection

Work Package 6 – Investigate emerging issues for future research planning

Converging technologies and environmental regulations

D6.2 : Literature review

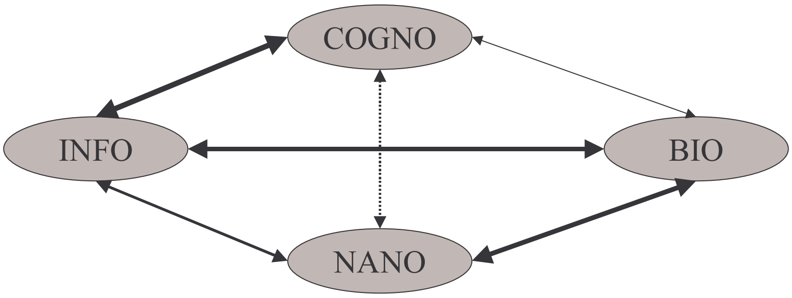
Document prepared by erdyn consultants

SIXTH FRAMEWORK PROGRAMME

Contents

Defining CTs

Converging Technologies are usually associated with the NBIC-vision of interdisciplinarity (fully described in the first place in the American NSF/DOC report (22) in 2002), which is the **integration** and the **convergence** of Nanotechnology, Biotechnology, Information technology and Cognitive sciences.



Actually, and as illustrated this figure, convergence is realized in pieces. Already today, there are many **interdisciplinary explorations in pairs** of the fields under consideration, such as:

I+C: Strong links exist since ages between Informatics and Cognitive Sciences, leading to well known disciplines such as artificial intelligence (AI). AI has remarkably progressed since the nineties and is now mature enough to be embedded in everyday IT products ranging from search engines (for the Web) to medical devices. AI is strongly coupled with the notion of autonomy of electronic devices, and more recently with the notion of cooperation between them (agent technology), thus of collective intelligence. The development of new observation techniques (imagery) has also allowed a better understanding of the cognitive functions of humans (vision, memory understanding, complex emotion, semantic, social cognition, etc.) leading to the new paradigm of sensory processing, which is foreseen in the near future as being a cornerstone of man/machine interfaces.

I+B: The convergence between Informatics and Biology concerns mainly two fields :

Bioinformatics (also called computational biology), characterized by the methodological approach that merges biological terms and knowledge with concepts from computer sciences, is often used as an example where technologies are successfully converging, even if the boundaries of this "domain" are not clearly drawn. One of the major developed field of bioinformatics is genome data mining (85) focusing on understanding the genome (and thus life !) thanks to the increased capacity of computers, powerful screening algorithms, automated discovery based on Artificial Intelligence (AI) and complex database architectures distributed all around the world ;

Neuroinformatics (47), where computer sciences (again mainly AI) are applied to the modelling of the aspects of the brain and conversely where neurosciences contributes to IT paradigms (also called Neuro-IT). This includes applications dealing with interfacing the brain with computers, such as Cybernetics (artificial vision systems, brain implants, electronic tissues for machines capable of evolution), but also Bioelectronics (Neuron on Silicon) combining the high efficiency of natural neurons with sophisticated microelectronics to achieve novel methods of information processing.

B+N: Nanobiotechs are composed on one hand by nanotechnologies that are finding applications in the field of biology, and on the other hand by the use of biotechnologies, acting at the molecular and thus at the nanoscale level, for other purposes than biological applications (such as material elaboration for example). This convergence is an illustration of the blurred boundaries between physics, chemistry and biology. Foreseen areas of applications of nanobiotechnologies applied to biology are [1] medical diagnosis (point of care), drug delivery (remote drug carriers to targeted cells), food and environmental monitoring (control of pathogens and toxicants). As for nanobiotechnologies for other applications, the next decade should see enormous efforts of R&D devoted to develop the use of protein within living cells to assemble nano-structures such as small molecular clusters (or tiny electronics circuits).

N+I: The convergence between nanotechnologies and informatics can easily be illustrated by nanoelectronics whose aim is to conceive and produce new computing systems (process, transmit and store information) by taking advantage of properties of matter that are distinctly different from macroscopic properties. Two fields are often mentioned (see for example (10)) when talking about nanoelectronics : molecular electronics (use of molecular building blocks for the fabrication of electronic components), and spintronics (exploits the quantum spin states of electrons).

Nanoelectronics is one of the foundations of the expected trend towards the ongoing miniaturization of computing devices, opening a new world where the real and virtual are closely coupled and drastically changing our way of life.

The full development of nanoelectronics should also allow to build computers using different architectures : this should bring a new field of computational sciences (Quantum computing) able to address problems that are well known to be too complex for current computational paradigms, and thus opening new perspectives.

[1] According to the European funded project Nano2Life

One may then emphasize the particular status of nanotechnology as it is commonly said to bring about, by itself, a convergence of domains. Due to its reputation to enable the engineering at the nanoscale level, and thereby possibly to reconfigure everything molecular, nanotechlogy is considered as a single engineering paradigm that is applicable to all the scientific and technological individual domains. As a consequence, nanotechnology is often drawing a lot of attention when debates related to CTs are concerned.

The convergence between "C" and "N" or "B" is subsequently achieved via "I", as the body of knowledge linked to Cognitive Sciences is mainly accessible for other disciplines throughout information and computer technologies. Thus, some may refer to CTs using the acronym "NBIT" (where "IT" is replacing "I"+"C") [2] not neglecting the important role of cognitive sciences, but merely estimating that the contribution of "C" to convergence is already "encompassed" in AI, which is often considered as being one of the foundation of CTs.

Beyond the convergence in pair and as we saw on some examples here above, CTs vision is based on the idea of continuum from this trend linking pairs of such pairs and so forth until NBIC will rely on numerous **integrated enabling technologies** and become a huge coherent discipline. The time horizon related to this vision, however, is not clear, but likely not considered to be happening before decades ! In its recent report (20), the US Congress is presenting a roadmap, where Cts are driven by nanotechnologies, which is envisioning the first market applications "truly convergent" by 2020, such as nanodevices able to fix DNA damaged cells, monitoring vital conditions and displaying readable form on skin cells or computer able to operate by reading the brain waves of the operator.

With an aim to enlarge this techno-oriented definition of CTs, and thus enlarging the vision promoted notably by the USA, the expert group brought together at the European level for the "HLEG – Foresigthting the New Technology Wave" initiative (see (5)), is proposing an application-driven approach of CTs emphasizing four characteristics (of CTs related applications) that are offering challenges and rising issues for the society and that should be addressed by R&D :

- *Embeddedness* : CTs will form an invisible technical infrastructure for human action. The better they work, the less we will notice our dependence on them. But this invisibility may have a profound effect on our sense of reality.

[2] This acronym was recently introduced by the joint-venture "Silicon Valley Network", which is characterizing what they call the "Next Wave of Innovation" as being the convergence between three technologies : Biotech, Nanotech, Infotech.

- *Unlimited reach*: Nanotechnology's potential to control everything molecular combined with its ability to transform everything into information may instil the belief that nothing can escape the reach of CTs. This could encourage complacency (a feeling of contentment or self-satisfaction, especially when coupled with an unawareness of danger, trouble, or controversy) towards pressing challenges such as the environment.
- *Engineering (for) the mind and (for) the body*: Some proponents of CTs argue in favour of using electronic implants to enhance our capabilities. But opponents see this as a step towards a world where human beings become virtual machines. A trade-off could be to focus on engineering **for** the mind and **for** the body.
- *Specificity:* The interaction of nano- and biotechnology allows for the development of designer pharmaceuticals tailored to an individual's genome. But it is feared that this process may increase the divisions between the rich and the poor.

According to Jean-Pierre Dupuy (73), this vision of CTs would tend to emphasize the idea that technology is shaped by the society (Social Construction of Technology) while the NBIC vision is fully oriented toward the idea that technology is evolving for itself, in a neutral fashion regarding the society needs and wishes.

