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RÉPUBLIQUE FRANÇAISE

PREMIER MINISTRE

Centre d'analyse stratégique

November 2011
No. 248
LA NOTE D'ANALYSE
Sustainable Development

Toward a responsible development of nanotechnologies?

Will nanotechnologies bring a revolution in industry – and even in lifestyles– in the 21st century? Nanotechnologies have resulted from advances in knowledge of matter at the scale of a billionth of a meter (10^{-9} m) and the possibility of manipulating such matter. Nanotechnologies are extremely heterogeneous, touching on a vast array of scientific disciplines within physics, chemistry, biology and engineering sciences. As a source of incremental change and, potentially, of technological disruption, they involve all sectors of economic activity and could generate considerable markets. While they have only recently begun to develop (in the early 2000s), many countries have invested massively in R&D and are competing intensely at the international level. These new technologies raise a lot of hopes, but uncertainties are considerable. Some nanomaterial-based applications carry toxicity risks for health and the environment. Later-generation nanotechnologies, which are at the interface with biology or information technologies, are raising ethical issues that must be addressed before nanotechnologies are unleashed on the market. How can we ensure the harmonious and consistent development of these technologies in the service of society? Answering this question emphasises that the quality of innovation will depend on the quality of governance, and on our ability to collectively control the development of nanotechnologies. ■

PROPOSALS

1. Following countries like Germany, the United States, etc., France should develop a strategic plan to structure its action and explain its policy for a responsible development of nanotechnologies.
2. It should also support the creation of an intergovernmental panel on nanotechnology-induced changes.
3. It should involve the general public and all stakeholders upstream and throughout the nanotechnology development chain.
4. It should prepare the competitive landscape of tomorrow by developing a perfectly integrated nanotechnology industry.
5. Preventing health and environmental risks should be taken into account along three channels: to stabilise materials from the design stage, to measure nanoparticles and make them traceable, and to control exposure.

CHALLENGES

Over the last decade, nanotechnologies have taken off on a global scale, as have the inflated promises and fears that they engender. Some argue that they offer the prospect of a new industrial revolution with the potential to improve our lives, while others believe they are a threat to the very human condition. Most people, however, are mainly ignorant of the issues that nanotechnologies raise. This has all created a great deal of confusion. As cross-disciplinary technologies straddling all economic sectors, they have received massive investment in R&D in recent years from many countries. But they raise many questions that are essential for their development: How to manage health and environmental risks incurred by nanoparticles? What ethical issues do they raise? How can they be developed responsibly?

The purpose of this paper is to take stock of the challenges engendered by nanotechnologies, and then to pave the way for further discussion on how these emerging technologies could be developed responsibly.

NANOTECHNOLOGIES : WHAT ARE THEY EXACTLY?

A shifting definition that is nonetheless essential

The term "nanotechnologies", sometimes abbreviated as "nanos", has been used increasingly in recent years without any consensus on a clear and single definition. Nanosciences are generally considered to involve all research and knowledge aiming to understand and use the new physical, chemical and mechanical properties created when shifting the dimensions of objects to the scale of a billionth of a meter[1]. Nanotechnologies include instruments, manufacturing techniques and derivative applications that exploit the special phenomena that occur at this nanometric scale. However, since being coined in 1974 by a Japanese researcher, the term "nanotechnologies" has drifted far and wide, with everyone – scientists and non-scientists, among scientists themselves, regulators, companies and environmental protection associations – every one having his own vision of what nanotechnologies are. To avoid turning into a genuine "tower of Babel", the highly heterogeneous field of nanotechnologies must be based on a set of operating definitions. The pre-standardisation in progress within international (ISO) and national (AFNOR) standards-setting organisations aims to establish a common language that can be used by different actors in different countries. This common language is a prerequisite to developing and regulating nanotechnologies: drafting and adapting legal frameworks (e.g., revising REACH[2] so that it applies effectively to nanomaterials[3]), streamlining industrial production, certifying their products for companies, settling litigation, etc. While much remains to be done in defining, describing and naming the nanoworld, the definition of a nomenclature has already made much progress, particularly for nanomaterials[4].

From nanosciences to nanotechnologies

In the 1980s, advances in microscopy (with the invention of the scanning tunnelling microscope in 1981) made it possible to observe matter with unprecedented resolution, i.e. on

(1) Order of magnitude of the distance between two atoms in a molecule.

(2) European regulation on the registration, evaluation, authorisation and restriction of chemicals.

(3) Nanoparticles are currently outside the scope of REACH, as they are often produced in quantities below the production threshold of 1 tonne/year triggering an obligation to study their toxicity.

