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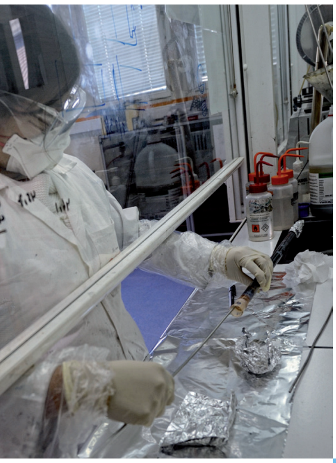
nano 2030

MANUFACTURED NANOMATERIALS BY 2030

Workplace health and safety consequences in small businesses in France



UBS Université de Bretagne-Sud
École des Ponts ParisTech
InVS Institut de Veille Sanitaire
issa
anses agence nationale de sécurité sanitaire alimentation, environnement, travail
Carsat Retraite & Santé au travail Alsace-Moselle
l'Assurance Maladie Risques Professionnels
suva

MANUFACTURED NANOMATERIALS BY 2030

Workplace health and safety consequences in small businesses in France

Notice to the reader

Forward planning is not a prediction of the future,
or a projection based on past trends.

Forward planning takes into account trends
and discontinuities to describe possible futures
and provide assistance in decision-making.

The scenarios presented in this collection
are the product of a joint effort and do not represent
the views or wishes of those participating
in the different working groups who contributed
to the writing of these documents.

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Message from the INRS Chairman and Vice-Chairman

"*Quelle France dans dix ans?*", a report on the future of France in ten years' time, published in June 2014 by *France Stratégie*, proposes 33 goals to achieve in the next ten years.

Among these goals are economic and technological targets such as:

- joining the group of European countries that are leading innovation,
- increasing the number of innovative SMEs to 50% of the total,
- increasing business R&D to 2% of GDP.

In addition, contextual aspects are addressed. France should aim to:

- be among the top-ten best OECD countries to live in,
- join the top third of European countries for employee satisfaction with work conditions.

When INRS decided to conduct a forward-looking study on the use of nanomaterials in small businesses in 2030 and their effects on occupational risk prevention, the consultation process for the *France Stratégie* study had not begun. Nevertheless, the decision to conduct this second forward-looking study at INRS was entirely consistent with a long-standing commitment of the INRS Board of Directors to produce data which can be used in decision-making when establishing the medium-term goals of the Institute.

It made sense, then, for the needs assessment carried out for our study to be similar in certain regards to the albeit more general one conducted later by other experts commissioned for the *France Stratégie* report submitted to the French government.

The question of preventing occupational risks linked to manufactured nanomaterials, a perfect example of an innovative product, in very small businesses, be they geared to research or production or whether they use these products, is consistent with issues addressed by the *France Stratégie* report: innovation – particularly in very small businesses – and respect for the individual, at his or her work station in particular, along with the creation of products that are safe for the environment.

This study, like those to follow, was conducted jointly by experts from different fields, as forward-looking research requires, in partnership with several organisations (Anses, CARSAT Alsace-Moselle, École des Ponts ParisTech, Institut Jean Lamour, InVS, ISSA, Suva, Université de Bretagne-Sud), in line with INRS's role as a partner in the occupational risk prevention network at the French and European level.

We would like to thank all of the experts and participants in this project, and the team which prepared this seminar over the last several months. We wish you an enjoyable and productive seminar.

Jean-François Naton, Chairman of the INRS Board of Directors
Marc Veyron, Vice-Chairman of the INRS Board of Directors

Message from the General Director of the INRS

When INRS launched its first forward-looking study, as Director General I emphasised the need for INRS to conduct this type of study and adopt a well-defined and robust method which ensures the traceability of the successive stages of the process and its results.
The Institute has made scientific rigour the cornerstone of its activities, and it seemed only natural that a forward-looking study should be carried out according to the same principles.

Beyond the factual components involved in defining variables, identifying breaking points and discontinuities, combining hypotheses in order to build micro-scenarios and then the scenarios themselves, the credibility of the process itself is at stake. Of course, no one expects a proposed scenario to occur in the future exactly as is; but the structure provided by the work method guarantees that the study was conducted in a coherent and organised manner; that all paths were explored, and that different hypotheses were submitted to a thorough and multidisciplinary joint review.

Identified risks and associated needs in prevention are also the result of pluridisciplinary efforts involving the different departments at the Institute which work in the identified domains.

Forward planning must also strengthen the Institute's ability to provide a global answer to workplace health and safety issues. Though it may seem purely academic, this exercise identifies workplace realities today and helps provide tangible responses to specific questions.

This collection of contributions is the reflection and guarantee of this rigour. Because it makes for difficult reading in some parts, I asked the production team to provide attendees with a shorter document that summarises the main features of the study. Not included in the first study conducted in 2013 on physically assistive robots, this is a new practice, and an important element: while forward planning at INRS must be based on a rigorous method, it should also be innovative in terms of methodology and communication.

For this reason, in close collaboration with the Institute's Board of Directors we are now working to develop a new study for 2015-2016 focused on the future of production in France by 2040 and the consequences in terms of occupational risk prevention needs. This study:

- will be more ambitious – carried out over a two-year period by an expanded team;
- will extend our focus outside the institute even more, since we envision working with dozens of experts from businesses, other prevention organisations and the academic world;
- will use updated methodology which enables more exchange between forward planners and experts – particularly those confronted with the day-to-day realities in the field and in risk management.

In conclusion, let me say again that INRS is solidly committed to conducting these forward planning activities within the framework of a diverse range of partnerships. Day by day, we carry out our work in a spirit of cooperation with all of our partners in the field of occupational risk prevention: this same context guides our examination of tomorrow's needs and the solutions we must deliver.

I am happy to report that in a sometimes difficult context, and despite the limitations we face, our proposals are well-received.
I would like to take this opportunity to express my gratitude to our partners.

Stéphane Pimbert, Director General of INRS

Methodology of the approach

Strategic foresight

Strategic foresight is not an exercise aimed at describing the future. It is not a prediction about the future which would be an extension of past patterns, because it takes into account probable discontinuities. It is a dynamic system exploring possible futures which therefore allows for the identification of desirable developments and assists in defining and implementing strategic policy. It is a tool for decision-makers providing them with decision-support elements enabling them to react better and faster to situations or events.

There are several foresight methods: the one chosen for this exercise is the “contrasting scenarios method”. It is based on a system of variables or a set of factors identified as having an influence on the future of the system being studied. The variation of these factors enables possible scenarios to be described.

The scenario method

This method consists in elaborating scenarios that describe possible medium and long-term futures according to the chosen time horizon. These scenarios are built based on a system of variables or a set of factors identified for which hypotheses about the future are formulated in view of the past and the prospects envisioned for each variable.

On the basis of the fluctuations of these variables, hypotheses are described and the combination of these hypotheses results in the building of scenarios. These scenarios therefore describe possible futures based on a rigorous system of variables identified.

Variables sheets

The key variables for the system studied are identified by pluridisciplinary experts from very diverse fields irrespective of the subject being studied (law, medicine, sociology, physics, toxicology, chemistry, etc.). Variables adopted are those that can influence the development of the issue: they must reflect the main trends and/or discontinuities in the field. It is essential for the group of experts to be as large as possible in terms of disciplines in order to take into account each aspect of the issue.

For each of the variables, a sheet is established. This sheet comprises a historical overview of the main trends over the last 20 years: the players involved, actual discontinuities and forecast discontinuities, etc. and a description of the potential future evolution of the variable.

For each sheet, hypotheses about the future emerge which are based on the observations made during the retrospective and future-oriented analysis.

These sheets provide a dynamic representation of the system, since they take into account mechanisms implemented and the way in which they evolve.

The hypotheses

The retrospective analysis identifies evolutions of the variable: dominant trends, major factors determining turns or breaking points in the variable in the past. These elements are used to build hypotheses. It is important for the hypotheses formulated to not be limited to desirable evolutions if the entire range of possible futures is to be taken into account.

Moreover, these hypotheses must meet a certain number of requirements: they must represent the entire spectrum of possible futures; they must be contrasting; they must be incompatible with each other and must fall exclusively within the scope of the variable.

Building exploratory scenarios

Scenarios describe possible futures that are or are not desirable. These scenarios portray an image of the situation at the time horizon envisioned. They are built based on the logical combination of hypotheses proposed for each variable. The scenarios described must be sufficiently contrasting so as to offer the largest (possible) vision of the plausible futures.

During the exercise, three or four contrasting scenarios are adopted. Only afterwards can the choice be made for desirable futures, strategic guidelines and implementation. Strategic foresight paves the way for political and/or strategic decision-making.

Organisation of this foresight exercise

This exercise was carried out by a working group comprising experts in different disciplines. All members of the group received the same training in the contrasting scenario method and then met on nine occasions over a period of ten months in order to establish exploratory scenarios. The foresight exercise was supervised by a steering committee and a support group, in charge of drawing up the repercussions on occupational safety and health.

The experts group

This group was in charge of defining: the methodology, and the scope of the foresight study (time horizon, territory, activities, actors, etc.), identifying the variables, formulating hypotheses, and building scenarios and analysing their implications. It was comprised of 15 people chosen for their expertise in the field of nanomaterials but also for their specialisations.

For this exercise, the group was made up of INRS personnel and outside experts:

- **Stéphane Binet**, Pharmacist-toxicologist, Carcinogenesis, Mutagenesis and Reprotoxicity laboratory, Toxicology and Biometrology Division, INRS
- **Nathalie Dedessus-Le Moustier**, Legal affairs advisor, specialised in labour relations, Université de Bretagne-Sud
- **Aurelie Delemarle**, specialised in the construction of markets for new products, Ecole des Ponts ParisTech
- **Stéphanie Devel**, Information officer, Horizon scanning and strategic foresight mission, INRS
- **Éric Drais**, Sociologist, Management and Safety laboratory, Working Life Division, INRS
- **Jean-Raymond Fontaine**, Physicist, Head of the Aerodynamics Engineering laboratory, Process Engineering Division, INRS
- **François de Jouvenel**, Historian, Director of *Futuribles*
- **Michaël Koller**, Physician and Biochemist, Suva (*Swiss national accident insurance fund*), ISSA representative
- **Éric Gaffet**, Chemist, Director of the Jean Lamour Institute, Université de Lorraine
- **Irina Guseva Canu**, Medical epidemiologist, InVS (*Institut national de veille sanitaire*)
- **Cécile Oillic-Tissier**, OSH practitioner and chemist, Carsat Alsace-Moselle
- **Martine Reynier**, Chemist, Executive Scientific Board, INRS
- **Myriam Ricaud**, Chemist, Chemical risk prevention expert, Technical Expertise and Consulting Division, INRS

- **Nathalie Thieriet**, Chemist, Science project leader, Risk assessment division, Anses (*Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail*)

- **Olivier Witschger**, Physicist, Aerosols Metrology Laboratory, Pollutants Metrology Division, INRS

The support group

It comprises:

- the division heads of INRS concerned by the foresight exercise:
  - Agnès Aublet-Cuvelier, Working Life Division
  - Alain Simonnard and Stéphane Binet (deputy head), Toxicology and Biometrology Division
  - Benoit Courrier, Pollutants Metrology Division
  - Michel Pourquet, Process Engineering Division
  - Jérôme Triolet, Technical Expertise and Consulting Division

- a representative of INRS's microenterprises/SME unit:
  - Marc Malenfer

- the Horizon Scanning and Strategic Foresight unit:
  - Michel Héry
  - Stéphanie Devel

- the scientific supervisor for the exercise:
  - Myriam Ricaud, Technical Expertise and Consulting Division, INRS

Its role was to reflect on the consequences and impacts of the scenarios on occupational safety and health in France in small enterprises. This work was carried out during a two-day seminar. The result of this work was discussed with the members of the experts group.

The steering committee

It comprised the initiators of the exercise: representatives of INRS management, of the INRS Board of Directors, of Division heads at INRS, and of our partners (Anses, Université de Bretagne-Sud, ISSA).

Its role was to ensure the proper functioning of operations, validate key stages, in particular the definition of variables and scenarios resulting from considerations by experts.

A three-stage operation

- **September to December 2013:** objectives set, scope of the exercise determined, steering committee selected, type of assistance selected (external body specialised in foresight), work method drawn up, partnerships required for the exercise identified and set up.

- **January to September 2014:** data collected (in particular bibliographical), working groups met, interviews held, contributions defined and drafted, scenarios built, communication strategy implemented, etc. This work resulted in the preparation of a briefing paper (October 2014) for discussion during the third stage.

- **December 2014:** event held to which were invited contributors, the French occupational risk prevention network, the Ministry of Labour, social partners, the activity sectors concerned, NGOs/consumer associations, etc. Presentation of the main elements of the briefing paper on that occasion.

Background elements

Discovery of the Nanoworld

During a conference held in 1959, physicist Richard Feynman stated that the principles of physics allowed the handling and controlled positioning of atoms and molecules individually like Lego® blocks. In saying this, the American physicist was suggesting to the science community to explore the world of the infinitely small.

The term "nanotechnology" was used for the first time in 1974. In the 1980s, with the discovery of the scanning tunnelling microscope, followed by that of the atomic force microscope, the Nanoworld was really revealed to researchers.

The unit of reference in the Nanoworld is the nanometer (abbreviated nm). The prefix nano comes from the Greek word "*nannos*", which means "dwarf". One nanometer is equal to one billionth of a meter (1 nm = 10^{-9} m = 0,000000001 m), i.e. approximately 1/50,000th of the thickness of a human hair. This scale is that of the atom, the elementary building block of all matter. There is therefore the same difference in scale between an atom and a tennis ball as between a tennis ball and planet Earth.

Nanotechnology is a multidisciplinary field of research and development that is based on knowledge and control of the infinitely small. It covers, more specifically, all of the techniques used for manufacturing, handling and characterising matter at nanometric scale.

Nanotechnology is the formalisation of concepts and processes related to nanosciences, i.e. sciences aimed at studying and understanding the properties of matter at atomic and molecular level.

THE GREY GOO SCENARIO, THERE WON'T BE AN APOCALYPSE*

Technological discoveries and innovations have always triggered fears and rejection, with their horde of catastrophic and even apocalyptic scenarios.

Nanotechnology has brought a spectre incarnating the darkest fears related to this technological development: the grey goo scenario, which refers to an indescribable mass into which the world will transform, due to out-of-control self-replicating robots consuming all matter on Earth to build more of themselves.

This scenario was first evoked in the 1980s by Éric Drexler, a nanotechnology pioneer, and was then taken up by numerous thinkers and researchers. In 2000, Robert Freitas, one of the founders of nanomedicine, created the term "ecocide" to describe this scenario, imagining that those nanobots would convert the natural environment (biomass) into replicas of themselves (nanomass).

This scenario has spread across fiction, with numerous variations portraying the end of the world brought about accidentally or maliciously, and continues to fuel the fears of the general population. To the point that Prince Charles requested the Royal Society, which is the UK academy of science, to analyse this risk in its report on the environmental and societal impacts of nanotechnology.

Research obviously shows that the probability of such scenarios is, to say the least, extremely low, especially because the technological requirements to make such nanobots fall within the realm of speculation. And even if out-of-control self-replicating machines do not exist as yet, these theories about them now recommend including controls to prevent such scenarios. Eric Drexler, the initial author of the scenario even attempted to publically retract the scenario in order to re-focus the debate on more realistic threats such as nanoterrorism.

They are cross-cutting technologies that blur or even break down the borders between physics, chemistry, biology, etc.

There are many definitions of the term "nanomaterial".

In October 2011 (OJEU of 20 October 2011, L. 275/38), the European Commission proposed a recommendation[1] for the definition of the term "nanomaterial". "Nanomaterial" is a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm-100 nm.

This recommendation specifies that a material should be considered as falling under the definition above once the specific surface area by volume of the material is greater than 60 m^2/cm^3.

It is also mentioned in this text, that in specific cases and where warranted by concerns for the environment, health, safety or competitiveness, the number size distribution threshold of 50% may be replaced by a threshold between 1 and 50%.

Other authorities and bodies such as the World Health Organisation have proposed definitions of the term "nanomaterial".

Nanomaterials produced intentionally with specific properties for specific applications are known as "manufactured nanomaterials". Some of these have been produced for many years now in significant quantities, such as titanium dioxide, carbon black, aluminium oxide, calcium carbonate and amorphous silica. Other more recent nanomaterials have been manufactured in lesser quantities such as carbon nanotubes, quantum dots and dendrimers.

There are also non-intentionally produced nanomaterials, sometimes called ultrafine particles, resulting from certain thermal and mechanical processes such as smoke from welding and thermal spraying, motor exhaust emissions, etc.

Lastly, natural ultrafine particles are present in our environment, such as volcanic smoke and viruses.

[1] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011H0696

* Article written by Jan Irmer, journalist.

Major economic stakes

Matter at nanometric dimensions has unexpected properties that are sometimes completely different to those of the same materials at micro or macroscopic size, for example in terms of mechanical resistance, chemical reactivity, electrical conduction and fluorescence. Nanotechnology therefore makes it possible to develop materials whose fundamental properties (chemical, mechanical, optical, biological, etc.) can be modified. For example, gold is totally unreactive at micrometric scale but is an excellent catalyst for chemical reactions at nanometric dimensions.

All of the major families of materials are concerned: metals, ceramics, dielectrics, magnetic oxides, polymers, carbons, etc.

Because of their varied and often original properties, nanomaterials have very diverse potential and their uses provide many possibilities.

They also enable incremental and disruptive innovations in many activity sectors such as health, transport, construction, cosmetics, energy, environment, food, chemistry, plastics, packaging, textile, defense and electronics: drug vectorisation, self-cleaning concrete, anti-bacterial textiles, scratch-proof paint, etc.

Nanomaterials therefore have considerable potential for economic and job development. Very large budgets are allocated to research and development throughout the world. An ever increasing number of private and public laboratories are therefore concerned by the growing deployment of this infinitely small technology. Also, the number of companies that make or use nanomaterials increases every day.

In 2012, the public authority for competition and industry published a study *Les réalités industrielles dans le domaine des nanomatériaux en France* (Industrial realities in the field of nanomaterials in France). This study presents the value chain from nanomaterial production to the different markets in which they are used. It shows that 80% of French nanomaterial producers are microenterprises or small and medium-sized enterprises. Annual production of nanomaterials is estimated at 135,000 tonnes. It should be noted that there is a large difference between this national estimate and that published in an INRS survey in 2007[2] and in another survey conducted by Afsset[3] in 2008.

The system for the annual notification of substances in nanoparticle form which has been in effect in France since 1 January 2013 in compliance with Articles L. 523-1 to L. 523-8 of the French Environment Code, is expected to provide more information on nanomaterials and their uses. This notification is imposed on manufacturers, importers and distributors of such substances placed on the market in France, and is mandatory for quantities exceeding 100 grammes per year and per substance. An initial public report concerning this notification was published at the end of 2013 on the website of the Ministry of Sustainable Development[4]. According to the report, 670 French entities submitted at least one notification (importers accounted for 22%, manufacturers 6%; distributors 68% and "other" players 4%). 280,000 tonnes of substances in nanoparticle form produced and 220,000 tonnes of substances in nanoparticle form imported in France in 2012 were notified, i.e. a total of 500,000 tonnes of substances in nanoparticle form placed on the French market in 2012.

[2] Production et utilisation industrielle des particules nanostructurées, ND 2277, INRS, Paris, 2007.

[3] Les nanomatériaux. Sécurité au travail, AFSSET, 2008.

[4] https://www.r-nano.fr/?locale=en

In the light of these studies, many employees are already potentially exposed to manufactured nanomaterials either in research laboratories, plants, or in places where they are used.

According to certain estimates, nanotechnologies currently employ between 300,000 and 400,000 people in Europe. In France, it is estimated that 5,000 employees in companies and 7,000 researchers are potentially exposed to manufactured nanomaterials.

A prevention priority

On the one hand, the development of nanotechnology and nanomaterials has been identified as an engine for economic growth and progress, of which we have probably seen only the beginning.

On the other hand, they raise questions as well as fears. Concerns about the health hazards in particular have been expressed. There are also ethical, legal and society-related questions.

All scientific and technical progress brings ambivalent consequences; nanotechnologies and nanomaterials are no exceptions.

Knowledge on the toxicity (and ecotoxicity) of manufactured nanomaterials is still poor, despite many studies published on the topic. The results are often limited in scope: *in vitro* studies carried out on cell models which are hard to extrapolate to humans; *in vivo* studies on animals carried out through non-representative routes of exposure, over short periods and with nanomaterials not sufficiently characterised from a physical and chemical point of view.

Similarly, there is little data on professional exposure to manufactured nanomaterials. This is due, in particular, to the lack of consensus on measurement criteria, a host of mostly inappropriate instruments and measurement strategies that have not been stabilised.

In this context, finding and proposing effective prevention methods with regard to manufactured nanomaterials is essential but delicate. Firstly, because there is no threshold value to ensure adequate protection, but also because of the high levels of protection that would be required for nanomaterials with a known health risk. However, it is crucial to check the performance of equipment used by referring to the state of the art and to knowledge currently available. As for particle pollution, prevention methods are based mainly on ventilation and air purification techniques.

Anticipating and controlling risks associated with manufactured nanomaterials are among the priorities of most occupational health and safety bodies throughout the world. INRS has been active for several years now to provide responses and make them available to all those who, in companies or laboratories, are in charge of risk prevention. In an initial summary published in 2007 by INRS[5], major needs were revealed concerning toxicology, metrology, etc. and the need to urgently develop and recommend suitable prevention measures.

5 Les nanoparticules. Un enjeu majeur pour la santé au travail ?, Avis d'experts, EDP Sciences, 2007.

The nature and the properties of nanomaterials

Nathalie Thieriet, Anses, and Éric Gaffet, Institut Jean Lamour

Definition

This datasheet addresses design, production, and marketing of new generations of manufactured nanomaterials having novel properties (regardless of whether or not they are developed to meet specific demands or needs).

Defining the term "nanomaterial" raises numerous questions in itself and is a subject of controversy. The definitions proposed are still the subjects of numerous discussions among the scientific, regulatory, and institutional communities and among civil society, and they are not fully satisfactory as they stand.

No current definition takes into account certain important parameters such as solubilisation (bringing a substance to the state of being in solution or in colloidal suspension) or mean size of the agglomerates and aggregates. And yet knowledge of these parameters contributes to understanding the mechanisms whereby manufactured nanomaterials act on the living world.

Retrospective analysis

The reference unit of the nanoscale world is the nanometre (abbreviated to "nm"). The prefix "nano" comes from the Greek "nannos", which means "dwarf". One nanometre equals one billionth of a metre (1 nm = 10^{-9} m = 0.000.000.001 m), i.e. approximately 1/50,000th of the thickness of one human hair (Figure 1). This scale is the scale of the atom, i.e. of the fundamental building block of all matter. The same difference in size exists between an atom and a tennis ball as between a tennis ball and the planet Earth.

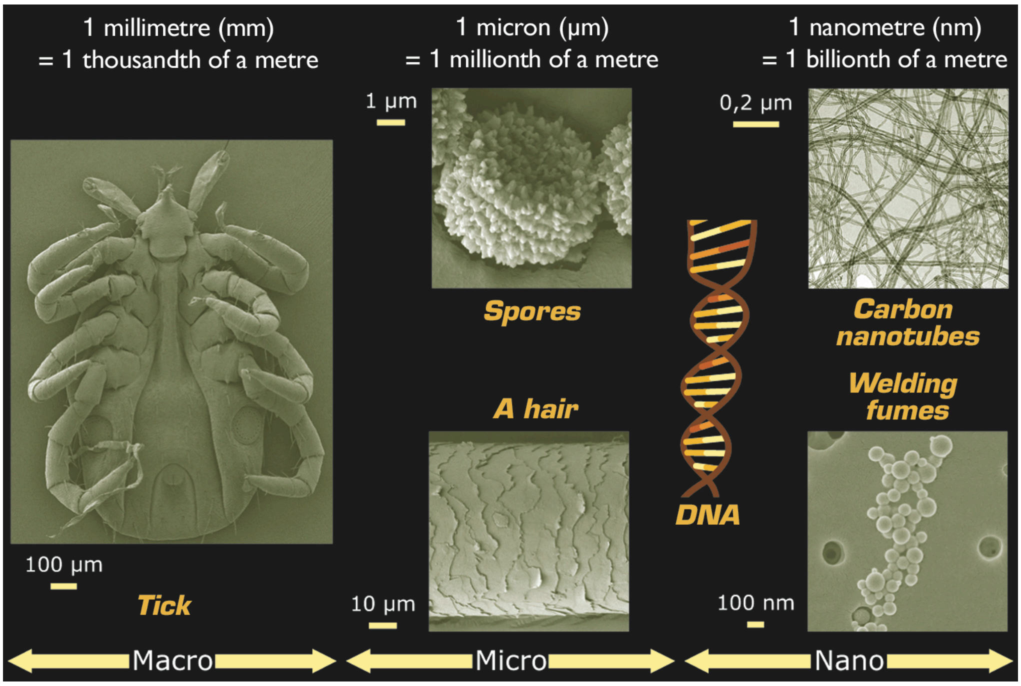

Figure 1. The scale of sizes, from the visible to the invisible.
Source: INRS, ED 6050

There are many definitions for the term "nanomaterial".

In October 2011, in a recommendation, the European Commission proposed a definition for the term "nanomaterial" [1]. According to that definition, a nanomaterial is a natural, incidental, or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate, and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm to 100 nm.

Any material is also to be considered as falling under the above-mentioned definition when its specific surface area by volume is greater than 60 m^2/cm^3.

It is stated in that definition that, in specific cases and where warranted by concerns for the environment, health, safety, or competitiveness, the number size distribution threshold of 50% may be replaced by a threshold between 1% and 50%.

It is also stated that, by derogation, fullerenes, graphene flakes, and single-wall carbon nanotubes with one or more external dimensions below 1 nm should be considered as nanomaterials.

According to Standard ISO TS 80004-1, a nanomaterial is a material with any external dimension in the nanoscale, i.e. approximately between 1 and 100 nm, or having an internal structure or surface structure in the nanoscale.

[1] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011H0696&from=EN

There are two main families of nanomaterials (Figure 2):

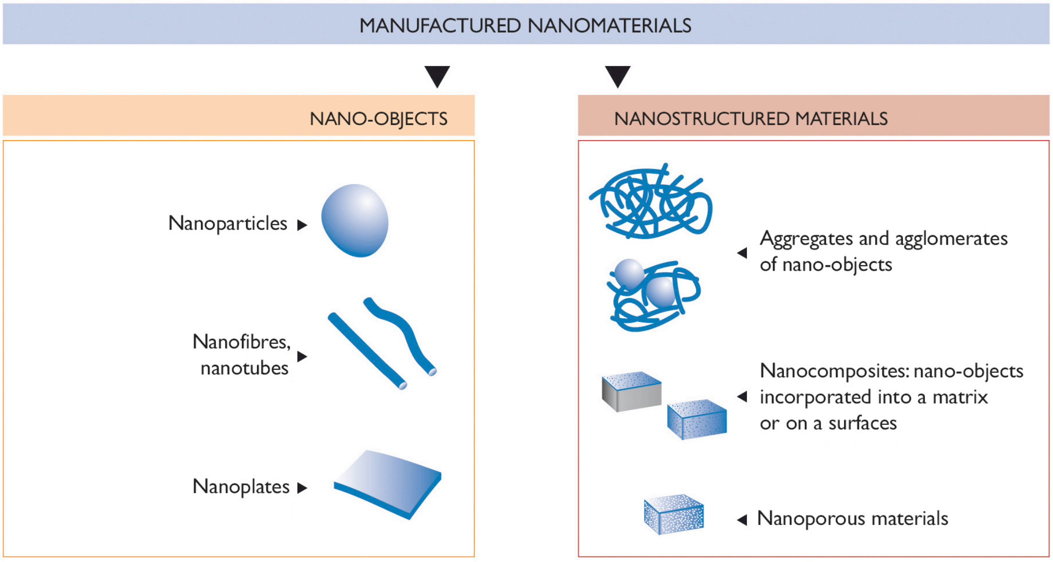

Figure 2. Classification of nanomaterials according to ISO Standard TS 80004-1.
Source: INRS, ED 6115

1. **Nano-objects** are materials with one, two or three external dimensions in the nanoscale, i.e. approximately between 1 and 100 nm.
Nano-objects can be divided into three categories:

- *nanoparticles*, which are nano-objects with three external dimensions in the nanoscale: nanoparticles of latex, of zinc, iron, and cerium oxides, of alumina, of titanium dioxide, of calcium carbonate, etc.;
- *nanofibres, nanotubes, nanofilaments, or nanorods*, which are nano-objects with two external dimensions in the nanoscale and the third dimension significantly larger (carbon nanotubes, polyester nanofibres, boron nanotubes, etc.). These terms refer to elongate nano-objects lying in the range 1 nm to a few tens of nm in cross-section, and in the range 500 nm to 10,000 nm in length;
- *nanoplates*, which are nano-objects with one external dimension in the nanoscale and the other two external dimensions significantly larger (clay nanoplates, cadmium selenide nanoplates, etc.).

Nano-objects can be used as they are in the form of powder, liquid suspension, or gel.

2. **Nanostructured materials** are materials that have an internal or surface structure in the nanoscale. Nanostructured materials can be divided into various families, including:

- *aggregates and agglomerates of nano-objects:* nano-objects can either be in individual form (i.e. in the form of primary particles), or in the form of aggregates or agglomerates whose size is significantly greater than 100 nm;

- *nanocomposites*: these materials are composed, either entirely or in part, of nano-objects that give them improved properties or properties that are specific to the nanoscale. Nano-objects are incorporated into a matrix or onto a surface to give it new functionality or to alter some of its mechanical, magnetic, thermal, or other properties. Polymers reinforced with carbon nanotubes and used in the sports equipment sector to improve the strength and to reduce the weight of such equipment are one example of nanocomposites;

- *nanoporous materials*: these materials have pores of nanoscale size. Silica aerogels are nanoporous materials that offer excellent thermal insulation properties.

Applications

In the nanoscale, matter takes on unexpected properties that are often totally different from the properties of the same materials in the microscopic or macroscopic scales, in particular in terms of mechanical strength, chemical reactivity, electrical conductivity, and fluorescence. Nanotechnologies thus lead to development of materials whose fundamental (chemical, mechanical, optical, biological, etc.) properties may have been altered. For instance, gold is completely inactive at the microscale, whereas it becomes an excellent catalyst of chemical reactions in the nanoscale.

All of the major families of materials are concerned: metals, ceramics, dielectrics, magnetic oxides, polymers, carbons, etc.

Due to their varied and often novel properties, nanomaterials have a wide range of potential applications, and their uses open up a host of new prospects.

Nanomaterials thus enable incremental and disruptive innovations to be made in numerous sectors, such as healthcare, the automotive industry, building and construction, the food industry, or electronics.

Manufacturing

Manufactured nanomaterials can be synthesised using two different approaches (Figure 3): the bottom-up approach and the top-down approach.

- The bottom-up approach originated from research laboratories and from nanoscience. It consists in building nanomaterials atom-by-atom, molecule-by-molecule, or aggregate-by-aggregate. The atoms, molecules, or aggregates are assembled or positioned in precise, controlled, and exponential manner, thus making it possible to produce functional materials whose structure is completely controlled.

- The top-down approach originated from microelectronics. It consists in reducing, and more specifically in miniaturising, existing systems (usually microstructured materials) by optimising existing industrial technologies. The systems or structures are thus gradually reduced in size or divided until they reach nanoscale size.

The two approaches tend to converge in terms of range of object sizes. However, the bottom-up approach appears to be richer in terms of type of material, diversity of architecture, and control of the nanoscale state, whereas the top-down approach makes it possible to obtain larger quantities of material but controlling the nanoscale state is trickier.

The bottom-up approach uses chemical and physical production methods (gas phase reactions, sol-gel techniques, laser-induced pyrolysis, microwave plasma, etc.), whereas the top-down approach mainly requires the use of mechanical methods (mechanosynthesis, strong deformation by torsion, etc.).