Convergence is then usually associated with the notion of **interdisciplinarity**. Induced by the idea that revolutionary inventions are tied up with a break with prevailing paradigms, interdisciplinarity has been widely encouraged by (R&D) funding agencies for decades, leading to a rapid increase of interaction between disciplines and thus, contributing to the progressive fading of boundaries between them. In a recent paper, Jan C. Schmidt (American researcher at the School of Public Policy, Georgia Institute of Technology) [3] is proposing a (philosophical) typology for interdisciplinarity, and is positioning CTs in this perspective :

- Object-interdisciplinarity (ontology): nanobots and nanofabrics ;
- Theory-interdisciplinarity (epistemiology): complex systems, self organization ;
- Method-interdisciplinarity (methodology): bionics, biomimicry, "learning from nature", econophysics ;
- Problem-oriented interdisciplinarity: has to deal with problem understanding, and societal aspects.

He argues that the "NBIC-advocates" (American NSF/DOC report above mentioned) are mainly positioning NBIC at the Object-interdisciplinarity level, while "CTEKs-advocates"

[3] "NBIC – Interdisciplinary ? A framework for a critical reflection on Inter- and Transdisciplinarity of the NBIC scenario", working paper series of Georgia Tech School of Public Policy, 2007

(European report above mentioned) are positioning convergence at a problem-oriented level.

He is also stressing out the fact that the term "interdisciplinarity" is eminently political as its simple evocation is raising an implicit societal theory "how can contemporary society be understood and how should the societal future be (shaped)".

Finally, the notion of **complexity** is often underlying the idea of convergence.

Classifying CTs

The following classification was suggested by the ETC group (66). It relies on the definition of 4 steps, approximately from short term to long term.

Step 1 : Bulk nano

Bulk nano consists in using macroscopic means to control the nanoscopic level (nanoscale materials).

Examples are : bulk production of nanoparticles (organic, inorganic), used as aggregates, powder, dispersed in a matrix, etc. ; colloids, tubes, layers, fibers, etc, all with the "nano" prefix.

This step corresponds to the lowest level of convergence. Although some applications are just emerging, Step 1 may be considered as the state of the art.

However, because of the "nano hype", the "nano" prefix tends to be abusively used (just like adding "dot com" a few years ago) : for instance, nanofibers are currently defined as fibers with a diameter smaller than 1 µm. Similar examples could be found in thin film technologies, or organic chemistry, for example.

Step 2 : Nanofabrication / building from atomic scratch

Nanofabrication consists in manipulating and assembling nano-scale particulates, to manufacture nanodevices. MEMS are a typical example of such devices.

Two approaches are generally defined :

- top-down, i.e. reducing the size of current technologies ; ex. : downsizing lithography ;
- bottom-up, i.e. by using tools specifically designed to build and manipulate objects at the nano-level ; ex. : applications of AFM (Atomic Force Microscopy).

Step 3 : Molecular manufacturing / atom-by-atom construction on the macro-scale

Molecular manufacturing aims at the mass production of any product on any scale, using Step 2. Inspired by Drexel's vision [4], it relies on self-assembly and self-replication.

Step 4 : Atom and Eve / bionic nano

Bionic nano results from the merging of biological and non-biological materials, and aims at producing hybrid living / non-living devices. It includes transforming biology into an industrial labor force, and represents the most advanced degree of convergence.

This step may be considered as a practical way of achieving Step 3, as self-replicating electromechanical nanobots may never exist. The idea consists in using biological processes (self-building, self-healing, etc.) : do not reinvent self-replicating processes, just borrow them.

As illustrated by this classification, **nanotechnology** is often considered as a starting point, or even a central node, for CTs.

However, nanotechnology is not easy to define, from both a scientific and technological point of view. The US EPA uses a definition derived from the one used by the National Nanotechnology Initiative (50), stating that :

> *(…) nanotechnology is defined as research and technology development at the atomic, molecular, or macromolecular levels using a length scale of approximately one to one hundred nanometers in one dimension ; the creation and use of structures, devices and systems that have novel properties and functions because of their small size ; and the ability to control or manipulate matter on an atomic scale.*

One could argue, for example, that organic chemistry corresponds to this definition : any polymer could be considered as a nanostructured material. As a matter of fact, the so-called "nanoscience" relies on conventional disciplines such as physics, chemistry or materials science (31). In fact, as David Berube states it, "nanotechnology is evolutionary not revolutionary" [5]. But, as a result of the ambiguity of its definition, the field covered by "nanotechnology" is sometimes described in an extensive manner (cf. the example of photovoltaics in the following chapter).

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[4] E. Drexler, "Engines of Creation", Anchor Press, 1986

[5] See D. Berube contribution at http://www.issues.org/22.1/forum.html. D. Berube recently published a study titled "Nano-Hype: The Truth Behind the Nanotechnology Buzz". He concludes that much of what is sold as "nanotechnology" is in fact a recasting of straightforward materials science, which is leading

The following synthesis is primarily based on reports prepared under the auspices of institutions such as the US EPA (50), the British DEFRA (48) and the German UBA (55), among others. Most of these documents adopt nanotechnology as a starting point.

As such, this synthesis should not be considered as a thorough state-of-the art of environmental CTs. It aims at illustrating what is currently identified as enviromentally relevant, through numerous examples of benefits from an environmental point of view [6].

1.1. Energy, resource saving and substitution

Concerning **energy production,** no radically new technology is expected : most of the examples presented hereafter are based on technogical principles established during the 1980s and the 1990s.

In the field of **photovoltaics**, one of the best known systems considered as based on "nanotechnology" is the Grätzel cell. First introduced by the EPFL (Ecole Polytechnique Fédérale de Lausanne) in 1991, it basically relies on the use of titanium oxide nanocrystals, associated with an organic dye, which acts as a photoelectron source.

This kind of cell is still under development, partly because of chemical stability problems. It potentially allows for the manufacturing of photovoltaic cells at a lower cost (as compared with conventional silicon cells), with a higher efficiency.

Another example sometimes quoted (48) is calcopyrite cells, also known as CIS (copper-indium-selenium) or CIGS (copper-indium-gallium-selenium) cells. In fact, such cells consist in the combination of several thin layers with different compositions and properties. They are manufactured using conventional deposition processes, such as evaporation, PVD (physical vapor deposition) or CBD (chemical bath deposition). Labelling this technology as "nanotechnology" is only justified by the fact that these cells contain "thin" films.

Nanotechnology will not, by itself, make the so-called "**hydrogen** economy" become a reality. However, nanomaterials have a role to play on the following aspects :

to a "nanotech industry built solely on selling nanotubes, nanowires, and the like" which will "end up with a few suppliers selling low margin products in huge volumes."

[6] However, they should not be overstated. D. Rejeski claimed that "Nanotechnology will fundamentally restructure the technologies currently used for manufacturing, medicine, defense, energy production, environmental management, transportation, communication, computation and education" (57), which sounds like an unrealistic promise.

- hydrogen electrolysis may become more efficient thanks to the use of nanostructured catalysts ; symetrically, such catalysts are also needed in fuel cells [7], which would help reduce the amount of platinum needed ;
- hydrogen being a low energy density gas, storage is considered as a critical aspect : higher density storage may be achieved thanks to materials with a better controlled nanostructure, such as light metal hydrides, carbon nanotubes or molecular sponges.

Concerning **fuel efficiency**, one of the most original ideas is the use of nanoparticles as a fuel additive. One (and only ?) example is the use of cerium oxide powders (48) (50) : in Diesel engines, these particles act as a catalyzer, allowing for a lower combustion temperature and lower emissions.

Other cited examples are fundamentally an evolution of current techniques : this is the case of the use of nanostructured ceramic coatings for turbines (ceramic coatings are already used), or catalytic converters including nanoscale materials (48).

Energy storage often relies on batteries. They can be improved by the use of nanostructured electrodes ; this is illustrated by the EU-funded ALISTORE project on batteries using nanostructured lithium cobalt oxide, although, in this particular example, the metal oxide is actually formed during the first charge cycle.

Aerogels are often quoted as an example of "nanomaterial" of great interest for **thermal isolation** (48). They are very low density solids (density lower than 0.1), with a highly porous structure. As a consequence, they are highly efficient thermal isolators. Silica aerogels are of particular interest ; however, because of their high cost, they are currently limited to application niches [8].

From a more conventional point of view, thin coatings are used by the building industry in order to improve various glazing properties, including optical and thermal properties. For example, low-e glazing, which has special coatings (thicknesses lower than 1 µm) which reduces the radiative heat losses, is of widespread use. However, they are seldom promoted and marketed as "nanotechnology" (48).