(4) First ISO document published on 15 August 2008: "Nanotechnologies – Terminology and definitions for nano-objects: nanoparticles, nanofibres and nanoplates", ISO/TS 27687. A nano-object is defined there as having one or more dimensions of nanometric scale, a nanoparticle, three dimensions of a nanometric scale, a nanofibre 2, and a nanoplate 1.

the atomic scale (0.1 nm). At this scale, matter possesses special properties that, in some cases, differ from the properties of the same materials at greater scales, including mechanical resistance, chemical reactivity, electrical conductivity and optical properties. This led to the discovery of new, previously unknown arrangements of carbon molecules, including the fullerene in 1985 (60 atoms of carbon arranged in the form of a ball), carbon nanotubes in 1991 (plates of carbon atoms forming hollow tubes), and graphene (carbon crystal planar sheets) in 2004. The latter arrangement of carbon seems to offer considerable potential applications (including replacing silicon in electronics). Research has gradually made it possible not only to observe, but also to control and use the special properties of matter at the nanometric scale. Materials with interesting and sometimes unprecedented or spectacularly modified properties have thus emerged (*Inset 1*).

A new industrial revolution?

Nanotechnologies cannot only be linked to one scientific discipline. They straddle the traditional borders between physics, chemistry, biology, mathematics, information technologies and engineering. In a way, they can be considered as a "toolbox" to modify processes and products ranging from mere incremental change (modification of the physical properties of a material by incorporating nanoparticles) to true technological disruptions (biology-inspired nanosenors).

The scope of their applications is extremely diverse, ranging from nanoelectronics to the vectorisation of drugs. This heterogeneous field is unified by the gradual rise of the ability to manipulate matter on a nanometric scale in numerous scientific disciplines. This gives nanotechnologies a "horizontal" nature, i.e., potentially irrigating a huge number of industrial and economic sectors. Their transformational capacities(5) have led some to consider that they will lead to an "industrial revolution" in the 21st century.

It is especially difficult to describe the landscape of nanotechnology applications, due both to their very great diversity and their lack –for the moment– of classification and systematic inventory. However, we can see families of applications linked by similar concerns and objectives, such as nanotechnologies applied to information and communications technologies, nanomaterials and nanobiology/nanomedicine.

Inset 1

A (non-exhaustive) panorama of nanotechnologies

Nano-objects are used either as such (for example, as catalysts for chemical reactions or as vectors to carry drugs to the target cells) or to develop nanomaterials(6). 70% of current technical innovations in nanotechnologies are made to enhance the properties of materials. They are being made in all industrial sectors, with numerous objectives: lightening and reinforcing (mainly for transport), properties of special surfaces (resistance, hydrophobia, adherence, etc.).

These include:

- nano-reinforced materials: incorporating carbon nanotubes into sporting equipments to modify properties, such as the ratio of resistance to weight;
- materials nanostructured in surface: for example titanium nitride coatings to prolong the life of cutting tools or antibacterial coatings of silver nanoparticles;
- materials nanostructured in volume: ceramic nanoporous membranes to filter water, for example.

In energy, the use of nanostructured surfaces could help enhance the yields of solar panels. Gains in autonomy are also possible for batteries, thanks to the use of electrodes designed on a nanometric scale.

In healthcare, a huge number of applications are being developed, particularly for diagnosis and treatment. Labs-on-a-chip uses a single drop of blood to detect a huge number of molecules, which enables faster and cheaper diagnosis. Vectorisation of drugs, which consists in integrating them into a molecular structure (for example, a liposome) to make them more effective, has already found applications in treating certain forms of resistant cancer, and research is being done to enhance the specificity of these vectors even more.

Microelectronics entered the world of nanotechnologies in 2003, when the thickness of patterns printed in integrated circuits crossed below the 100 nm barrier. Constant miniaturisation now makes it possible to produce transistors with engraving thicknesses of 22nm. In addition to this top-down approach, nanoelectronics could

(5) The ability to transform uses and behaviour; the Internet is an example of a transformational technology.
(6) All materials possessing one or more internal or external dimensions on a nanometric scale.

radically reshape information media, for example by developing coding systems based on purely quantum systems (for example, coding information using the spins of electrons). These new molecular electronics are currently at the stage of basic research.

THE INTERNATIONAL NANOTECHNOLOGY LANDSCAPE

The state of the nanotechnologies market

Nanotechnologies are already used in a number of commercial applications. In 2011, the US initiative *The Project on Emerging Nanotechnologies*(7) inventoried more than 1300 commercial products incorporating nanotechnologies. Some studies(8) estimate the global market at 147 billion dollars in 2007, with predictions of about 3100 billion dollars by 2015. However, such estimates should be treated with caution, given the lack of inventory of industries producing or using nanotechnologies, as well as the lack of international nomenclature that could be used for comparisons.