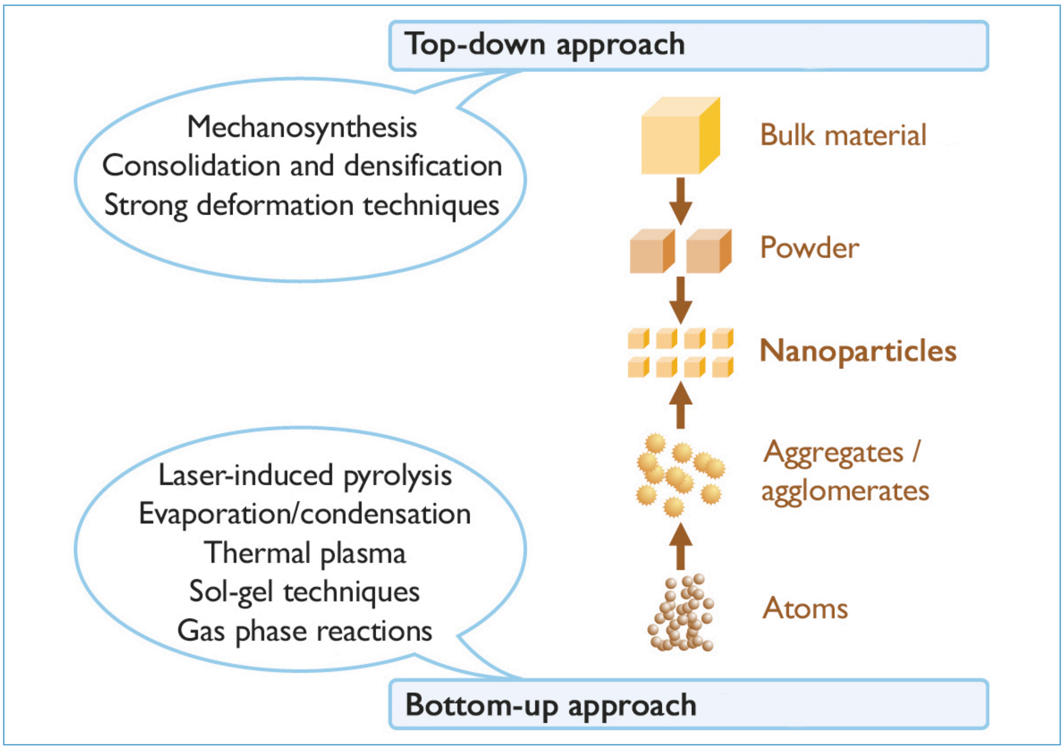

Figure 3. The two approaches to producing manufactured nanomaterials.
Source: INRS, ED 6050

Prospective analysis

According to the analysis developed as early as 2004 by M. C. Rocco[2], nanotechnologies / nanomaterials will develop in four stages or "generations": passive nanostructures, active nanostructures, systems of nanosystems, and, finally, molecular nanosystems. Figure 4 illustrates this analysis. The nanoproducts that are currently on the market essentially belong to the category of passive nanostructures, and a few active nanostructures are in the development pipeline.

[2] Rocco M.C., 2004. Nanoscale Science and Engineering: Unifying and Transforming Tools, AIChE Journal 50 (5), 890–897.

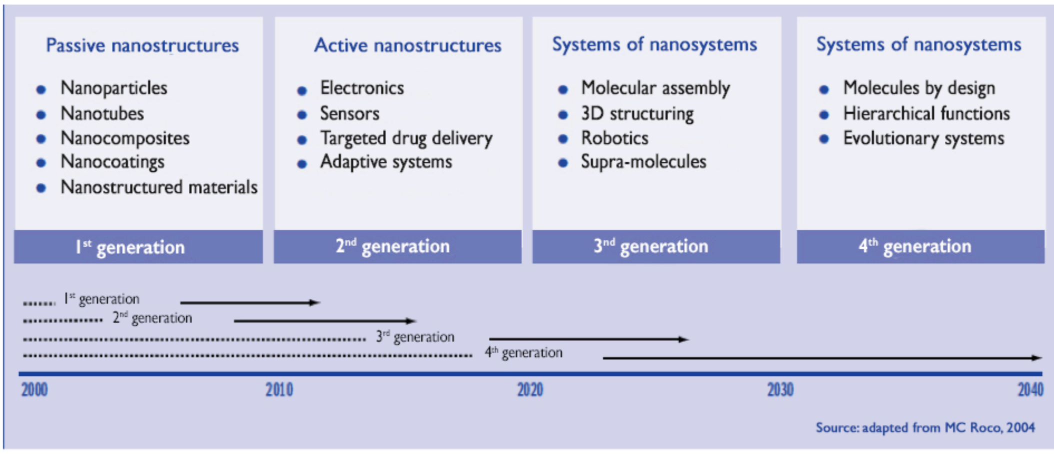

Figure 4. Development of nanotechnologies.
The four generations of nanostructures / nanosystems.
Source: Gaffet Éric, Nanomatériaux : différentes voies de synthèse, propriétés, applications et marchés, Actualité et dossier en santé publique n° 64, septembre 2008, Haut conseil de la santé publique, Paris.

An active nanostructure is a structure capable of changing its state (morphology, shape, or mechanical, electronic, magnetic, optical, or biological properties, etc.) while it is being used. For instance, nanostructures (often nanoparticles) can be implemented that are capable of dissolving over time or else that are of chemical composition suitable for crossing biological barriers in order to be vehicles for delivering active ingredients in the medical field. Examples of such active nanostructures are nano-electromechanical systems (NEMS), biological nano-devices, transistors, amplifiers, pharmaceutical and chemical vehicles or vectors, molecular machines, light-activated molecular motors, devices using nanofluidics, sensors, or indeed radiofrequency devices (RFID devices).

Hypotheses

Hypothesis 1. Development of nanomaterials in line with current trends

The development of technologies and knowledge makes it possible to achieve production of 4th generation nanomaterials.

This hypothesis assumes low manufacturing costs, few risks, and high utility.

Hypothesis 2. Nanomaterials develop at a moderate or slower rate

The development of technologies and knowledge does not make it possible to achieve production of 4th generation nanomaterials, and we remain between the 2nd and 3rd generations.

This hypothesis assumes:

- high manufacturing costs, few risks, and high utility; or
- low manufacturing costs, possible risks, and high utility; or
- low manufacturing costs, possible risks, and low utility.

Hypothesis 3. Nanomaterials cease to be developed

The development of technologies and knowledge does not make it possible to achieve production of 3rd generation nanomaterials.

This hypothesis assumes high cost, possible risks, and low utility.

Technologies and processes

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Definition

This variables datasheet addresses the technologies and processes making it possible to synthesise and to characterise manufactured nanomaterials.

Retrospective analysis

Nanomaterials are among the vehicles through which nanosciences are developing. Today, if they represent one of the most innovative areas of technological development, it is because in France and in the rest of the world, for more than twenty years now, numerous stakeholders (research bodies, and companies) have been investing, forming partnerships, and taking part in a multitude of research & development projects for defining, assessing, improving the reliability of, and industrialising the technologies and processes for synthesising nanomaterials. As shown in Figure 1, the technologies and processes are generally classified into two co-existing approaches: one is said to be "top-down" and the other to be "bottom-up".

The bottom-up approach consists in using fundamental or basic units (atoms, molecules, or aggregates) to build structures or assemblies of larger size and offering a wealth of functionality and features, the building being based on physical, chemical, or mechanical processes. There are many such processes; for example, there are evaporation-condensation technologies for obtaining nanostructured powders, sputtering technologies for growing continuous thin layers or grains at the surface of substrates, sol-gel technologies that enable nanomaterials to be produced from solutions, etc.

The top-down approach consists in miniaturising existing structures or materials. For over thirty years now, the microelectronics industry has been implementing this approach for integrating as many elementary components (transistors, filters, etc.) as possible into a given area. This is how lithography (optical, X-ray, or electronic lithography) technologies, or ion beam etching technologies have been developed that make it possible to produce a stack of thin layers of various materials appropriate for various uses (semiconductor, metal, or insulating layers). In the top-down approach, there is also a mechanical process for producing nanomaterials. It uses technologies originating from powder metallurgy technologies, such as, for example mechanosynthesis (or high-energy grinding) for producing nanostructured powders, or consolidation for obtaining solid parts from powder (metal, ceramic, semiconductor, and organic powders).

Although, for nearly twenty years now, the two approaches have been tending to converge in terms of the sizes of the primary objects obtained, the bottom-up approach seems richer in terms of type of material, diversity of structures, and control of the nanoscale state (size, size dispersions, phases, etc.). Today, the top-down approach makes it possible to obtain larger volumes of nanomaterials, but the nanoscale state is trickier to control. A large number of these processes are still evolving and use of them is very often limited to the research & development world.

France has been contributing very actively to such technologies and processes in the academic research field (since the early 1990s, France has been one of the five largest contributors), but it has been much less active in patenting them (with fewer than 5% of the patent applications filed at global level being filed in France).

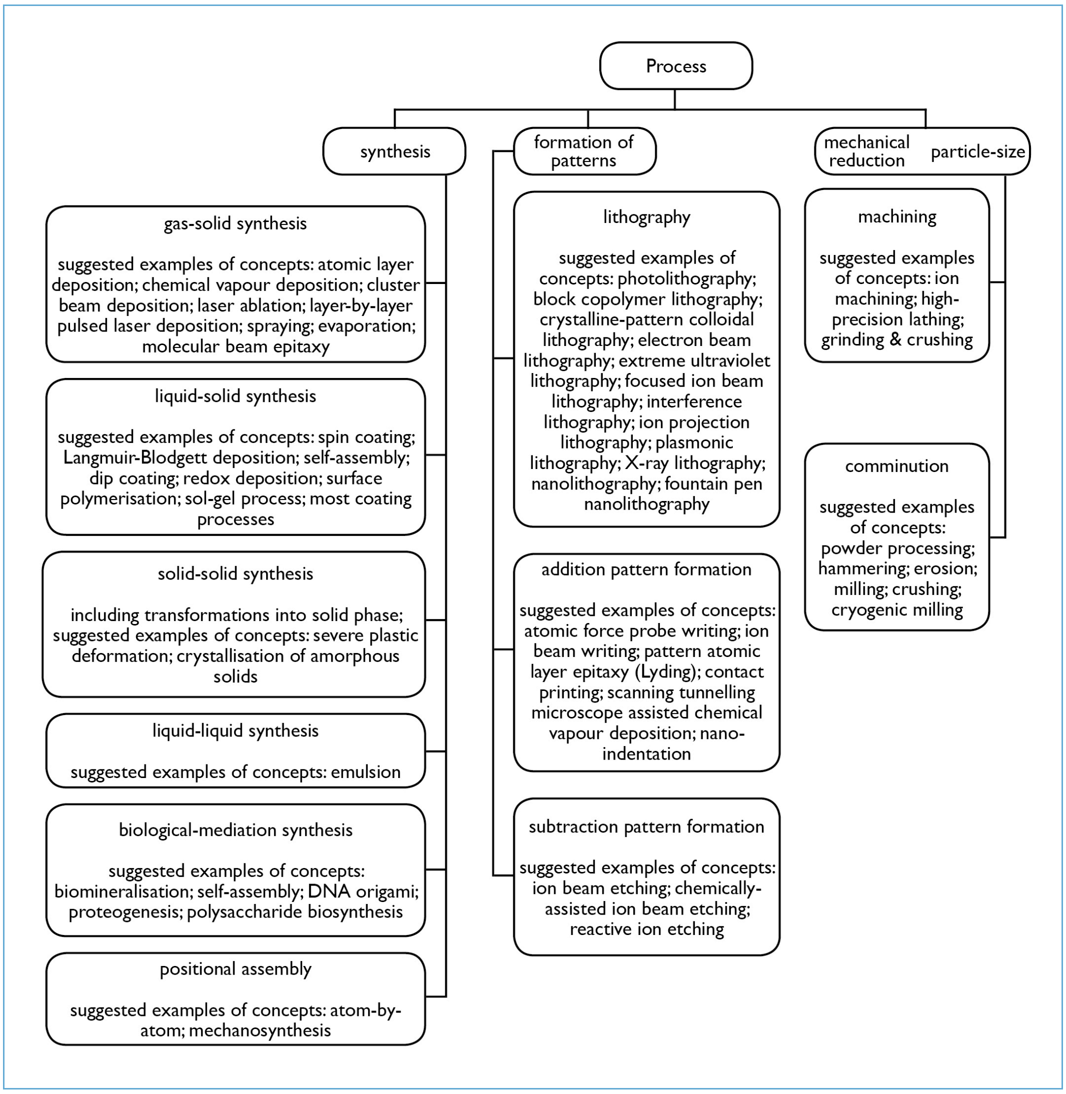

Figure 1. The various technologies and processes for synthesising nanomaterials (ISO / TR 12802: 2010).

The progress in the synthesis technologies and processes has been possible only because it was accompanied by significant progress in the physical and chemical characterisation techniques (for characterizing size, shape, polydispersity, chemical composition, state of aggregation/agglomeration, surface charge, specific surface area, crystalline structure, solubility, etc.). However, the various traceability chains remain to be established and measurement protocols and sampling methods remain to be defined before we are capable of associating an optimum confidence level with each measurement.

Prospective analysis

The state of current knowledge, the research avenues explored, and the technologies and processes developed, some of which are already mature, offer hope that, in the coming decades, discoveries and numerous technological innovations will be made. Manufacturing nanomaterials at industrial level, i.e. in large volumes, with good quality and good reproducibility, and at a cost that is acceptable remains a major challenge for the coming years.

It should be emphasised that industrialisation of the technologies and processes will, inevitably, take place at the crossroads of disciplines that are not generally associated with one another naturally (chemistry, physics, biology, and process engineering). Thus, one of the key success factors for development involves implementing approaches that are genuinely cross-disciplinary and that will need increasing amounts of research, technology clusters, and profiles capable of linking up and establishing synergic effects between the various fields. In France, the development between conceptualisation and industrialisation at small to medium sized enterprises (SMEs) and very small enterprises (VSEs) will depend, in part, on this being taken into account through, for example, specific training (similar to the schemes set up under the Nanotechnology Education Act in the United States), and support for industrial innovation projects taking into account the entire value chain (collaboration between companies, universities, and extra-academic research).

Hypotheses

The hypotheses are built on the fact that the road from fundamental properties to applications is rarely an open one; it is generally strewn with obstacles. These obstacles can block up the unavoidable passageways that lead from conceptualisation to industrialisation via the essential laboratory validation stage.

Hypothesis 1. Obstacles between conceptualisation and laboratory

Through lack of growth in research, developments are blocked by certain obstacles. The only innovations made have come from optimisation of conventional production processes.

Hypothesis 2. Obstacles between laboratory and industrialisation

The growth in research for high-potential technologies and processes has led to demonstrations of feasibility at industrial pilot level. A network of SMEs/VSEs with good command of these innovative processes and technologies for numerous applications has started to become structured. However, the industrialisation stage is often not reached.

Hypothesis 3. No more obstacles

Numerous obstacles have been overcome and industrialisation has been made possible through research. Innovative technologies and processes have been developed; they meet the needs of markets such as aviation, space, defence, transport, and electronics.

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Public and private investment

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Definition

There is no widely shared indicator for quantifying investment in nanosciences and nanotechnologies. The data, identified in the various reports, is difficult to compare because it is based on different and not very explicit methodologies.

There are various reasons for this lack of comparable data:

- the first reason is that the visible (and measurable) investments are only relatively recent (since about the 2000s);
- the second reason concerns the difficulty of grasping the field of "nanosciences and nanotechnologies". There is no shared definition of "nanosciences and nanotechnologies". Efforts have been made by the OECD and the ISO or the European Union for developing common statistics and indicators (FP7 European projects: *Observatory Nano, NMPscoreboard, NanoIndicators*) but no methodology is shared. The prefix "nano" is merely an indicator of size: sectors working at such scales have existed for a long time. It is therefore necessary to take into account the notion of "relabeling" of scientific or technological projects to take advantage of the funding and opportunities offered by the recent enthusiasm or indeed "craze" for nanosciences and nanotechnologies;
- the third reason, linked to the two preceding ones, relates to the cross-cutting nature of nanosciences and nanotechnologies. They are known as "generic" or "general purpose" technologies (Bresnahan et Trajtenberg, 1995);
- finally, the last reason relates to the fact that it is difficult to compare national public funding, beyond the few available indicators, because:
  - depending on the country, the programmes incorporating funding for nanosciences and nanotechnologies can be specific (NNI in the United States) or generic (FP 7 in Europe, *Nanosciences, technologies, materials and new production technologies*);

- the funding is fragmented to a greater or lesser extent. In Germany and in the United States, a national agency or a multi-agency strategy structures and harmonises the investments. In France and in the United Kingdom, various agencies have funding that is not co-ordinated;
- there are programmes of very different levels: the focus can be put on major societal challenges (United Kingdom and Japan) or on technologies.

Indicators

1. **Input indicators:**
   - public investments (specific or generic programmes);
   - private investments (funding by companies).
2. **Output indicators:**
   - number of scientific publications (proxy for investment in fundamental research);
   - number of patents filed (proxy for investment in applied research);
   - number of companies: this indicator is rejected because it is too difficult to define since companies have different degrees of use and command of nanotechnologies.

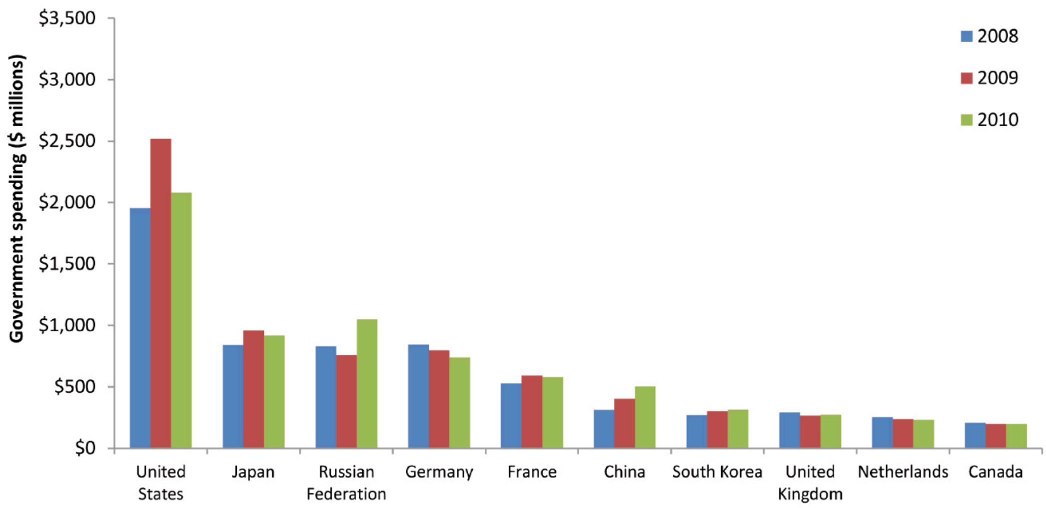
Retrospective analysis

Public investment: major programmes in all countries, beyond the Triad

Table I and Figure I show the main national programmes for public funding of nanotechnologies. Following the United States' example, almost all of the leading countries have developed public funding programmes for funding nanotechnologies. However, the United States remains the largest funder.

Country	Funding programmes	Nano-specific	Period	Amount over the period => mean annual value
Brazil	Ministry for Science & Technology	No	annual estimate	€ 4.9 million
China	Medium & Long Term Development Plan	Yes	2006 - 2008	€ 29.1 million
European Union	Framework Programme 7	No	2007 - 2013	€ 3.5 billion
France	Nano 2012 Programme	Yes	2008 - 2012	€ 500 million
Germany	Nano Initiative - Action Plan 2010	Yes	2008 - 2013	€ 370 million
India	Nano Mission	Yes	2007 - 2012	€ 144.8 million
Japan	MEXT	No	annual estimate	€ 470 million
Russia	Development of nanotechnology infrastructure in the Russian Federation for 2008 - 2011	Yes	2008 - 2011	€ 693.3 million
United Kingdom	Research Councils UK / Technology Strategy Board	No	annual estimate	€ 256 million
United States	National Nanotechnology Initiative	Yes	2012	€ 1.6 billion

Table 1. The main national public funding programmes for nanotechnologies (equivalent in euros).
Source: O'Rourke, Morrison DSTI/STP/Nano, 2012

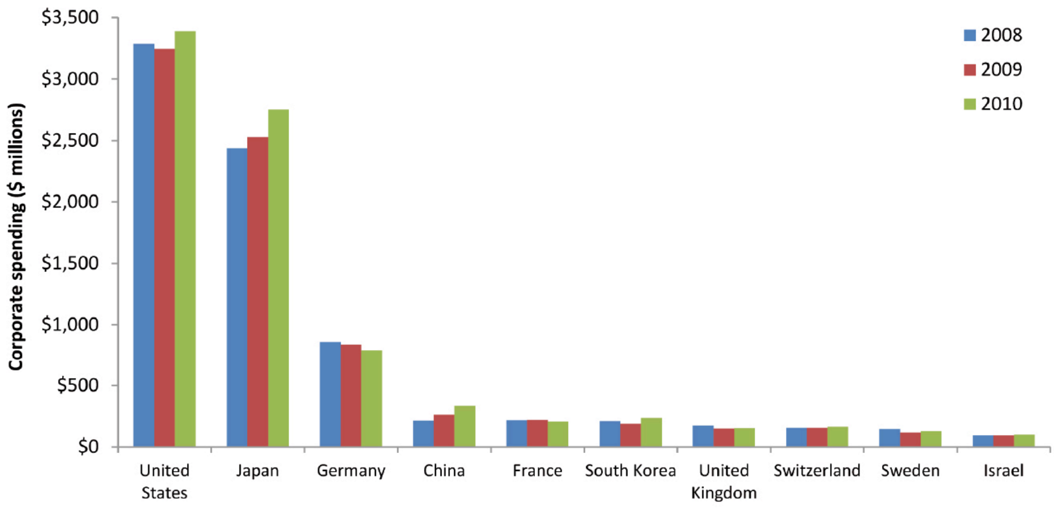


Source: A. Xue and D. Hwang, "Nanotechnology Funding: Corporations Grab the Reins," *Lux Research,* April 2011.

Figure 1. The 10 largest public funders of nanotechnologies (2008-2010) in dollars.
Source: Reproduced from PCAST, 2012

Private investment: widely contrasting situations

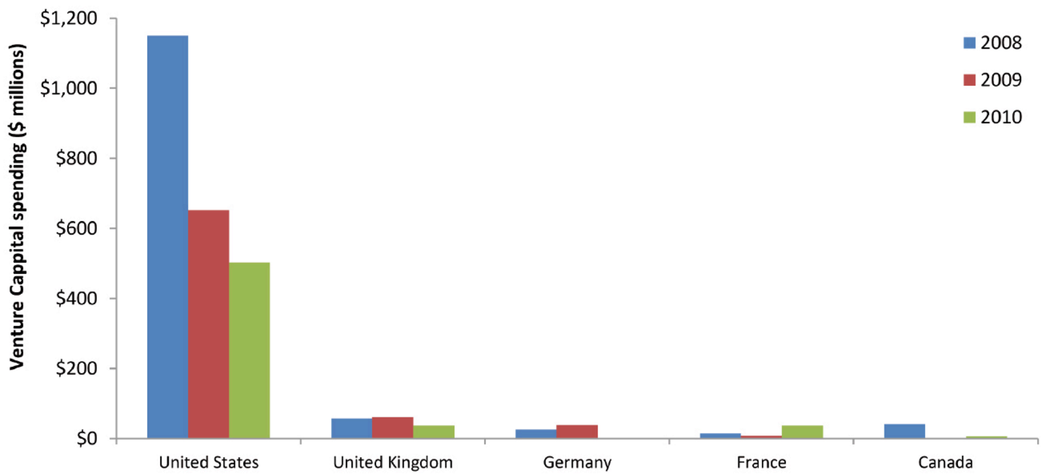
The graph of private investments (Figure 2) clearly shows that companies in the leading countries are also present in the field of nanotechnologies. France remains in the same position (5th). However, Russia does not make the top 10 investors whereas smaller countries like Switzerland, Sweden, or Israel do.



Source: A. Xue and D. Hwang, "Nanotechnology Funding: Corporations Grab the Reins," *Lux Research*, April 2011.

Figure 2. Private spending on R&D for the top 10 countries (2008-2010).
Source: Reproduced from PCAST, 2012

Figure 3 shows venture capital funding, and indicates a huge contrast between the United States and the rest of the world. The United States is the only country to have a structure supporting funding of risky projects.



Source: A. Xue and D. Hwang, "Nanotechnology Funding: Corporations Grab the Reins," *Lux Research*, April 2011.
Note: No data were available for Germany's Venture Capital spending for 2010.

Figure 3. Venture capital funding related to nanotechnologies (top 5 countries; 2008-2010).
Source: Reproduced from PCAST, 2012

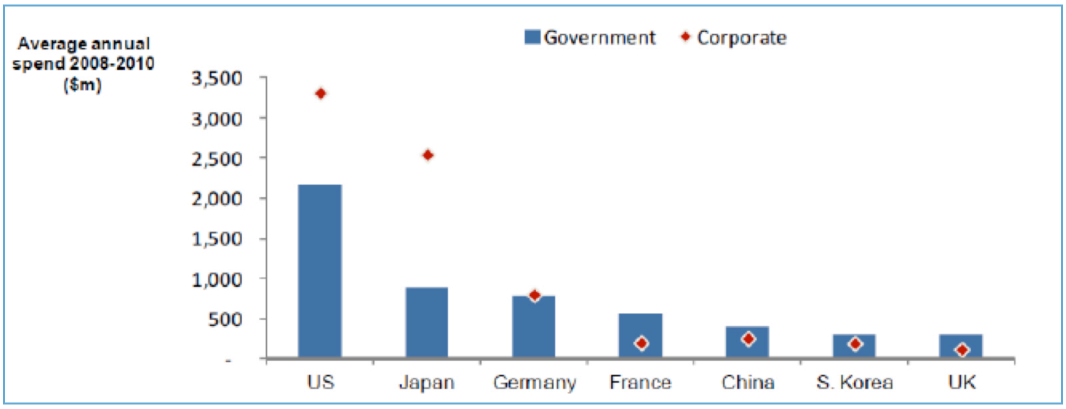


Figure 4. Comparison of public/private investment per country.
Source: Reproduced from PCAST, 2012

Figure 4 takes the above-indicated data and shows two major trends:

- the United States and Japan are clear leaders in terms of investment, both public and private;
- the funding structures can differ widely depending on the country. There are three main categories:
  - countries with major private investment (United States/Japan);
  - countries with shared funding (Germany/South Korea/China); and
  - countries where public funding predominates (France/United Kingdom).

Multi-sector investment in technologies

As indicated in Table 2, investments in nanotechnologies concern all sectors of activity; they are not specific to particular industries. Nanotechnologies really are "general purpose" technologies. Table 2 is based on patents incorporating nanotechnologies (PATSTAT database); investment in nanotechnologies can be expressed through patents[1]. Despite the limitations of that indicator[2], it is possible to observe main trends (Figure 5).

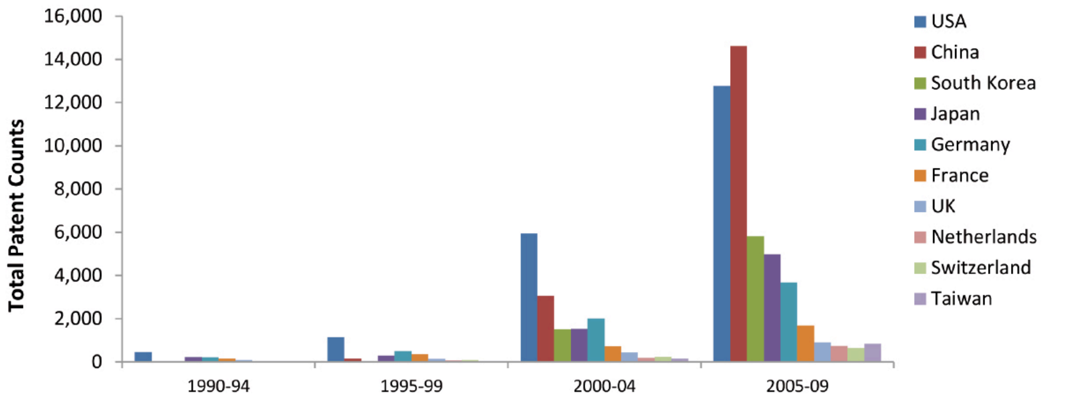
[1] Patents are not indicators of private investment alone, because public institutions also file patent applications.

[2] Patents as indicators of R&D investment have many limitations:

- patents are merely an "output" indicator of R&D investment;
- not all research results lead to patents; and
- the publishing practices differ from one country to another. Strict comparison is therefore impossible, and patents do not all have the same value.

Field of firms	Total number of patents	Total number of nano-related patents	% of patents in nanotechnologies
Electronic & electrical equipment	103	70	68%
Technology hardware & equipment	226	150	66%
Chemicals	96	84	88%
Pharmaceuticals & biotechnology	153	73	48%
Health care equipment & services	53	39	74%
Automobiles & transport	86	59	69%
Aerospace & defence	35	24	69%
Materials & construction	55	42	76%
Oil, Gas & Electricity	53	39	74%
Food producers inc. Beverages	32	16	50%
General industrials	38	24	63%
Household & personal goods	40	21	53%
Industrial engineering	70	35	50%
Telecom & media	32	14	44%
Software & computer services	110	14	13%
Banks, insurance, retail, leisure	49	6	12%
Total	1231	710	58%

Table 2. The presence of the biggest companies (DTI scoreboard) in nanotechnologies on the basis of studying patent counts.
Source: DTI scoreboard and NanoBench/ NanoTrendChart project, 2009



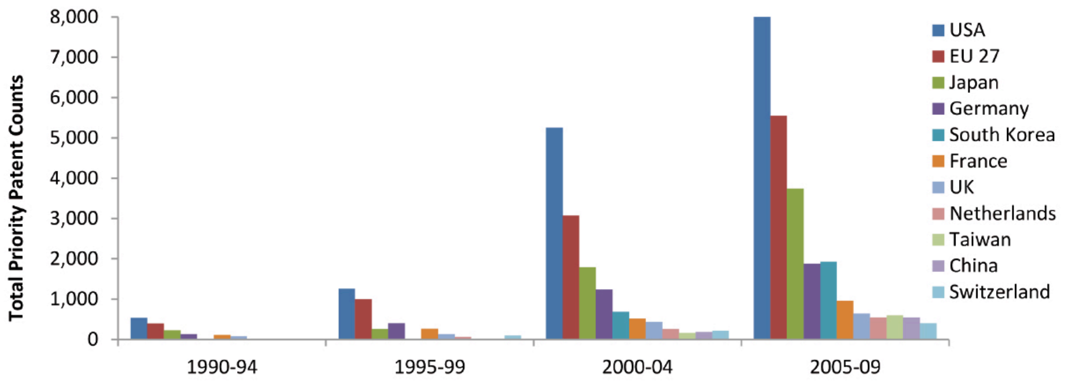
Source: L. Kay, P. Shapira, J. Youtie, and A. L. Porter, Program on Nanotechnology Research and Innovation System Assessment Georgia Institute of Technology, Atlanta, Georgia, with support from the National Science Foundation (NSF) through the Center for Nanotechnology in Society (Arizona State University; Award No. 0937591) [Data as of January 2010].PATSTAT stands for the Patent Statistical Database, which is maintained by the European Patent Office.

Note: Based on definition of "nanotechnology" by A. L. Porter, J. Youtie, P. Shapira, and D. Schoeneck, "Refining Search Terms for Nanotechnology," *Journal of Nanoparticle Research*, 10 (5): 715–728.