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[7] As a matter of fact, the principle used in fuel cells may be qualified as "reverse electrolysis".

[8] For example, Aspen Aerogels developed its first products for the NASA.

Resource savings may result from reduced weight or optimized function. This is illustrated by the case of lighter (nano)composites ; a typical example is the use of carbon nanotubes in composites, currently limited by the cost and the low level of industrial production.

More generally speaking, a better control of materials at the nanoscopic level should allow for a more economical use of raw materials ; however, this is a very general principle, that does not seem specific to "nanotechnology" [9].

Nanolayer systems are of particular interest (55). Their current and potential applications are the same as the usual applications of thin films ; concerning materials protection, they include :

- hard coatings, improving scratch resistance ;
- tribological coatings, improving wear resistance ;
- anticorrosion coatings.

Other properties may be of interest, such as in the case of antireflective coatings, but do not bring about any direct environmental benefit. However, as a general rule, using thinner coatings reduces the consumption of raw materials needed for these coatings.

Concerning the **reduction of the use and replacement of dangerous substances,** two examples are frequently quoted :

- biocides : up to date, the use of silver nanoparticles has received much attention, owing to their antimicrobial properties ; some products are already marketed [10] ;
- flame retardants : this is motivated by the replacement of current borated substances used as flame retardants ; concerning plastics, nanocharges such as nanoclay or alumina nanoparticles are of particular interest.

As a matter of fact, many of the previous examples rely on the improvement of known applications : nanocomposites may allow for the design of lighter materials, but this is true for composites in general. The mention of some specific properties that are of particular interest from the point of view of energy, such white LEDs, thermoelectric materials or organic LEDs (11) (50), does not find its origins in nanotechnology, but in materials science, solid state physics and chemistry. In fact, as a general principle, *any* macroscopic property can

[9] For example, a new category of thermoplastics is known as "Liquid Crystal Polymers" (the expression is ambiguous : in fact, they have nothing to see with LCDs), which makes it possible to manufacture thinner plastic parts, without lowering the mechanical performances. They are already commercialized, but have never been labelled as "nanotechnology".

[10] Examples are AgION and HyGate.

theorically be improved by acting at a nanoscopic level. Using this point of view, any environmental technology could potentially be improved by "nanotechnology".

A much more prospective possibility is associated with the concept of **molecular manufacturing**, which, according to its promoters, would be a radical improvement in manufacturing activities (62) :

> *A fabricator that is itself constructed entirely of molecular parts that it is capable of building, and that includes mechanisms for putting the parts together, should be able to be directed to build a copy of itself. In other words, a properly designed molecular manufacturing system could be directed to build a second manufacturing system as cheaply and easily as it could create any other product of similar mass and composition.* (extract from (61), p. 870)

The idea of "nanoassemblers" able to build *any* macroscopic objects in nanofactories which might be "the size of a microwave oven" (63) [11] finds its origin in E. Drexler's vision, and is actively promoted by the Foresight Institute, co-founded by E. Drexler in 1986. It is also the basis of the "grey goo" scenario (61), in which self-replicating nanorobots escape into the environment and convert all matter into a large, continuing growing goo [12]. It was later included among the dark scenarii depicted by Bill Joy (86), who emphasized the ability of GNR technologies (Genetic technology, Nanotechnology, Robotics) to reproduce and multiply.

This vision has been largely criticized by the scientific community for a few years. According to Robert Wolkow (82), "the fantastic outcomes promised by some are based on a most limited understanding of molecular science and no experimental or theorical backing". The US EPA cautiously recognizes that such capability "is not likely to happen for some time" (50) ; its Nanotechnology White Paper (50) contains a small chapter dedicated to CTs, which suggests that nanobiotechnologies offer more realistic opportunities.

It should be emphasized that this does not discard nanotechnology as such. A more realistic point of view was formulated by R. Wolkow (82) :

> *Changes in materials and technologies will emerge incremently and steadily for a very long time – beyond the lifetime of anyone living today. Early manifestations of*

[11] Which raises the question of the ability to manufacture weapons "at will", an activity labelled as "illicit nanofacturing" (63).

[12] It inspired M. Crichton for its novel "Prey" (2002) : "In the Nevada desert, an experiment has gone horribly wrong. A cloud of nanoparticles -- micro-robots -- has escaped from the laboratory. This cloud is self-sustaining and self-reproducing. It is intelligent and learns from experience. For all practical purposes, it is alive. It has been programmed as a predator. It is evolving swiftly, becoming more deadly with each passing hour. Every attempt to destroy it has failed. And we are the prey." (summary by the author).

nanotechnology will not be dramatic – perhaps improved plastic packages will emerge – allowing less material to be used while providing strength equal to today's materials. Later, new sensors, for medical diagnostics and new devices for communication and information processing will likely emerge. In general there appears to be scope for materials and process improvements that will allow "greener" technologies to develop.

1.2. Remediation

Remediation consists in the degradation, sequestration and/or removal of pollutants, allowing for the reduction of risks to human beings and the environment.

In principle, the properties of nanomaterials (enhanced reactivity, larger surface area, sequestration characteristics, etc.) may prove useful in the case of remediation.

Various nanomaterials are currently investigated for remediation applications (50) (56). Some examples are :

- metal oxide nanoparticles for the reduction of nitrogen oxides ;
- titanium dioxide is known for its photocatalytic properties ; it may be used in a nanostructured form in order to degrade VOCs, including chlorinated compounds ;
- the use of nanoscale iron particles : laboratory studies have shown that such particles could dechlorinate various chlorinated hydrocarbons [13]. Iron oxide nanoparticles were also found to bind arsenic irreversibly ; the nanoparticles can then be separated from water by the application of a magnetic field, allowing for the removal of arsenic from groundwater ;
- nanostructured silica can sorb metals (such as lead) generated in combustion environments ;
- nanoporous membranes and filters (ex. : filters based on nanofibers) are another example of nanostructured materials potentially useful for removing contaminants from aqueous or gaseous media.

As can be seen through these examples, the mechanisms used are conventional : they fundamentally consist in sorption, filtration and catalysis [14],[15]. Their originality comes from the fact that they partly rely on the different physical/chemical properties that materials exhibit when they are used in nanostructured or nanoparticle forms : as a result, they may be more

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[13] A few products are now being marketed, such as Polymetallix.

[14] For a description of research carried out on these subjects, see for example the Center for Biological and Environmental Nanotechnology at Rice University (http://cben.rice.edu), theme 3 : "Effective, high-performance water purification systems".

[15] CONCORDE (Coordination of Nanostructured Catalytic Oxides Research and Development in Europe) is an exemple of EU-funded research on nanomaterials and catalysis.

efficient, but this has to be evaluated on a case-by-case basis. It also raises the question of potential side-effects, i.e. non desirable interactions with the medium (land, water, air) to be treated.

1.3. Monitoring

Sensors directly benefit from the developments carried out in microelectronics. The availability of nanoscale manufacturing techniques may result in the wide diffusion of sensors with enhanced functionality, reduced size, at a reasonable cost.

In the short term, one focus is the development of sensors dedicated to the detection of chemical or biological contaminants (52), such as solid-state gas sensors, using thin films, which would make possible the monitoring of localized pollution peaks (54). Tin oxide thin films are an example : as their electrical conductivity changes because of adsorption phenomena, they can selectively detect carbon monoxide and nitrogen dioxide. Other examples are indium, zinc and tungsten oxides thin films [16].

DNA chips, or biochips, were developed during the 1990s. By using photolithography (a process used in silicon chip manufacturing), small bioreceptors (dots typically a few microns) are designed on a substrate. If the biosubstance under investigation reacts with a predefined receptor, fluorescence occurs and light is emitted. Biochips are mainly used for testing DNA fragment, but they are also useful for the detection of biological contaminants in water, for example.

One limit of current systems is that, in the case of air quality monitoring, they rely on relatively large, high cost, fixed stations ; practically speaking, their use is limited to the most polluted areas.