Strong international competition

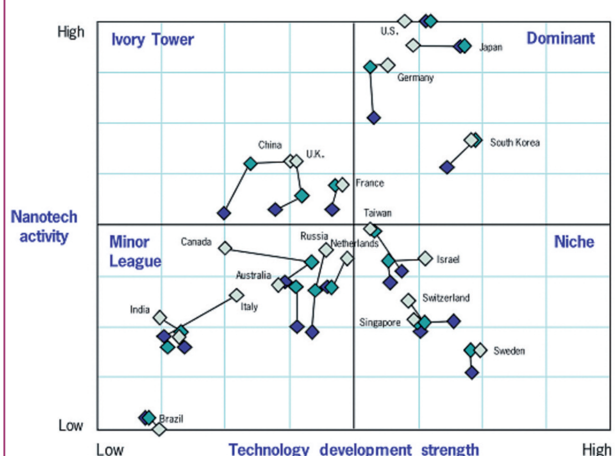
Since the launch of the US National Nanotechnology Initiative (NNI – *Inset 2*) in 2000, almost all countries have launched a national nanotechnology development program. Worldwide, governments are currently investing 10 billion euros annually in R&D in the field encompassed by the term "nanotechnologies". The United States dominates, followed by Japan and Germany. But aggressive entrants, such as China, South Korea and Russia are advancing fast according to the number of their publications and patents. For the first time, Chinese investment (in purchasing power parity terms) is estimated to have surpassed US investments in 2011(9).

France can improve in technology transfer and commercial applications…

However, sheer investment volumes do not tell which countries are best at translating research findings into economic benefits. A July 2011 ranking, based on a transfer efficiency indicator, pointed out that the United States were far ahead, followed by China, Russia, Germany, Japan, the EU, South Korea, Taiwan, the United Kingdom and India. France is not ranked in the benchmark, as it has thus far suffered from the "ivory tower" syndrome, i.e., good research activity, but inefficient transfer of technology into industrial and commercial applications.

Figure 1

Countries ranked on the strength of their nanotechnology research activities and their ability to translate them into industrial and commercial applications



Source: Lux research Inc (2009), *Nanomaterials State of the Market Q1 2009.*

… by getting greater value from its many nanotechnology research programs

To close this gap and to translate discoveries into industrial applications, France has established a set of mechanisms to support innovation: in micro and nanotechnologies, there are five competitiveness clusters to promote cooperation between companies, research laboratories and educational establishments.

Major funding programs for nanotechnologies have been set up, including *Nano-Innov*, which was funded in 2009 with 70 million euros granted for economic stimulus spendings and which focuses mainly on creating nanotechnology integration centres in Grenoble, Saclay and Toulouse. In nanoelectronics, the Nano 2012 plan, launched in April 2009, aims to develop and produce the next generations of integrated circuits. This five-year 2.3 billion euro R&D program, includes 477 million euros from the French State and 180 million from local governments,

(7) Project on Emerging Nanotechnologies, *Nanotech-enabled Consumer Products Continue to Rise*, 10 March 2011.
(8) Lux Research Inc (2009), *Nanomaterial: State of the Market Q1 2009*.
(9) Cientifica Ltd (2011), *Global Funding of Nanotechnologies and its Impact*, July.

partners CEA-Léti, STMicroelectronics and other members of the Minalogic competitiveness cluster (located in Grenoble).

Under the program "Investments for the future" and on top of the Nano 2012 plan, the French government allocated in 2011 135 million euros to nanoelectronics[10], 80 million euros to nanotechnology research equipment, and 15 million euros to six nanobiotechnology programs.

France is also an European leader on the market for nanocomponents for embedded systems. However, the potential of nanotechnologies in biology and healthcare is still underdeveloped.

Inset 2

Ten years of nanotechnologies in the US: an assessment of the NNI progam

Led by an influential group of American researchers and political leaders, who early on glimpsed the possibilities offered by nanotechnologies, the United States designed a federal program in 2000 to fund nanotechnologies, called the National Nanotechnology Initiative. 14 billion dollars have been invested in this program, whose budget has risen five-fold in 10 years. NNI was aimed to coordinate the various federal agencies to protect them from their relatively isolated functioning practices, and in order to develop an explicit and consistent strategy for developing nanotechnologies in the US. Under NNI, a "signature initiative" was set up in 2011 for the funding of targeted projects (nanosolar, nanoelectronics and nanomanufacturing), in which at least three agencies must cooperate.

The environmental and health impact of nanomaterials was a neglected issue when NNI was set up, but has been studied intensely in recent years.