Figure 5. Number of patents filed in nanotechnologies in the PATSTAT database per country of origin 1990-2009.
Source: Reproduced from PCAST, 2012

The number of patents filed has grown considerably since the 1990s. Two phenomena should be noted: firstly, the overall share of the United States decreased over the last period, while China moved into the top slot. Secondly, new countries, outside the Triad of Europe/United States/Japan entered the rankings in the 2000s: China, South Korea and Taiwan (Figure 5). France is in 6th position in terms of number of patents over the last 10 years, behind China, the United States, South Korea, Japan, and Germany. Over this period, China and South Korea have enjoyed the highest growth.

Considering the limitations of patents as indicators, it is worth looking at priority patent counts only. A priority patent represents the paternity of a family of technological patents. Analysis in terms of priority patents gives a better picture of the distribution of intellectual property ownership. Thus, although China files the largest number of patents, it is only ranked 8th in terms of possession of priority patents (Figure 6).



Source: L. Kay, P. Shapira, J. Youtie, and A. L. Porter, Program on Nanotechnology Research and Innovation System Assessment Georgia Institute of Technology, Atlanta, Georgia, with support from the National Science Foundation (NSF) through the Center for Nanotechnology in Society (Arizona State University; Award No. 0937591) [Data as of January 2010]. PATSTAT stands for the Patent Statistical Database, which is maintained by the European Patent Office.

Note: Based on definition of "nanotechnology" by A. L. Porter, J. Youtie, P. Shapira, and D. Schoeneck, "Refining Search Terms for Nanotechnology," *Journal of Nanoparticle Research*, 10 (5): 715–728. Priority applications are patent documents in PATSTAT that report priority sequence of "1."

Figure 6. Number of priority patents filed in nanotechnologies in the PATSTAT database per country of origin 1990-2009.
Source: Reproduced from PCAST, 2012

However, although the increase in the total patent count has been continuous, a levelling-off has been observed since 2006: the researchers on the NanoBench project point out the impact of uncertainties (scientific and technological, and also toxicological and societal uncertainties) on the number of patents filed.

High growth in scientific publications

Figure 7 presents the results of the investments in nanosciences in terms of number of publications in scientific journals[3]. The number of publications expresses investment in research that is essentially government-funded. The growth in the number of publications over the period studied was about 14% per year whereas the average is 3%. These figures show the interest in and enthusiasm for nanosciences. A parallel can be drawn between this variation and the variation in public funding.

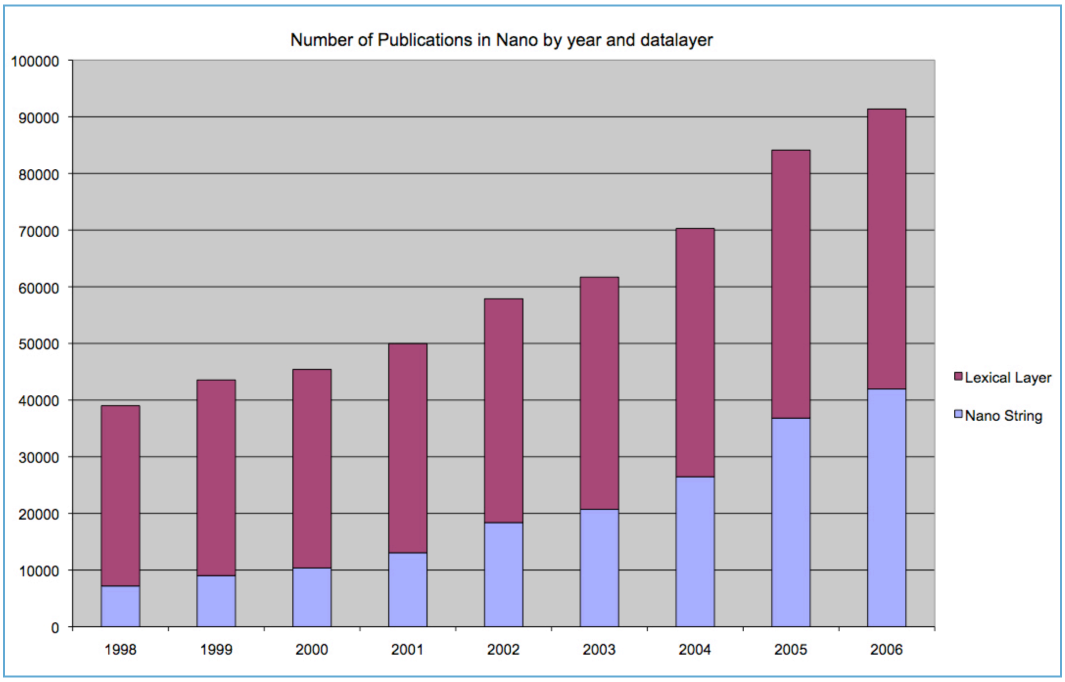


Figure 7. Nano publications in the Web of Science 1998-2006.
Source: NanoBench/ NanoTrendChart project, 2008

Prospective analysis

Various items can have an impact on the variation of the variable. The first item relates to the overall amount of funding available. In a context of recession and crisis, R&D investment can decrease except if nanosciences and nanotechnologies are considered as a priority. The uncertainties relating to the toxicity and to the ecotoxicity of nanomaterials is another point to be considered: so long as these uncertainties have not be removed, companies could be hesitant about investing in the field, leading to decreases in private investment. Conversely, such uncertainties can cause public funding to increase. The uncertainties are not only scientific; they are also societal, as the many public debates have shown. The philosophical and ethical questions remain very present in the field. The issue of the utility of certain innovations remains on the agenda.

[3] For details of the methodology, see Mogoutov and Kahane, 2007.

The issue of regulations can also influence the variation in funding, in particular private funding: Absence of regulations induces uncertainty for companies about marketing constraints. So long as uncertainty exists, private investment will be more limited.

Finally, the maturity of the emerging markets (China, India, and Brazil) is leading to an increase in the demand for goods (including goods incorporating nanotechnologies), which can also influence the variable.

Hypotheses

Hypothesis 1. Funding continues and applications are developed

This hypothesis assumes that the investment in the field of nanosciences and technologies continues. There will no longer be as many uncertainties as in 2014, which will enable companies to invest in applications and to propose increasing numbers of products resulting from research conducted in the field of nanosciences and nanotechnologies. This type of funding will inevitably overtake public funding, which is more focused on fundamental research.

Hypothesis 2. Slowdown in funding

This hypothesis assumes that, for various reasons (funding crisis, uncertainties about toxicity, rejection by the population, etc.), investment slows down. Such a slowdown concerns both public-sector and corporate funding.

Hypothesis 3. Funding focused on particular issues (water, food, etc.)

This hypothesis assumes that investments in the field of nanosciences and of nanotechnologies decrease. However, certain circumstances, such as specific issues related to development or to the need to cope with global population growth, focus public and private funding on certain topics.

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Technology transfer

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Definition

The innovation economy is built on sustainable and fertile relations between education, research, and innovation. This interaction model is known as the "knowledge triangle". Research contributes to economic development by creating enterprises – start-ups and spin-offs – and by transferring technologies to existing enterprises, such as SMEs[1].

Technology transfer is the formal transfer process whereby discoveries from academic or private research are transferred to industry with a view to marketing them in the form of new products or new services. Technology transfer consists in an exchange of knowledge, skills, techniques or know-how from one organisation to another. It can lead to a financial transaction or be embodied in various ways: purchase of patent, cooperation, making human and material resources available, etc.

In France, according to the Ministry for Higher Education and Research, the total spending on research and development is about 42 billion euros per year[2]. Of that amount, fundamental (basic) research accounts for about 15 billion euros, and this is a recognised strength of France. For its part, industrial development accounts for about 25 billion euros, ranking France well up with the average (according to the French Ministry for Higher Education and Research). There is a bottleneck between these two poles, i.e. between fundamental research and industrial development: France only devotes from 2 to 3 billion euros to the maturing and technology transfer stage, i.e. about 7% of the total amount of research & development spending, as against 22% for the United States, for example[2].

The financial effort made by France in the field of nanotechnologies and manufactured nanomaterials ranks it 2nd in Europe behind Germany[3]. The United States is the current leader in investment in the sector, and in terms of scientific output and of capitalising on (extracting added value from) research.

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1 Small and Medium-sized Enterprises

2 Valorisation & transfert technologique. CEA, acteur de l'innovation industrielle, avril 2014 (Capitalising on research, and technology transfer. CEA, a stakeholder in industrial innovation, April 2014)

3 http://www.economie.gouv.fr/cedef/dossier-documentaire-nanotechnologies

Retrospective analysis and analysis of the current situation

Manufactured nanomaterials have spread to a very large number of sectors of activity. They were rapidly identified as Key Enabling Technologies (KETs). They are essential to manufacture of a vast range of applications having high added value.

That is why, as of the late nineteen nineties, similarly to the United States who set up the National Nanotechnology Initiative (NNI) in 2000, France took a host of measures to build its strategy on research, transfer, and industrial development of nanotechnologies and manufactured nanomaterials.

The French Ministry for Higher Education and Research thus set up in 1999 a structure specifically in charge of promoting research, in particular partnership research, and of transferring nanomaterials to industry: the French Research Network for Supporting the Development of Micro- and Nano-Technology Projects (RMNT). After merging with the Incentive Concerted Action for Nanosciences (*ACI Nanosciences*)[4] to become the National Nanosciences and Nanotechnologies Network (R3N), The RMNT was discontinued with the setting up of the French National Research Agency (ANR). ANR's mission, which is more comprehensive, is to implement funding for projects with the aim of making the research sector more dynamic. Since 2005, ANR has regularly proposed calls for partnership projects related to nanomaterials, nanotechnologies, and nanosciences, in particular through the PNANO programme (Nanosciences and Nanotechnologies Programme) and the P3N programme (Nanosciences, Nanotechnologies, and Nanosystems Programme). In May 2009, the French Ministry for Higher Education and Research also launched the Nano-INNOV Plan, aiming to put in place a strategy for innovation in nanotechnologies and nanomaterials. That plan is based on setting up Nanotechnology and Nanomaterial Integration Centres in Grenoble, Saclay, and Toulouse, at which fundamental researchers work with companies to develop technologies, file for patents, and develop products. In addition, the Network for Basic Technological Research (RTB)[5] was set up in 2003, and six nanoscience skills centres known as C'Nano[6] were set up in 2004 (C'Nano, for example, together with the LNE[7], initiated the setting up of the Nanometrology Club[8] in 2012, one of the aims of that club being to build a bridge between industry and academia by pooling metrological issues associated with nanomaterials).

Apart from these few bodies and networks, most of the stakeholders currently involved in technology transfer from discoveries associated with manufactured nanomaterials in France are not specific to the nanotechnologies and manufactured nanomaterials sector. They are numerous, varied and spread across the entire territory of France:

- Technology Transfer Acceleration Companies (SATTs), set up in 2011 on the initiative of the Investments for the Future Programme (*Programme des investissements d'avenir*), with the objectives of capitalising on academic research and of improving the process of transferring technologies to industry. There are 14 SATTs spread over France, grouping together over 250 people specialised in

[4] The Nanosciences Incentive Concerted Action was launched in 2002 to support fundamental research projects through partnerships between academic research laboratories

[5] http://www.rtb.cnrs.fr/rubrique1.html

[6] http://www.cnano.fr

[7] Laboratoire national de métrologie et d'essais (National Laboratory for Metrology and Testing)

[8] http://club-nanometrologie.fr

intellectual property, technological project engineering, law, marketing, and commercial development;

- Technological Research Institutes (IRTs), also set up through the Investments for the Future Programme, and that are cross-disciplinary topic-based entities bringing together skills from industry and from publicly funded research, with the rationale being for public-private co-investment and for close collaboration;

- Carnot Institutes. The Carnot Label, set up in 2006, makes it possible to identify public laboratories that are committed to doing research in partnership with companies. The network currently has 34 institutes across France, representing over 27,000 researchers. 65 enterprises spin off from the Carnot Network every year and 970 priority patents were filed in 2012;

- Contract Research Companies (SRCs). The main activity of these private structures, of which there are 43, is to do research & development work on behalf of VSEs[9], SMEs, ISEs[10], or big businesses;

- Labelled structures, which, since 2007, have been awarded a label by the French Ministry for Higher Education and Research: CDTs (Technology Dissemination Units, which are lightweight structures in charge of doing prospecting on VSEs and SMEs to raise their awareness of innovation, to help them formalise their technological issues, and to put them into contact with the skills centres); CRTs (Technological Resources Centres, which do technological service assignments for meeting the needs of VSEs and SMEs); and PFTs (Technology Platforms, which are platforms that are located in education establishments and that make their equipment and skills available to VSEs and SMEs). There are currently 200 CDTs, CRTs, and PFTs across France;

- Clusters of competitiveness, which, since 2005, have been gathering small and large enterprises, research laboratories, and training establishments together into clearly identified geographical areas on targeted topics, with the aim of developing growth and employment;

- Incubators, whose missions are to detect, host, and assist innovative enterprise creation projects, business nurseries that host young enterprises, and provide services, in particular material services, and technopoles that provide support for the policy of developing local areas through innovation; all of these innovation stakeholders are co-ordinated by an association called Retis;

- Curie Network, which promotes and assists structures for transferring research findings from the public sector to companies. Its over 150 members are French institutions working in the field of public research, such as universities, university hospitals, *grandes écoles* (prestigious higher education establishments with competitive entry examinations), and national research bodies;

- Industrial technical centres, which operate with support from trade associations and act in support of particular industrial sectors that generally have large percentages of VSEs and SMEs. There are 14 technical centres in France;

- Chambers of commerce and industry, etc.

9 Very Small Enterprises

10 Intermediate-Sized Enterprises

Various bodies, such as Inserm transfert (the knowledge-transfer subsidiary of the French National Institute of Health and Medical Research), CNRS, France's National Centre for Scientific Research (through its subsidiary FIST SA (France Innovation Scientifique et Transfert)), the Curie Institute (Patents and Industrial Partnerships Division), CEA tech (the innovation accelerator of France's Alternative Energies and Atomic Energy Commission), etc. also have internal business development units for extracting added value from their research work.

Of the 71 clusters of competitiveness spread over the French territory, two centres called Elastopôle and Materialia have nanomaterials as their main topics. Materialia, located in Eastern France, is a cluster made up of 25 large businesses, 68 SMEs, and 18 research and training bodies. Elastopôle, located in Central France, is a cluster made up of 56 large businesses, 42 SMEs, 8 research bodies, and 17 training centres. Two clusters of competitiveness also have nanotechnologies as their main topics, namely Minalogic, a cluster established in the Rhône-Alpes Region and made up of 29 large businesses, 145 SMEs, 6 research bodies, and 6 training centres, and Microtechniques, a cluster located in the Doubs Region and made up of 65 large businesses, 61 SMEs, 12 research bodies, and 7 training centres. Other clusters of competitiveness such as Aerospace Valley, Cosmetic Valley, Optique et Photonique (Optics and Photonics), Lyonbiopôle, etc. also handle capitalising on research work that is more or less strongly related to manufactured nanomaterials.

Various Carnot Institutes are focused on nanomaterials, e.g. the institutes CIRIMAT and LAAS in the Midi-Pyrénées Region, the CEA institutes Leti, Ingénierie@Lyon and PolyNat in the Rhône-Alpes Region, Mica in Alsace, Chimie Balard in Hérault, Mines in the Paris Ile-de-France Region, etc.

Similarly, various contract research companies such as Armines or Rescoll, and various industrial technical centres such as the *Centre technique des industries aérauliques et thermiques* (CETIAT, the Technical Centre for the Heating, Ventilation, and Air Conditioning Industries), the *Centre technique des industries mécaniques* (CETIM, the Technical Centre for the Mechanical Engineering Industries), which is also a Carnot Institute, and the *Institut français de l'habillement et du textile* (IFTH, the French Institute for the Textile and Clothing Industries) propose to promote university research work associated with nanomaterials and to make such work more developable with a view to extracting more added value from it.

Finally, there are some private structures in France that are specifically dedicated to transferring technologies relating to manufactured nanomaterials, such as the CANOE[11] Platform (CANOE is a technology transfer platform that proposes pooled human and material resources for assisting the development of the economic fabric of the Aquitaine Region in the field of nanostructured materials).

Initiatives in Europe can also be reported, such as the European knowledge transfer network for transferring knowledge on carbon nanomaterials used in the automobile and building sectors, set up in 2011 under the Carbon Inspired project[12], or the NANO4M (Nanotechnology for Market) project (2008-2011) whose ambition was to define novel transfer methods and to develop emerging economic opportunities (the project involved 12 academic and institutional partners from four regions of Europe: Tuscany, North Rhine-Westphalia, Asturias, and Lorraine).

[11] Technology Centre of the Aquitaine Region for Advanced Materials and Composites

[12] http://carboninspired.com/?lang=en

Technology transfer requires all of these structures to co-ordinate implementation of various tools: analysis of the potential market (segment, volumes, dynamism, etc.), identification of the component elements of the technology that is to be transferred, analysis of the intellectual property (trademark, copyright, know-how, registered designs, and patents), characterisation of the regulatory and legal framework, choice of the type of technology transfer that is suited to the context and to the objectives (assignment of a patent, disclosure of know-how, creation of a joint-venture, creation of a spin-off, takeover of a business), calculation of the economic value of the transfer, and financial engineering for the transfer.

In spite of the presence of a very large number of public or private structures working to capitalise on and to transfer the findings of research while also developing nanomaterials so that they can be put on the market, the production stage would appear to be difficult to reach, in particular for SMEs (which account for over 60% of the businesses that are active in the field of manufactured nanomaterials in France, according to the survey conducted in 2011 and commissioned by France's Directorate-General for Competitiveness, Industry, and Services[13]).

This can be explained firstly by the fact that, while there are indeed a large number of structures involved in technology transfer, they are also not very highly structured, their missions are sometimes redundant and their objectives rather imprecise.

In addition, reaching the production stage requires major investment, e.g. in machinery and equipment, and also in property. All of the work relating to demonstrating the industrial and economic viability of the innovative solutions that are developed remains incumbent on the companies, big or small. Very often, French SMEs do not have the financial, technical, and management resources necessary for paying for such long-term projects (typically from 2 to 5 years), which are no longer research projects even though they require a good command of the details of the research, and which are not yet at the industrial stage even though they require investment of a similar magnitude. In addition, finding outlets for these new materials requires multi-sector approaches, for which SMEs are not always prepared. The level of risk associated with this stage makes it not only one of the primary causes of mortality of start-ups and spin-offs, but also an often insurmountable obstacle to the development of innovative sectors in the more conventional SMEs.

A public and/or private funding link also appears to be missing from the chain leading to industrialisation. Funding for innovative businesses, start-ups, and spin-offs does not appear to be fully anchored yet in French investors' way of thinking. And yet, in the course of their research & development activities, small and large businesses alike can ask for assistance from numerous funding schemes, one of the foremost of which is the tax credit for research (*crédit d'impôt recherche*).

[13] *Les réalités industrielles dans le domaine des nanomatériaux en France. Analyse de la réalité du poids des nanomatériaux dans la filière industrielle concernée* (Industrial realities in the field of nanomaterials in France. Analysis of the reality of the significance of nanomaterials in the industrial sector in question), Direction générale de la compétitivité, de l'industrie et des services, June 2012

Mention should also be made of the timidity of some French manufacturers when it comes to actually becoming involved both in funding of research and also in industrial application of the discoveries made by such research. The share of private R&D investment in the field of nanomaterials in 2007 was about 30% (European average), i.e. much lower than in Germany, which stood apart with private sector involvement as high as 70%. In the United States, that share was 60%[14].

Finally, there is sometimes a mismatch between the academic research and the local industrial fabric in France, and that can be a real obstacle to efficient technology transfer.

Prospective analysis

French research on nanotechnologies and manufactured nanomaterials is highly renowned. Public spending on such research is increasingly substantial (for the year 2007, it was about 280 million euros[15]). Conversely, the capacity to transform such research into industrial successes, and thus into jobs and growth, still remains limited.

France shows weakness in its capacity to capitalise on research, resulting in a deficit of technology transfer to its industrial fabric.

This weakness is confirmed by the absence of France from the global rankings established by the Strategic Analysis Centre Centifica[16] in July 2011 and based on how well countries convert discoveries into marketable products. In those rankings, the United States' position of leader was confirmed, followed, in order, by China, Russia, Germany, Japan, the European Union, South Korea, Taiwan, the United Kingdom, and India.

It can also be observed that 2/3 of the patents filed in the sector are held by Asia (China, Japan, and South Korea), leaving the United States and Europe some considerable distance behind. Germany accounts for 2/3 of the European patents, ahead of France and the United Kingdom. The applicants are mainly from industry (70%) and more particularly multinational companies[17].

Furthermore, it should be noted that the number of start-ups and spin-offs in the sector of manufactured nanomaterials in France is significantly lower than in the United States, China, or Japan. It would seem that the business creation incentives are inappropriate or have not yet been fruitful. The lack of mobilisation and of appetite among venture capital investors in this field in France is thus marked.

Given the economic issues, the French effort, in particular the public sector effort, should, in the coming years, be intensified with the aim of facilitating creation and development of innovative companies in the manufactured nanomaterials sector in order to create jobs.

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14 Conseil national de la consommation (National Consumer Council), June 2010

15 http://www.economie.gouv.fr/cedef/dossier-documentaire-nanotechnologies

16 Global funding of nanotechnologies and its impact, Cientifica, July 2011 (http://cientifica.com/wp-content/uploads/downloads/2011/07/Global-Nanotechnology-Funding-Report-2011.pdf)

17 Les nanotechnologies, Conseil économique et social (Nanotechnologies report by the French Economic and Social Council), 2008

Sustained support for organising public and private communities and bridges between them for improving the targeting of the research work and for accelerating transfer, in particular to SMEs/ISEs, also appears to be emerging.

Joint laboratories run jointly by academic research bodies and by PMEs/ISEs are also being set up, such as, for example, the Laboratoire des Sciences et Technologies des Nanomatériaux (Nanomaterial Science and Technology Laboratory) located in Nancy[18] and supported in part by the ANR (French National Research Agency) since March 2014. The interactions between the public research structures and the private companies are particularly well consolidated since a fraction of the premises and facilities is dedicated to the industrial partners in order to enable genuine technology transfer to take place. Various laboratories of the CEA (France's Alternative Energies and Atomic Energy Commission) are also presented as being transfer centres for transfer between upstream research and industry (such as the laboratory "Liten" that has helped produce four start-ups specialised in new energy technologies).

Finally, the new European programme for funding research and innovation and known as "Horizon 2020" [19] came into effect on 1st January 2014. This programme, for which 79 billion euros has been allocated, combines funding from the European Union for the 2014-2020 period both for research and also for innovation, and it focuses on three main priorities: excellent science, industrial leadership, and tackling societal challenges. Among the industrial leadership topics is the one on nanotechnologies and nanomaterials (this topic being known as "NMP" for "Nanotechnologies, Advanced Materials, and Production"). This programme aims to encourage scientific and technological progress by facilitating integration of such progress into competitive products and services for a whole series of applications and sectors. 20 calls for projects relating to nanomaterials were launched in December 2013.

Hypotheses

Hypothesis 1. Technology transfer is well structured and efficient

Major support, in particular public sector support, is given to capitalising on the results of research coupled with developing manufactured nanomaterials, and well-organised, fast, and efficient technology transfer to all of the markets develops with numerous and fruitful exchanges between industry and academia.

Hypothesis 2. Technology transfer takes place with difficulties

Public and private structures dedicated to capitalising on the results of research coupled with developing manufactured nanomaterials are manifold but not very structured, their action is moderate, and technology transfer to markets takes place with difficulties.

[18] Laboratory run jointly by CNRS, University of Lorraine, and the company Vinci Technologies
[19] http://ec.europa.eu/programmes/horizon2020/

Hypothesis 3. Technology transfer is focused on a few strategic markets

Public and also private structures dedicated to capitalising on the results of research coupled with developing certain manufactured nanomaterials having high economic stakes are put in place, and technology transfer focused on a selection of associated strategic and buoyant markets is deployed.

The skills networks

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Definition

The aim of a skills network is to create and to structure a community of interests in nanotechnologies so as to facilitate research, development, and marketing of products and services.

There are many skills networks in France and they are very often structured around the regional industrial and university fabric.

Examples of skills networks

Clusters of competitiveness

In a global economy that was becoming increasingly competitive, France launched its clusters of competitiveness programme in 2004 for building capacity for innovation, growth, and employment on buoyant markets.

A cluster of competitiveness gathers small and large enterprises, research laboratories, and training establishments together into clearly identified geographical areas on targeted topics. Central and local governments are closely involved in the process.

There are 71 clusters of competitiveness in France, several of which are working to develop and facilitate innovation in the field of nanotechnologies:

- **Lyonbiopôle:** it develops products and services based on smart miniaturised solutions (micro- and nano-technologies and embedded software intelligence) for industry[1].

[1] http://www.lyonbiopole.com

- **Minalogic:** located in Grenoble, it proposes smart miniaturised solutions (micro- and nano-technologies and embedded software intelligence) for industry[2].

- **Microtechniques:** located in Besançon, it is centred around technological know-how, mainly coming from watch-making and clock-making. Its output relates to smart cards, telephones, broadcasting relay transmitters, parameters, satellites, pacemakers, wheels, dashboards and instrument panels, and engines for aircraft and automobiles, etc.[3]

- **Optique et Photonique (POPSUD):** located in the Provence-Alpes-Côte d'Azur Region, this optics & photonics cluster is specialised in complex optical and imaging systems dedicated for hostile environments[4].

- **Sciences et systèmes de l'énergie électrique (S2E2):** this electrical energy science and systems cluster located in the Centre and Limousin Regions of France focuses on the entire value chain of electrical energy[5].

- **Solutions communicantes sécurisées (SCS):** located in the Provence-Alpes-Côte d'Azur Region, this secure communicating solutions cluster of competitiveness integrates hardware and software for transmitting, exchanging, and processing information securely and reliably[6].

C'NANO skills centres (universities and CNRS)

Six "C'Nano" nanoscience skills centres[7] set up in 2004 are supported by a network of higher education establishments and of businesses for producing technological innovations that are necessary for industry.

The six C'Nano skills centres cover the entire territory of France and bring together all of the 290 laboratories and their 560 academic research teams working in nanosciences, as well as 48 universities and 44 engineering or vocational schools. C'Nano currently brings together nearly 7,000 researchers, teaching researchers, post-doctoral researchers, PhD students and technical staff from various disciplines so that all of the aspects of nanosciences, from hard sciences to human and social sciences, can be addressed within the network.

RENATECH that groups together 6 major manufacturing platforms

The specificity of nanoscience research in France is that it is supported by a very dense network of specific technological structures that are necessary to the applications.
A national network of large technology facilities for Basic Technological Research (known as "RTB" in French) was initiated as early as 2003 by the French Ministry for

[2] http://www.minalogic.com
[3] http://www.polemicrotechniques.fr
[4] http://www.popsud.org
[5] http://www.s2e2.fr
[6] http://www.pole-scs.org
[7] http://www.cnano.fr/spip.php?rubrique5

Higher Education and Research; it implements a plan for supporting a network of large nano-manufacturing facilities and enables the research teams from the laboratories to use a set of nano-manufacturing methods that are competitive at global level.

France's Alternative Energies and Atomic Energy Commission (CEA) and its National Centre for Scientific Research (CNRS) coordinate this national network within which five topics are developed:

- integration of heterogeneous systems and technologies;
- micro-, nano-, and bio-systems;
- micro- and nano-electronics and "ultimate" (e.g. single-molecule) electronics;
- nanotechnologies, nanomagnetism, and nanomaterials;
- optoelectronics and photonics.

These large facilities have been clustered in five areas:

The Rhône-Alpes cluster

This cluster includes the CEA Leti facility (the CEA's electronics and information technology laboratory) and the Upstream Technological Platform (PTA). The topics include, in particular, quantum nanoelectronics, nanomagnetism, and spin electronics, as well as the interface between biology and nanoelectronics, nanophotonics, molecular electronics, mechanical nanosystems, and nanomaterials, and together with the main research topics of the Leti facility: microelectroncis, photonic systems, and biochips.

The Rhône-Alpes cluster also incorporates several other structures on various sites:

- the Minatec centre, set up at the initiative of CEA Leti Grenoble and of INP Grenoble, and for which 4000 people work[8]
- the Crolles site where STMicroelectronics is located, with the only 300 µm nanoelectronics factory in France, where about 1,000 researchers work on architectures for transistors and integrated circuits, and on manufacturing processes and design methodologies. This centre provides a service for manufacturing experimental circuits for laboratories throughout the world[9].
- the Micro- and Nano-Technologies Federation (FMNT) that brings six laboratories together[10].

The Nord cluster

This cluster includes the Institut d'Electronique, de Microélectronique et de Nanotechnologie (IEMN), set up in 1992 by the CNRS, the Université des Sciences et Technologies de Lille (USTL), the Université de Valenciennes et du Hainaut-Cambrésis (UVHC), and the Institut Supérieur d'Electronique et du Numérique (ISEN). In this cluster, physicists, electronics specialists, and acousticians study, in particular, materials and nanostructures, microtechnologies and microsystems, micro- and opto-electronics, etc.[11]

[8] http://www.minatec.org
[9] http://www.st.com
[10] http://fmnt.online.fr
[11] http://www.iemn.univ-lille1.fr

The Sud-Ouest cluster

The Toulouse facility of the Laboratory for Analysis and Architecture of Systems (LAAS) [12], with its Carnot Institute Label[13], is a CNRS research unit that works in partnership with Université Paul-Sabatier-Toulouse 3, INSA de Toulouse, and INP de Toulouse.
The LAAS-CNRS research activities bring together 17 research teams organised into four groups:

- the Micro- and Nano-Systems (MINAS) group;
- the Systems Modelling, Optimisation and Operation ((MOCOSY) group;the Robotics and Artificial Intelligence (RIA) group; and
- the Critical Information Systems (SINC) group.

The Île-de-France (Paris Region) cluster

Three establishments:

- the Photonics and Nanostructures Laboratory (LPN) facility. LPN is a CNRS research unit. Its research covers the fields of quantum information processing, optical communications, "all-optical" signal processing, high-density information storage, and microfluidics combined with the use of nanostructures, a field at the interface between physics, chemistry, and biology[14].
- the Fundamental Electronics Institute (IEF) facility. A joint CNRS-Université Paris Sud-XI research unit, the IEF is located at the scientific centre of Orsay. Its research focuses on silicon III-V nanoelectronics (semiconductor-based micro- and nano-electronics), nanomagnetism, micro- and nano-photonics, and software-centric and hardware-centric microsystems and systems[15].
- the Institut d'Optique Graduate School (IOGS). Located on the campus of the "Ecole Polytechnique" (one of France's most prestigious education and research establishments) and labelled as a Carnot Institute, this institute is specialised in atomic and quantum physics, nanophotonics, non-linear materials, lasers, optical systems, etc. It is currently the West's leading centre for engineer-level and master-level training in optics in terms of number of graduates[16].

The Grand-Est cluster

This cluster is based on the FEMTO-ST facility (the Franche-Comté Electronic, Mechanical, Thermal, and Optical Sciences and Technologies facility). A joint CNRS research unit, it is affiliated to the Université de Franche-Comté (UFC), to the École Nationale Supérieure de Mécanique et de Microtechniques (ENSMM), and to the Université Technologique de Belfort-Montbéliard (UTBM). Its research focuses on the fields of mechanics, optics, telecommunications, electronics, time-frequency, energetics, and fluidics[17].

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[12] http://www.laas.fr

[13] The Carnot Label identifies public laboratories who are committed to doing research in partnership with industry.

[14] http://www.lpn.cnrs.fr

[15] http://www.ief.u-psud.fr

[16] http://www.institutoptique.fr

[17] http://www.femto-st.fr

Transnational networks

The objective of transnational networks is to make it easier for SMEs to enter the nanotechnologies market by transnational interlinking of the various financial assistance programmes, by developing new transnational support structures, and by putting in place transnational skills clusters.