The potential use of environmental sensors on a much larger scale could change this situation (8). Such sensors could even be remotely controlled, linked with GPS, for centralized, real-time analysis, which requires a high density of devices, thus building environment monitoring networks. Key requirements are low cost, autonomy (which raises the question of energy storage and consumption), reliability and longevity. Of course, dedicated data processing capabilities are needed. Moreover, such a network should be easily maintained, which implies, for example, that the sensors need not be recalibrated frequently.

In the long term, environmental sensors might be included in non-stationary equipments, such as cars or mobile phones. For example, a fully instrumentated car, with on-board computers, could be more precisely operated, allowing for less fuel consumption and lower emissions.

Such networks are currently progressively integrated in cars, but firstly for safety or dysfunction detection.

Ambient Intelligence (ubiquitous computing) for the environment

The generalization of captors, RFID, systems of captors and associated (intelligent) computing tools, ensuring the global monitoring of earth (climate), resources (water, air), and so on, is commonly agreed as being an expected positive environmental impact of CTs.

Environmental sensors benefit from progress made in microelectonics. New and enhanced sensors to detect biological or chemical pollutants should be available in the near-term, allowing for an easier collection of large numbers of measurements at a lower cost, possibly in real time, with remote data transmission.

More generally speaking, in addition and thanks to its ability to provide assistance to human with a "global conscience" of his actions, ambient intelligence could also contribute to "reduce our environmental footprint".

Beyond monitoring (the environment or our actions), the spectacular development of computerized exploration and simulation methods might allow for a better understanding of natural phenomenon. Improved modelling techniques could be significant contribution to the establishment of new methodologies for risk anticipation and assessment in this context of "unknown rapidly converging world".

Such a prospect is illustrated by a forecast proposed by the Institute for Alternative Futures for 2029 (84) :

> *Miniaturized Research Infrastructure*
>
> *Bio-chips and nano-labs proliferate allowing research to operate at various scales from molecular to global. Interconnected sensors communicate through a network that links trillions of information sources. A large human population contributes data directly through biomonitors in the form of implants and wearables. Most species of animals have sentinel members to monitor species health and environmental change with implanted biomonitors allowing continuous tracking. Massive computational models continue to account for changing environments and genetics, and to calculate effects such as emerging diseases. Scientists are constantly looking for perturbations that could signal phase changes potentially affecting evolution.*

But ambient intelligence is also raising issues regarding its possible (negative) environmental impact : proliferation of electronic devices, recyclability, perturbation of the ecosystem,

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[16] See the EU-funded project NanoS4 for more details.

misuse, etc. For example, the prospect that environmental, GPS-connected sensors might be embedded in everyday life equipement (cars, cellular phones, etc.) raises questions from the point of view of personal data protection : such sensors, as a side-effect, would gather information on each individual's way of life (9).

1.4. Open questions

Beyond nanomaterials : what about nanobiotechnologies for the environment ?

When reviewing the R&D activities aiming at remediation, resource saving or energy production, most current and potential technologies under consideration are essentially "bulk-nano", i.e. application of nanoparticles and nanomaterials. Typical examples are nanostructured catalytic or photovoltaic materials, nanostructured membranes, etc.

Strictly speaking, whatever the benefits they may generate from an environmental point of view, these first generation materials, also labelled as "passive nanostructures", are not genuine CTs.

The next technological generation may result from the convergence of nano- and biotechnologies (1) (13). Such a convergence is of first importance in the medical field, which is the main driver for R&D activities in this area. However, information on its potential interest for environmental applications is scarce, with a few exceptions, such as the use of biochips in monitoring.

It may take the form of biologically inspired production [17] : microbiological processes may serve as models for the organization, assembly and transformation of nanoscale materials production (50). "Biomimetic materials" [18] would have the ability of self-organization, self-healing and self-replication, as a result of the combination of synthetic and biological materials and architectures.

However, these ideas are still partly speculative, and, until now, such potential applications have not received enough attention. As a matter of fact, they are still at the laboratory stage and mainly described in academic publications (1). Examples are : the extraction and use of photosynthetic proteins in nanostructures ; biomineralisation, relying on bacteria or viruses producing materials with specific properties ; the association of enzymes and nanoparticles, for remedial applications.

More work is needed in order to answer questions such as : What is the current scientific and technical knowledge on this subject ? What can actually be expected ? What are the

[17] Or, as D. Rejeski states it : "Production goes biological" (59).

environmental benefits and risks (as illustrated by the "green goo" scenario described by ETC Group [19]) ? Who are the industrial actors involved (if any) ? What is the time framework ?

Towards a (scientific/technical) roadmap for converging technologies

An important conclusion of the HLEG (47) is that divergences are enduring among specialists regarding essential points concerning CTs promises and impacts (in the large sense), despite numerous exchanges and an extensive literature review. They identified that this absence of capabilities for the group to "converge" was widely due to the large variety of speculative hypothesis they were working with regarding the time-scales of various perspectives of CTs applications (not forgetting to mention the feasibility of such applications). Indeed, time-scales qualifying the readiness level of enabling technologies for CTS, or of possible applications, goes throughout the literature from *"this idea has been raised in the 80's"* to *"It won't happen before decades"*, not forgetting the usual *"it's already on the market"* when referring to RFID, genetic databases or titanium dioxide nanoparticules for example. The point is that when raising the issue of the evaluation of CTs (covering positive impact assessment, risks identification, societal acceptability, priorities setting), time horizon and likeliness to happen matters ! In this context, it might become a challenge for SKEP members to achieve the proper level of understanding of CTs for the environment required to decide on R&D orientations.

Science & Technology (S&T) roadmapping is a specific foresighting approach that has the potential to support S&T strategy and planning. Initiated first in the field of IT (Motorola), roadmapping techniques have proved their interest in many domains where the context was rapidly evolving as a tool to monitor and assess technological progress. Such maps can take various specific forms, but generally comprise a time-based chart linking S&T developments to future products, market requirements and social trends. Moreover, a roadmap is the view of a group of how to get where they want to go or achieve their desired objective. Thus, a roadmap can be seen as a tool useful to support strategic decisions having a view on several dimensions: technology readiness, social and market drivers, economical impact. This concerns both R&D and policies orientations. This also concerns communication towards external parties: thus, a roadmap is a useful tool to disseminate a vision and might be of particular importance as a tool for teaching the opinion.

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[18] This expression is sometimes used in a broader sense. A well known example is water repellant surfaces imitating lotus leaves (53) ; in fact, such surfaces are typically coated by nanoparticles (silica) in a fluorinated polymer matrix : they belong to the "bulk nano" category.

[19] Green Goo Theory : "Scientists combine biological organisms and mechanical machines for industrial uses. The organisms continue to do what nature intended – they procreate – but they've been made more powerful by their boost from human technology : the emboldened bacteriophage becomes the omniphage." (66)

For all these reasons, the opportunity of a roadmapping initiative should be considered as a way to achieve a better understanding of CTs perspectives for environment. Nevertheless, drafting a single roadmap for CTs seems to be unrealistic and probably a more reasonable approach would be to consider a concerted action where individual application domain experts could be in charge of drafting individual (but coherent) roadmaps. A working group could focus on deciding upon the opportunity of such a roadmap and address the following questions :

- What kind of information is lacking in the current vision of CTs perspectives for the environment ?
- Would a roadmap (several roadmaps) contribute to a better understanding of the situation ? To identify priorities in terms of R&D orientations ? If not, what else ?
- What would be the scope of this roadmap ? The time horizon ? The time scale ? The structure ?
- Who should be in charge of managing this initiative ? What "kind" of experts would be needed to perform ? What about involving representatives of the civil society ?
- How to convince "other application domain experts group" to initiate similar roadmapping initiatives (possibly integrating the environmental dimension) ?

Beyond the debate focusing on the toxicity of nanoparticles

For Dr Paulo Martins (Institute of Technological Research, Brazil), there are theoritical problems related to the "construction of a new nature" in the sense that we are placing into the environment structures that do not exist in the natural ecosystems, with a lack of a theoritical approach to take into account the complexity of the issue (37). Data have to be reassessed due to the fact that, at the nanoscale, chemical and physical properties are often drastically altered.

Self-replicating systems should be too small to be easily recaptured and could do serious damage to the environment. So, environmentalists are concerned both about the effects of nanomaterials on the biology of individual organisms and about the consequences on local and global ecologies of the widespread dispersion of nanomaterial into the environment.