An assessment of the NNI after ten years of implementation

The program has been successful in its difficult task of coordinating and getting different agencies to work together. The other positive point is the formalisation of an all-encompassing, consistent program with set priorities and allocated R&D funding. The program is evaluated periodically by two independent bodies, which has improved it constantly over the last 10 years. The United States has built upon this program to develop a solid research infrastructure, on which it is relying to move to an intensive phase of transfer to industrial and commercial applications in the coming decade.

The context in which NNI was born is especially interesting and instructive. NNI was developed in by Mihail Roco, co-author of the report *Converging Technologies for Improving Human Performance*[11], who is well known by specialists for his unique vision of the end objectives of NBIC convergence[12], i.e., the enhancement of human performances. As a result, NNI was promoted to decision-makers in the United States without the end results of the technology development being discussed.

For example, while NNI has citizen participation features, they are not supposed to discuss the end objectives and directions of research, but merely to work on "acceptability".

All in all, NNI's organisation and pragmatism are attractive, but its underlying philosophy is more questionable *(Inset3)*.

CONCERNS OF VARIOUS NATURES

Risks for health and the environment

Because of their size, nanoparticles can cross the barriers that separate the outside from the inside of an organism and even enter various organs, including the brain. Their special properties at the molecular scale, combined with a high surface-to-volume ratio, which greatly increases the available chemical reaction surfaces, endows them with great capacities to interact with living tissue at the cellular level. Toxicology research in recent years has started to deliver laws and principles of these new and complex interactions (e.g., auto-immune diseases). However, despite advances in metrology and the characterisation of nanoparticles, we still know little about the potential effects on health and the environment of their large-scale dissemination. Meanwhile, most of the data from manufacturers using them are for the moment neither available nor systematically collected. The life cycle of nanoparticles, from production to its end of life, remains unknown and, hence, an issue of public health. Some initial findings have emerged over the recent past years from extensive research conducted on nanotoxico-

(10) Speech by Éric Besson, "Pour que la nanoélectronique française soit à l'avant-garde des grandes ruptures technologiques, nous soutenons l'innovation", 21 July 2011.
(11) Mihail R. and Bainbridge W. (2002), *Converging Technologies for Improving Human Performance*, National Science Foundation.
(12) For a definition of these terms, see Inset 3.

logy. They show that assessing the toxicity of all nanomaterials on a case-by-case basis is not sustainable. According to some studies[13], it would take almost 50 years just to test the toxicity of all the existing nanomaterials; testing just 2000 substances annually could cost 10 billion dollars, and require sacrificing a large number of laboratory animals every year for in vivo toxicity testing[14]. Hence, instead of testing the toxicity of nanomaterials on a case-by-case basis "at the end of the pipe", the idea is suggested to try to mitigate the potential risks of nanoparticles during the design stage rather than downstream (the "safe by design" approach[15]). As the risk for health or for the environment depends both on toxicity and exposure, it is possible to limit the risks by intervening at the design stage on different parameters (e.g., the minimum size of agglomerates to keep titanium dioxide particles in sunscreens from penetrating into the skin, nanoparticles integrated into a matrix to limit its toxicity, etc.).

Ethical issues and concerns raised by the societal impact of nanotechnologies

While toxicity issues are now discussed, regarding the use of nanotechnologies as materials, many other issues relating to emerging applications of nanotechnologies as systems will become more pressing. Ethical issues involved in the impact of technologies on lifestyles, freedoms and the nature of man – which have arisen in particular since the advent of ICTs– will be revisited in detail with the burst of nanotechnologies. Nanoelectronic applications, in particular in RFID[16] chips, bring to a new level the debate over the hyper-traceability of individuals, which could potentially trample on individual freedoms. Unprecedented ethical issues will probably emerge from the possibilities offered by the growing convergence and fit of nanotechnologies with other technologies, particularly biotechnologies, information and communications technologies (ITC) and cognitive sciences. Synthetic biology foresees the development of life-like biological mechanisms, and we are beginning to glimpse the possibilities of making a hybrid human body with active artificial (mechanical, electronic, etc.) mechanisms, and even "to enhance" the physical and cognitive performances of human beings.

In the words of the philosopher Jean-Pierre Dupuy: "Nanotechnologies are opening up an immense continent that man will have to normalize, if he wants to give them any meaning and finality. Human beings will have to draw fully on their reserves of will-power and conscience in determining not what they can do, but what they *ought* to do"[17]. More fundamentally, the erasing of the currently clear frontiers between the living biological being and the non-living one could profoundly affect what we consider to be human. For example modifying a person's cerebral activity by implanting nanoelectrodes, does it undermine human integrity? How will those who could not or would not want to access "enhancing" technologies be regarded? These are questions that have to be identified, asked, evaluated and mulled over collectively.