Thus, for example, through the NANORA (Nano Regions Alliance) project, the key players in seven regions (Hessen (D), Saarland (D), Nord-Pas de Calais (F), the Cork Region (Ir), Wallonia (B), the Netherlands (NL), and the Lancaster Region (GB)) have joined forces with the aim of developing a concerted response for supporting the nanotechnologies economy at a transnational level.

The European Research & Development Programmes

The European Union initiatives related to research are steered by the Framework Programmes (FPs) for Research and Technological Development. Through this mechanism, the European Union has funded numerous (nearly 2,000) European projects in the field of nanotechnologies.

Horizon 2020

This Horizon 2020 Programme combines funding from the European Union both for research and also for innovation, and it focuses on three main priorities: excellent science, industrial leadership, and tackling societal challenges.

With this new programme, the European Union will fund projects that are resolutely interdisciplinary and that are able to take up the major economic and social challenges. It will cover the entire innovation chain, from idea to market, and will reinforce the support for commercialisation of research findings and for creativity in businesses.

Horizon 2020 has funding of 79 billion euros for the period from 2014 to 2020, for supporting the work of stakeholders in research and innovation (organisations, higher education and research establishments, companies, etc.).

In this programme, six Key Enabling Technologies (KETs) are positioned as being the most promising:

- nanotechnology;
- micro- and nano-electronics;
- biotechnology;
- photonics;
- advanced materials; and
- advanced manufacturing systems, for producing cutting edge components and combining one or more KETs.

The European Community's Smart Specialisation Strategy

For the programming of European funds for the period from 2014 to 2020, the European Union expects regions to develop a smart specialisation strategy ("3S" or "S^3") for research and innovation.

Such an innovation and research strategy should make it possible to identify certain innovative activities that will participate in the economic development of the region in question for the coming seven years. Developing a smart specialisation strategy is a perquisite for obtaining European Regional Development Fund (ERDF) funding. ERDF funding will be, in part, earmarked for innovation fields noted for their growth potential.

The challenge is thus to identify the region's fields of innovation so that the stakeholders on the ground (entrepreneurs, researchers, etc) share and propose a common vision on collective projects for new activities conducive to creating significant economic development in the medium term (by the 2020 horizon).

Business clusters

These are networks of companies, most of which are SMEs or VSEs, and which are strongly anchored in the local area, often working in the same production segment and in the same sector of activity. The primary advantage of a cluster is that it increases the turnover and the economic efficiency of the company, and it also enables the company to detect growth-facilitating factors in its environment.

Importance of partnerships for companies involved in nanotechnologies

A survey was conducted in 2011 by the French Directorate-General for Competitiveness, Industry, and Services (DGCIS) on French companies committed to the field of nanotechnologies. It highlighted various obstacles to the development of the French industrial fabric, including:

- industrial feasibility: going from the laboratory scale to the industrial scale is a challenge that the nanomaterials industry now needs to address.

  In order to take up this challenge, two points need to be validated:
  - producing evidence of the reality of the added value procured by using nanomaterials in products, in particular in terms of improving functional properties;
  - the technico-economic feasibility needs to be evidenced, in particular during the scaling-up. One of the obstacles observed is the lack of pre-industrial pilots validating the technical characteristics of the nanomaterials at industrial scale, and at an economically competitive cost.

- structuring the ecosystem: this obstacle concerns how the various links in the chain of the sector are structured; what characterises that structuring is that the stakeholders are scattered.

  In order to facilitate the emergence of a structured ecosystem, various actions can be considered, such as putting in place support platforms, developing tools for sharing knowledge about the findings of finalised and on-going R&D projects.

Clearly, reinforcing the skills networks policies should ultimately remove these obstacles.

The same survey reveals that more than two-thirds of nanotechnologies companies have partnerships with French organisations, be they companies or research institutes, and one half have partnerships with foreign organisations. One half of companies engaged in nanotechnologies belong to clusters of competitiveness.

Hypotheses

Hypothesis 1. The developments are spurred by national nanotechnology networks

As a result of the national public policies and of the needs expressed by manufacturers, specific skills networks continue to develop, essentially within France.

Hypothesis 2. The developments are steered by international nanotechnology networks

Specific skills networks develop at European or even global level (national networks do not progress any further). The complexity of the product development chain (making the products, industrial validation, ecotoxicology, etc.) requires the investments to be spread across transnational networks, a little like what is done in the field of nuclear fusion, for example. The industrial development is exponential and the decision centre is at least at European or even global scale for making the products and managing the associated risks. One or more transnational structures exist.

Hypothesis 3. The specific nanotechnologies networks disappear in favour of sector-based groupings

There are no longer any skills networks specific to nanomaterials; the activities are incorporated into more general networks per sector of activity at French and European levels (e.g. Plastipolis, a cluster of competitiveness for the plastics industry).

References

There are nanotechnology skills maps in various countries, and they identify the networks, SMEs, research centres, large companies, etc.

- **Germany:** 186 networks identified
- **United States:** http://www.nanotechproject.org/inventories/map/, http://www.nano.gov/
- **Europe:** http://www.nanofutures.info/regional-contacts: list of networks identified per country by the EU
- **France:** https://www.nanothinking.com/: service sold by a French startup that lists global companies involved in nanotechnologies.

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Le déploiement industriel des nanotechnologies et de la biologie de synthèse sur les territoires, précurseur des manufactures du futur (Industrial deployment of nanotechnologies and synthetic biology across France, as a precursor to the factories of the future). Report of December 2013 on behalf of the following French ministries: Ministry for the Economy and Finance, Ministry for Industrial Renewal, Ministry of Defence, Ministry of Agriculture, Food, and Forestry, Ministry for the Ecology, Sustainable Development and Energy, Ministry of Higher education and Research, General Council for the Environment and Sustainable Development, Inspectorate-General for Administration of National Education and Research.

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Education and training

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Definition

According to Article L. 6111-1 of the French Labour Code (*Code du Travail*), lifelong vocational training is a national obligation. It includes initial training and subsequent training for adults and young people already in the working world or about to enter it. The subsequent training corresponds to further vocational training, which has been a legal obligation since 1971, and aims to give employees or jobseekers training for reinforcing, improving, or acquiring vocational knowledge (source: Insee, France's National Institute of Statistics and Economic Studies).

Lifelong vocational training therefore differs from vocational qualifications, which show capacity to do a particular trade or job, and are obtained through training or education validated by a diploma awarded by a recognised training body, which may be approved by the State, or through personal or occupational experience acquired on the ground. Training through apprenticeships, lying between initial training and further training, makes it possible to prepare for passing vocational and technological diplomas awarded by France's National Education authority, while also including periods of occupational activity in a company. Finally, a skill or a competency requires mastery of various aptitudes and the ability to mobilise them to solve problems. In France, education is provided mainly by the State (central government), with local authorities playing a growing role in the public sector. Europe plays a part in steering education and training policies and is pushing for harmonisation of the systems and of the qualifications and certifications.

Retrospective analysis

Context

Technological progress and increasingly complex tasks require operators who are increasingly qualified and capable of mobilising their knowledge so as to take initiatives and work with less supervision. The Education and training systems should henceforth enable broader and deeper skills to be acquired in various fields, those skills being enriched through work experience. These changes should help to produce more dynamic skills that are increasingly cross-cutting and transferable, in contrast to the unmoving nature of qualifications. It appears that skills of all kinds play major parts in economic growth. The more the population is trained, the more economic growth can be underpinned by qualified jobs that are, in theory, stable and competitive.

Inventory of vocational training in France

Training levels have considerably increased over the last 30 years, with the number of people with higher education qualifications now being greater than the number of people without such qualifications in the 25-34 age bracket, whereas the reverse applies for the 55-64 age bracket. The younger generations are, on average, much higher qualified than their parents. The current trend is for the level of qualifications to be generally rising but this trend seems to be slowing as a plateau is being reached that appears difficult to go beyond.

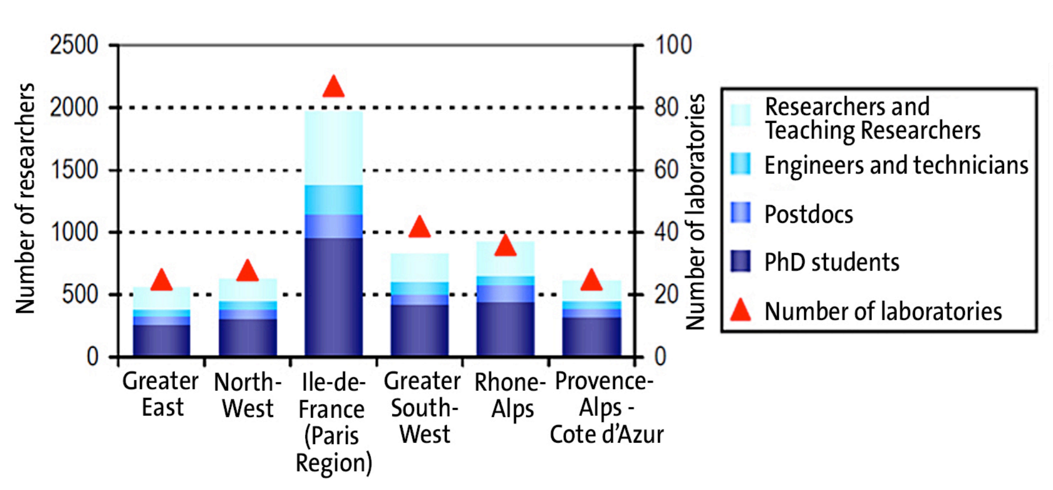
Match between initial training and the needs of industry

There is a partial mismatch between the training that is on offer and the sectors that are creating jobs. There are major disparities depending on the sectors being considered. Thus, certain sectors are facing huge recruitment difficulties. Conversely, some courses are taking in many more students than there are expected job opportunities. The increasing number of workforce planning systems aim to mitigate this partial mismatch.

Initial learning in higher education

Organisation of higher education is complex and involves both public and private institutions. However, only the French State can award university degrees and qualifications, and national diplomas. A distinction can be made between universities, which combine research and teaching, and vocational training schools, which provide training in occupational fields and are often less focused on research issues. In 2011, in France, 2,347,000 students were enrolled on higher education courses, with average annual growth of 1.1% since 1999, sustained, in particular, by a rise in the number of foreign students.

France currently has over 243 laboratories doing nanotechnology research and in which 5,300 researchers work, including numerous PhD students and post-doctoral researchers.



***Geographical distribution of nanotechnology researchers in France*[1].**

The European higher education systems are undergoing major reforms aimed at harmonising them at world level. The main driver of these reforms is the choice to adapt to the innovation economy, in which producing and using knowledge are the sources of economic productivity. The emerging sector of nanosciences and nanotechnology constitutes a striking example of this transformation that is establishing the university as the place of training that is adapted to training workers in the innovation economy. In particular, higher education has the role of training knowledge workers who are adapted to this new economy. It should be noted that this transformation is taking place in a context in which science courses are tending to attract fewer students than other courses.

In France, the LOPR law (a framework law laying down guiding principles for research) enacted in 2006 and the LRU law (law on the liberties and responsibilities of universities) passed in 2007 have been the main reforms to the higher education and research system. They marked the advent of universities that are henceforth designed on the corporate model: competing for prestige and funding, they are forced to develop on the entrepreneurial model, developing strategies for remaining or becoming competitive on the global higher education market. The need to become or remain profitable has led universities to forge closer ties with the private sector, in particular in strategic fields such as nanotechnology. This has often led to universities and businesses grouping together to form clusters of competitiveness.

In this context, it is interesting to observe that the nanoscience and nanotechnology sector, due to its newness and to it being strongly anchored in the private sector, offers an enlightening example of these transformations.

For instance, in the field of nanoelectronics, big microelectronics groups are closely involved in their sector in the development of public research and teaching related to nanomaterials in the nanomaterials of their sector:

[1] http://cache.media.enseignementsup-recherche.gouv.fr/file/Plan_Nano_innov/32/0/Fiche_recherche_nanos_52320.pdf

- funding nanoscience and nanotechnology research and education platforms: it is in the interest of manufacturers to fund research in this field and to train students on their own equipment, so as to build a reserve of labour qualified in this field;
- manufacturers participating in setting up models for teaching new training courses in nanoscience and nanotechnology, and sitting on boards steering such courses; this illustrates the reinforcement of relations between academia and industry in a context of reform of higher education and research, bringing a culture of assessment, based to a large extent on the profitability of the training courses and on their outlets in terms of job opportunities in industry.

Over the last decade, projects for networks with major focuses on nanomaterials research and training have emerged. Among such networks, mention can be made of:

- the French national networks: Nanomat, Club Nano-Micro-Technologies, CNFM (National Coordination of Training in Microelectronics and Nanotechnology);
- the European networks such as the European Research Area Network (ERANET) Nano-Sci-ERA;
- the clusters of competitiveness that include research and training sections;
- the regional and interregional networks; CNRT materiaux (National Centre for Technological Research on Materials), and the C'Nano network.

The new nanoscience and nanotechnology training courses that have blossomed in recent years, mainly at master's degree level, are particularly well suited to building a workforce corresponding to the needs of the international labour market, in the current context of globalisation. These master's degrees are often international, and the teaching programmes have large parts devoted to acquisition of skills coming directly from and intended for the private sector. Currently, there are over fifteen master's degree courses in nanosciences.

The emergence of nanoscience and nanotechnology courses at universities is not due solely to progress by fundamental research in the field, and, to an even lesser extent, is the result of a societal choice. It results above all from the economic promises of the applications expected from the "nano revolution".

In a context of racing for productivity in an innovation economy, companies have enormous R&D needs, in particular in an emerging sector like the nanoscience and nanotechnology sector. They are therefore tending to join forces particularly closely with the public research and education systems so as to pool their research, and their R&D spending, and so as to train specialists adapted to their research fields.

An example

To meet the needs of micro- and nano-electronics companies, the French National Coordination of Training in Microelectronics and Nanotechnology (CNFM) was set up. Developing micro- and nano-electronics companies requires excellent practical training of the students on courses in those fields. The facilities associated with such training are often costly both to build or install and also to run. That is why it is necessary to pool the required resources nationally. This has led to the CNFM being set up as a public interest group (GIP) made up of twelve centres. These regional or interregional interuniversity centres group together manufacturing and characterisation facilities, and computer hardware and software for computer aided design, for testing the integrated systems and circuits, and for prototyping.

However, it should be noted that the local facilities also provide practical training for universities and for certain local SMEs. In addition, they have broadened their scope to include sectors other than electronics, and in particular physics and chemistry. It is therefore necessary to optimise this scheme as well as possible, at national level, and to clarify the objectives of each of the structures.

The Euro Training project that is funded by the European Union is aimed at providing high-quality training in the field of nanotechnologies in order to facilitate business competitiveness on the global market. This initiative focuses on nanotechnology training through a range of innovative courses intended for industrial stakeholders, researchers, and students.

Launched in January 2013, Euro Training is embodied by an on-line platform that proposes a broad selection of advanced training, summer schools, downloadable documents, videos, etc. It is intended for engineers working in industry, and for researchers or teaching staff at universities. The platform operates as a dissemination and communications space that identifies the specialist courses proposed by partner European universities and the major events in the nanotechnology sector.

This project is a response to a genuine need that exists out in the companies. One of the main missions of the project is to train the engineers in the companies in order to optimise their competitiveness.

The further training courses available in these new technologies remains relatively poor so far. Generally, the suppliers of equipment dedicated to nanomaterials provide training for the future users. A few bodies propose further training, including courses leading to qualifications or certificates and intended for updating knowledge or for induction to new science and technology. Among such bodies, mention can be made of the INSTN (French National Institute for Nuclear Science and Technology), the SERFA (a further vocational training body in Alsace), or the CIME (Inter-University Centre of Microelectronics and Nanotechnologies). Mention should also be made of the further training courses for acquiring knowledge on nanomaterials with a view to engaging in a risk prevention approach. This applies to the training courses proposed by INRS (the French Research and Safety Institute for the Prevention of Occupational Accidents and Diseases).

Prospective analysis

The French education system needs to take up challenges of various types in order to remain a high-performance system.
The development of enterprises in the field of nanomaterials is based on major and fast technological changes: excellent practical training for young engineers is a decisive factor in the success of such enterprises.

Cross-disciplinarity is very advantageous for nanosciences and nanotechnology, but conventional education and training systems do not prepare for it. New products, new services, and new production methods will generate demand for totally new trades. It is thus necessary to encourage initial and further cross-disciplinary training in order to take up the challenges of these new technologies, and to encourage teaching in nanoscience and nanotechnology R&D, while emphasising physics, chemistry, biology, toxicology, and ecotoxicology, as well as engineering, and not forgetting studies on entrepreneurial development, risk assessment, and social sciences and humanities, where necessary. As regards further training, programmes should also be specifically targeted on SMEs, who often lack the necessary expertise or internal resources.

The public authorities are contributing to the development of the knowledge economy across France and across the European Research Area. If the development of nanosciences becomes a priority, one of the challenges will be to reinforce the partnership between the academic research networks and the industrial world in the field of nanomaterials, in the form of industry and research cooperation projects aiming to increase the competitiveness of businesses.

Laboratories and businesses will then need to appropriate this new approach concerning developing and extracting added value from nanomaterials, and will need to be proactive in making proposals on the main focuses of practical training.

An example of such collaboration is the nanosciences and nanotechnology centre that is to be set up at Paris-Saclay in 2017. It will be a national centre of reference for nanoscience and nanotechnology on the Paris-Saclay campus. It will be open both to academic and industrial stakeholders, in order to enable them to develop their strategic research focuses in the fields of materials, nanophotonics, nanoelectronics, nanobiotechnologies, and micro- and nano-systems.

The development of specific and structured training in nanoscience appears necessary to the emergence of a genuine industrial sector in France in the field, while also being watchful to target the expectations of businesses as regards training related to nanotechnologies.

In addition, in view of the diversity of applications that are possible with nanomaterials, including nanoscience and nanotechnology training modules in the conventional curricula such as chemistry, biology, electronics, etc. would contribute to the economic development of nanotechnology.

Hypotheses

Hypothesis 1. Dispersion of training courses

The training efforts, in particular as regards initial training, are upheld, with qualification levels equivalent to the current levels, in a context of improving the match between the training courses on offer and the needs of the sectors of activity. New nanoscience and nanotechnology training courses are proposed within the conventional curricula, in particular via specialist master's degrees. This multitude of master's degrees tends to give rise to a lack of consistency between the courses and a lack of visibility.

Further training develops episodically and is mainly provided by nanomaterials producers and by suppliers of equipment related to nanomaterials.

Conversely, training in these new technologies continues to remain absent from the secondary education programmes.

Hypothesis 2. Consistency and organisation of initial and further training courses

Strong public policy is implemented for massively developing training in nanosciences, with the training being structured on the nanomaterials activities, so as to bring together and target the skills necessary to developing nanomaterials, based on networks of both initial and further training, and on networks of training through research that enjoys national and international recognition. Information, resources and skills are pooled and structured over all of the French institutions concerned by higher education in nanomaterials.

At the same time, ties become closer between the universities and the businesses in the field, making it possible to develop interactive training networks that are meshed between laboratories and industrial sites, and to set up training courses that match the needs of manufacturers.

Implementing measures giving financial support to specific research and training projects generated by these networks (PhD and post-doctoral grants, scholarships, and fellowships) makes it possible:

- to facilitate the development of nanomaterials by using the existing scientific and industrial skills and fabric, and by reinforcing the multi-disciplinary approach of the initial and further training courses; and
- to develop applied research and training projects within the same network or by working in partnership with several networks and with the industrial fabric.

In order to promote university courses dedicated to nanotechnologies, training actions are also scheduled during secondary education, requiring prior action to raise the teachers' awareness of this topic.

Hypothesis 3. Targeted organisation of training courses

Developing initial training in nanotechnology and nanomaterials takes place only in a few fields and in buoyant sectors. Such specific training is developed with the industrial stakeholders of the identified sectors.

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The industrial fabric

Irina Guseva-Canu, InVS

Definition

The global production of nanomaterials grew tenfold from 2002 to 2011, to reach over 270,000 metric tons in 2011. A conservative estimate for 2016 is about 400,000 metric tons, mainly covering the demand from the microelectronics, energy, medicine, chemicals, coating and catalysis markets (1). It is expected that ultimately nanotechnologies will allow France's technology and energy dependency on other countries to decrease, in particular through the capacity of nanomaterials to act as substitutes for certain rare earths or raw materials. In the shorter term, they might have a strong impact on dissemination of technological progress and on job creation, because they could generate from 2 to 10 million direct jobs globally, and represent about 10% of manufacturing employment in Europe by 2015 (1). The amounts currently being invested globally total several hundreds of billions of dollars. However, the impact on employment and on the local areas is very difficult to assess. Based on various analyses (amounts invested in R&D, market analyses, relative share between countries, etc.), the potential impact can be estimated to be approximately 20% more industrial jobs in the short and medium terms. However, the real impact on jobs will depend on a whole set of very complex factors (1).

Indicators

1. Momentum of growth in the number of companies engaged in nanotechnology (NT).
2. Momentum of internal growth (size and structure) of companies engaged in NT.

Retrospective analysis

So far, NT and nanomaterials do not constitute either a sector or a branch in the sense of French national accounting. They are not included in statistics on foreign trade, and they are not represented in any French, European, or international classification or nomenclature of activities or of products (2). The most exhaustive inventory of French enterprises that produce or import nanomaterials (quantity > 100 grams per year and per substance) in France is the mandatory annual declaration of substances with nanoparticle status, known as R-nano (3). According to that source, the number of French entities (an "entity" being an enterprise or its subsidiaries) having submitted at least one declaration by 1st July 2013 was 670 (3). The published data does not make it possible to know the sizes of the enterprises or to find out about their organisational structures. Assuming that NT enterprises are of the same size as in other sectors, it could be supposed that 90% of French NT enterprises are SMEs[1].

In 2011, the DGCIS[2] conducted a survey on 300 enterprises (4). In that survey, the nanomaterials industry was looked at as a subset of the sector in France. The survey focused to a large extent on nanomaterial producers; therefore, its findings are not representative of the entire NT industrial fabric (4). According to that survey, about 60% of the enterprises are SMEs, including micro-enterprises that account for nearly one quarter of the enterprises, 15% are subsidiaries of foreign groups, and 18% are subsidiaries of large French groups such as l'Oréal, Michelin, Sanofi Aventis, Veolia Environnement, Sagem, etc. (Figure 1). One third of the NT enterprises were created post 2000(4).

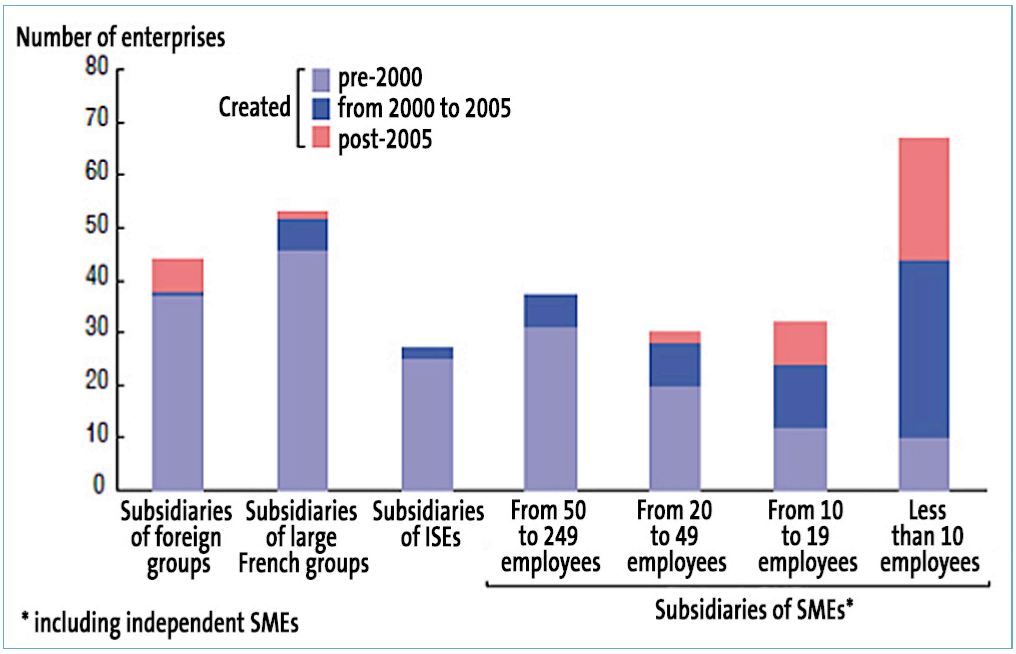

Figure 1. Breakdown of the enterprises according to size and date of creation.
Source: DGCIS survey, June 2011

[1] Small and Medium-sized Enterprises

[2] Direction générale de la compétitivité, de l'industrie et des services (French Directorate-General for Competitiveness, Industry, and Services).

About 15% of the NT enterprises constitute the core companies, having activities at various stages of the value chain and in various NT fields, investing large proportions of their R&D budget and of their staff in such activities, or drawing significant turnover from them. Most of these enterprises have fewer than 50 employees, and nearly all of them were created post-2000. The following structures were set up during the period from 1999 to 2005: the French Research Network for Supporting the Development of Micro- and Nano-technology projects (RMNT); large technology facilities for basic technological research; and clusters of competitiveness for facilitating technology transfer; and then, as of 2007, three theme-based advanced research networks were set up (pooling very large research facilities). This appears to have benefited creation of very small enterprises (over 25% created since 2005) and creation of about ten enterprises having from 10 to 20 employees, and subsidiaries of foreign groups (Figure 1) (4).

Nearly 20% of the enterprises engaged in NT enjoyed "Young Innovative Enterprise" ("JEI") status in 2010, as against 16% in 2009 and 2008. They account for 2% of the total welfare contribution and tax exemptions granted by the JEI scheme. 60% of them are service providers, 40% do R&D, and 60% belong to clusters of competitiveness.

The size of the enterprise appears to be a determining factor in the degree of its involvement in NT (Figures 2 and 3). The economic significance of NT is the highest (≈ 30% of total turnover) in the enterprises that employ between 250 and 500 workers (Arkema, STMicroelectronics, NXP Semi-conductors). It is 20% in French SMEs and ISEs (Intermediate-Sized Enterprises having from 250 to less than 5,000 employees), 22% in subsidiaries of foreign groups located in France, and only 6% in large French groups engaged in NT. Over one half of the enterprises having over 250 employees export products and services related to NT, as against 30% of small enterprises having fewer than 50 employees (4).

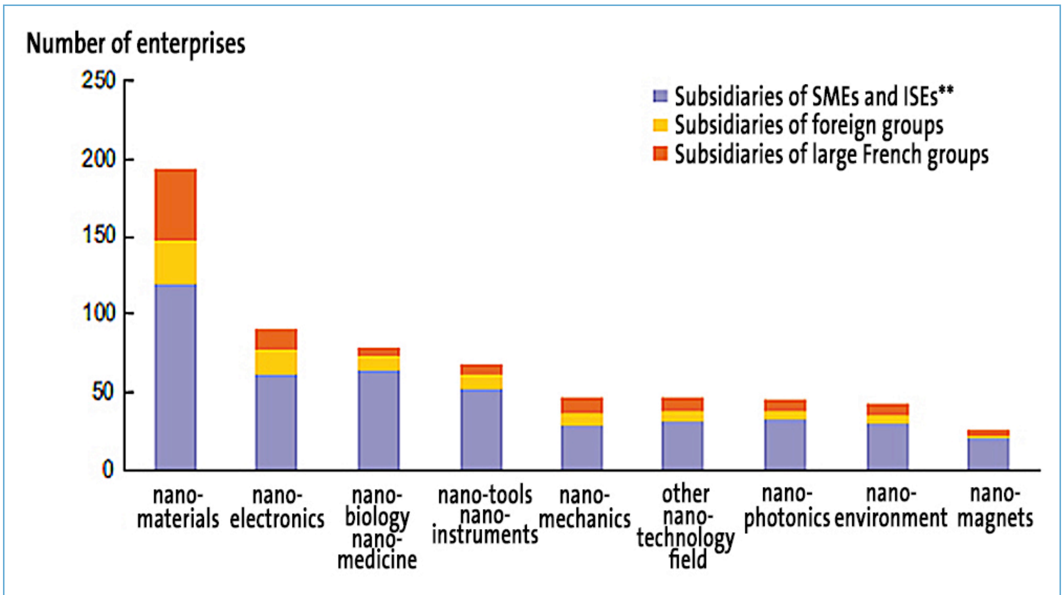

Figure 2. Breakdown of the enterprises according to nanotechnology field of activity*.

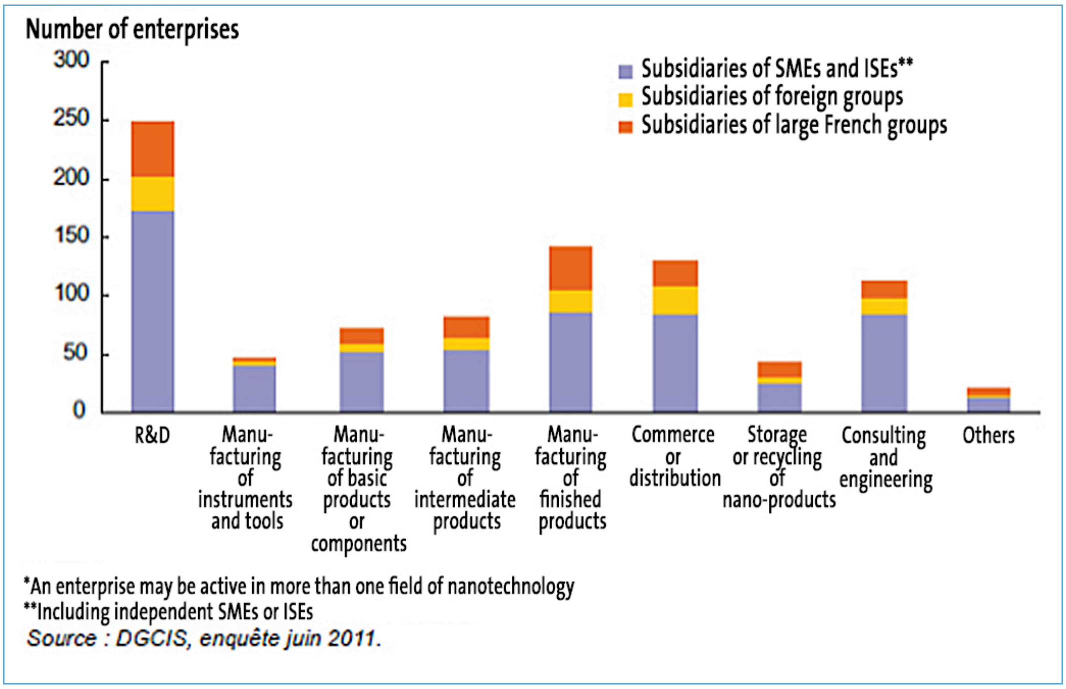

Figure 3. Breakdown of the enterprises according to activity in the value chain*.
Source: DGCIS survey, June 2011

The R&D effort made for NT also varies depending on the size and on the type of the enterprise. One half of the enterprises devote less than 10% of their research budget to NT R&D. That half includes 90% of the subsidiaries of large French groups and 50% of the subsidiaries of foreign groups. At the other end of the scale, 15% of the enterprises devote 90% of their R&D budget to NT R&D. These are small specialised enterprises having fewer than 50 employees and turnover of about 5 million euros. The lack of funds available for start-ups is problematic because, since they cannot give evidence of turnover, they find it difficult to obtain significant aid for starting up in business. The nanomaterial production activities also require a number of skills that is too high to be found within any one start-up. Thus, it would seem that start-ups are developing to a greater extent around instrumentation activities.

The SMEs, and mainly the start-ups, are characterised by business models that are very heterogeneous, in particular because of their unclearly defined positioning in the value chain, ranging from pure R&D to manufacturing, and including recycling, consulting and engineering (4).

As regards capacity to convert research findings into products and into value, France ranks second in Europe. Two-thirds of the European patents in the sector are held by Germany. The applicants are mainly from industry (70%) and more particularly multinational companies (4).