Some say that nanotech manufacturing could produce much less pollution than traditional methods . Nanotech products could use mechanical means to do what is done today by a variety of dangerous chemicals. Cheap local manufacturing will reduce the transportation of goods, and may save land and water by allowing more efficient farming (64). But small does not necessarily mean little resource use, in particular as long as we use top-down technologies, in which bulk materials are processed down to the nano-level (37). We must consider the entire life-cycle to assess the resource efficiency. First studies on nanotech applications show that these are not necessarily contributing to an increased resource efficiency. In particular, the use of highprocessed materials and precious metals is an issue that should be looked at.

The promises are made expressly to market a project or a product (42). The benefits are touted particulary loudly when the public is getting a hunch that there also might be some risks associated with the product. Cheap electricity was never a result of the nuclear power, nor did its boosters ever think to offer any warnings about the health and safety issues associated with the disposal of nuclear waste. Environmentalists that value the historical evolutionary process have particular reasons to see through this kind of talk. Such rhetoric may encourage people to drop their guard with prudential actions that are important today. The promise of "electricity too cheap to meter" does not encourage energy conservation in the present. The promise of the end of resources scarcity can do nothing but foster the profligate use of currently available ressources. Promises to end all pollutions and clean up all toxic waste dissuade people from worrying about the messes they are creating today. In each case, existing environmental values such as clean water, intact habitat, and species diversity end up being imperiled by the extreme optimism of the boosters of a technology. Since ecological harms like extinction are not likely to be reversible, it seems prudent to be initially skeptical of the kinds of promisory images that many of the boosters of nanotechnology promulgate.

As said in (25) concerning nanotechnologies "Broad range of technologies, variety of risks" : based on the current literature, it would be indeed presumptuous (perilous ?) to draft an exhaustive list/typology of/for possible risks linked to CTs, but one may still attempt to distinguish between two families.

First, CTs are a consequence of advanced technological evolution in each individual field of NBIC, and are thus naturally accompanied by a wide range of "traditional issues" that current methodologies and approaches of assessment should be able to handle, with possibly some necessary adaptations : toxicity (chemistry), epidemiology (biomedicine), dependability (computing systems), management of waste materials (environment).

A typical example of such works are the Nanosafe projects (1 and on-going 2), on nanomaterials and nanoparticles [20]. The whole chain is under consideration : "production, conditioning, storage, transportation, transformation into final product, during product life and at the end of product life (disposal)". Moreover, they "will also develop innovative

[20] See for example (28). More generally speaking, the question of the risks associated with nanoparticles has been largely analyzed (24) (55) ; uncertainties are identified, and so are the studies needed.

detection, traceability and characterization techniques for engineered nanoparticles" and create a database on toxicology related to nanoparticles. Practically speaking, the objective is to thoroughly analyze a limited number of reference particles and situations.

Second, and according to several authors (as Jean-Pierre Dupuy (74)) CTs are bringing a novel kind of uncertainty by their ability to set off complex phenomena (in the sense of the complexity theory such as presented by Von Neumann), that are necessarily bringing new reasons of concern, and would certainly require different (revolutionary ?) approaches or paradigms for risk assessment. For example, Jean-Pierre Dupuy argues that a consequence of this complexity is to make the Precautionary Principle irrelevant : indeed the complexity theory can be used to prove that it is no longer possible to discriminate between "known" risks and "potential" risks (complexity does not belong to the category of epistemic uncertainty). Without going that far, it may be anticipated that the intrinsic interdisciplinary character of CTs, which is often stressed-out as being the essence of CTs, might also be a source of richness establishing "new ways of thinking" risks.

Several questions are raised (or appearing) throughout the literature, which could be addressed by a group working on risk assessment methodologies, emphasizing the pluridisciplinarity of CTs, such as:

Near Term

- Based on the current information available, are we able to list the scientific (independent) reviews or individual aspects of CTs that are necessary to be driven prior any further consideration or statement on their (positive/negative) impact : toxicity of nanoparticules, state of the art in term of "molecular manufacturing" ?
- What are the limitations of current approaches of risk assessment in the new landscape of CTs ?
- Can we benefit from the cross-fertilization between each individual field of NBIC to anticipate new theories for risk assessment ?

Advanced (Term)

- Are CTs really raising new uncertainties ? Do we need different risk assessment paradigms to deal with theses? How to handle the complexity ?
- Is the Precautionary Principle relevant ?

2. Ethical questions, public acceptability

Do converging technologies necessitate some specific approach or could we use the understanding that we have developed on some specific parts of the CTs (GMO...) ? How could we develop the public information and participation in a so complicated scientific field ? How will we deal with some currently unknown risks ?

Those questions have been treated in the literature with different answers or new questions. To have a clearer view, we will deal with those questions from several different analysis axes :

- Do we need a specific approach of ethical questions related to converging technologies, and if yes, which one ?
- Risk acceptability could be a major question for the future of the converging technologies and it will necessitate a very high level of vulgarisation and information of the public. Is it necessary and / or possible to develop a real public information on a so complicated scientific field ?
- What should be a new scheme to develop the public participation ?

2.1. Ethics

Converging technologies are questioning our concept of humanity and of the relationship between humanity and technology. Complex ontological questions raised by nanotechnology about the relationship between the natural and the artificial are also firmly within the purview of environmental philosophy and have been discussed by environmental philosophers in relation to biotechnology and genetics (42). Nanotechnology is capable of turning biotic and abiotic entities into artefacts, which is constituting a radical threat to the ontological category of the natural. But the value of the unmanipulated nature is not an absolute one. After all, every organism must manipulate nature in order to stay alive (42). We could object that the replacement of nature by a world of artefacts represent a significant ontological loss in itself.

So, in these terms, converging technologies, and specially nanobiotechnology, are introducing some very specific questions as compared to nanotechnogy (34).

We can also say that the nano and converging technologies are developing on a triple transgression of the distinction between nature and artefacts and between nature and culture (36) :

- If we consider that the nano and converging technologies are natural evolution, this means that we have no choice. The technical constructions became natural and the human societies have to follow this evolution. So, on this way, we consider that technological progress is included in a natural progression (like the evolution), which means that we can work on acceptance but not on decision. The transgression is about applying natural schemes to human constructions, which means that we abandon our self decision power and just follow the possible technical evolutions as far as they will go.

- There is also an implicit transgression with metaphoric language (molecular machines, etc.) : they express a project of nature control in a technological finality. This means that we do not just control the nature and model it at a macro level to our needs, but also that we will have the power to change it at the nano level to upgrade our possibilities. In fact, we have done it in the past : a hydraulic electricity power station is a kind of nature control in a technological finality. The main differences are about scale and the possibility to go back if the negative and unexpected effects are too important.
- The third transgression is a practical one : we are using nature capability (like the DNA ones) to create new components or machines. This transgression open the way to the most frightening possiblity of the CTs : the self-replicating systems without limitations.

A question of this item is the value that we accept to give to the nature. In our world, nature is still modificated and this tendency has been boosted by the last ten years progress in molecular and biological engineering. This is probably one of the most significant attitude of the humanity : we prefer changing our environment than adapting to it.

With CTs, there is a new philosophical gap to cross if we consider that the self-replicating nano-machine is a realistic perspective. With this kind of technology, we can change the environment with the introduction of an artefact (very usual for us), we can modify the nature at the molecular scale (this a large subject of debate since the GMO development), but now, we can also create some « machine » which are partly alive and have the capacity of self-replicating. The self-replicating issue has been largely discussed since the seventies about the robots. But the fact that, with CTs, they could be so small that we cannot detect and / or recaptured them and that they are partly living engine introduces some new questions :

- What should be their legal definition : are they things, animals, ... ? The answer implies some consequences if we want to eliminate them.
- What is the place that we want to keep for non-modificated nature ? Do CTs, which are supposed to be very easy to disseminate, can stay where we want or will we modify the nature at an earth scale ?
- How we can evaluate the balance between risks and benefits (with a special focus on environment), especially if we suppose that there will be winning nations or social groups

and some will not benefit from this technological progess but will probably have to support some negative effects ?