Inset 3

NBIC convergence and converging technologies

The term "NBIC convergence" refers to the many technological changes that will come from the joint exploitation and synergies of advances in nanotechnologies, biotechnologies, information technologies and cognitive sciences. More and more applications are being developed from converging technologies, including the creation of a brain-controlled synthetic hand with artificial sensitivity, using nanosensors or research conducted at the MIT Institute for Soldier Nanotechnology on combat fatigues for the 21st century, in which biological engineering, robotics and nanotechnologies converge to form an exoskeleton.

In 2001, the workshop held by the National Science Foundation (NSF) in the US, entitled *Converging Technologies for Improving Human Performance* presented a vision of the NBIC's convergence, with the long-term objective of modifying human beings' physical and intellectual capacities. Echoing the American approach, in 2004 the European Commission published a report[18] proposing a specifically European approach to the issue of converging technologies (CTEKS: Converging Technologies for the European Knowledge Society), which set itself off from the American approach by framing the development of these technologies in ethical terms, targeting the general interest and not individual enhancement. While the

(13) Choi J.Y., Ramachandran G., Kandlikar M. (2009), *The Impact of Toxicity Testing Costs on Nanomaterial Regulation*, Environmental Science & Technology.
(14) Motavalli J. (2010), *Wanted: Nano-Cops*, The New Haven Independent.
(15) Tinkle S. (2010), *Examining the Holy Grail of Nanotechnology: Safe by Design.*
(16) Radio Frequency Identification.
(17) Dupuy J.P. and Roure F. (2004), *Les nanotechnologies : éthique et prospective industrielle*, Conseil général des mines and Conseil général des technologies de l'information.
(18) Nordmann A. (2004), *Converging Technologies – Shaping the Future of European Societies*, European Commission.

possibilities described by the NSF in its report were then deemed "futuristic" and lacking in credibility, it is undeniable that new applications, formerly technically unimaginable, have gradually been made possible by the fit of different disciplines, generating a true "cluster of ethical issues".

For example the contribution of nanotechnologies and bioinformatics to biotechnology has been such that it has made possible the emergence of synthetic biology, a discipline that aims at "intentional design of artificial biological systems".

TOWARDS A RESPONSIBLE DEVELOPMENT OF NANOTECHNOLOGIES

Task forces are now at work on an international scale

The European Commission released in 2008 a **Code of Conduct for Responsible Nanosciences and Nanotechnology Research**[19] which expresses the will to define the major principles that should prevail for a responsible development of nanotechnologies. Coordination efforts are being made to pave the way to an international governance of nanotechnologies, including standardisation undertaken by the ISO or by a dedicated OECD working group. In 2004, an "international dialogue for responsible development of nanotechnologies and converging technologies" was set up on the initiative of the US NNI's head. The purpose of this dialogue, called the "Alexandria process"[20], which is open to all countries, is to anticipate potential conflicts (economic, ethical, etc.) between countries and to create the basis for a global governance in nanotechnologies. France takes active part in these international initiatives; and its continued involvement is crucial, given the stakes adressed by the international regulation.

These reflexions converge towards the idea that good governance will require to identify three key roles:

- the observation of changes brought on by nanotechnologies;
- the consultation with the public and all stakeholders;
- the decision-making, based on the contribution of observation and consultation.

FramingNano[21], the European research project, stresses the importance of dynamic governance, with a dialogue between consultation, observation and decision-making roles. Consultation with all stakeholders helps to identify the relevant criteria for assessing the changes brought on by nanotechnologies (benefits, risks, and systemic effects). The permanent task force on nanotechnologies, comprising experts from different disciplines, reports on the latest developments and changes brought on by nanotechnologies, based on technical, environmental, health-related, ethical, societal, legal, and economic impact criteria. Public decisions are thus informed by a panel of different stakeholders to take stock regularly. On the European scale, such a task force has been set up by the *ObservatoryNano*[22] project but must be made permanent.

The need for strong, transparent and open governance

In France, the public authorities asked the National Commission for Public Debate to organise a consultation on how to promote a responsible development of nanotechnologies. This debate was held from October 2009 to February 2010[23], and highlighted several items although it was disrupted by radical opposition from certain groups. First, the general public is grossly ignorant of the scientific aspects of nanotechnologies, but also of the related societal challenges. Moreover, the vast majority of stakeholders represented expressed the need for more

(19) European Commission (2008), *Recommendation of the Commission on a Code of Conduct for Responsible Nanosciences and Nanotechnology Research*. This code specifies in particular that the enhancement of human performances for non-therapeutic purposes is inappropriate and that decisions should be guided by the principle of precaution.