In spite of an honourable position at the beginning of the 2000s, and genuine investment in public and private research, France is lagging behind its main partners in terms of industrial deployment of nanotechnology and of products and systems to which nanotechnology leads, because of certain barriers. These barriers, which are deemed to be surmountable, can be put into three main categories (1):

1. The regulatory framework and society's perception of the direct and systemic risks;
2. Clear fragility in transferring the progress resulting from research to an industrial scale;

3. How the supporting ecosystem is structured to accommodate a cross-cutting sector, which is a difficulty that is specific to enabling technologies. The stakeholders are highly dispersed and there are few ties between them. In addition, the "downstream" specialisations chosen by the clusters of competitiveness do not explicitly support the Key Enabling Technologies (KETs) whose cross-cutting aspect preconditions the innovation success of most of them. In addition, there is a lack of a consistent vision of the future prospects for these industrial sectors in France in central government, whose action is not organised synergistically.

Prospective analysis

In the absence of representative data on the structures, sizes, and modes of governance of NT enterprises in France, it is assumed that there is a similitude between the NT enterprises and the remainder of the industrial fabric (90% of French enterprises are SMEs).

Hypotheses

Hypothesis 1

There is positive momentum for creating innovative enterprises, stimulated by demand from large organisations, or indeed by State subsidies, and then increasing independence, and creation of production lines and of jobs.

Hypothesis 2

Only enterprises from certain clusters of competitiveness survive, thanks to the financial support from existing structures. The situation is worsened by fear and rejection of NT by consumers, NT products remain expensive and do not find markets. The enterprises disinvest and "recycle" the resources and jobs initially devoted to NT and/or relocate production.

Hypothesis 3

One or two of the most robust sectors, such as micro- and nano-electronics or defence, develop and make it possible to create new enterprises and/or jobs. Gradually, they become exemplary and profitable. The development of NT-related services continues at the same rate. Some of these services are specific and in great demand, and they enable France to enjoy a position of renown.

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Organisation of production

Myriam Ricaud, INRS

Definition

The potential impact of manufactured nanomaterials on the global economy is very promising. There are a multitude of applications, most of which are innovative and unprecedented, and they concern an extremely wide variety of traditional and emerging sectors.
By 2015, 15% of global manufacturing activity is expected to involve products using progress resulting from nanotechnology and from nanomaterials[1].

According to a Market Publishers report[2], from 2002 to 2011, the global output of manufactured nanomaterials grew tenfold to reach approximately 230,000 tons in 2011[3]. That output could reach over 350,000 tons in 2016, driven, in particular, by numerous industrial outlets in the sectors of chemicals, medicine, electronics, and energy. According to that report, there are over 400 nanomaterial producers in the world.

The main manufactured nanomaterial producing countries are to be found in North America, Western Europe, and Asia.

Retrospective analysis

At a conference organised in California in 1959, the physicist Richard Feynman declared that the principles of physics would allow atoms and molecules to be individually manipulated and positioned in controlled manner like building blocks or bricks of the

1 http://www.economie.gouv.fr/cedef/dossier-documentaire-nanotechnologies

2 The Global Market for Nanomaterials 2002-2016: Production Volumes, Revenues and End User Market Demand, Market Publishers, April 2012.

3 It should be emphasised that the data varies very widely depending on the sources consulted.

Lego® type. Through that talk, the American physicist was suggesting the scientific community should explore the world of the infinitely small.

The term "nanotechnology" was used for the first time in 1974. In the nineteen eighties with the discovery by two German physicists from IBM of the tunnel effect microscope, and then of the atomic force microscope, the nanoworld really began to open up to researchers, and then to industry. Firstly in the United States, Western Europe, and Japan, and then, in the early 2000s, in China, South Korea, Taiwan, etc.

Manufactured nanomaterials were then developed and produced mainly by the chemicals industry (and to a lesser extent by the pharmaceuticals industry).

This production was achieved not only by large global industrial groups such as Dow Chemical, Exxon Mobil, Lyondell Basell and DuPont (United States), BASF, Evonik Industries and Bayer (Germany), Shell (Netherlands), AkzoNobel, Solvay (Belgium), Arkema and Saint-Gobain (France), Mitsubishi Chemicals and Toray Industries (Japan), Sinopec (China), etc., but also by a multitude of small structures (start-ups, spin-offs, SMEs[4] and VSEs[5]).

Production of manufactured nanomaterials is one of the major avenues for development and competitiveness for the chemicals industry across the world. International competition in this field has been fierce for about twenty years now.

Manufacturers have therefore been devoting large proportions of their budgets to research and innovation. They have also been tending to increase their production capacities over the years, with a view to reducing the cost of manufacturing manufactured nanomaterials, and developing certain existing markets or creating new ones. The demand for nanomaterials should reach 5.5 billion dollars in 2016[6], and the most innovative businesses should win the biggest shares in the markets.

The main manufactured nanomaterials produced over the last fifteen years at industrial scale across the world have been those for which the manufacturing processes are old and therefore mature, such as the processes for manufacturing titanium dioxide, carbon black, amorphous silica, calcium carbonate, zinc oxide, alumina, iron oxides, and cerium oxides. Generally, those nanomaterials have been produced by large chemicals groups in very large quantities (several tens to several hundreds of thousands of tons per year). For their parts, start-ups, SMEs and VSEs have been developing and producing more customized nanomaterials for more confidential markets such as fullerenes, quantum dots, or dendrimers.

The United States remains one of the main manufactured nanomaterials producing countries in the world. Nanomaterials production has been doped by considerable financial support, in particular public funding, that has been allocated to research & development and has been growing continuously for more than twenty years now, and it has also been boosted by structured technology transfer. Nanomaterials production is underpinned not only by large international-calibre chemicals and pharmaceuticals groups, but also by a fabric of start-up and spin-off businesses, most of which have come out of universities and research institutes, and of more traditional SMEs and VSEs. Canadian output remains well below that of the United States.

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4 Small and Medium-sized Enterprises

5 Very Small Enterprises

6 http://www.economie.gouv.fr/cedef/dossier-documentaire-nanotechnologies

In Europe, the main nanomaterials producing countries are, in decreasing order, Germany who has a chemicals industry that is still dynamic, the United Kingdom, and then France (80% of French nanomaterials producers are SMEs[7]). Switzerland, Italy, and Belgium are also European stakeholders in the field.

In Asia, the stand-out countries are Japan, South Korea and China. Japan remains one of the countries that are most involved in developing and producing nanomaterials, with a very significant amount of public funding having been devoted to research for a great many years now. Whereas, it was only at the end of the nineteen eighties that the Chinese academic world started to become interested in the concept of nanotechnology, without finding any real echo at national level. Up to the end of the nineteen nineties, the Chinese media made almost no mention of the concept or of its potential. What finally made the Chinese government sit up and take note was the scale of the potential scientific and technological impact of nanotechnology, and mainly of nanomaterials, in China. Since then, China has been vying with the United States in the race to become a major power in the field of nanomaterials production.

Prospective analysis

Higher labour costs, regulations that are often perceived as being more stringent, the need to import most raw materials, and a poor image of nanomaterials and of chemicals in general in society are driving some companies, in particular European ones, to relocate their production (in part or in full) in Asia, and in particular in China. For instance, this applies to the French chemicals group Arkema who has recently invested massively in China (Changshu has become the group's leading industrial site in the world).

Others, like the German company Bayer, who was, for several years, one of the world's heavyweights in carbon nanotube production, decided to discontinue that activity in 2013 (and therefore to close one of its factories in Germany) so as to focus on its products that enjoyed more dynamic markets.

In spite of a difficult European context, the chemicals industry (in particular in Germany, the United Kingdom, and France) should record a small amount of growth in 2014. The European chemicals industry is also well aware of the strategic and economic issues represented by nanotechnology and nanomaterials, in particular with a view to continuing to occupy a leading role in developing innovative and high-performance materials and products.

[7] *Les réalités industrielles dans le domaine des nanomatériaux en France. Analyse de la réalité du poids des nanomatériaux dans la filière industrielle concernée* (Industrial realities in the field of nanomaterials in France. Analysis of the reality of the significance of nanomaterials in the industrial sector in question), Direction générale de la compétitivité, de l'industrie et des services (Directorate-General for Competitiveness, Industry and Services, June 2012

Underpinned by public research that is structured and well-funded, by technology transfer that is operational and efficient, and by companies who have been engaged in innovation for many years, the United States should, in the coming years, consolidate its supremacy in the field of development and production of manufactured nanomaterials. China, where the very rapid rise of nanotechnology and nanomaterials is due to a large extent to central government intervention, is hot on its heels.

Hypotheses

Hypothesis 1. Drastic limitation of nanomaterials production in France

Due to regulations being perceived by producers as increasingly stringent, and due to chemicals (and therefore manufactured nanomaterials) having a very poor image in society, the French companies limit their production of manufactured nanomaterials drastically. Most of the production takes place in countries where labour costs remain lower and regulations remain thinner, in particular in Asia.

Hypothesis 2. Production of nanomaterials increases in France

Manufactured nanomaterials are one of the fields of excellence of developed countries, and in particular of France. Private and also public investment is abundant, conducive to ambitious innovation. The French companies also have genuine reaction capacity through the know-how acquired and mastered over many years. French production opens up to all sectors of activity.

Hypothesis 3. Production of a few high added value nanomaterials in France

With costly but qualified labour, and cutting edge facilities, the French chemicals industry becomes specialised in developing and manufacturing custom manufactured nanomaterials having high added value and designed for strategic markets. Very large-scale production of "old" manufactured nanomaterials that are less profitable, but that also require less investment, is concentrated in Asia.

French and European political determination

Nathalie Thieriet, Anses

Definition

This sheet covers French and European involvement and political determination concerning the development of nanotechnology and more specifically, of manufactured nanomaterials.

Retrospective analysis

A State's support and political determination to develop a key economic subject can take various forms. It may define missions and the resources of the relevant national organisations to federate development efforts, bring together decision-makers (industries, authorities, NGOs, etc.) to promote the development of the subject, implement financial strategies to fund research (implementation of national plans, definition of specific budgets for precise research topics, etc.).

Therefore, it is thanks to political determination that nanotechnologies and manufactured nanomaterials exist, through the allocation of funds and other resources and the setting up of the appropriate research structures at international and national levels[1].

In 2000, spurred on by Bill Clinton, the USA launched the National Nanotechnology Initiative (NNI) aimed at making nanotechnologies the next industrial revolution: with space conquered, on to the infinitely small. Since its creation, the NNI programme has been allocated $15 billion. NNI brings together the 25 major national departments of the USA (education, defence, science and technology, health, food, etc.), technical and

[1] Laurent B. Les politiques des nanotechnologies: pour un traitement démocratique d'une science émergente. Éditions Charles Léopold Mayer edn. ECLM, Paris, 2010, 248 p.

scientific institutions (MIT, NIST, NIOSH, etc.) through their supervising ministries and different public and private establishments. NNI reports directly to the President of the USA[2]. It is in charge of obtaining funding and proposing calls for interdisciplinary projects in order to transform industrial organisation and practices, change society accordingly and increase productivity. For that purpose, it uses roadmaps. For example, federal investment is usually about $2 billion per year ($1.8 billion in 2010).

A few years later, in 2004, Europe launched a strategic action plan Towards a European Strategy for Nanotechnology[3] aimed at making Europe a "knowledge society" in favour of nanotechnologies. The successive Framework Programmes for Research and Technological Development (FPs) which organise calls for research projects will give priority to nanotechnologies. They cover not only the content of the studies to be carried out but also the organisation of the research. This is how different European programmes such as NanoImpactNet[4] and NanoSafety Cluster[5] emerged, and fuelled the next FPs. Within the framework of the seventh FP (FP7), nanotechnologies and nanomaterials were included in the Nanotechnologies, materials, processes (NMP) programme. In 2008, European research efforts represented over $2 billion. For 2010-2015, the NanoAction Plan 2010-2015 marks a shift towards innovation and to more specific consideration of society's expectations. Europe wishes to ensure the safety of nanomaterials based on transparency and dialogue with stakeholders. Therefore, over the 2007-2011 period, the Directorate general for health and consumers (DG SANCO) organised four annual meetings, as part of Nano Safety for Success Dialogue[6] to discuss the safety of nanomaterials.

In France, organisation of nanotechnologies is more dispersed. Political awareness was raised in 2003 through microelectronics followed by nanomedicine.
This then led to the creation of a micro and nanotechnology network, which offers public funding for collaborative projects. When the national research agency (ANR) was founded in 2005, nanotechnologies rapidly appeared as a priority and led to the PNano programme launched in 2009. Nanotechnologies also triggered the setting up of competitiveness clusters (Minatec for example) and coordination approaches aimed at linking laboratories and research centres at regional level. This organisation draws both on public research programmes and industrial development (Figure 1).

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[2] Lourtioz J-M, Lahmani M, Dupas-Haeberlin C, Hesto P. Nanosciences et nanotechnologies. Évolution ou révolution ? Belin, Paris, 2014, 416 p.

[3] European Union, European Commission. Towards a European strategy for nanotechnology: Communication from the Commission. EUR-OP, Luxembourg, 2004.

[4] http://www.nanoimpactnet.eu/

[5] http://www.nanosafetycluster.eu/

[6] http://ec.europa.eu/health/nanotechnology/events/ev_20110329_en.htm

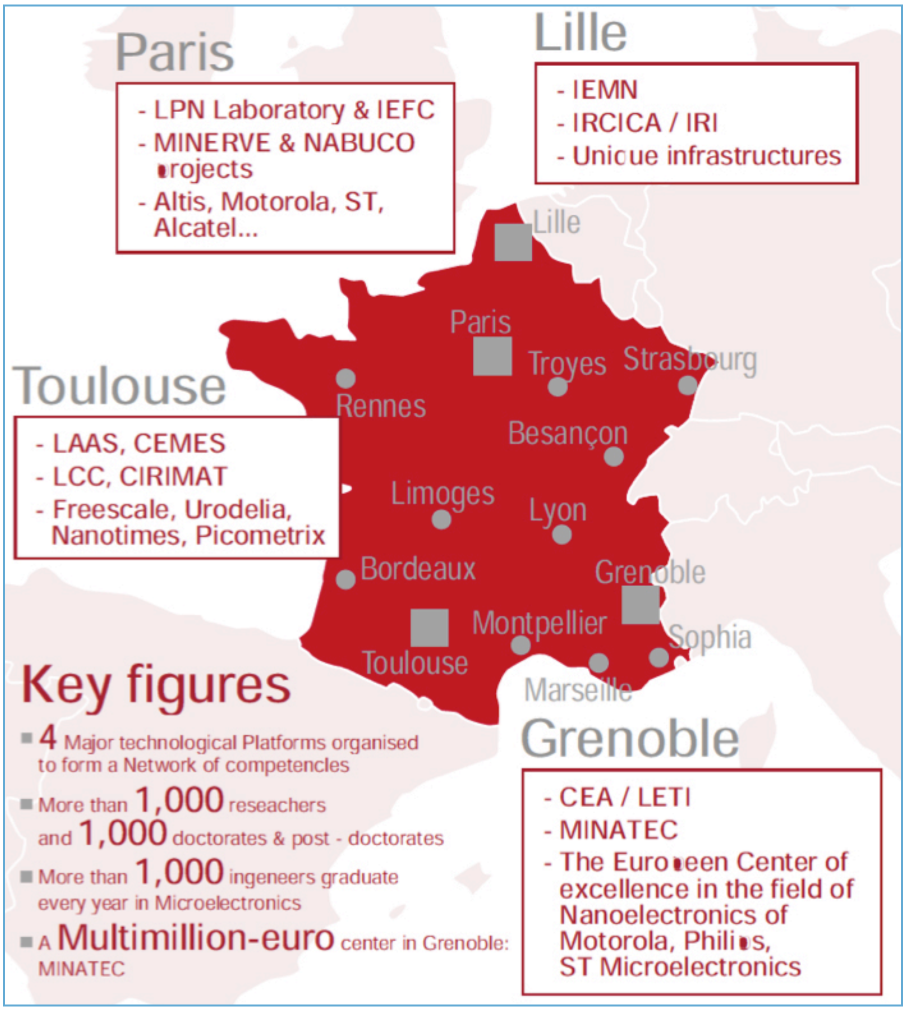

***Figure 1. Network of French nanotechnology platforms*[7].**

Other research funding mechanisms are also possible for promoting the development of nanotechnologies: funding from the public investment bank (BPI), the budgets of the different ministries concerned, but also the interests from the major loan launched in 2011 (Investment for the future). Lastly, the NanoInnov action, with a budget of €70 million, was launched within the framework of the 2009 recovery plan, aimed at developing three nanotechnology integration centres in Grenoble, Saclay and Toulouse.

France ranks fifth in terms of the number of nanosciences publications; and public financial effort places France second in Europe behind Germany.

In France, the questions raised by nanotechnology applications, including nanomaterials, have been the subject, on many occasions, of public discussions since the start of the 2000s[8]. Some of these discussions were organised by public institutions as was the case for the Nanoforum of the Conservatoire national des arts et métiers[9], during the Grenelle environment round table (2007, health-environment workshop), by the Commission nationale

7 Bensaude-Vincent Bernadette. Nanotechnologies. Défis éthique et politique. In Programme du séminaire des invités 2012-2013, Changements institutionnels, risques et vulnérabilités sociales, master recherche de sociologie, université de Caen, 2013.

8 Bullich V. Du mode d'existence des nanosciences et des nanotechnologies dans l'espace public. In EHESS - GSPR), 2009.

9 Cnam. Online: http://securite-sanitaire.cnam.fr/nanoforum/le-nanoforum-2007-2009–577215.kjsp

du débat public[10] and the Cité des sciences (January-February 2006 then June 2007). These institutional initiatives complement many public meetings organised by civil society, such as Nanomonde[11], Nanoviv[12], Avicenn[13] (Sciences et Démocratie 2013).

Examples

Tours 2015[14] (launched in March 2012)

François Baroin, Minister for the Economy, Finance and Industry, Laurent Wauquiez, Minister for Higher Education and Research, Éric Besson, Minister for Industry, Energy, and the Digital Economy, and René Ricol, commissioner-general for investment stated that 103 million euros would be invested in the Tours 2015 project.

This research and development project, initiated by the production site STMicroelectronics in Tours in connection with the French Atomic Energy and Alternative Energies Commission (CEA) and 13 CNRS laboratories, was selected within the framework of the first call for nanoelectronic projects for the digital economy programme. The cost of this five-year project (2012-2016) is 164 million euros, and aid allocated by the State for supporting research and development is 69 million euros, including 34 million for STMicroelectronics.

The investing-in-the-future programme will also fund the setting up by public research of a pilot installation, for a cost of 34 million euros on the manufacturer's site, shared among partners and aimed at studying and making micro-batteries.

This programme aims to study and develop new components aimed at the advanced management of energy in electronic devices. It covers in particular:

- innovative components for the conversion of energy using new semi-conductor materials;
- passive components with improved performance and very little loss thanks to the use of new insulating materials;
- the integration of micro-batteries and circuits for recovering energy in electronic components.

Technologies developed within the framework of Tours 2015 have many applications. They will therefore be a source of innovation for actors in the various industrial sectors: housing, automobile, transport, energy, medical, industrial applications, consumer goods, etc.

It should also strengthen the ecosystem comprising the components industry and research laboratories in a renewed public-private partnership, and ultimately result in a

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[10] CNDP. Online : http://cpdp.debatpublic.fr/cpdp-nano/

[11] Fondation Sciences citoyennes Nanodéfis pour l'énergie : quels développements durables et équitables ? In Cafés du vivant (cycle de conférences), 03/08/2006. Paris.

[12] Vivagora Nanobiotechnologies : quelles responsabilités ? quelles finalités ? In Cycle Nanoviv, 12/11/2006. Grenoble.

[13] Sciences et Démocratie. Les citoyens face aux nanotechnologies : quels défis ? In Débats de société sur les enjeux des technologies et des sciences, 05/18/2013, Paris.

[14] Tours 2015 initiated by STMicroelectronics, winner of the first call for tenders for the Nanoelectronics project. 22/03/2012. Online: http://investissement-avenir.gouvernement.fr/content/tours-2015-port% C3%A9-par-stmicroelectronics-laur%C3%A9-du-premier-appel-%C3%A0-projets-%C2%AB-nano%C3%A9 lectronique-

strengthening of competition and the increase of industrial production in territories. It is part of the national innovation drive in the strategic field of nanoelectronics.

Nano 2017

More recently, the Rhône-Alpes region formalised its commitment to the Nano 2017 project[15], presented in July 2013 by Jean-Marc Ayrault, granting it an envelope of €25 million. Nano 2017, which logically builds on the Nano 2012 programme (€2.3 billion), aims to support STMicroelectronics in making a technological leap, while increasing its production capacity at the Crolles site, and to make this region one of the first three in the European research programme Horizon 2020. A total of €3.5 billion will be invested, including €400 million by Europe, €600 million by the State and €100 million by local authorities.

The STMicroelectronics factory in Crolles is one of the most advanced from a technological point of view in Europe, capable of etching below 0.22 nm. Ultimately, this site will be equipped with a production capacity of 7,000 silicon wafers per week, compared to 3,500 currently.

In a press release, the French-Italian industrial group stated that this plan would also enable it to place emphasis on the development of advanced technology, such as the Fully Depleted-Silicon On Insulator (FD-SOI), a technology that reduces energy consumption while maintaining performance), next-generation imaging (image processing, sensors) and lastly, embedded non-volatile memory (eNVM).

Nano 2017 will therefore succeed the previous Nano 2012 plan, launched in 2008. With R&D research of €2.3 billion (including €457 million from the State), the former Nano 2012 plan had also aimed to develop the technological dynamism of semi-conductors in the Grenoble region, by supporting the development of STMicroelectronics, CEA Leti, and IBM's research centres. At the time, it covered CMOS technologies (22 and 32 mn) and systems-on-chip.

The Nano 2017 project[16] will allow the Grenoble-Crolles cluster to be one of the three pillars of the Horizon 2020 European research programme announced by the European Commission, which aims to set up a genuine European micro-nano-electronic sector. In May 2014, within the framework of a major €5 billion project to fund the semi-conductor industry, Neelie Kroes, vice-chairman of the Commission, had in fact identified the Crolles site as one of the R&D clusters capable of re-boosting the production of components in Europe, together with the Dresden site in Germany and the sites of Eindhoven and Leuven in the Netherlands and Belgium.

This seven-year European project should therefore contribute to funding Nano 2017. Brussels intends to provide 30% of funding, with the remaining 70% to be paid for by Member States. "Public support for Nano 2017 will be notified to the European Commission and will only be effective following its authorisation", the Prime Minister of France specified, while asserting that this major programme also aims to support employment in the region.

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[15] The region has granted 25 million euros to the Nano 2017 programme. Published on 30/10/2013. http://www.info-economique.com/actualite/la-region-accorde-25-millions-d-euros-au-programme-nano-2017-84424

[16] http://www.lemagit.fr/economie/business/constructeurs/2013/07/23/nano-2017-un-programme-de-35-mde-dont-600-me-publics-pour-les-semi-conducteurs-en-france

The microelectronics sector in the Rhône-Alpes region is one of the five largest in the world. It represents about 22,000 jobs in the whereabouts of the city of Grenoble and almost 34,000 in the Rhône-Alpes region. STMicroelectronics in Crolles has almost 4,200 employees and over 1,000 contract hires. It is one of the main global centres of integrated circuit production. The site's annual expenses total close to €1 billion, 50% of which is spent in the Rhône-Alpes region.

Hypotheses

Hypothesis 1. No change in political determination

This hypothesis assumes that there is no change in the organisation of research funding, no drastic reduction in the budget for calls for tenders, and that industrial needs are growing without any technological leap. There is no specific framework put in place by decision-makers for discussion among stakeholders.

Hypothesis 2. Restructuration of political determination in favour of a given sector at national level

This hypothesis assumes that there is a change in research funding, for different reasons, which require that priority be given to certain research sectors:

- drop in the research budget
- technological leap in a specific branch (major industrial needs)
- major discovery leading to the elimination of a whole area of current research

National involvement in the development of platforms (industry-research coordination), continuation of dialogue on the sector considered.

Hypothesis 3. Strong regional political determination, however without national support

Major investments of certain regions in the field of nanomaterials and nanotechnology, relying in particular on European funding, and drawing on the local industrial fabric. Dialogue at regional level among stakeholders.

Geopolitics

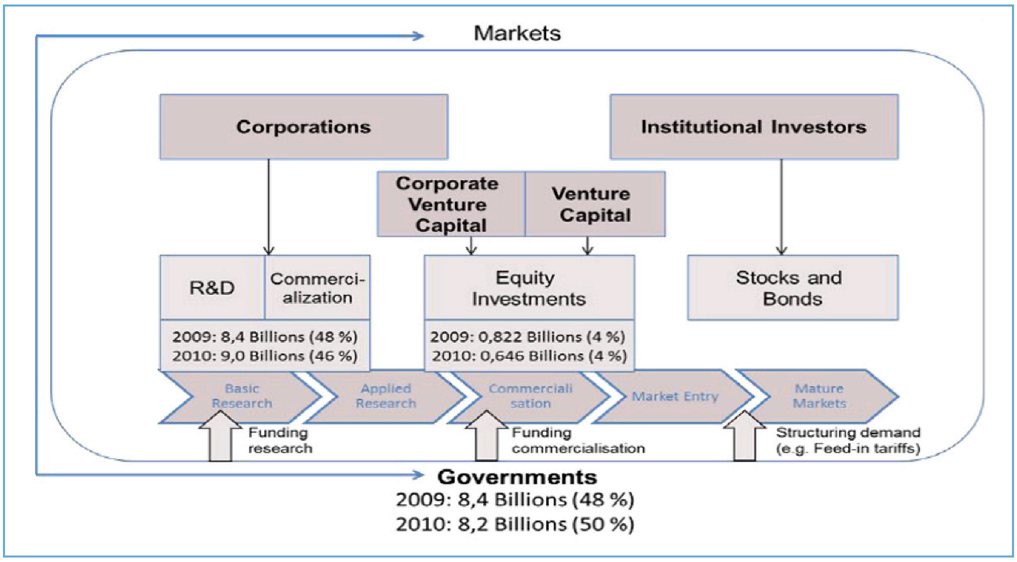
Éric Gaffet, Institut Jean Lamour

Definition

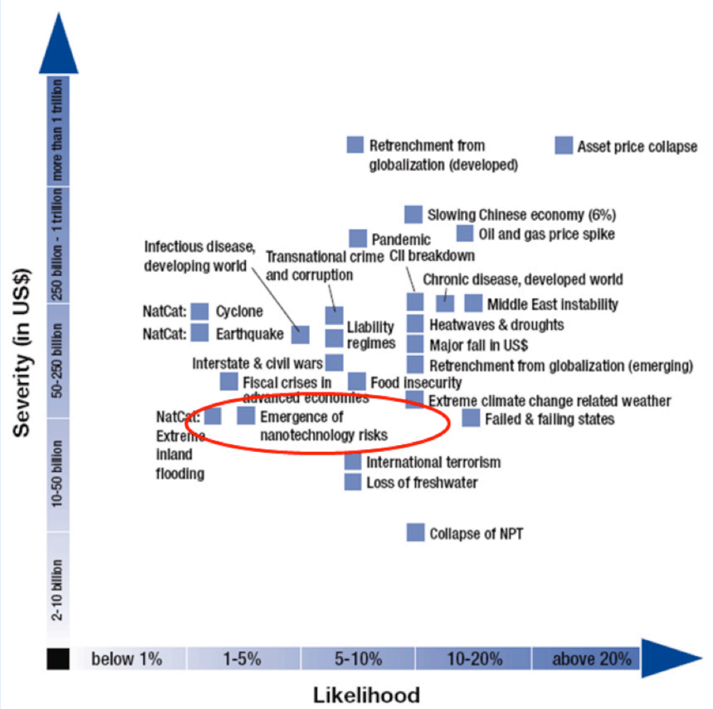
Governance of nanotechnologies at global level is reflected, in particular, by the structural framework at OECD level with the Working Party on Nanotechnology (WPN) and the Working Party on Manufactured Nanomaterials (WPMN) and their mirror-structures at the level of the different Member States, and at normative level with the International Standardisation Organisation (ISO).

Financial support to the different actions undertaken is represented in Figure 1 for the years 2009 and 2010.

***Figure 1. Comparison of public and private investments in 2009 and 2010*[1].**
Source: Presentation by F. Roure - NanoNorma 16 March 2012 in Paris



[1] Original source of the data provided by F. Roure's presentation at Nanonorma 2012: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/STP/NANO(2012)15&docLanguage=En



The economic sector has also taken up nanotechnology and it is curious to note the semantic change related to the impact of nanotechnology development on economic projections made within the framework of the Davos world economic forum. While in 2008, nanotechnologies were classed in the economic category under the 26 Core global risks (Figure 2), in 2011, they were considered as an economic threat (“*Threats from new technologies”*), alongside genetic engineering and synthetic biology.

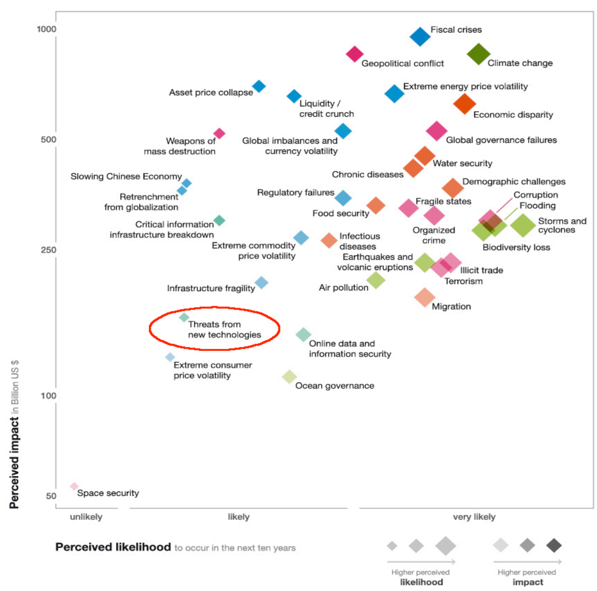
Figure 2. The 26 core global risks: likelihood with severity by economic loss.
Source: World Economic Forum, Davos, 2008

This is a profound shift both for the consideration of the socio-economic impact of the development of nanotechnology and for its “trivialisation”, with nanotechnology being included in a more general framework – “new technology” (Figure 3).

Figure 3. Threats to economic development.
Source: World Economic Forum, Davos, 2011[2]

A final outlier is threats from new technologies – unintended consequences for human, animal or plant life from the release of agents in the biosphere created by genetic engineering, synthetic biology or nanotechnology.

Stakeholders rated this threat as of low impact and likelihood. However while experts interviewed concurred that numerous regulatory authorities in this area lower the risk’s likelihood, it was being underestimated in terms of impact.



[2] Global Risks 2011 - Sixth Edition- An initiative of the Risk Response Network World Economic Forum in collaboration with: Marsh & McLennan Companies, Swiss Reinsurance Company, Wharton Center for Risk Management, University of Pennsylvania, Zurich Financial Services - January 2011.

Retrospective analysis

The development of nanotechnology, driven by the National Nanotechnology Initiative (USA), was considered at the start of the 2000s by a large number of States as a political tool for becoming world leaders. This goal and nanotechnology involvement has since then been pursued by Russia[3,4], India[5], and Iran[6], among others.

On this basis, the initial intentions of the different countries were to become "dominant in all activity sectors". This is shown in Figures 4 to 6 for the years 2005 to 2008, adapted from data produced by Lux Research.