Are questions about ethics and CTs so specific, and do we need any new approach ? We can consider that independent « nano-ethics » seems exagerated (36) : too many criteria, which some of them contradicting the others, join the cognitive fuzziness, caused by a lack of knowledge of the real possibility of the technical innovations concerned (43). On a more moderated way, we could consider that on many aspects, there are no really new ethical questions, but rather an intensification of problems of distribution already rife. For example, the problem of equity belongs in principle to the ethical aspects of modern technology. Nanotechnology innovations can accelerate or facilitate the realization of certain technical possibilities, and therefore increase the urgency of the problematics of consequences ; in this area, however, they do not give rise to qualitatively new ethical questions. Those questions are also questioning the definition of common good. We can note that the answer to this fundamental question should be very different in different socio-cultural contexts. So, maybe we also have to focus on the difference of appreciation of the CTs development considering the country where people live, the level of instruction, etc. : individually and collectively, many of our most intensely defended interests and important needs correlate highly with our respective standing in various socioeconomic and power structures, level of formal education, political views, religious views, etc. (34).

Schummer (quoted in (34)) points out that the use of the term "social and ethical issues" could have some different signification depending of who is speaking. For scientists and engineers engaged in nanotechnogy research, those considerations mostly refer to the tangible societal implications of the technological developments. Policy-makers and science managers think in terms of national progress and global leadership.

Nonetheless, we do not have to reckon with a « Nano-ethics » as a new branch of applied ethics. The propagation of nano-ethics overlooks the fact that many of the ethical questions raised by nanotechnology are already known from other contexts of ethical reflection. The ethics of technology, bioethics, the ethics of medecine or also the theoritical philosophy of technology concern themselves with questions of sustainability, of risk assessment, of the interface between human being and technology, especially between living beings and technology. These questions are in themselves not new. Partially new, however, is their convergence in nanotechnology (43). Analogous to the well-known fact that nanosciences and nanotechnology are fields in which the traditional borders between physics, chemistry, biology, and the engineering sciences are crossed, various traditional lines of ethical reflection also converge in ethical questions in nanotechnology. The fashionable creativity in coining terms, as it precipitates itself in designation like "Neurophilosophy" or "Nano-ethics" obscures the integrative cross-sectional nature of many ethical challenges, rather than being particularly helpful.

If we consider converging technologies, the classical barrier between technology and life is increasingly being breached and crossed. This is, at a first glance, a cognitively and technically extremely interesting process, with a great deal of promise and danger. New ethical aspects are certainly to be expected in this field. A wide range of future ethical discussions is opening, for which at present there is insufficient practical background for concrete reflection (43). In particular, advances in brain science and development of converging technologies would justify ethical reflection in advance. We also have to consider the impact of enhancement technologies on the right of the disabled and the potential impact of nano-scale technologies on democracy and dissent. Therefore, there are also questions about whether these technical solutions will be available for poorer countries, both in term of price as well as the knowledge that is required to work, operate and develop them. A new technical revolution will not help much, and in some cases, could even worsen disparities. Those reflections have been formulated in other contexts (bioethics, for example), but some are considering that CTs are developing those interrogations in a new direction where the lessons from the past may not be necessarily useful.

2.2. Acceptability

Throughout the literature, one may identify several issues, which are commonly raised, as far as potential risks of CTs (see also(79), (67) and (25)) are concerned :

- Toxicity of Nanomaterials and Nanoparticules : the fear of commercialization of nanomaterials or harmful components that could "crumble" during their use or finally degrade the environment is one of the risk the most mentioned (and studied) ;
- Privacy and chips : the growing risk of an individual losing control of information about his or her private life when confronted to an environment where digital information is all around, being processed, transmitted and stored ;
- Human implants, such as RFID or "smart dusts" in the human body, allowing the marking of individuals (for surveillance purpose) but also raising issues regarding the biocompatibility on the long run ;
- The military use of CTs and the cyborg myth stressing out the fear of human enhancement and self-replication of (nano)machines ;
- The impact on the economical development of regions and countries, and in the same spirit the risk related to intellectual property used as a tool ;
- Last but not the least, the "Gray and green goo", dramatic symbol of the vision of CTs.

It might be useful to learn from some previous experience : when one consider nanotechnology there are many parallels with the debate over GM crops (41). In the study of potential risks, it is important to remember that any risk must be balanced with benefits, and that risks may only be present in certain contexts. In certain circumstances, inaction itself may lead to a worse outcome. In addition, it is important to take account of the viewpoint of different cultures and populations that have the potential to be radically different. What may be an acceptable risk to one group may be totally unacceptable to another (41).

Acceptance of new technology necessitates an understanding of not only the science behind them, but also the value of this technology to society. What is often necessary is not to focus on a future development that may have a major and comprehensive impact on society, but to explain and describe the processes in between (41). There is a difference between simply delivering information on ethics to the public and engaging the public in "ethics talk" about a new technology (41). There is also a risk in speculating about the potential dangers of nanotechnology as this might weaken public support for it and thus hinder the many positive aspects nanotechnology could bring about (40).

Bainbridge has conducted a qualitative analysis into the public perception of nanotechnology based on an Internet survey (40). His study revealed "a high level of enthusiasm for the potential benefits of nanotechnology and little concern about possible dangers". As one might expect, the public mentally connected nanotechnology with other areas of sciences such as the space program, nuclear power, and cloning research, but viewed nanotechnology in a more favorable light. But this study has to be consider for what it is : a very limitative work with some slanting. Firstly, it is an Internet survey, so we can suppose that people have a favorable opinion on new technology. Secondly, the sample was too small to be representative. So, we think that it is very risky to extrapolate general tendencies from this analysis and apply it to a European context. We recommend to consider it as a point of view, like other ones.

We can also use a risk perception criteria list which is more or less based on Covello's work [21] :

- The first series of criteria is based on the way that individual people are dealing with the risk : How familiar they are with the potential hazard, do they understand it, are they personally implicated, what is the probability of realization, do they accept it, do they feel they control them ;
- The second one deals with the nature of the risk : will it be a catastrophic one, do we have some experience about it, is it a long term perspective, could we reverse the consequences, will the children be affected, do we know the potential victims ;

[21] V.T. Covello, "Social and behavioral research on risk : uses in risk management decision making", in *Environmental impact assessment, technology assessment and risk analysis*, Springer, Berlin, 1985.

- And the last one is about social managing of the risk : do we have an equal repartition of the risk accross the population, are there any beneficial counterparts, could we trust our institutions and what is the media exposition of the risk.

Listing those questions and trying to have some answers is a good way to evaluate how acceptable the risks are.

To conclude on this aspect, we can just suggest that some of the technologies on the horizon pose risks that tend to be less acceptable than many ordinary risks of life and that they will be introduced into an environment that may be less resilient than it once was. The chemical technology experiences since World War 2 suggest that we should approach new technologies with considerable humility and try to ensure that they do not escape social understanding and control as many chemicals have (29).

Acceptance is dealing with the existing or so predictable risks. Participation is about the development that we want. How could we imagine a more developed public participation in such a complicated scientific field ?

Today, it seems difficult to predict how nanotechnology will change our future because it requires foreseeing how it will affect society and, in return, societal and economic forces will shape it (31).

Currently there is a widespread confusion between the reality of nanotechnologies (in the short term), their potential (in the medium and long term) and the "stuff" of science-fiction, and not only on the part of general public (37). In the media, articles are predominantly very positive. Nanotechnology is often mentioned as an example of an advanced technology. If criticism is mentioned, it rarely adresses the risk of nanotechnology but more often problems in the utilization of project results, the lack of funding or describes nanotechnology as a momentary hype. The solution rests on solving media issues since the media is responsible for amplifying and attenuating information for the public. Then the public should be well served and can participate in stakeholders. According to Roco (quoted in (34)), "education and training (in scientific concepts at the nanoscale) must be introduced at all levels, from kindergarden to continuing education, from scientists to non-technical audiences that may decide the use of technology and its funding".

At a time when nano-scale technologies and their convergence are developing faster than public policies can evolve to adress them, it is critical to broaden the community of participants who play a role in determining how nano-scale technologies will affect our future (37). But the public's understanding of nanotechnology is low. So educating the everyday person on nanotechnology and nanoethics is important for oversight and to drive industry responsability (37).