(20) In reference to the US city of Alexandria, where the first session was held in 2004, with representatives of 25 countries and the European Commission.

(21) Project from 2008 to 2010 to propose an international model for nanotechnology governance, based on an analysis of existing practices and the contribution of various stakeholders: http://www.framingnano.eu.

(22) Project from 2008 to 2012 to bring together European expertise in technological and economic analysis of nanotechnologies, as well as health, environmental, ethical and societal issues: http://www.observatory-nano.eu.

(23) For a concise presentation of the context and proceedings of the debate, see Philippe Deslandes, Chairman of CNDP (2010), *Bilan du débat public sur le development et la régulation des nanotechnologies*.

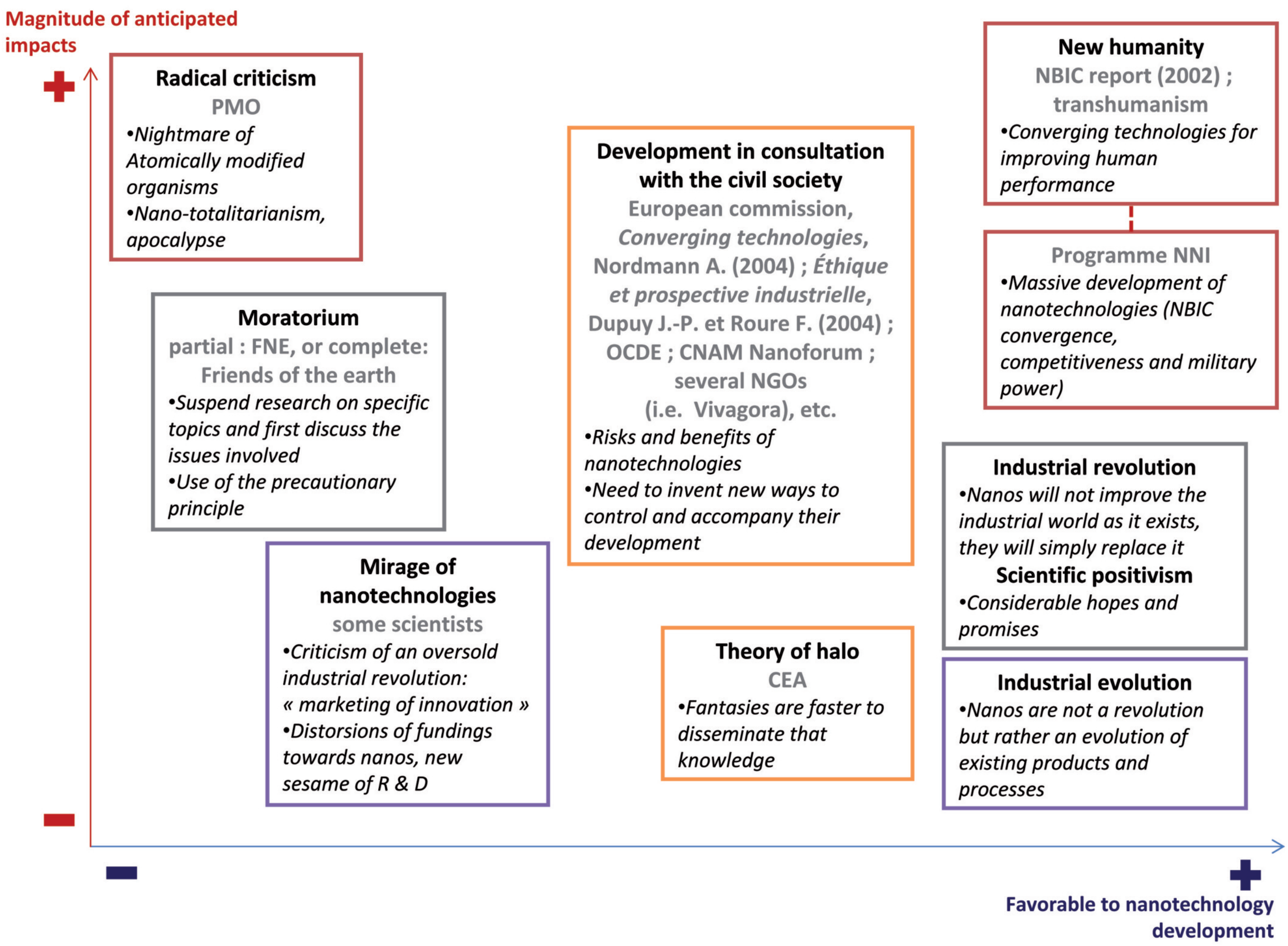
transparent and more open governance. Governance is the way in which we decide to share power: who makes which decisions? On which basis?