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[3] $36Bln Set Aside for Nanotechnology (2008)
Source: The Moscow Times - Author: Anatoly Medetsky.
http://www.themoscowtimes.com/stories/2008/01/18/041.html
The Russian cabinet has approved a plan to increase sales in the country's nanotechnology sector by a factor of 130 by 2015. The article says that the plan "focuses on funding research and expanding the number of companies producing new materials and equipment commercially." According to the article, Russian Prime Minister Viktor Zubkov has estimated that the government will spend US$9.6 billion on the plan and has expressed concerns that there is a lack of ideas on how to effectively apply the funding. Svetlana-Optoelektronika, a Russian company that produces power-saving light emitting diodes for Russian Railways, said that it anticipates that energy efficiency will be one of the government's priorities in nanotechnology development. Lev Trusov of Association Aspect, a Russian company that produces nanomembranes for processing gas generated through oil production, indicated his expectation that "the government's plan would help large-scale projects in the sector take off, including in the production of biofuels." The article can be viewed online at the link below.

[4] Russia to Invest $10 Billion in Nanotechnology in Mid-Term (2008)
Source: Russian News and Information Agency Author: n/a (3 December 2008)
http://en.rian.ru/russia/20081203/118663658.html
Sergei Ivanov, Deputy Prime Minister of Russia, announced that Russia plans to invest US$10 billion in nanotechnology development programs in the mid-term. The plan was announced today at an international nanotechnology forum being held in Moscow. Half of the funds will come from the Russian Nanotechnology Corporation, which is set to invest US$714 million in more than 20 projects over the next three months. A statement from Russian President Dmitry Medvedev said that Russia has "...all the required conditions for a future breakthrough to create a potential dominance in the sphere of nanotechnology." The article can be viewed online at the link below.

[5] WNEC India conference, Mumbai - 28th - 29th March, 2006
Source: http://www.world-nano.com/india/
The First World Nano-Economic Congress (WNEC) India represents the seventh edition of this successful event series with previous events having been held in Washington, DC, London, UK, Munich Germany, Dublin, Ireland, Singapore.
The World Nano-Economic Congress (WNEC) is the one comprehensive event that brings together the thought leaders in science, government, and business to discuss the entire value chain of nanotechnology's commercial development.
Already established as an annual event in Singapore, the WNEC now comes to one of Asia's fastest growing economies, helping delegates and exhibitors tap into India's emerging rich seam of technology talent.
With a stock market hitting record highs, an annual production of engineering graduates five times higher than the United States, and industries from textiles to automotive already taking advantage of nanotechnologies for both domestic and export markets, India is poised to be one of the 21st Century's nanotech winners.
The WNEC events have been able to bring together both comprehensive programme on the varied applications of nanotechnologies within industry with world-renowned speakers. Past speakers include.

[6] Islamic states: Science and Technology Innovation (6 April 2010)
Source: University World News - Author: Wagdy Sawahel
http://www.universityworldnews.com/article.php?story=20100403082552829
The Committee for Scientific and Technological Cooperation of the 57 member states of the Organization of Islamic Conference (OIC) has announced the creation of a science and technology innovation organization, or STIO, which will focus on maximizing the scientific talent and technological potential of the Muslim world. The STIO will work to pool the resources of the private and public sectors for research and development. The Muslim world comprises approximately 25 percent of the world's population but its research and development manpower amounts to only 1.1 percent of the worldwide total. The recent list of the top 100 universities in the world does not include even one from an Islamic country. Ali Karami, an associate professor at the Research Center of Molecular Biology of Baqiyatallah University of Medical Science, Iran, said "[S]uch regional projects for collaboration and capacity building in Islamic countries stretching from Indonesia to Morocco are crucial for strengthening R&D, not only in nanotechnology but also in biomedical technologies, emerging science and technologies." The Islamic states also approved an Iranian proposal to establish a world-class nanotechnology network to boost science and technology and strengthen research capacity.

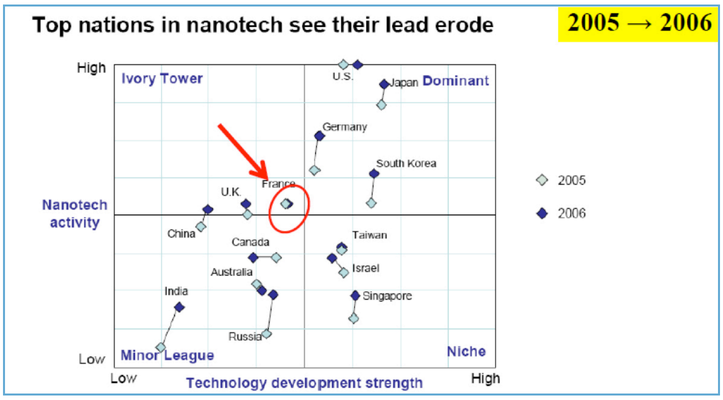

Figure 4. Development of the positions of the different States (2005-2006).
Source: Lux Research, 2006

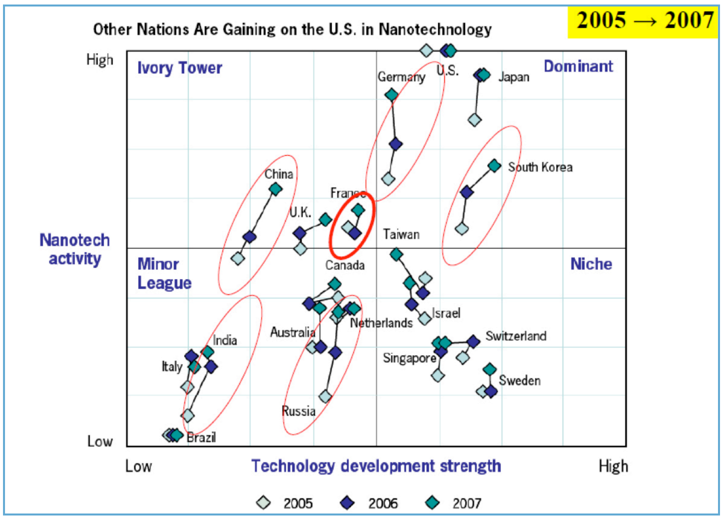

Figure 5. Development of the positions of the different States (2005-2007).
Source: Lux Research support "International Activity Drives Nanotechnology Forward", December 2007

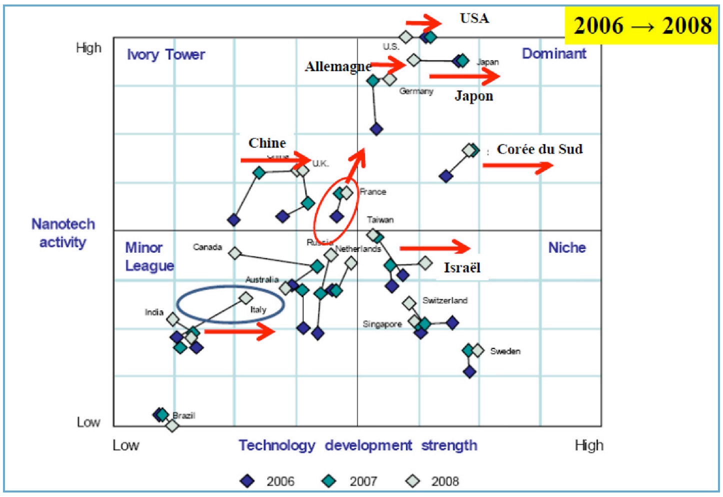

Figure 6. Development of the positions of the different States (2006-2008).

While it was expected that all of the countries involved in nanotechnologies would continue to build on that momentum and reach a dominant position at world level, regardless of the activity sector (Figure 7, projection for 2012 established in 2008), a clear swing in strategy occurred for certain States (Figure 8).

This shift was reflected by what is termed "a crossing into ivory tower territory", where States concentrate on certain sectors deemed strategic, rather than on development in all sectors.

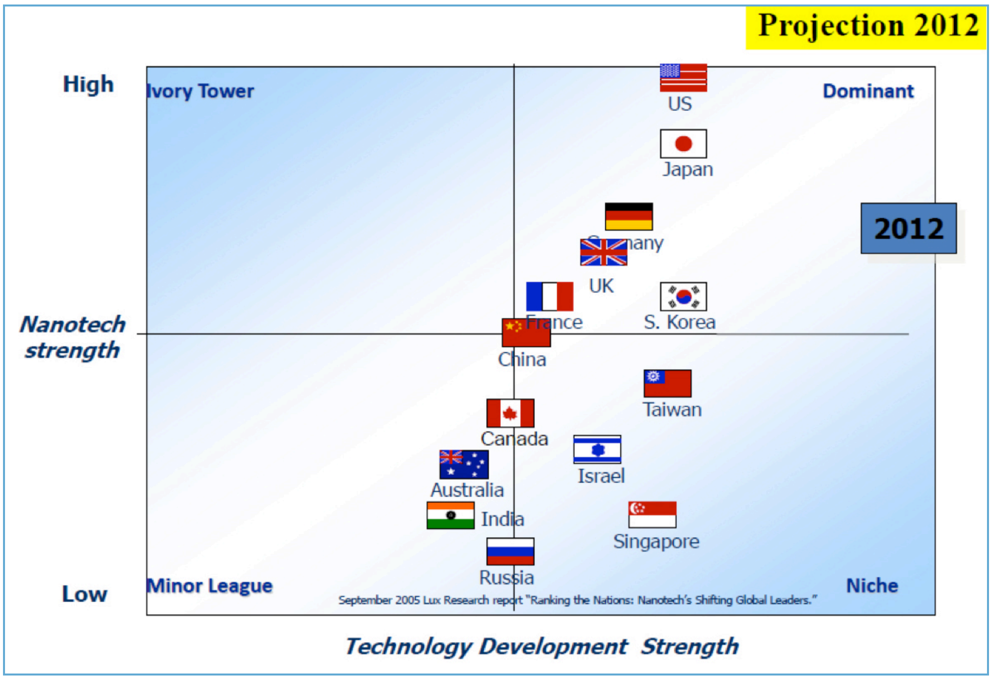

Figure 7. Projection for 2012 of the positioning of States in the filed of nanotechnology.

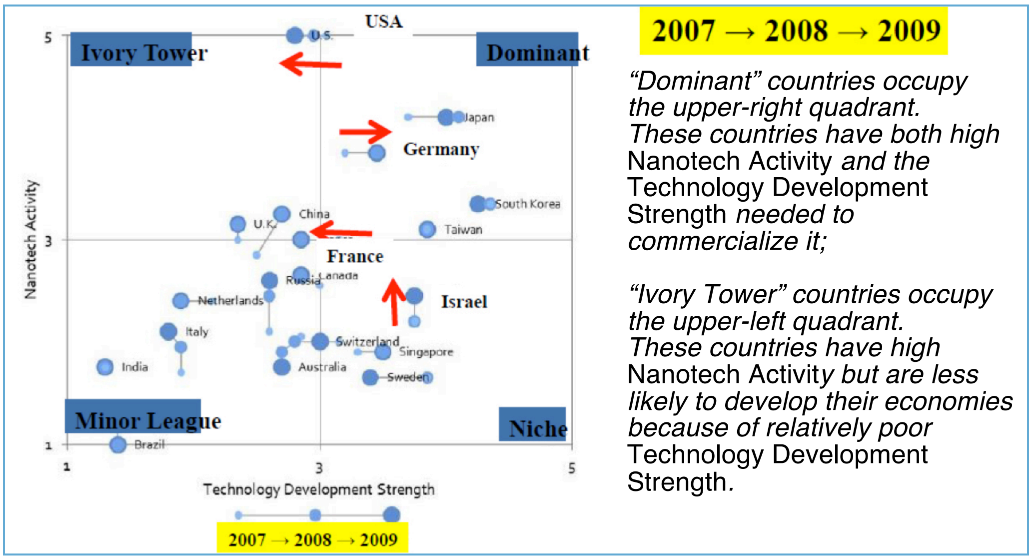

Figure 8. Evolution of the positions of the different States (2007-2009) reflecting a change in strategy from a dominant position to an ivory tower position.
Source: http://www.electroiq.com/articles/stm/2010/08/ranking-the-nations.html, August 2010

Hypotheses

Hypothesis 1. Continued development in all sectors

The development of nanomaterials continues in all sectors and in all countries, with, perhaps, a general slowdown due to the general reduction in funds allocated regardless of the country.

Hypothesis 2. Specialisation based on costs

Given the use of nanomaterials and nanotechnology in classic industrial cycles, nanomaterials become a chemical agent like any other agent and the notion of cost reduction takes priority along with consideration of health risks. In that regard, low-value-added nanomaterials are increasingly produced in low-cost countries. High-value-added nanomaterials deemed strategic are concentrated in high-labour-cost and high-technology countries.

Hypothesis 3. Sector-specific specialisation, strategic selection

Countries or regions invest in specific sectors considered strategic according to a process that can be qualified as ivory tower.

Legal framework

Nathalie Dedessous-Le Moustier, Université de Bretagne-Sud

Nanomaterials may be part of our daily lives, but knowledge about their effects on health, and in particular on the health of employees that make them and handle them, is incomplete. However, as early as 2008, Afsset1 (now Anses2) recommended identifying people that work with nanomaterials, monitoring their work conditions and strengthening exposure prevention measures in the work environment. How does law, and in particular, labour law take into account the risks related to nanomaterials?

Definition

There is currently no specific legal framework applicable to the protection of the health of workers likely to be exposed to nanomaterials. Can the provisions set out by the French labour code to prevent known risks be used for "uncertain" risks? The context of uncertainty can lead to an opposition between the principles of prevention and the principle of precaution.

Uncertain risk: French labour law takes into account known risks. However, certain provisions of the labour code which cover chemical risks appear to also take into account uncertain risks. Article R. 4411-6, which classifies substances and preparations considered dangerous, also covers substances and preparations that are carcinogenic, mutagenic or reprotoxic (CMR) of category 2, "substances and preparations for which there is a strong presumption that human exposure […] may result in the development of a cancer or the increase in cancer incidence" and category 3 CMRs, "substances and preparations of concern for human health […] but for which the information available is insufficient to classify these substances and preparations in category 2".

[1] Agence française de sécurité sanitaire, de l'environnement et du travail (French agency for environmental and occupational helath protection)
[2] Agence nationale de sécurité sanitaire, de l'alimentation, de l'environnement et du travail (French Agency for Food, Environmental and Occupational Health & Safety)

Principle of prevention: This is an essential principle with regard to the protection of workers' health. The labour code devotes a section to the "general principles of prevention" which result in obligations on the employer but also on the employee. Article L. 4121-2 lists nine general principles of prevention which the employer must follow in order to protect occupational health. Even the compensation system, which comes into play in the event of a failure, and which, for a long time was given priority from a legal point of view, now has a preventive purpose. It can be considered that in a context of uncertain risks, prevention principles must be applied (in that sense: memorandum by the Ministry of Labour of 18 February 2008: "Despite the uncertainty about hazards, it is important to reiterate that current occupational risk prevention legislation must apply, under the responsibility of the employer").

Principle of precaution: This principle is the expression of the desire to create a framework for decisions concerning risk situations for the environment and public health for which knowledge is lacking. It is most often used excessively, without thought for its original legal framework which is that of environmental health, nor for its target audience which is public authorities. Within the framework of companies' occupational health and safety policies, the principle of precaution does not fall within the scope of public decision. Its influence on occupational risk management is debatable. However, with regard to information, the use of the principle of precaution appears to be justified as it underpins an essential principle of information seeking which implies following the evolution of knowledge about risks and assessing the actions conducted to know those risks.

Retrospective analysis

Currently, there is no specific legal mechanism applicable to the protection of the health of workers likely to be exposed to nanomaterials. The provisions specified by the labour code to protect workers' health can be used. In addition, legal instruments not necessarily devoted to the protection of workers are also valuable.

Use of legal instruments not specific to nanomaterials to protect workers: general regulations and regulations concerning chemicals

It can be considered that currently the prevention of risks for workers exposed to nanomaterials falls, to the same extent, under the general measures specified by the labour code and the measures specific to chemical risk. Health agencies, which consider nanoparticles equally toxic, or even more toxic than larger substances of the same chemical composition, propose to apply to them the same regulatory requirements as for dangerous chemicals (Afsset, *Nanomatériaux et sécurité au travail*, report, May 2008).

Since the law on social modernisation of 17 January 2002, transposing Directive 89/391/EEC of 12 June 1989, labour law adopts a broader approach to occupational health with the recognition of its psychological dimension. It also entrusts the mission of protecting occupational health to several players. Recent development is reflected in the strengthening of employers' obligations, through the recognition of workers' rights, the development of health protection through collective bargaining and by an extension of the role of the occupational physician.

Article L. 4121-1 of the labour code specifies that the employer must take "the measures necessary to ensure the safety and protect the physical and mental health of workers" by drawing on the general principles of prevention. The judge considerably broadened the scope of this provision by placing a safety obligation on the employer which must be reflected in the introduction of effective prevention measures. With regard to new risks such as nanomaterial-related risks, it can be considered that the "effectiveness" of the prevention measures implies that the employer must adjust them regularly depending on the development of scientific knowledge. One of the main difficulties is related to their risk assessment obligation due to the lack of reliable measurement instruments in the subject. As regards chemical risk prevention, the provisions specific to dangerous products are even more precise. The employer must, in particular, minimise the number of workers exposed or likely to be exposed, which can be envisaged for nanomaterials, which are generally handled in small quantities.

Workers' participation in the management of nanomaterial-related risks implies that those workers are made aware of the risks and the measures taken to prevent them and are trained in safety and in the use of means of prevention. Employees' safety obligation depends on the employers' efforts. Workers have another obligation, that of reporting hazards. But do they have an obligation to report uncertain risks? They may just as easily fear being sanctioned for not reporting as being reprehended for reporting without a valid reason. There is also the matter of whether the worker can exercise their right to stop work in the event of an uncertain risk. Does the fear of being exposed to a risk that, for the time being is not certain, allow the employee to be protected under Article L. 4131-3 of the French labour code?

In general, the action of staff representative bodies is essential for revealing situations in which workers' health may be affected. Legal provisions on collective bargaining and labour relations are of the utmost importance for developing vigilance regarding the risk related to nanomaterials. The CHSCT[3], first of all, has a very broad mission which consists in "contributing to the protection of workers' physical and mental health and to their safety". These missions were gradually extended by law and jurisprudence. In particular, an expert could be used to at least temporarily stall a company project, when, for example, the CHSCT is not certain that the project has no risks for workers' health or that those risks are controlled. However, what type of expertise can be sought when there is no certified expert competent in the matter of nanomaterials? Staff representatives can also act to protect the health of workers exposed to nanomaterials since they have the power to report occupational health hazards and this can be used for this type of risk.

[3] Comité d'hygiène, de sécurité et des conditions de travail (French health, safety and working conditions committee)

The occupational physician's main role, which is to avoid any damage to workers' health because of their work, may also be disrupted by the uncertainty related to nanomaterials. The reform on the organisation of occupational medicine in France is part of reflection on the surveillance of new risks, some of which such as asbestos have delayed effects. It formalises the practice of occupational medicine within multi-disciplinary teams. One of the initiatives of the reform that is particularly useful in a debate on uncertain risks is the implementation of a procedure involving a written report to which the employer must respond also in writing in the event of a rejection of the physician's proposals (Article L. 4624-3 of the labour code).

There are some difficulties in applying the rules mentioned to nanomaterials since they were elaborated for known risks. In any event, uncertainty should not prevent the company from taking measures. The problem about risk knowledge or information can be addressed by mechanisms not devoted to worker protection.

Use of legal instruments not devoted to worker protection: REACh[4] regulation and the annual declaration of substances in nanoparticle form

The REACh regulation of 18 December 2006 requires manufacturers to transmit relevant information on the substances they produce or use to the European Chemicals Agency (ECHA). It also specifies a procedure for authorising substances "of very high concern" in order to limit the risks for humans and the environment. Although nanomaterials are not specifically targeted by the regulation, they are concerned as substances. The main difficulty with regard to the registration procedure is that it only applies to productions exceeding one tonne per year per manufacturer. However, most nanomaterials are produced or imported in lesser quantities, and therefore are not concerned by this procedure. As for the authorisation procedure, the difficulty is related to the qualification of substances "of very high concern".

The annual declaration of substances in nanoparticle form, set out by the French law of 12 July 2010, known as *Grenelle II*, entered into force in France on 1 January 2013. For over 100 grams per year and per substance, manufacturers, importers and distributors must notify their identity, the quantities, properties and uses of these substances, as well as the identity of the business users (Decree No 2012-232 of 17 February 2012). They are also required to forward information on the hazards and the possible exposures caused by these substances, or information useful for the assessment of health and environmental risks.

[4] Registration, Evaluation, Authorisation and restriction of CHemicals

Prospective analysis

On that subject, a preliminary remark is useful for clarifying the direction of the development of the legal framework for nanomaterials in the upcoming years. This study provokes thought on the relationship between law and science. It can be considered that the lawmaker's role is in particular to organise scientific progress by supporting it and by sometimes resisting it, since technology must not take precedence over humans.

The exact number of workers exposed to nanomaterials is still not precise, but it is certain that the population concerned has not ceased to increase since nanotechnology has become part of most industry sectors (chemicals, automotive, cosmetics, pharmaceuticals, energy, etc.). According to the European Commission, nanotechnology could directly create over two million jobs by 2015. The matter of the legal framework of nanomaterials in the years to come remains relevant.

Can past trends continue?

Lessons learned with the asbestos affair can be very useful. They should prevent occupational health and safety catastrophes from reoccurring. Regulations have evolved resulting in a widespread ban on the use of asbestos and its placement on the market. However, despite the awareness of this risk starting at the end of the XIX century, regulations were tardy, insufficient and poorly enforced, demonstrating the State's shortcomings and the responsibility of companies. This profoundly changed occupational health law. It also showed trade unions' difficulty in effectively and quickly taking up matters related to toxic products at work.

With regard to the role entrusted to prevention players, the recent development which led to additional obligations on employers, the recognition of additional workers' rights, the development of health protection with the use of collective bargaining, and the broadening of the role of the occupational physician, should continue. The same goes for the trend towards increasing the missions of the CHSCT in its role to safeguard occupational health. This strengthening of its powers can however raise certain difficulties in particular with regard to the professionalisation of the CHSCT.

Many risks invite us to consider extending the prevention of risks at work to public and environmental health matters. In that regard, the law of 16 April 2013 on the independence of public and environmental health assessment and the protection of those who report hazards introduces, in companies, a legitimate reporting right to workers and to the CHSCT concerning public and environmental health. The right to information is now completed by information to workers on the risks that products or manufacturing processes may expose the environment or public health to and on the measures taken to prevent this.

The trend towards the diversification of reporting mechanisms is particularly valuable in the case of uncertain risks such as nanomaterials. In addition to specifying the staff representative's and worker's right to report hazards, the law of 20 July 2011 set out a reporting procedure at the initiative of the occupational physician, and the law of 16 April 2013 extended the CHSCT's reporting right to include serious risks to public and environmental health.

Faced with the uncertainty of the legal framework as regards nanomaterials, certain companies may stop using them, while others may undertake the elaboration of private standards. Pending the adoption of specific regulatory provisions, manufacturers have chosen to implement private worker protection standards. These standards may be recorded in charters, good practice guides, rules of procedure, or in contracts. This approach is approved by those who consider that the rules of the labour code are ill-adapted to handling scientific uncertainty.

With regard to REACh, its revision is not expected to fundamentally modify the current mechanism. The European Commission, in its general report on REACH of 5 February 2013, considers that "the REACh regulation sets the best possible framework for the risk management of nanomaterials, […] but more specific requirements for nanomaterials within the framework have proven necessary. The Commission envisages modifications in some of the REACh Annexes and encourages ECHA to further develop guidance for registrations after 2013." The Commission will carry out an impact assessment for the relevant regulatory options, in particular for any changes in the annexes of the REACh regulation, in order to ensure greater clarity regarding the way in which nanomaterials are handled and whose safety is demonstrated in the registration files.

More generally, the European Commission considers that European legislation covers the potential risks of nanomaterials.

What could cause a break in past trends?

Breaks can be political, reflecting a desire either to favour the protection of worker health and to ban the use of nanomaterials as long as there are doubts about their toxicity, or to promote the development of nanomaterials and accept that rules of law do not apply to uncertain risks. These two breaks do not seem very likely, due both to the diversity in nanomaterial size, shape, processes, their development potential and how rules, particularly labour law is poised to evolve.

Hypotheses

Hypothesis 1. No change in nanomaterial-specific regulation in the very short term

Due to the lack of scientific progress establishing the specific type of hazards related to a determined exposure to nanomaterials, there are no legislative developments in the matter. In this context, the companies that are most technologically advanced in the manufacture and use of nanoproducts continue to apply the methods offering the highest possible safety protection. This strategy could enable them to use their experience to influence future legislative work resulting in the adoption of specific rules.

Hypothesis 2. Elaboration of specific regulations for nanomaterials due to better knowledge of risks

Elaboration of specific regulations for the manufacture and use of nanomaterials reflected in particular by the strengthening of employers' obligations and an improvement in the information to be provided to workers and their representatives. This hypothesis implies scientific progress in terms of instruments to measure nanomaterial-related risks. Despite the tightening of regulations, this situation is a legal guarantee of safety for companies and promotes the development of nanomaterials.

Hypothesis 3. Elaboration of very restrictive legislation leading to a ban on certain nanomaterials

Very restrictive legislation leading to a ban on the manufacture and use of certain nanomaterials such as carbon nanotubes. In this hypothesis, there is a considerable limit on the development of nanomaterials in general, due to the major constraints on companies and the risk of confusion between the different categories.

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Standards and *normes techniques*

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Definition

A "*norme technique*" (in English, standard) designates a series of specifications describing an object, a being or an operating method. The standard is elaborated within the framework of expert committees in specific bodies[1]. ISO, the main standard-making body, defines it as "a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose" (www.iso.org). It results in a principle used as a rule and a technical reference. It is important to note that a standard is not mandatory, complying with it is voluntary, except if it is made mandatory through a regulatory text or a piece of legislation.

Standards aim to ensure the development of products and services that are effective (guarantee compared to the description and conformity) and safe (consumer protection). They also aim to facilitate the interoperability of goods and services and thus improve trade between countries (ISO[2], 2009), which contributes to disseminating inventions.

Standards also give competitive advantage to companies. Standardisation of production processes can improve efficiency. Standards can also be used to differentiate from the competition. This is why standards are mostly developed by manufacturers.

[1] Standardisation bodies operate at different levels :
* at national level: AFNOR (French standardisation association); SSC (Standards Council of Canada); DIN (Deutsche Industrie Normen); BSI (British Standards Institute); ANSI (American National Standard Institute); JISC (Japanese Industrial Standards Committee); KATS (Korean Association for Technology and Standards)
* at international level : ISO (International Organization for Standardization), 1947; IEC (International Electrotechnical Commission); ITU (International Telecommunication Union);
* at European level: CEN (European committee for standardisation), 1961; CENELEC (European Committee for Electrotechnical Standardization); ETSI (European Telecommunications Standard Institute);
* international committees have national mirror committees in each of the organisation's member country. Standardisation bodies can be general-interest such as ISO, or specialised in industry or application fields such as IEC in electronics.

[2] http://www.iso.org/iso/fr/about/discover-iso_what-standards-do.htm

Standard in French is close in meaning to *norme technique*. *Standard* can be defined as a reference system published by a body other than a standardisation organisation. *Standards* therefore result from a more limited consensus than the *norme* since it is elaborated only by a small group of players within a consortium. If this standard is disseminated far beyond this group, and is accepted by the market as the dominant standard, it is then referred to as a *de facto standard*.

This variable may be followed by observing the activity of standardisation bodies and monitoring the activities of consortiums that develop documents to be adopted as widely as possible, so that they may become de facto standards.

Retrospective analysis

Standards developed by consortiums

To date, there are very little "nanotechnology" *standards* on the market. The existing *standards* concern risk management support and follow-up.
They were developed by all types of organisations, NGOs, companies, governments or researchers. Their success, that is to say their use by third parties, remains very limited. Only Environmental Defense and DuPont have managed to promote their *standard* by including it as a major part of the ISO TC229 technical *standard*.

The British Responsible NanoCode[3]

The British Responsible NanoCode (2008) is the result of a joint initiative by three British organisations: an asset management company (Insight Investment), a professional association (Nanotechnology Industries Association) and a research institute (the Royal Society). The project, launched in 2006, aims to explore the social and economic repercussions of scientific, technological, social and commercial uncertainty related to nanotechnology. The NanoCode has seven principles. It aims to establish a consensus on what is considered good practice so that companies may align their processes with emerging good practices. The goal was thus to create a basis for the elaboration of conformity indicators.

Code of conduct for responsible nanosciences and nanotechnologies research

The code of conduct for responsible nanosciences and nanotechnologies research is an initiative by the European Commission (2008)[4]. Developed based on the British NanoCode, it was adopted by the European Commission with the support of industrial partners and research institutes. All of the other volunteer players were invited (through the internet site) to complete and comment on the code of conduct[5]. On the basis of the precautionary principle, this code, of voluntary application, covers seven general principles, including sustainability, precaution, inclusiveness and accountability. Its main goal is to help research institutes, universities and companies within the EU to ensure the safe development and use of nanotechnology in a context of scientific and

[3] http://www.nanoandme.org/social-and-ethical/corporate-responsibility/responsible-nano-code/
[4] http://ec.europa.eu/nanotechnology/pdf/nanocode-rec_pe0894c_en.pdf
[5] http://ec.europa.eu/research/science-society/document_library/pdf_06/nanocode-apr09_en.pdf

toxicological uncertainty. The code of conduct was evaluated in 2012. In 2013, its use remains very limited: no major nanosciences or technology actors have reported on its use (Delemarle and Larédo, forthcoming).

NanoRisk

NanoRisk stems from the collaboration between the chemical company DuPont and the Environmental Defense NGO. The goal is to assist "organisations that develop nanomaterial applications by providing a means to handle cases in which information is incomplete or uncertain by using appropriate reasonable and practical risk management hypotheses" (Environmental Defense and DuPont, 2007). The document includes advice on how to communicate information and decisions to stakeholders. The document was taken up and adapted within the framework of ISO TC229.

BASF's code of conduct

The BASF company was the first in 2007 to develop a specific code of conduct[6] for nanotechnology. On the basis of the principles of responsible management, the code describes four commitments presenting the company's approach[7].

Soil Association Organic Certification

In 2008, Soil Association Certification Ltd became the first organisation in the world to ban man-made nanomaterials in products it certified "organic". In accordance with the *standard* developed by this association, organic farmers and processors must not use ingredients containing manufactured nanomaterials[8]. In 2011, the application of the Soil Association Logo concerned mainly cosmetics, foodstuffs and textiles.

OECD's working party on manufactured nanomaterials

There is a longstanding tradition upheld by the decision-makers of OECD member countries that involves discussing chemical-related risks. As part of this tradition, OECD carried out reflections on nanoparticle-related health risks. Created in 2006, the working party on the safety of manufactured nanomaterials (WPMN) describes its mission as follows: "to ensure that the approaches for hazard, exposure and risk assessment for manufactured nanomaterials are of a high quality, science-based and internationally harmonised"[9]. Its missions are to "elaborate and implement a programme of work (...), which aims to promote international cooperation in the health and environmental safety-related aspects of manufactured nanomaterials…". The main topic areas in its work programme are: definitions, nomenclature and characterisation (physicochemical properties, uses); environmental fate and effects (hazard identification, exposure and risk assessment methods); exchange of information on regulatory and risk management frameworks (limited mainly to the chemicals sector) as well as environmental benefits. The documents developed by OECD aim to become the most widely used documents and therefore transformed into *standards* or *normes*.

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[6] Many companies involved in nanosciences and technologies have also developed/formalised specific guidelines without developing a code of conduct as such.

[7] http://www.basf.com/group/corporate/nanotechnology/en/microsites/nanotechnology/safety/code-of-conduct.

[8] The average size of particles must be 200 nm or less, and the minimum size of these particles, 125nm or less.

[9] www.oecd.org, July 2014, http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?doclanguage=en&cote=env/jm/mono(2008).