As nanotechnology is among the first areas of research where such public dialogue is started in a very early stage of development, when there are still few products on the market, dialogue projects are an experiment in themselves. So, it is a unique occasion to have a pro-active approach of the ethical and public participation questions by opposition of what has been done with GMO development.

Dr Matsuura (quoted in (40)) discussed at the Nanotech 2004 conference in Boston (March 7-11) that public perception of nanotechnology is perhaps developing along a similar track as with biotechnology : "Like those of biotechnology, the first applications of nanotechnology will bring little obvious benefits to consumers. Better, cheaper materials, and hidden manufacturing efficiencies that benefit producers first, are redolent of the « advantages » of biotech namely reduced applications of agricultural chemicals, which help to keep the cost down while raising yields. Obvious consumer benefits, such as the improvement of medecine etc., are further away".

Open questions

Utopian dreams vs. apocalyptic nightmares [22] *: the influence of extreme positions in current debates*

Current public debates are still dominated by positions overstating the promises of nanotechnologies and CTs, and opponents emphasizing potential catastrophes [23].

The "nano-hype" has predictably given birth to strong criticism. As a matter of fact, some experts emphasize the fact that the "nano" prefix has often been used to re-label some S&T fields, such as catalysis or thin film technologies. As The Economist states it, "nano-enthusiasts" are "recklessly setting impossibly high expectations for the economic benefits". The same comment would apply to CTs.

In fact, as Greenpeace underlines it (69), when the US National Nanotechnology Initiative was launched, with potential breakthroughs such as "making materials and products from the bottom-up" (mainly derived from Drexler's vision), little serious investigation of their feasability was carried out. Greenpeace's opinion is that, although "molecular manufacturing holds significant promise", it remains the "least concrete" of all the technologies under consideration.

As a consequence, most public debates on nanotechnologies and CTs are "unstable" and confused, and might result in violent rejection reactions and unnecessary backlashes.

[22] This title is inspired by an article by B. Gordijn (38).
[23] This tendency was underlined in the STOA report (1), which recommends a "down to earth attitude".

Moreover, another limit of current debates is that they are often dominated by all encompassing generalizations.

For these debates to be fruitful, more moderate (and realistic) arguments are needed, for both the public and the policy makers. In particular, a clearer distinction between short-term applications and more visionary (and sometimes, highly unrealistic) aspects is essential : as R.A. Wolkow states it, "distinguish the ruse from the reality" (82) [24].

Practically speaking, in each debate, a first step would be : what are we precisely talking about ? Speaking of energy and the environment, what is actually relevant ? Should we definitely get rid of images such as "nanoassemblers" ?

Rational decision making under uncertainties and complexity: bringing the debate to the public

The notion of CT is difficult to handle for the civil population due notably (and without reduction) to its intrinsic complexity, the surrounding uncertainties linked to its development path, promises that are made on its possible applications, and the potential degree of transgression of basic individual values (or ethics) its plain development may lead to (molecular manufacturing). However the (recent) past experience (notably with regard to GMO) is alerting the CTs community (scientists, industries, governments, regulators) on the need for a more direct determination of public values at each step of the CTs development process (upstream research orientations, technology assessment, standardization, normalization, public policies [25], etc.).

Thus, the co-ordination of environmental research in Europe on emerging issues, such as CTs, will certainly require the establishment of new approaches that are suitable to deal with the public participation, taking into account the complexity and the uncertainties [26]. According to the current moderated position of several opinion groups (such as Greenpeace for example (69)), one may expect a constructive debate on the topic of CTs as long as this issue is properly handled as up to now.

This is raising several issues that could be discussed by a working group :

- What can be learnt from the past (Vision of the future related to the nuclear power in the 50's, perception of robots in the 70's, debates on GMO and the biotech in the 90's, ...) in term of public participation ?

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[24] As P. Litton suggests it, "we should not spend resources developing the ethics for a Drexlerian world. Predictions about the underlying science and technology are simply too speculative." (31)
[25] The "public participation principle" is one of the foundations of "Environment policies".
[26] As the UK government states it, "Enable citizens to understand and reflect on issues related to nanoscience and nanotechnologies, both personally and through inclusive processes involving citizens, policy-makers and researchers" (18).

- What are the specificities of CTs (with regard to nuclear, GMO, etc.) regarding people basic needs and desires hierarchy (According to Maslov (1943): (1) Physiological (2) Safety (3) Social needs (4) Esteem (5) Self-actualisation) that could constitute barriers/drivers for the plain development of CTs ?
- How to achieve a proper communication on this topic that is difficult to handle ? As recalled by Julien Colin (author and director of the French movie "Le silence des Nano" (81)), a huge amount of (good) information [27] is already available on the Internet to forge individual opinion, so this is not only a question of accessing the information, but merely to organize its communication and its understanding.
- Several groups of influence (ETC group, Greenpeace, Fondation Sciences Citoyennes) are requesting the generalization of "conferences of citizen" to accompany each stage involving decisions related to CT development (comprising the decision to finance or not some research). Is this approach suitable ? What is the real costs of this ? Who will take the charge for this cost ? What is the risk of not doing it ? In this wide domain (CTs) how to prioritize topics/issues to be handled ?
- What is the "right place" of the citizen voice in the debate (can they have the final decision ?). How to ensure that the viewpoint of different cultures and populations is taken into account ?

[27] All the material included in his movie (information, video) has been found freely on the Internet.

3. Governance and regulation

According to Chris Phoenix , there are three ethical systems (quoted in (41)) :

- Guardian : ensure security and maintains the status quo. Such a system is governed by tradition, loyalty and authority and must be incorruptible.
- Commercial : ensure increased value through trade. Such a system is governed by negociation, competition and industry, and must be capable of adapting to new situation.
- Information : ensure increased knowledge through dissemination. Such a system is governed by honesty, cooperation and idealism and must be freeely accessible to all.

One question is : which one should be the more adapted to the new field of converging technologies ? In fact, there is no clear answer and the good attitude is maybe in a combination of these three regulation systems. The state authority and researchers are some kind of guardian and incarnation of our common interest. They should be the more powerful part of the regulation system that we need to manage the development of CTs. This assertion implicates that there is a specific responsability for the public authority which could have some legal implications. Commercial is more represented by firms. They are here to place some technological innovations and development in the real market world. They also have an important responsibility in terms of products and the conditions of the production. At least, information is a growing needed of the developed nations who want more transparency and public participation. Considering these three kinds of regulation we can say that converging technologies does not need a very new system, but should implicate a new balance of power between the three classical decision's poles of a society.

In a so risky research, we can defend some prudent approach in terms of valuation of the research on the commercial market, but also in the management of the research itself.

Considering the commercialization of NBIC technologies, many ethical discourses propound the value of "precautionary principle" :

- Taking precautionary action before scientific certainty of cause and effect,
- Setting goals,
- Seeking out and evaluating alternatives,
- Shifting burdens of proof,
- Developing more democratic and thorough decision-making criteria and methods.

Considering the management of the research, the safest opinion (CRN : Center for Responsible Nanotechnology) is the creation of one – and only one – molecular nanotechnology program, and the widespread but restricted use of the resulting manufacturing capability. Some activists groups are also calling for a moratorium on research involving nanoparticules until we understand their hazards (31).

A proper framework of governance shoud be as follows (46) :

- It should be designed and provided with ressources at the early stages of conflicts emerging.
- It shoud take care of all « Meta » issues : are this issues tackled in the framework and how ? When some of this issues are excluded, where will they come in then ?
- It should design for a long period of time, generally for several years.
- It should be framed by governments and the political context.
- It should have legitimating structures or processes, under S&T and NGO's.
- Framework should have a flexible content related to the state of affairs. In the beginning of an articulation of value and risks, reflection, studies, etc. Later on, there is an increasing requirement for negociation and political decision-making.
- No framework should exist without a monitoring device. It should be exercised by independent authorities on a frequent basis.
- Case-by-case conclusions and decisions on value and risks should always have "preliminary" status.