Figure 2 shows some views that are often encountered. Note that, for the moment, the missing person in this landscape is the general public.

Public debate was a first step, which needs a response to be useful and calls for sticking to a nanotechnology development policy that includes consultation with various components of the civil society in its operating mode. The many challenges raised by nanotechnologies – competitiveness, risk management, ethical issues and social

Figure 2

A plethora of stances and discourses on nanotechnologies



This chart is a simplified presentation that does not necessarily reflect the complexity of the stances of the various actors.

Source: Centre d'analyse stratégique.

acceptability – call for an innovative form of governance, in which governments and components of society interact dynamically to collectively determine the desired trajectory of development for nanotechnologies. This approach presupposes that some popular wisdom be set aside, like the belief that information and scientific training are enough to ensure the support of the general public to technological developments. In reality, studies[24] tend to show that laymen's opinions are based not so much on understanding and being informed of the special characteristics of nanotechnologies, as on the prejudices they have on technologies and the institutions that manage them. Here we can see the full importance of transparency in consultation procedures for obtaining informed trust from citizens: transparency on how decisions are made (i.e., governance), R&D funding, ethics, the end objectives of development, risk management, etc. Citizen involvement at a very early stage, based on procedures that must still be developed to a large extent, would allow nanotechnologies to develop in accordance with societal expectations. If, in the short term, regulation can be regarded as a barrier to developing markets, in the longer term, no doubt that it will constitute the main factor of the French companies' competitiveness in nanotechnologies, by creating a more stable and secure environment for investment and consumption.

PROPOSAL 1

Following countries like Germany, the United States, etc., France should develop a strategic plan to structure its action and explain its policy for a responsible development of nanotechnologies.

Many initiatives are being taken in France to develop and regulate nanotechnologies, but no strategic framework has been created as clear and explicit as, for example, the NNI in the United States. There are several good reasons to develop such an overall strategic plan:

- It would focus on the required efforts to boost an inter-ministerial approach, which is essential, given the cross-disciplinary nature of nanotechnology issues;
- It would be a tool of transparency *vis-à-vis* all stakeholders by stating the government's priorities, the programs that have been set up, the division of roles and responsibilities among the various institutions, etc.;
- It would clarify France's position and support its active involvement in European and international initiatives.

For example, the German plan is based on the following objectives: coordinating ministerial departments and supporting standardisation, accelerating technology transfer to industrial sectors, and carrying on an intense dialogue with the public on the opportunities and risks related to nanotechnologies. The Netherlands are especially active in the science/society dialogue and its plan for action includes the creation of a committee on which all components of the society are present to advise the government on ethical and societal aspects.

In order to design and implement this plan for action effectively in France, ongoing inter-ministerial coordination would have to be set up. A website, based on the comprehensive model of NNI[25] for example, would help relay the various components of the strategic plan.

PROPOSAL 2

It should also support the creation of an intergovernmental panel on nanotechnology-induced changes.

Setting up a permanent nanotechnology task force, which would make a running assessment of the technical, environmental, health, ethical and societal criteria would be an essential element of nanotechnology governance. Lending support to making the European *Observatory-Nano* task force permanent is the first step. Meanwhile, in France OMNT (the task force on micro and nanotechnologies), managed jointly by the CNRS and the CEA, already monitors scientific and technical criteria, but the other aspects must still be developed. Ultimately, the international dialogue for responsible development of nanosciences (called the "Alexandria process") could give rise to such a task force on the global scale, as a sort of "nano IPCC".

(24) European Commission (2010), *Understanding Public Debate on Nanotechnologies – Options for Framing Public Policy*.
(25) The NNI website offers background information on nanotechnologies, their major applications, the program's objectives and content, a full database of research projects, industrial partnerships, and numerous teaching tools and news on the subject; see www.nano.gov

PROPOSAL 3

It should involve the general public and all stakeholders upstream and throughout the nanotechnology development chain.

While many reports stress the need to involve civil society in defining and treating the challenges of nanotechnologies, it is clear that the shape that such participation should take is far from having been set. The field of citizen participation is mostly on a trial-by-error basis, and it is necessary to acknowledge both the importance of such involvement and its complexity. However, some keys can be found by analysing[26] the last five years of debates in Europe on nanotechnologies. Two complementary approaches to public consultation seem possible: it seems essential to set up permanent forums that are open to all stakeholders and whose objective is not to arrive at a consensus on a given issue but to express diverging points of view freely. Such a framework would help identify the scientific, ethical and social issues raised by these new technologies. A sample initiative of this type is the CNAM's Nanoforum, which, among other things, promotes territorial partnerships and helps structure civil society, which is essential to the debate. This first form of consultation does not aim to shed light on a particular political decision and is not intended to produce recommendations. As the development of nanotechnologies is still at an early stage, this phase of consultation and of anticipation of challenges, ethical and societal ones in particular, is quite possible.