Projects launched between 2006 and 2011 by OECD WPMN	Main outcomes (end 2013)
Project 1. Development of a database on human health and environmental safety (EHS) research	Includes more than 803 research projects
Project 2. EHS Research Strategies on Manufactured Nanomaterials	
Project 3. Safety Testing of a Representative Set of Manufactured Nanomaterials	Guidance Manual for the Testing of Manufactured Nanomaterials: OECD's Sponsorship Programme
Project 4. Manufactured Nanomaterials and Test Guidelines	"Preliminary Guidance Notes on Sample Preparation and Dosimetry for the Safety Testing of Manufactured Nanomaterials" and "Non-Inhalation Exposure Methods for Studies on the Pulmonary Toxicology of Nanoparticles" "Guidance Notes on Sample Preparation and Dosimetry for the Safety Testing of Manufactured Nanomaterials"
Project 5. Co-operation on Voluntary Schemes and Regulatory Programmes.	"Analysis of Information-Gathering Initiatives on Manufactured Nanomaterials" "Report of the Questionnaire on Regulatory Regimes for Manufactured Nanomaterials
Project 6. Co-operation on Risk Assessments	Report of a seminar "Risk Assessment of Manufactured Nanomaterials in Regulatory Context "(2009) "Risk Assessment of Manufactured Nanomaterials – Critical Issues"
Project 7. The Role of Alternative Test Methods in Nanotoxicology	Meeting of experts
Project 8. Co-operation on Exposure mitigation and Exposure measurement	3 projects in progress. 2 case studies (nano-silver and nano-gold)
Project 9. Environmentally Sustainable Use of Nanotechnology	OECD Conference on the Potential Environmental Benefits of Nanotechnology: Fostering Innovation-Led Growth (2009) "National Activities on Life Cycle Assessment of Nanomaterials" and workshop on the Environmentally Sustainable Use of Manufactured Nanomaterials

Standards

The standards that have become compulsory upon being transcribed in law[10] are not addressed in this variables sheet.

ISO TC229

Standardisation has often been introduced after the product has been placed on the market. ISO's technical committee (TC) 229 was created in 2005 well ahead of the placement on the market of products resulting from nanotechnology research. In fact, the TC229's mission statement includes this element: *"to develop science-based standards for the field of nanotechnology in order to promote its commercial applications in a secure manner"*[11]. It is rare to see a technical committee involved so far upstream while a scientific field is still emerging. However, as group leaders explain, this work is essential for enabling products that are safe for humans and the environment to be put on the market. ISO's work also aims to serve as a foundation for international legislation.

In 2013, 34 countries were members of this committee and took part in its work and there were 11 observer countries. The most highly involved actors (in number) and the most active are from: USA, UK, Germany, Japan, South Korea and China. It should be noted that only the nationality of the delegates is supposed to have any importance in the discussions and they must all work towards a common good. Nevertheless, strategies according to country exist, but so do underlying actor-related strategies. The creation of the ISO technical committee 229 triggered the creation of national mirror committees, and, rather unusually, technical standardisation plays out directly at international level: only the Chinese proposed a Chinese standard as a basis for reflection at international level (leading to the creation of the working group 4 on nanomaterial specifications). In almost all other situations, it is the discussions within TC229 that fuelled draft standards (co-developed at national and international level). This marked a significant change in market governance. Another important point is that ISO TC229 is positioned as an international coordinating body: it develops cross-cutting standards, sector-specific technical committees then develop sector-specific standards (for example, TC229 develops nanocellulose terminology as well as measurement and characterisation aspects while TAPPI, an organisation specialised in pulp and paper industry standardisation, develops nanocellulose standards). In order to play its coordinator role, ISO TC229 liaises with 30 other ISO committees and 10 organisations outside of ISO (including OECD and the

[10] Today, most of what is considered in laws or regulation concerns adaptations to existing laws or regulations (Table 1).

REACH, EU, 2006
Novel Food Regulation, EU, 1997
Cosmetic products Regulation, EU, 2009
Toxic Substances Control Act Inventory Status Carbon Nanotubes, US, 2008
Federal Insecticide, Fungicide, and Rodenticide Act, US, 1996
DTSC chemical call-in: carbon nanotubes, US - California, 2009
The Manufactured Nanoscale Health & Safety Ordinance, US - Berkeley, 2006
OSH Framework Directive, EU, 1989
NIOSH Occupational Exposure to Titanium Dioxide, US, 2011
French Environment Code, France, 2010

Table 1. Laws or regulations adapted or being adapted for nanomaterials, country/region, year.

[11] Minutes of the General Assembly of 12 June 2009.

European Commission). In addition, two of ISO's TC229 working groups (JWG 1 and 2) are shared with the large electronics and electrotechnical standardisation organisation IEC.

ISO TC229 has met every six months since 2005 (in addition to specific work meetings, conference calls and remote work). The biannual meeting of the committee has strategic objectives for the actors that endeavour to obtain support for their projects and to influence the positioning of other projects to their advantage. This is why numerous countries (among which USA, Japan, South Korea and China) have stated that nanotechnology standardisation is strategic for development and for domestic competitiveness. The committee no longer accepts new draft projects outside of the objectives defined in its global roadmap. The functioning of the TC229 committee is in fact slightly different to that of the other technical committees, since most of its activity is geared towards the creation of new documents, while the activity of the other committees is more focused on updating existing technical documents.

Up until 2012, the committee was chaired by a British coating manufacturer (IonBond ltd). In 2012, chairmanship was passed onto a British pharmaceutical manufacturer. It opened up TC229's activities to nanomedicine and pharmaceuticals, thus renewing the topics included in the technical committee's programme.

JWG1 Terminology and nomenclature (shared between ISO and IEC)

The goal of JWG1 is to enable secure and safe commercial transactions by clarifying the very object involved in the transaction and by guaranteeing to the customer and citizen the safety of the object. In order to do this, JWG1 is working on establishing terminology to give an "unambiguous and clear" description and definition of nanotechnologies. It is also exploring the framework and nomenclature possibilities that would be appropriate for regulation. In this instance, JWG1 is particularly important for harmonising rules developed at national and supranational levels.

A great difficulty for this group is that the definition and classification of words are based on science, but the results must be useful for manufacturers, for products that are not yet on the market. There may be different scientific and industrial terms to designate the same things. Or purely scientific terms may not be considered relevant by manufacturers. Hence important discussions between manufacturers and scientists (academics or members of public laboratories).

JWG2 Measurement and characterisation (shared between ISO and IEC)

This group essentially prepares technical specifications, each based on a measurement method or an instrument that can be used in the field of nanoscience and nanotechnology.

WG 3 Health, Safety and Environmental Aspects of Nanotechnologies

This working group is directed by the English participants who have major institutions specialised in the field. This strength enabled them to propose work projects and to follow them through with finalised work documents that leave little room for major modifications to the text structure. Of note is the project on risk assessment by control banding, the only project coordinated by France. WG3 is the largest working group.

WG4 Material specifications
Working group 4 is the closest to products and markets. Created in 2008, it is led by the Chinese members. This group is mostly made up of Korean, Taiwanese and Japanese companies, which are major manufacturers of nanomaterials. Two working documents have since been produced: one on calcium carbonate ($CaCO_3$) and the other on titanium dioxide (TiO_2). They aim to establish documents characterising nanomaterials in order to facilitate B2B transactions. The difficulty of this work lies in the fact that the tests recommended must be feasible and reproducible by manufacturers and they do not always have the resources to use very sophisticated instruments. During sessions, experts present methods that can be used by manufacturers.

There are two cross-cutting discussion groups within TC229, demonstrating the desire for openness and to take into account more general topics: "*nanotechnology and sustainability*" and "*societal dimensions of nanotechnology*".

To date, TC229 has published 32 documents and 18 others are being elaborated (see Appendix 1).

CEN TC352
The Nanotechnologies technical committee TC352 of the European Committee for Standardisation (CEN) structured its activity to complement that of ISO TC229 (European Commission mandate 98/34). CEN, CENELEC and ETSI were therefore requested to coordinate with the European Technology Platforms, interest groups (ANEC), environmental associations (ECOS) and workers' associations (ETUI-REHS and NORMAPME).

Seventh European framework programme (FP7)
The European projects under FP7 have also developed an activity area related to standardisation. They are focused on measurement and characterisation on the one hand, and toxicology on the other. Toxicology investments are very high in Europe and have been criticised to a certain extent, since investments in other fields (i.e. applications), more related to the competitiveness of Europe, have been limited as a result.

NMP – 2007-1.2-4: coordination in nanometrology
This coordination action was expected to address the identification and coordination of nanometrology activities conducted in Europe; in particular regarding (i) characterisation of nanoscale reactions, materials, mechanisms, structures and systems, and (ii) assessment of performance and improvement of methodology, operational practice and use of equipment. The "health, safety and environmental impact" aspects of nanotechnology are not specifically at the centre of this coordination action.

NMP – 2007-2.1-3: characterisation of nanostructured materials
This action is centred on the dissemination of new techniques and the elaboration of standards in nanomaterial characterisation (in particular for SMEs). The goal is also to develop or to launch preparatory work for the development of standards relating to the characterisation of nanostructured materials.

Nanosafe

This research project is focused on the safe production and use of nanomaterials. The project develops the assessment and management of risks for the safe industrial production of nanoparticles. Building on Nanosafe, Nanosafe 2 is an integrated project covering a vast number of technical fields: (1) detection and characterisation techniques; (2) assessment of health risks; (3) development of secure industrial production systems; (4) environmental and societal aspects (www.nanosafe.org).

Nano-Strand

The *Laboratoire national de métrologie et d'essais* (LNE) coordinates this project whose main objectives are to identify the needs, expectations and priorities of all actors concerned by the characterisation of nanomaterials and to determine who can best respond, in order to subsequently draw up a roadmap for European standardisation. The roadmap must also provide research topics for FP7.

Prospective analysis

Work on standards will intensify since the markets for nanotechnologies are becoming structured; there will therefore be a growth in standardisation needs.

Several elements will be key in the development of standards:

- *normes* and standards are recognised as strategic competitiveness tools for both public and private actors;
- standardisation apparently occurs at international level especially. As stated previously, standards are no longer elaborated at country-level first, but directly at international level (for example CEN-ISO).

There are major coordination challenges:

- no public or private actor or country can develop *normes* or standards alone given the complexity of objects and the sum of expertise required;
- a single organisation cannot develop *normes* or standards because no single organisation has legitimacy over all topics due to the complexity of nanotechnologies;
- sector-specific bodies coordinate with ISO or IEC to organise distribution of roles for the drafting of standards. It appears that cross-cutting standards are developed within coordinating bodies such as ISO and that standards that are more sector-specific are then elaborated within specific industry bodies;

- coordination is developed at all levels to avoid redundancies of work. Therefore, standards on ultrafine particles must also be taken into account even though they are not included in a nanotechnology-labelled technical committee. The challenge is therefore to target all activities relating to nanotechnologies.

Hypotheses

Hypothesis 1. Strengthening of the strategic dimension of standardisation: coordination by industrial actors

In this hypothesis, industrial actors, in order to develop their activity, work to structure the markets through the use of standardisation. Standardisation is increasingly becoming a strategic tool, used by manufacturers to ensure their competitiveness. States are not catalysts of this movement, at best, they support it.

Nevertheless, actors' behaviour is not erratic. They cannot each develop their own individual standards, and to promote exchanges, they continue to work together in the major international standardisation bodies. They coordinate their actions through standardisation bodies that have gained importance such as ISO. These have recognised legitimacy in combining the expertise necessary for elaborating *normes techniques*. These bodies enhance their cooperation to avoid redundancies in work. Cross-cutting standards are developed in nanotechnology-labelled coordinating bodies, while sectoral standardisation bodies develop standards specific to each industry.

Hypothesis 2. Market coordination by State actors

In this hypothesis, State actors organise the markets: matters concerning safety, human and environmental health are important as nanotechnology products enter the market. Since markets are global, States cannot allow actors to singlehandedly structure the markets. They develop common strategies and priorities and coordinate in bodies such as OECD. They can also intervene in standardisation by giving major priorities to organisations that ensure these functions (such as CEN).

Hypothesis 3. Chaotic markets / competing for governance (OECD, ISO, multiple labels, etc.)

In this hypothesis, public and private actors are unable to get organised collectively. Each actor or group of actors acts individually. Some invest heavily in standardisation either at national level, or at international level. Others develop labels, codes of conduct, good practices or standards with each one attempting to have others adopt their products in order to be more competitive. Consequently, governance is very fragmented and markets are not very structured or organised, which affects the profitability of the sectors concerned.

Appendix 1. Projects developed within ISO TC229

Standard and/or project	Stage
ISO/TS 10797:2012 Nanotechnologies - Characterization of single-wall carbon nanotubes using transmission electron microscopy	published
ISO/TS 10798:2011 Nanotechnologies - Characterization of single-wall carbon nanotubes using scanning electron microscopy and energy dispersive X-ray spectrometry analysis	published
ISO 10801:2010 Nanotechnologies - Generation of metal nanoparticles for inhalation toxicity testing using the evaporation/condensation method	published
ISO 10808:2010 Nanotechnologies - Characterization of nanoparticles in inhalation exposure chambers for inhalation toxicity testing	published
ISO/TS 10867:2010 Nanotechnologies - Characterization of single-wall carbon nanotubes using near infrared photoluminescence spectroscopy	published
ISO/TS 10868:2011 Nanotechnologies - Characterization of single-wall carbon nanotubes using ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectroscopy	published
ISO/TR 10929:2012 Nanotechnologies - Characterization of multiwall carbon nanotube (MWCNT) samples	published
ISO/TS 11251:2010 Nanotechnologies - Characterization of volatile components in single-wall carbon nanotube samples using evolved gas analysis/gas chromatograph-mass spectrometry	published
ISO/TS 11308:2011 Nanotechnologies - Characterization of single-wall carbon nanotubes using thermogravimetric analysis	published
ISO/TR 11360:2010 Nanotechnologies - Methodology for the classification and categorization of nanomaterials	published
ISO/TR 11811:2012 Nanotechnologies - Guidance on methods for nano- and microtribology measurements	published
ISO/TS 11888:2011 Nanotechnologies - Characterization of multiwall carbon nanotubes - Mesoscopic shape factors	published
ISO/TS 11931:2012 Nanotechnologies - Nanoscale calcium carbonate in powder form - Characteristics and measurement	published
ISO/TS 11937:2012 Nanotechnologies - Nanoscale titanium dioxide in powder form - Characteristics and measurement	published
ISO/DIS 12025 Nanomaterials - Quantification of nano-object release from powders by generation of aerosols	on-going project
ISO/TS 12025:2012 Nanomaterials - Quantification of nano-object release from powders by generation of aerosols	published
ISO/TR 12802:2010 Nanotechnologies - Model taxonomic framework for use in developing vocabularies - Core concepts	published
ISO/TS 12805:2011 Nanotechnologies - Materials specifications - Guidance on specifying nano-objects	published

Standard and/or project	Stage
ISO/TR 12885:2008 Nanotechnologies - Health and safety practices in occupational settings relevant to nanotechnologies	published
ISO/TS 12901-1:2012 Nanotechnologies - Occupational risk management applied to engineered nanomaterials - Part 1: Principles and approaches	published
ISO/DTS 12901-2 Nanotechnologies - Occupational risk management applied to engineered nanomaterials - Part 2: Use of the control banding approach	on-going project
ISO/TR 13014:2012 Nanotechnologies - Guidance on physico-chemical characterization of engineered nanoscale materials for toxicologic assessment	published
ISO/TR 13014:2012/Cor 1:2012	published
ISO/TR 13121:2011 Nanotechnologies - Nanomaterial risk evaluation	published
ISO/TS 13278:2011 Nanotechnologies - Determination of elemental impurities in samples of carbon nanotubes using inductively coupled plasma mass spectrometry	published
ISO/TR 13329:2012 Nanomaterials - Preparation of material safety data sheet (MSDS)	published
ISO/PRF TS 13830 Guidance on the labelling of manufactured nano-objects and products containing manufactured nano-objects	on-going project
ISO/TS 14101:2012 Surface characterization of gold nanoparticles for nanomaterial specific toxicity screening: FT-IR method	published
ISO/DTR 14786 Nanotechnologies - Framework for nomenclature models for nano-objects	on-going project
ISO/DTS 16195 Nanotechnologies - Generic requirements for reference materials for development of methods for characteristic testing, performance testing and safety testing of nanoparticle and nanofibre powders	on-going project
ISO/NP TR 16196 Nanotechnologies - Guidance on sample preparation methods and dosimetry considerations for manufactured nanomaterials	on-going project
ISO/NP TR 16197 Nanotechnologies - Guidance on toxicological screening methods for manufactured nanomaterials	on-going project
ISO/NP TS 16550 Nanoparticles - Determination of muramic acid as a biomarker for silver nanoparticles activity	on-going project
ISO/DTS 17200 Nanotechnology - Nanoparticles in powder form - Characteristics and measurements	on-going project
ISO/NP TR 17302 Nanotechnologies - Framework for identifying vocabulary development for nanotechnology applications in human healthcare	on-going project
ISO/TS 27687:2008 Nanotechnologies - Terminology and definitions for nano-objects - Nanoparticle, nanofibre and nanoplate	revision
ISO 29701:2010 Nanotechnologies - Endotoxin test on nanomaterial samples for in vitro systems - Limulus amebocyte lysate (LAL) test	published

Standard and/or project	Stage
IEC/CD TS 62607-2-1 Nanomanufacturing - Key control characteristics for CNT film applications - Resistivity	on-going project
IEC/TS 62622:2012 Artificial gratings used in nanotechnology - Description and measurement of dimensional quality parameters	published
ISO/TS 80004-1:2010 Nanotechnologies - Vocabulary - Part 1: Core terms	published
IEC/NP TS 80004-2 Nanotechnologies - Vocabulary - Part 2: Nano-objects: Nanoparticle, nanofibre and nanoplate	on-going project
ISO/TS 80004-3:2010 Nanotechnologies - Vocabulary - Part 3: Carbon nano-objects	published
ISO/TS 80004-4:2011 Nanotechnologies - Vocabulary - Part 4: Nanostructured materials	published
ISO/TS 80004-5:2011 Nanotechnologies - Vocabulary - Part 5: Nano/bio interface	published
ISO/DTS 80004-6 Nanotechnologies - Vocabulary - Part 6: Nanoscale measurement and instrumentation	on-going project
ISO/TS 80004-7:2011 Nanotechnologies - Vocabulary - Part 7: Diagnostics and therapeutics for healthcare	published
ISO/DTS 80004-8 Nanotechnologies - Vocabulary - Part 8: Nanomanufacturing processes	on-going project
ISO/AWI TS 80004-9 Nanotechnologies - Vocabulary - Part 9: Nano-enabled electrotechnical products and systems	on-going project
ISO/AWI TS 80004-10 Nanotechnologies - Vocabulary - Part 10: Nano-enabled photonic components and systems	on-going project
ISO/WD TS 80004-11 Nanotechnologies - Vocabulary - Part 11: Nanolayer, nanocoating, nanofilm, and related terms	on-going project

Source: ISO TC229, www.iso.org.

Building and civil engineering

Martine Reynier, INRS

Definition

The economic sector of "building and civil engineering", also known as "construction", covers all of the activities involved in designing and building public or private buildings, industrial or otherwise, and infrastructures, such as roads or pipes. In 2012, the French occupational risk prevention body of the building and civil engineering industry (OPPBTP) had 221,800 member companies, most of whom were self-employed tradespersons and very small enterprises (VSEs): 185,646 employed fewer than 10 employees, 34,823 employed from 10 to 99 employees, and 1,331 over 100 employees. In France the construction industry provides work for 265,000 self-employed workers, and 1.5 million employees, including over 117,000 temporary workers. Numerous trades are associated with this highly fragmented sector of activity.

Historically, the construction industry is considered not to be very research-oriented: whereas, in 2010, it contributed 11% of the gross domestic product of France, its research & development spending represented only 0.3% of France's R&D expenses (0.1% for the building trade, and 0.5% for civil engineering) as against a national average of 2.4% of GDP for R&D spending. This is one of the sticking points holding back innovation that were identified as requiring action following on from the "*Grenelle de l'Environnement*" talks and from the resulting "Plan Bâtiment" (plan to improve the energy efficiency and sustainability of buildings). The research efforts in the building and civil engineering industry are aimed primarily at limiting CO_2 emissions in cement production, and at producing buildings that offer higher energy efficiency and that are built with more sustainable materials. The construction industry is also benefiting from progress made in other industries that supply it with materials or products (glass, paints, varnishes, adhesives, insulation products, plastics, etc.).

Relevant indicators

- Number of patents for applications in the construction industry.
- Quantity of substances in the nanoparticulate state declared in R-Nano (for use in building and construction work).

Retrospective analysis

Knowledge about uses of nanomaterials in the construction industry, about their availability and about their performance is currently limited. In the first assessment, established at the end of 2013, of the declarations of substances in the nanoparticulate state (R-nano database), the "Building and Construction Work" use is mentioned for 1.4% of the declarations (i.e. about 39 declarations out of 2,776).

On the basis of the information collected in the scientific and technical literature and on the Internet, the uses appear to be concentrated in the fields of cement-based building materials and of surface coatings that improve the functionality of the materials.

Synthetic amorphous silica

Silica fume has, for over 25 years now, been used to make high-performance concrete (HPC) not only to increase its fluidity, and strength, in particular compression strength, but also to reduce its permeability. HPC is used for structures subjected to high mechanical stresses (high-rise buildings, bridges, reservoirs, nuclear power stations, etc.), for works in hostile environments (e.g. marine environments) or indeed when the concrete needs to be pumped over a great height. Silica fume is incorporated into the cement/concrete in proportions in the range 5% to 10% by weight, at the production companies or at the worksites. It is also used in repair mortars and shotcrete.

Another use of nanometric silica in road-building is proposed by a German manufacturer: adding the nanomaterial to a cement-based dispersion improves the frost resistance of the road surface.

Silica aerogel is being presented as a new-generation thermal insulator that is three times as effective as glass wool. It is already marketed in various forms, but its cost, which is exorbitant compared with conventional insulation materials, is holding back its industrial development.

Titanium dioxide

The use of nanometric titanium dioxide (anatase) in the construction industry is more recent. It is being used for its photocatalytic properties that accelerate decomposition of organic pollutants deposited on structures, and that make surfaces hydrophilic. This use makes it possible to preserve the appearance of buildings and to minimise cleaning and maintenance. It is also being proposed for improving air quality around roads. The titanium dioxide can be incorporated through to the core of the material to be treated (1% by weight in cement) or else it can be added by surface coating with a coating charged with titanium dioxide. It is used mainly during manufacturing of finished or semi-finished materials that are prefabricated on industrial sites: architectural or "architectonic" concrete for self-cleaning façades, noise barrier walls, paving, tiles, and asphalt roofing. According to a survey conducted in 2012 by INRS, the quantities of titanium dioxide consumed in France in the construction industry were several hundred metric tons, showing that consumption was still quite moderate. The number of workers potentially exposed in the sector of structural building work and civil engineering was assessed at fewer than 100 people. However, the survey concludes that this market offers considerable development potential.

Titanium dioxide is also used in producing self-cleaning glazing. The glass is covered with a fine layer containing titanium dioxide and generally deposited during manufacture of the glass, but it is also proposed to apply such layers *in situ*.

"Anti-germ" coatings containing nanometric titanium dioxide are proposed to cover interior surfaces of buildings, in particular in the medical sector. That use remains marginal.

Other nanomaterials

Other nanomaterials have recently appeared on the construction market, such as nanoclay (when added to cement, it increases the fluidity of the mix and reduces the setting time), or nano lithium silicate in solution (when applied to concrete floors, it procures a less porous and stronger surface).

Due to their exceptional physical properties, carbon nanotubes have been proposed as the ideal material for reinforcing concrete. The studies conducted to date have not achieved the expected results and this application, up against obstacles of cost and of health uncertainties, has not yet been developed. Various other particles are also being studied with a view to increasing the strength of concrete: nano-alumina, nano-lime, inorganic nanotubes, etc.

Prospective analysis

Building and civil engineering is one of the fields in which nanomaterials are already used as additives in structural materials (concrete, asphalt, glass, plastics, etc.) or in coatings. Significant quantities of synthetic amorphous silica, and, to a lesser extent, of titanium dioxide are already present in this sector. The current cost of nanotechnologies, their fundamentally high-tech nature, and the few practical applications yet available do not facilitate movement towards changes. However, nanotechnologies could open up new prospects in construction of buildings and of road infrastructures: improvements in strength of materials, in insulation, in structural safety, and in impacts on the environment and on energy consumption.

In addition to the innovation and research capacities of the construction sector and of related sectors, other factors have impacts on the development of nanotechnologies in this sector:

- the cost price needs to be reduced: construction materials are generally used in large quantities, and a small difference in price can give rise to a large increase in construction costs;
- the construction industry often uses raw materials that are available locally, and such materials can be incompatible with the processes for incorporating or adding the nanomaterials;
- the technical performance and durability of the materials and of the products over the long term needs to be demonstrated; numerous mandatory technical specifications and standards that regulate the construction market are likely to curb innovations;

- implementing processes using nanomaterials can prove to be more difficult than implementing processes using conventional materials, it then being necessary to use specialist workers who have been specially trained;
- absence of information on the risks for health and for the environment is arousing even greater suspicions about nanomaterials in this sector since it has suffered a large number of occupational diseases related to asbestos;
- the regulatory and societal environment, in particular consumer acceptability of products incorporating nanomaterials, needs to be favourable.

Hypotheses

Hypothesis 1. A few innovations and marginal use

The research and development efforts of the construction industry remain stable. The new uses in this sector are marginal for various reasons: cost, risks, etc.

Hypothesis 2. Deployment continues in certain applications

The construction industry invests in emerging high-technology activities. Major benefits make it possible to use nanomaterials for certain applications, which develop responsibly and without involving a revolution.

Hypothesis 3. Intensive development of nanomaterials in construction

Technological progress takes place, in particular in France, and numerous processes or products incorporating nanomaterials invade the market with multiple applications and affordable costs. The building and civil engineering sector benefits from these innovations, and nanomaterials find themselves in all sectors of construction.

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Chemicals and plastics

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Definition

The chemicals industry spans a broad spectrum of products and of activities that range from the upstream end to the downstream end. This sector covers, among other fields: petrochemicals, phytosanitary chemicals, the pharmaceutical industry, polymer manufacturing, paint manufacturing, and oleochemicals. The chemicals industry manufactures starting chemicals, intermediate chemical products, and finished products. The chemicals industry in France, which is the 7th largest producer in the world and the 2nd largest in Europe, is a major stakeholder in the French economy. It groups together 3,350 businesses, 94% of which are VSEs[1]/SMEs[2], and it employs 155,740 employees directly, and provides work for 500,000 indirect jobs.

Plastics

In 2008, France ranked seventh in the world for plastics production (with a market share of 4.7%), the top two being Germany (with a market share of 14.1%), and China (with 11%). Made up essentially of SMEs, the plastics industry is highly diversified in terms of markets and of technologies.

The future of the chemicals industry depends on a large number of factors:

- cost of raw materials;
- cost of energy / increases in energy and raw material prices;
- increasing scarcity of petroleum;
- shale gas extraction on the other side of the Atlantic;
- pressure from health and environment regulations / increasing environmental concerns;

[1] Very Small Enterprises
[2] Small and Medium-Sized Enterprises

- globalisation with, in particular, the rise of emerging stakeholders in Asia and in the Middle East.

But it also depends on the choices made by the stakeholders and on the strength of their will to invest in research and on their capacities to anticipate the skills of tomorrow. Its future lies in investment in research and in innovation.

Up against the international chemicals groups who supply the raw materials, the companies who transform the raw materials do not have sufficient size to negotiate the purchase prices.

The plastics industry is directly affected by the lack of stability of raw materials prices. Upstream, it is subjected to pressure from major international chemicals groups and, downstream, it is also subjected to considerable pressure from the clients from the automobile and food industries.

There are a very large number of small industrial companies with fewer than 20 employees in the plastics industry. This scattered configuration of the industrial structures makes it difficult to access external markets.

Retrospective analysis

The history of the chemicals industry is made up of great scientific discoveries that have then facilitated creation of technological applications. Of all of the industrial sectors, it is the chemicals industry that devotes the most money to R&D. However, over the last 10 years, research budgets have been stagnating. Nevertheless, research and innovation remain preconditions for maintaining the performance of the sector. Today, the chemicals industry is has to take up a series of considerable challenges.

The issues for the chemical industry are clearly defined by the needs of the industries downstream, and in particular the ones that are in market leader positions (transport, energy, building, etc.). In addition, the chemicals industry is heavily dependent on the raw materials it transforms into consumer products. The current increase in raw material prices is problematic for the sector. To mitigate these soaring prices, the industry is seeking alternatives, in a difficult economic context.

Conducive to the development of R&D activities, recession or crisis can be a driver resulting in the sector undergoing a paradigm shift in facing up to the major industrial sectors. That is why one of the strong trends is targeting the development of nanomaterials.

Production of nanomaterials represents one of the avenues for development and competitiveness of France's chemicals industry, for the benefit of all industrial sectors (automobile, building, cosmetics, pharmaceuticals, textiles, etc.). Strong international competition is already under way in the development of these technologies, which represent a major challenge for the competitiveness of the French and European industries. This development of nanomaterials in the chemicals industry also needs to cope with the distrust, or indeed hostility and protest, of populations who are as fearful of the environmental and health risks as they are of the economic consequences.

Nanomaterials and nanotechnologies are part of France's domains of excellence. France's industrial fabric has genuine capacity to react, thanks to advanced know-how and skills, in particular in nanomaterials. It should also be noted that the industrial fabric of the chemicals sector is dynamic and capable of calling itself into question and of staying on course through diversification and innovation. SMEs have maintained their efforts to enrich technologies, in particular in nanomaterials.

Plastics

Innovation has enabled plastics to acquire qualities that are highly appreciated on numerous markets: the automobile, packaging, and building industries, the electrical and electronic industry, the aircraft and aerospace industries, or the medical and surgical sectors. The technological progress is continuous and gradual.

Prospective analysis

Today, the chemicals industry needs to take up new challenges related to the global environment, to changes in the regulations, and to the economic context. Far from being a handicap, they offer opportunities to improve the processes and the image of the sector.

In spite of a difficult European context, the chemicals industry in France should record a small amount of growth in 2013. The UIC (*Union des industries chimiques*, France's Chemicals Industry Association) thus expects to see a slight growth of 0.5% in chemicals output in 2013, followed by growth of more than 1% in 2014.

The issue of nanotechnologies is a strategic one if France is to maintain its position as a leading light in developing innovative materials. However, nanomaterials will only be developed if the risks they present are kept under control.

While taking on board the industrial and environmental context associated with the sector of nanomaterials, it is by taking eco-design parameters into account that, for the same level of functionality, it will be possible to make nanomaterials easier to incorporate into industrial products, while sometimes highlighting problems of end-of-life management.

However, there is the problem of what strategy to use for incorporating nanomaterials into the chemicals industry. Two main options are being looked at:

- diversification: an incremental approach to innovation; is the sector-based approach appropriate contextually and technically?
- listening to the market: being open to disruptive innovation; does current know-how make it possible to take a medium-term and long-term approach to markets having futures?

Plastics
Faced with this growing globalisation in trade, innovation is at the core of the strategies of plastics manufacturers for maintaining their market shares.

The suppliers of basic plastics materials are innovating to meet the needs of their clients not only from the automobile, aircraft, electrical & electronic equipment, sports & leisure, and medical sectors, but also from the cosmetics and construction sectors, with whom they are cooperating to satisfy their needs as well as possible. The increasing use of nanomaterials is enabling client needs to be satisfied better.

Booming, and with continuous concern for innovation, the plastics industry is fully mobilised on a daily basis for adapting the materials of tomorrow: eco-design, smart plastics, ecological materials, etc.

Hypotheses

Hypothesis 1. Decline of the sector of activity in France

Nanomaterials are not deployed in the chemicals industry or in the plastics industry.