During the process, visions – and perceptions – might change :

- Framework should always be based on proper regulatory pillars, it should be governed by the rule of law, but in choosing the regulatory framework one should explore worldwide best practices and always be guided by proportionality. Soft legal framework (for instance of codes and conducts) which support the autonomy and responsability of the actor's as a community are prefered.
- Framework shoud be transparent and under Parliamentary control.
- Public discourse in which media are involved is prerequisite for getting wider legitimation in society as a whole.
- In most case specific institutions are created to organise the setting (also suitable for negociations).
- Governments should design framework in which S&T are forced to engage in a more or less continuous constructive dialogue with societal partners.

As we can see, there is a specific reponsability for political control of CT research and development. The legal transcription of these responsibility has never been defined specifically, but we can suppose that it will be on the same framework than the ones in use for GMO or every new hazardous technology.

In an immature technology like converging technology related to nanotechnology the emphasis should be on (46) :

- Conditions for reflection and expert discourse,
- Monitoring systems for early warning signals,
- Interactive cooperation of S&T and subsets in society in order to construct new ideas and language on specific issues,
- Systematically public and media debates on the results of these monitoring and deliberating procedures,
- Specific measure should be taken for risk assessment. In most case, risk assessment is embedded in formal admission procedures for experiments and the introduction of products in the marketplace. Very often, these procedures cover more than one link in the production chain.

Considering some bad experiences in a recent past (technological incident or accident with nuclear power or chemical plants), there are three very high needs (36) :

- Transparency : public must participate to the debate and the decision. A pure technocratic governance is not still acceptable.
- Responsibility : research needs public funding. So, researchers have to communicate their projects and results in a comprehensive language and also pay attention to the consequences of their work on our way of life.
- Governance : we have not to consider only if an innovation is acceptable, but also if it is desirable : do we need it, do we want it ? These questions necessitate a high public implication on the research governance, and not only a private talk between experts, researchers and politics.

As we can see, there is some very specific responsibility for the public authorities and the researcher in terms of information of the public, but also in terms of decision (evaluation, autorisation, funding, etc.) .

The response to those questions have been different in some european countries (36) :

- In the Netherlands, the answer has been a constructive technology assessment, which means that the decision is an arrangement between numerous actors.
- In the United Kingdom, the answer has been a public engagement in science, which means a more political and social approach. Public needs and fears benefit to high level of consideration and are the basis to the dialogue with the researchers.
- In Germany and France, we are looking for a symbiose between science and culture. This means a more ethical and philosophical approach which pays attention to the values and the sense of the research programmes. Those informations comes from the researchers' actions.

Open questions

Adapting the regulatory framework : the question of the applicability of the current regulatory framework

The regulatory framework relevant to nanoparticles and nanomaterials ("bulk nano") is currently under review, especially in Europe (5) (32) (49) ; this analysis is motivated by the fact that some products are already marketed. Examples of applicable directives are :

- IPPC directive (Integrated Pollution Prevention and Control) : this text defines rules for permitting and controlling industrial installations, and aims at reducing the pollution resulting from various industrial activities ; it would concern nanoproducts manufacturing activities (49) ;
- dangerous substances and REACh : the basis of the regulatory framework for chemical substances was the Directive 67/548 ; the latest evolution of this framework is the regime change introduced by REACh (Registration, Evaluation, Authorization and restriction of Chemicals). Concerning REACh and nanoparticles, two potential limitations are identified (49) : the quantitative thresholds necessary to trigger registration (compared with the small quantities of nanoparticles currently produced) ; the fact that the same substance can have different properties in the nanoscale form than in another form (especially in the bulk form), an aspect that is not taken into account in the dangerous substances regulations ;
- fuel additives : this is an example of regulation for a particular category of products. It is based on Directive 98/70 on the quality of petrol and diesel fuels, which would apply in the case of nanoparticles used as fuel additives (cf. §1.1), although this text does not currently provide any requirement for this particular category (49).

Concerning nanofabrication and nanobiotechnologies, this analysis remains to be done. The listed directives might be completed by other texts, such as the WEEE directive (Waste Electric and Electronic Equipment), which potentially concerns any electric and electronic nanosystems (sensors, for example) ; the new waste framework directive (under negociation), which will have an impact on the conception of *any* product (in terms of recyclability, for example) ; the environmental liability directive, which defines a general framework for hazards affecting the environment ; the product liability directive, which defines a general framework for the damages caused by "defective" products ; etc. Moreover, there might be significant differences between member states (39).

More generally speaking, this raises the question of the regulatory framework that would apply to CTs. Is there a need to define regulations specific to CTs, equivalent to what was done with GMOs ? Or should we rely on existing texts, which should be interpreted through specific case law ?

Moreover, as a first step, a preliminary question has to be answered : is it possible to clearly define (in legal terms) and qualify the objects under scrutiny ? For example, labelling an object as "living matter" or "non-living matter" subsequently determines the regulations that apply. Do "hybrid objects" make any sense from a legal point of view ?

Governance defines what we want and who makes the choices. Regulation systems deals with the management of the decision. The first question related to CTs is the specificities of this S&T area. Governance and regulation systems have been discussed in the separate areas (bio, nano, IT) but with different interpretations. We can ask if CTs need a specific governance practice and regulation system, if we can extrapolate from the past reflexions or if we will have to do a synthesis of former works on partly related subjects.

A second question is related to the time. CTs may be longer to develop than what we have observed in the precedent technological main progress. So, we can define by advance what is desirable and what is not in terms of development and pay more attention to the public / common interest. This possibility implicates a high level of quality but also a pro-active approach, which is a relatively new opportunity if we consider the history of sciences and technology in the recent past.

We also have to ask who can take this decision and what is the management system that we can imagine. This requires a good repartition between technological expertises and the necessary vulgarisation of research, political decision and public participation. So, we can debate on the influence of each of this category on the decision. A fourth category, which is not so often mentioned in the literature, are private firms. On those very risky developments, many people think that they will not apply the precautionary principle ; however, insurance companies may have a strong incentive role [28]. What the role of private firms should be in the

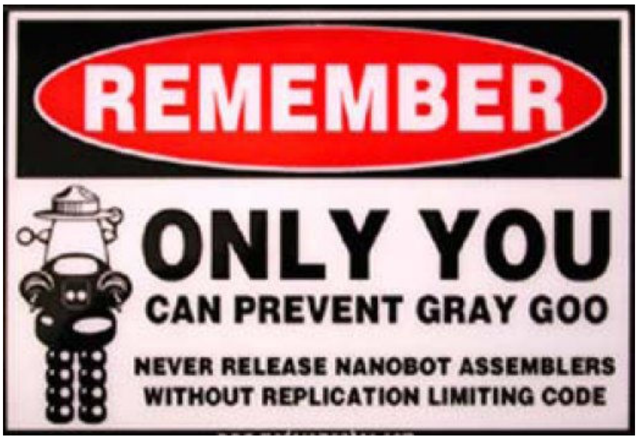
[28] See for example the report prepared by Swiss Re : "Nanotechnology: small matter, many unknowns", 2004

governance and regulation system needs to be debated. Their contribution should be good for a more realistic approach on what should be developped what is so far that we are not concerned in a short time.

Those questions also introduce the question of the legal responsibility for the different categories (including governement) and the transcription of the precautionary principle in the law. In a very concrete way, this is also questioning the construction of the expertise on those very complex scientific fields with diverging evaluation methodology, for example, between living sciences and nanotech.

To conclude this part on the governance and regulation systems we have also to place the question on an international scale [29]. Some of the promises of CTs are related to the environment and may have planetary effects (positive but also negative). So, this concerns the North / South relations and the place of the decision. This is not an usual question if we consider that, in the past, every country (and the EU) has had its own approach. But, one of the specificity of CTs is their high potential of dissemination and the fact that we may have some time before they will product their main effects. This should be an opportunity for a new worldwide governance about environment impacts of new technologies. What could be the right place to discuss this question ? How will the decision making work ? What will the regulation system be ? An international dialogue is needed, we cannot limit ourselves to purely European debates.

[29] Concerning nanotechnologies, an example is the Alexandria process, started in 2004 (44), which consists in an international dialogue on "responsible nanotechnologies".



(illustration available at http://nanobot.blogspot.com/ ; see also http://www.boingboing.net/2004/06/16/only_you_can_prevent.html)

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