In parallel, a second form of consultation could be set up at a later stage of the process, consisting in discussing a specific issue, in order to assist a given political decision. In this type of consultation, it is essential to pose the issue in clear terms, to present the different alternatives to the political decision and, once consultation has been concluded, to give transparent feedback to participants on how the findings of the consultation were taken into account. Without this feedback, there is a steady decline in citizens' trust in the institutions that manage the technologies in question, thus undermining the construction of informed trust of citizens in new technologies[27].

PROPOSAL 4

It should prepare the competitive landscape of tomorrow by developing a perfectly integrated nanotechnology industry.

The notion of a perfectly integrated nanotechnology industry, supported in particular in Germany, considers the development of nanotechnologies as a continuum from research to technology transfer and innovation to marketing to the end of the products' life cycle.

However, while conducting high level fundamental research (as seen in the number of scientific papers) and maintaining solid infrastructures in nanotechnologies, France looks less well placed for transferring discoveries to industry and commercial applications. In a perfectly integrated industry, as soon as an interesting material is discovered, its potential for industrialisation is verified, in order to avoid the heavy losses that occur from a failure when transitioning to an industrial prototype. There are central facilities that make clean rooms[28] available to nanoelectronics researchers and manufacturers; the equivalent does not exist for nanomaterials, for example. This type of platform would make it possible to rapidly test the potential for industrialisation, and also to integrate safety and security issues from the stage of material design. Based on the model of competitiveness clusters and technological research institutes, all initiatives promoting the interaction between research and industry should be encouraged in fields that are still little developed but highly promising, such as nanobiology and nanomedicine.

While staying at the forefront in nanoelectronics, a diversification of investments into the latter sectors, which are expected to expand considerably between now and 2015[29] could make it possible in the future to move in on promising markets.

(26) Rathenau Institute (2008), *Ten Lessons for a Nanodialogue – The Dutch Debate about Nanotechnology thus Far.*

(27) Plancher B. (2011), *La concertation au service de la démocratie environnementale.*

(28) An experimentation and manufacturing room where the concentration of air in particles is controlled to keep from interfering with the manufacture of semiconductors, most notably.

(29) Nanomedicine, which accounted for 2% of the nano market in 2007 could move up to 17% by 2015. Source: *Lux Research*.

PROPOSAL 5

Preventing health and environmental risks should be taken into account along three channels: to stabilise materials from the design stage, to measure nanoparticles and make them traceable, and to control exposure.

The risk to health and the environment is the combined result of two factors: exposure and toxicity. Recent shifts in the field of study of the toxicity of nanoparticles and nanomaterials call for a significant change in strategy. While further study into toxicity is, of course, necessary, a case-by-case approach is not possible, as each material is likely to possess its own toxicity. It is therefore necessary to support the development of approaches such as "safe by design", which aims to minimise the toxicity and risks of exposure to nanoparticles from the product design stage. This approach will require having toxicologists, physico-chemists, material specialists and other to work together.

In parallel, action must be taken on the exposure side. Precautionary measures must be taken to protect workers at nanomaterial production facilities. Real traceability and a systematic inventory of nanomaterials and industries using them, which is being developed, is a prerequisite, whose applicability and effectiveness must be ensured to prevent a counterproductive outcome.

France will have an important role to play in adapting REACH European regulations, in order to specifically include nanomaterials, or even to develop a "nano REACH" especially for nanoparticles.

CONCLUSION

Nanotechnologies are a major challenge for future growth, and France possesses high-level skills in basic research that it can exploit in these emerging fields. However, we are still far from truly understanding the applicability of nanotechnologies, and the risks and benefits that they present. To cope with these uncertainties, it is increasingly clear that these technologies will not reveal their full potential – in terms of societal benefits, as well as competitiveness– unless their development is controlled. An opportunity is emerging for an in-depth examination of what good nanotechnology governance should look like, and consultation will play a big role in it. Nanotechnology regulation could thus serve as a springboard to a broader examination of responsible development of new technologies in general.

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The author is grateful to Jean Bergougnoux, Éric Gaffet, Jean-Luc Pujol and Françoise Roure for help and comments provided for this paper.

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Note de d'analyse n° 248 - November 2011 is a publication of the Centre d'analyse stratégique
Director of Publication: Vincent Chriqui, Director General
Chief Editor: Pierre-François Mourier, Deputy Director general
Copy Editors: Delphine Gorges
Sylvie Hurion
Printer: Centre d'analyse stratégique
Copyright: November 2011
N° ISSN: 1760 -5733

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