The sector is no longer competitive in France:

- either because of specific regulations;
  e.g.: adaptations to the REACh[3] Regulation are made to take account of nanomaterials and of their safety assessment; due to this new regulation, the European chemicals industry cuts back on investment in nanomaterials;

- or because of rising energy costs, the chemicals industry then moving closer to sources of energy.
  e.g.: the abundance of gas caused on the other side of the Atlantic by massive extraction of shale gas changes the deal; it causes a lasting reduction in the price of American gas; this upheaval causes an impressive resurgence in the American chemicals industry; As fast as new projects are created in the United States, European and non-European operators close their plants in Europe; companies do not invest in research & development, and do not incorporate nanomaterials into their processes.

Hypothesis 2. Deployment in certain sectors of activity: niche markets, and high added value products

In order to maintain their competitive edge, certain chemicals groups invest massively in new sections of the chemicals industry, such as nanotechnologies. The investments are refocused on products where the added value is higher and the competition is less tough. Knowledge and know-how in the field of nanomaterials makes smooth inroads.
e.g.: The development of self-cleaning products, top-of-the-range sports equipment, etc.

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[3] Registration, Evaluation, Authorisation and Restriction of Chemicals.

Hypothesis 3. Massive deployment across all sectors

The development of nanomaterials grows and is based on innovation that aims for wide dissemination of the technology or of the process. The resulting solutions adapt to suit the industrial processes and the regulatory requirements and constraints.

Command is acquired of the industrial know-how and of the new cutting-edge technologies in the field of nanomaterials.

For the chemicals industry, nanomaterials follow on from the innovative work conducted to develop products offering high technical and energy performance, while also keeping health and environmental risks better under control. They make it possible to manufacture innovative manufactured products while consuming less energy.

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Packaging

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Definition

Packaging is designed to contain and protect goods, in order for them to be handled and brought from the producer to the consumer or the user, and for them to be presented, preserved, or transported. Packaging also plays an important part in legally and commercially informing the consumer.

Production of packaging is a major economic activity: generally, in the food industry alone, it is assessed as constituting 2% of GDP[1] in developed countries. It consumes mainly plastics, cardboards, and derivatives of those materials.

In France, packaging is the 8th largest industrial sector (SESSI 2004), on a par with the aircraft industry. In 2006, the packaging industry comprised 850 companies each having at least 20 employees, the industry as a whole employing 110,000 people.

It is a heterogeneous sector, where labour-intensive industries with scattered structures, such as the plastics and wood industries, are mixed with much more capital-intensive and concentrated sectors such as the glass industry.

Food hygiene and safety, informing the consumer, design, and environmental friendliness are important issues for this innovative and dynamic industry.

Raw materials prices are creating favourable conditions for seeking alternatives: manufacturers are working on using new raw materials that should offer the same qualities at competitive prices. Considerable innovation efforts are being made to achieve this.

[1] Gross Domestic Product

Retrospective analysis

Although the major groups, who are world leaders, have predominant positions on the segments that require heavy investment, the capacity of small businesses to change and to adapt contributes to a large extent to the competitiveness of this sector in which the proximity between clients and of the manufacturers plays an important part.

Although strongly focused on the food industry, the packaging industry also operates in all sectors of industry, and in particular in the pharmaceuticals and cosmetics sectors. This industry holds an essential position in the production chain that links the raw product to the final consumer.

The food industry is the leading consumer of packaging, accounting for 66% of the turnover of the packaging industry. It is also the industry that faces the most regulatory requirements at all stages of the production chain, down to consumption of the products.

Current food packaging should contribute to preserving the healthiness and the organoleptic and nutritional properties of the packaged product, to prolonging the life of the food, to protecting the environment, to increasing profitability, to improving comfort of use, and to differentiating between products. In this respect, the food packaging sector is a dynamic sector in which innovation is an essential vector of development.

Nanotechnologies are among the most promising examples of technological progress because they offer new solutions for food packaging that can be beneficial both to consumers and to the industry. The major companies in the food industry are already conducting research projects on the use of nanotechnologies in packaging, and certain applications are already available on the market. Currently, it is estimated that 400 to 500 packaging nanoproducts are on the market.

Prospective analysis

Packaging, whose main outlet is the food industry, is characterised by an innovation content that is increasingly large. Their functionality features now go far beyond the main purposes consisting in containing, transporting, and storing products. In recent years, we have seen the development of active packaging, which changes the conditions for the product so as to improve the length of its life, and of smart packaging, which monitors and controls the transport and storage conditions.

The desired features for active and smart packaging should now make the following possible or guarantee the following:

- eco-design (weight, and physical strength);
- microbial regulation / preservation of food (anti-microbial packaging);
- quality control (freshness indicator, detection of pathogenic micro-organisms);

- traceability and better stock management (RFID tags);
- food safety, trademark protection, and authenticity of the products (nano-printing).

Currently, the major trends in new packaging research & development are focusing on:

- improving the properties of packaging to lengthen the lives of the products (interior coating or lining having a "barrier" effect);
- improving the mechanical and thermal properties of the packaging;
- incorporating antibacterial and antioxidant functions;
- creating interactive packaging;
- creating new functional properties (coating, covering, lining, detectors, smart ink, etc.);
- manufacturing printed smart sensors and indicators for flexible packaging.

One of the development focuses is also based on nano-printed smart packaging:

- nano-sensors for detecting:
  - pathogens and contaminants in the food;
  - allergenic proteins, so as to prevent reactions to the food;
- nanometric-scale freshness indicators;
- nanoparticles for smart inks: highlighting whether the modified atmosphere remains intact in the packaging during the distribution chain;
- nano-barcodes for monitoring and traceability: improving the security of the packaging to safeguard the brand and the authenticity of the product (inexpensive to manufacture and to use, excellent compatibility and durability, difficult to counterfeit).

In the coming decade, it is expected that nanotechnologies will be used in manufacturing 25% of all food packaging.

Hypotheses

Hypothesis I. Packaging is reduced to a minimum and simplified (without using nanomaterials)

Raw materials and energy costs remain very high. There is a strong ecological trend among the population. Manufacturers need to satisfy consumers who are more attentive to the environment and they have to cope with the decline in packaging demand (development of recyclable packaging).

Hypothesis 2. Limited development of smart and active packaging (with nanomaterials being used) in certain sectors, e.g. for increasing traceability

Smart nano-printing has a major influence on the packaging sector because it is the perfect response to the strategy of procuring safety and security, trademark protection, and guaranteed authenticity for the products developed by the food industry.

The manufacturers of the packaging product printing sector innovate and develop new processes based on nanomaterials. This development nevertheless remains limited to food product safety and security.

Hypothesis 3. Intensive development, and optimisation of the packaging by means of nanomaterials

This development fits into a social context that is marked by health scandals (e.g.: Spanghero, serious food poisoning, etc.) leading to the need to improve traceability of the food production and distribution channels. Nanometric-scale sensors appear to be imposing themselves as the preferred applications for food safety and quality measurement.

Packaging that extends the lives of the products or that gives warnings or sets off alarms in the event that the foodstuffs are degraded become a reality with the development of "active" and "smart" packaging.

In order to guarantee food safety and quality, consumers are prepared to pay more. This is an opportunity for manufacturers, and in particular for packaging manufacturers.

Thanks to the progress in smart packaging technologies, packaging manufacturers are able to offer sophisticated packaging, capable of delivering information in real time on the level of freshness of its contents or indeed of participating actively in lengthening the time for which its contents can be kept. Thus, in tune with consumer demand, packaging contributes to securing greater traceability and to procuring reinforced protection (in particular through anti-microbial systems).

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Healthcare and pharmaceuticals

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Definition

This variable covers all of the fields of use and application for nanomaterials in the medical sector. It is designated by the term "nanomedicine". Nanomaterials and nanotechnologies may be used for diagnostic, monitoring, or treatment purposes, either as medication or in medical devices, without there being any strict border between these two aspects.

The global nanomedicine market, estimated at 63.8 billion US dollars in 2010, could reach 100-to-130 billion US dollars by 2016, according to estimates by Bionest. *"In France, nanomedicine has got off to a good start, based on sound academic research, spread across the entire country,"* observes Claude Allary, a consultant at Bionest. Two major clusters have emerged, however: Grenoble, with the CEA Leti (an electronics and information technology laboratory of the French Alternative Energies and Atomic Energy Commission) and the Université Joseph-Fourier; and Île-de-France (Paris Region), with the Université Paris-Sud, the ENS Cachan, etc. It is in and around these two clusters that most of the SMEs[1] are located, such as Fluoptics (*in vivo* imaging), Axialys (vectors of medicines), Cytoo (cell testing), Fluigent (microfluidics), BioAlliance (nanoparticulate medicines), Nanobiotix (radiotherapy), etc. The youth of this industry and its particularly innovative nature explain that there are not yet any major players, but today France has about thirty industrial companies who are specialised in or who use nanomedicine technologies. Convinced of the utility of helping an industrial sector to emerge, the Banque Publique d'Investissement supported the setting up of the consortium NICE (Nano Innovation for Cancer), the leading partner of which is BioAlliance, the other partners being Nanobiotix, the CEA Leti, and the Institut Galien (Université Paris-Sud). The aim of the consortium is to set up a platform designed to accelerate the development and industrialisation of nanomedicines in France by making advantageous use of the expertise of the partners. Due to the rarity of venture capital in the healthcare field, a public structure is thus, for the first time, going to fund clinical trials.

[1] Small and Medium-sized Enterprises.

The French stakeholders in the sector also see the full advantage of the European dimension. They were driving forces in the setting up, in 2005, of the European Technology Platform for Nanomedicine, because certain facilities, necessary for taking production to an industrial scale, such as a characterisation laboratory and a pilot production unit, can be cost-effective only at the scale of Europe.

Retrospective analysis

Nanomedicine is in its infancy, but it is developing extremely fast, like all fields of nanotechnology. The area for research is growing unceasingly, publications are becoming increasingly numerous, as are application possibilities. However, most applications are still at the research stage. The research work is focusing both on the techniques applicable to active ingredients, and also on diagnostic tools. The importance of nanotechnologies for the medical field lies in the fact that a good many biological processes take place at the nanometre scale. The main fields of research and of application for nanomaterials and nanotechnologies in the medical sector are presented below.

Vectors, systems for delivering medicines

Nanomaterials can help to transport medicines in targeted manner through the system (by acting as vectors). Surrounding the medicine, they protect it from contact with the immune system and prevent it from being degraded. They are colloidal systems such as liposomes, micelles, fullerenes, carbon nanotubes, polymer nanoparticles (in particular polyethylene glycol), products of conjugation of a polymer and of an active ingredient, etc. The aim is that the medicines transported in this way perform their action at the targeted point only, thereby reducing adverse effects. The vectors can be biodegradable, soluble, insoluble, or slowly soluble. Nanovectors can be modified so that they can pass through biological barriers (e.g. the blood-brain barrier). Nanosystems (devices or robots) are also being developed that make it possible to identify and to administer targeted treatment to diseased cells.

Active ingredients

Nanomaterials are being used as active ingredients. This applies, for example, to dendrimers, which have tree-like structures, and which, at their surfaces, have specific functional groups that perform clearly-defined actions. Active ingredients in the broad sense of the word can also be nanomaterials that, due to certain physical characteristics that they posses, have therapeutic effects; for instance, in hyperthermia therapy processes used in treating cancer, metal nanoparticles that are heated under the action of electromagnetic radiation are used to kill cancer cells. The use of nanomaterials makes it possible to target the destruction of the tissues and thus to limit the effects to the tumour.

Diagnostics

Various techniques, such as scanning tunnelling microscopy, or atomic force microscopy, make it possible to observe nanostructures. Nano-imaging makes it possible, by using nanomaterials such as carbon nanotubes or fullerenes, to reduce the quantities of contrast agent (e.g. gadolinium) that need to be used. In the field of medical biology, nanotechnologies make it possible, on increasingly small quantities of biological liquid, to do an increasing number of analyses (Lab-on-a-Chip (LOC) devices). A multitude of measurement systems based on nanotechnologies (cantilever sensors and Surface Plasmon Resonance (SPR), biochips and biosensors) are also being developed. In the field of diabetes, instruments for analysing patients' breath are also being developed. Finally, for *in vitro* diagnostics, nanomaterials can be used as biological molecule markers.

Biomaterials and medical devices

Nanomaterials are used in surface treatment of implantable devices such as coronary stents, pacemakers, or joint prostheses, in order to facilitate acceptance of them by the system and so as to avoid them being rejected. Surface treatment of coronary stents should make it possible, more precisely, to avoid restenosis and thrombosis. Other examples of surface treatment by nanomaterials are the use of coatings or linings based on silver nanoparticles such as germicides in dressings, medical fabrics, and other devices (e.g. catheters). Nanomaterials are also used for making cements close to bone tissue that are intended to present optimised mechanical properties, or for making dental amalgams (hydroxyapatite). In the field of dialysis, nanopore filters are designed to be used in dialysis machines or in artificial kidneys. Another implant that is being developed is the nanoelectronic retinal prosthesis.

Unlike in human medicine, nanotechnologies are as yet little used in veterinary medicine, but there is genuine market potential in that sector.

Prospective analysis

Determinants of the future changes in the variable

- Current and foreseeable applications for nanomaterials and nanotechnologies in the medical sector.
- Long-term effects (desired ones or undesirable ones).
- Regulatory provisions and acceptability of the risk.
- Demographic structure.
- Costs.
- Competitiveness of French output.

Like many other fields of nanotechnologies, nanomedicine is in its infancy. The potential applications are manifold. Nanotechnologies offer possibilities for improving current therapies and for developing novel therapeutic approaches. This applies in particular for cancer, cardiovascular diseases, and neurodegenerative diseases. In its *Recommandations relatives à l'évaluation toxicologique des médicaments sous forme nanoparticulaire*

(Recommendations on toxicological assessment of medicines in particulate form), the ANSM[2] indicates that a spectacular development is foreseeable. In an ageing western society, the need for medical treatment is a constant, and it is unlikely that this trend will be reversed. However, in addition to the need for new forms of therapies, the cost aspect is also playing an increasingly large part. The healthcare sector is undergoing a genuine explosion of costs in a good many western countries; since nanotechnologies are relatively costly, the issue is to determine whether their medical applications contribute to any reduction in costs, by means of an improvement in therapies and in prevention.

Toxicological characterisation of a nanomaterial relates firstly to the physical and chemical properties that directly influence its toxicological behaviour. This includes, in particular, composition, form, tendency to aggregate or to agglomerate, solubility, structure and surface charge density, biopersistence, degradation and excretion mechanisms, etc. In addition, the way the nanomaterial interacts with the system also needs to be assessed; thus, the physical and chemical properties determining aggregation can differ, in serum, from properties observed during *in vitro* tests, or adsorption of proteins at the surface of a nanomaterial can influence the distribution in the system and the response of the cells. The toxicokinetics and the toxicodynamics also need to be characterised (in particular depending on the absorption channel, on the size of the object and on its surface area), as do the distribution, the elimination, and the biodegradation, the cytotoxicity and the genotoxicity, the risk of sensitisation, the carcinogenicity, the haemocompatibility, the reprotoxicity, etc. A risk of a chronic effect should be considered (although there are currently few conclusive studies) when a nanomaterial is not degraded or eliminated, but rather it is biopersistent and tends to accumulate. It must be admitted that, generally, we still know little about the toxicity in humans.

An important factor for the development of nanomedicine is the toxicological behaviour of the nanomaterials that are used. There are many uncertainties on this subject, in particular as regards their long-term efficacy and their long-term effects in humans. Nanomaterials are so heterogeneous that it is not possible to assess the risks in general. It is often difficult to establish to what extent data from *in vitro* or *in silico* studies and data from experiments on animals can be extrapolated to humans. As things currently stand, it is not really possible to give a general answer to that question, since each nanomaterial needs to undergo specific toxicological characterisation. In addition, the toxicological data established by studies mainly concerns pure nanomaterials, and not pharmaceuticals or medical devices; it is important to assess, with the greatest of care, to what extent that data is transposable to such pharmaceuticals and medical devices.

In addition to the toxicity inherent to nanomaterials, account should also be taken, when assessing the risks, of the effects of substances that are harmful to the environment or of manufacturing impurities, in particular since most of the published nanotoxicology studies do not concern medical devices or medicines, but rather they focus on the nanomaterial itself, and are thus not directly transposable.

Examples of potential risks debated between experts are, for example, induction of growth processes in soft tissue, in the case of materials provided with surface coatings; triggering of inflammatory processes by carbon nanotubes or fullerenes; presence of particles coming from abrasion of the surfaces of prostheses (cobalt-chrome or titanium dioxide); sensitisation to silver compounds due to frequent use of coatings/linings based on silver nanoparticles, etc.

In order to be able to compare the potential hazards of materials used in nanomedicine (if such comparison is possible, given their heterogeneity), a uniform approach to

[2] French National Agency for Medicines and Health Products Safety.

toxicological assessment is essential, and it is necessary to work to develop standard criteria. Reproducibility of results should be guaranteed not only within any one laboratory, but also between laboratories. To that end, it is necessary to have common and validated testing methods. This is an essential precondition for securing consistency in risk analyses at international level.

A problem that should not be underestimated when assessing risks is the exponential growth in the number of publications in the field of nanotechnologies. It is becoming difficult to have a full overview, and to make sure they are of good quality and to sort through the results depending on how relevant they are. It would be desirable for there to be fewer publications but for them to be of more constant quality.

Medical research is highly regulated. There are innumerable directives, standards and codes at national or international levels. Inspections are strict. Clinical trials concern not only efficacy but also adverse effects, thereby making it possible to assess the hazards of a new pharmaceutical product or medical device. For a product or device to be covered by the health insurance system, it is not only the efficacy but also the utility and the cost-benefit ratio that need to be established. And yet, in this process, account is not taken of the long-term effect, this aspect being addressed in the phase after the product or device comes onto the market. Generally speaking, the regulatory provisions make it possible to limit the risk to a certain extent. For the authorities, it is not easy to strike a fair balance in regulations, without putting too many obstacles in the way of research.

Uncertainties

- Financial resources for research.
- Findings of research.
- Transition to the application stage (including financial means).

Persistent trend

Demand for therapeutic and diagnostic resources remains constant in a context of growing demographic ageing.

Hypotheses

Hypothesis 1. The French industry is competitive

In this sector, nanotechnology (nanomedicine) is in an increasingly strong position because of its long-term positive effects on health and because its cost is reasonable. Budgets set aside for innovation in France continue to grow. Research is thus very dynamic and the transition to the industrial stage takes place easily in France. The French industry remains very competitive.

Hypothesis 2. Research takes place in France, but not production.

In this sector, nanotechnology (nanomedicine) is in an increasingly strong position because of its long-term positive effects on health and because its cost is reasonable. Budgets set aside for innovation in France continue to grow. Research is thus very dynamic but the transition to the application stage undergoes major difficulties in France. The French industry cannot withstand foreign competition. Production takes place outside France.

Hypothesis 3. Neither research nor production takes place in France

In this sector, nanotechnology (nanomedicine) is in an increasingly strong position because of its long-term positive effects on health and because its cost is reasonable. Nevertheless, the budgets allocated to research in France remain small. The findings are inconclusive and they do not lead to industrial applications. French research and industrial production cannot withstand foreign competition, and both research and production take place outside France.

Hypothesis 4. Market limited to very specific applications produced in France

In this sector, nanotechnology (nanomedicine) is in a marginal position because of its multiple long-term adverse effects on health or because of very stringent regulations. The market is limited. In view of their technical specificity, these applications are produced in France.

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Cosmetics

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Definition

The term "cosmetics" is used to mean any product designed to be in contact with the surface portions external parts of the human body (epidermis, hair system, nails, lips, teeth, etc.) with a view to cleaning them, perfuming them, changing their appearance, protecting them, keeping them in good condition, or correcting body odours (as defined in Article L. 5131-1 of the French Public Health Code (*Code de la Santé Publique*). This definition covers a very large number of products used in everyday life: hygiene, health, appearance, well-being, etc. Products designed to be ingested, inhaled, injected, or implanted in the human body are not considered to be cosmetic products.

The cosmetics industry is one of the rare sectors in which France remains the world leader, with a 25% market share. This good performance is being confirmed, above all for exports, and the cosmetics industry is thus the 3rd biggest economic sector in France in terms of net balance of trade. SMEs make up 80% of the industry and it has 450 sites across France (for manufacture or research) spread across 74 *départements*. It accounts for 54,000 direct jobs and 25,000 indirect jobs[1]. Innovation is a key factor in its development: the company that is ranked third in France in terms of number of patent applications filed every year belongs to the cosmetics industry.

The global market for cosmetics is estimated to be worth 425 billion euros[2]. The main centre of consumption in 2011 was Europe, with 72 billion euros, followed by the United States with 37.8 billion euros, and then Japan with 29.3 billion euros. However, those markets have reached maturity, with annual growth rates levelling off at 2%, while demand is increasing on emerging markets (Brazil, Russia, India, Mexico, and China), which are recording growth rates between 5% and 9%.

1 http://www.redressement-productif.gouv.fr/semaine-industrie/activites-industrielles/beaute-cosmetique.

2 Euromonitor International, 2009.

Nanomaterials have been used by the cosmetics industry for several decades now, as colourants, ultraviolet filters, preservatives, antibacterial agents, etc. In addition to nanomaterials, nano-emulsions, and nano-capsules are also used in the cosmetics industry.

Retrospective analysis and analysis of the current situation

Applications

In the cosmetics industry, the best-known and most-used nanomaterial is currently titanium dioxide. This mineral filter is known for its capacity to reflect, disperse, and absorb ultraviolet radiation. Because of this property, it has been used in sun protection products in nanoscale form for about 20 years now (and in care products and creams). Titanium dioxide is also used as a pigment in hair dyes and decolourisers, toothpaste and makeup, and as an antibacterial agent in deodorants and care equipment (hairbrushes, electric razors, curling irons, etc.).

Many other nanomaterials are also used in a wide range of cosmetics applications:

- iron oxides are used as pigments in hair dyes and decolourisers, and in makeup (mascara, nail varnish, eye shadow, etc.); ;
- amorphous silica is used as an abrasive, an opacifier and a thickener in hair dyes and decolourisers, creams and other care products (makeup removers, exfoliants, etc.), toothpaste, and as a matting agent in makeup;
- silver is used as an antibacterial agent in care products and creams, toothpaste, deodorants, care equipment, and shampoos and soaps;
- clay is used as a matting agent in creams and other care products, and in makeup;
- zinc oxide is used as a UV filter in care creams, sunscreen creams, and makeup;
- calcium carbonate is used as an abrasive and as a thickening agent in toothpaste and as an opacifier in makeup;
- carbon black is used as a pigment in makeup, as is aluminium oxide;
- cerium oxide is used as a UV filter in sunscreen creams;
- fullerenes and gold are used in care creams because of their antioxidant properties;
- etc.

Nanocapsules and dendrimers are also used in creams and other care products.

Since 2005, the Wilson Center in the United States has been establishing an inventory[3] of consumer products that contain nanomaterials and that are marketed across the world. Currently, 168 cosmetics or care products containing nanomaterials or nano-emulsions have been identified, including 29 French cosmetics products marketed by 6 companies (while only 33 French products containing nanomaterials are identified in the entire database). In 2005, 31 cosmetics products containing nanomaterials or nano-emulsions and marketed across the world were identified. According to that non-exhaustive database, the number of cosmetics or of care products containing nanomaterials and marketed across the world has thus been multiplied by a little more than 5 in 9 years.

In the first assessment, established at the end of 2013 by the French Ministry for Ecology, Sustainable Development, and Energy[4], of the declarations of "substances in nanoparticulate state" put on the market in France in 2012, it is indicated that 6.1% of the declared uses of the nanomaterials produced, distributed, or imported concern cosmetics and care products (i.e. about 170 declarations out of 2,776). In spite of a percentage that might seem low, cosmetics and care products are ranked in fourth position for the declared uses, just behind paints and coatings & coverings.

Regulations

No prior marketing authorisation exists for cosmetics products in France. The requirement laid down by the texts is absence of harmfulness to health. It is incumbent on the manufacturers to guarantee that their products satisfy the legislative and regulatory requirements, and are not dangerous to health. Manufacturers must thus compile a technical file, to be kept available to the inspection authorities, and that contains the qualitative and quantitative formula of the product, the description of the manufacturing and control/monitoring conditions, and the assessment of the safeness for human health of the finished product. In France, the French National Agency for Medicines and Health Products Safety (ANSM) lays down the requirements for assessing the quality and safety of use of cosmetics products.

The Cosmetics Regulation[5], voted in on 24 March 2009 by the European Parliament, introduces a definition of the term "nanomaterial" that differs from the one recommended by the European Commission in October 2011, and that reads as follows: " 'nanomaterial' means an insoluble or biopersistent and intentionally manufactured material with one or more external dimensions, or an internal structure, on the scale from 1 to 100 nm". It also stipulates that any company who wishes to market a product containing nanomaterials should so inform the European Commission six months prior to putting it on the market. If the Commission has safety concerns, it may request an opinion from the Scientific Committee for Consumer Safety (SCCS). In addition, since 1 July 2013, it has been mandatory for the company to indicate any presence of nanomaterials in the list of ingredients that was already mandatory on all products. A specific labelling rule has been issued for

[3] http://www.nanotechproject.org/cpi.

[4] Éléments issus des déclarations des substances à l'état nanoparticulaire, novembre 2013 : http://www.developpement-durable.gouv.fr/IMG/pdf/Rapport_public_format_final_20131125.pdf.

[5] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R1223&from=EN.

this purpose: name of the ingredient [nano]. The cosmetics industry is thus one of the first economic sectors to have a regulatory framework specific to nanomaterials.

While the finished cosmetic products must satisfy the requirements of the Cosmetics Regulation, the ingredients used to make them lie within the scope of application of the European Regulation REACh[6]. In practice, cosmetics ingredients that are produced or imported in quantities greater than 1 metric ton per year in Europe must be recorded pursuant to the Regulation.

The cosmetics industry is also governed by the system of annual declaration of "substances in the nanoparticulate state" that came into force in France on 1 January 2013 (Articles L. 523-1 to L. 523-3 of the French Environment Code (*Code de l'Environnement*)). That obligation to declare applies to manufacturers, importers, and distributors of "substances in the nanoparticulate state" put on the market in France, when the quantity of each such substance is greater than 100 grams per year. The declaration contains the identity of the declaring party, the quantity, the physical and chemical properties, and the uses of such substances, and the names of the professional users. Similarly, all of the available information that relates to the hazards of these substances and to the exposures to which they might lead, or that might be useful for assessing the risks for health and for the environment, must be disclosed at the request of the administrative authorities.

Health hazards and social acceptability

Cosmetics products containing nanomaterials are raising numerous questions and concerns from the scientific community, the public authorities, non-governmental organisations, and the general public as regards the potential dangers they represent for human health. For instance, in a report published in July 2012, Friends of the Earth Australia[7] point out the need for specific regulations for nanomaterials contained in sunscreen products.

Among such questions, percutaneous penetration of insoluble manufactured nanomaterials is one of the most debated issues.

A lot of research work (some of which is being done through European projects, such as Nanoderm[8]) has been undertaken on percutaneous penetration of various nanomaterials, and in particular titanium dioxide and zinc oxide nanoparticles. This work has been done on various *in vivo* and *in vitro* models, after single or reiterated administration, on healthy or damaged skin, and by stakeholders as varied as manufacturers, academic research teams, and government agencies.

Most of those studies would appear to indicate that percutaneous penetration of insoluble nanomaterials such as titanium dioxide is unlikely except when the skin is damaged. However, data on the subject is sometimes contradictory and does not make it possible formally to exclude any risk of transcutaneous penetration. In addition to the

6 Registration, Evaluation, Authorisation, and Restriction of Chemicals.

7 http://nano.foe.org.au/sites/default/files/Nano-ingredients%20in%20sunscreen%202012.pdf.

8 http://www.uni-leipzig.de/~nanoderm.

fact that many parameters might influence penetration of particles through the skin (size, elasticity, and surface properties of the particles, state of the skin, mechanical stresses, presence of sweat, etc.), studies have often been conducted over short times with nanomaterials that are not characterised or that are hardly characterised in terms of size, crystalline form, coating, etc. In addition, certain studies do not use standardised and validated protocols pursuant to the recommendations of the Scientific Committee for Consumer Safety (SCCS) or of the Organisation for Economic Co-operation and Development (OECD).

Those conclusions are taken up in numerous reports, including the one by the Danish Environmental Protection Agency[9] published in 2013, and the one by Afssaps (which has become the ANSM (French National Agency for Medicines and Health Products Safety)) published in 2011. At the beginning of 2008, Afssaps was asked by the French Directorate-General for Health (DGS) to look at nanomaterials in cosmetic products and to give an opinion about the risks of cutaneous penetration, of genotoxicity, and of carcinogenicity induced by the use of titanium dioxide and of zinc dioxide. Afssaps concluded that the lack of relevant and representative studies on the nanomaterials actually used in cosmetic products did not make it possible to conclude that those materials were innocuous when used in cosmetic products.

That referral to Afssaps for an opinion followed the assessment made by the International Agency for Research on Cancer (IARC) in 2006, published in 2010[10], leading to titanium dioxide, regardless of its particle-size, being classified as a Group 2B agent, i.e. as an agent possibly carcinogenic to humans, because there was sufficient evidence of carcinogenicity in experimental animals, even though there was inadequate evidence of carcinogenicity in humans. A carcinogenic effect had indeed been observed in rats exposed by inhalation to high doses of nanoscale titanium dioxide.

After establishing a guide on assessing the risks of nanomaterials in cosmetics, the SCCS has also given opinions on the main nanoscale ingredients used in cosmetics. The SCCS acknowledges that blind spots remain about the biological behaviour of nanomaterials. However, in view of the available data, in particular in view of the absence of information arguing in favour of percutaneous penetration, the SCCS considers that the use of nanoscale titanium dioxide and of nanoscale zinc oxide, at concentrations of up to as high as 25%, as an ultraviolet filter in sun creams, does not, *a priori,* induce a risk for health, after application on healthy skin. The same applies for carbon black used as a colourant in concentrations of up to 10% in cosmetics. The SCCS points out that coating of nanomaterials can significantly change their behaviour.

9 http://www2.mst.dk/Udgiv/publications/2013/09/978-87-93026-50-6.pdf
10 http://monographs.iarc.fr/ENG/Monographs/vol93/mono93.pdf

Prospective analysis

The possibilities for use of nanomaterials in cosmetics and care products appear to be manifold and various. Nanomaterials could make it possible to improve the performance of existing cosmetics and to develop novel products.

In a context of increasing demographic ageing and of a cult of youth, demand for cosmetics and care products that are ever more innovative, elaborate, and efficacious can but grow.

However, a factor limiting the use of nanomaterials in cosmetics and care products remains their toxicological behaviour. There are many uncertainties on this subject, in particular as regards their long-term effects in humans. It is often difficult to establish to what extent data from *in vitro* or *in silico* studies and data from experiments on animals can be extrapolated to humans. Nanomaterials are so heterogeneous that, as things currently stand, it is not really possible to give a general answer to that question, since each nanomaterial needs to undergo specific toxicological characterisation. In addition, the toxicological data established by studies mainly concerns nanomaterials on their own, and not cosmetic products; it is important to assess, with the greatest of care, to what extent that data is transposable to such products.

In addition, the scientific knowledge available on percutaneous penetration of insoluble manufactured nanomaterials remains contradictory and therefore does not make it possible to formally exclude any risk of penetration.

Another thing that is holding back the development of manufactured nanomaterials in the cosmetics industry and that is directly related to the previous point is lack of consumer trust in these new products as regards both their innocuousness and their efficacy.

In this context, titanium dioxide is going to be assessed as of 2015 under work for the European Regulation REACh. This assessment, entrusted to France (and more precisely to the French Agency for Food, Environmental and Occupational Health & Safety (Anses)), is aimed at determining whether manufacture and use of titanium dioxide can constitute a risk for human health and for the environment. This specific assessment process is generally initiated when there are legitimate concerns about the potential risks of a chemical substance. If, after examining the available data, the assessing Member State (France, for this assessment)considers that manufacture and/or use of titanium dioxide presents a risk, it can then supplement the assessment by:

- a proposal for harmonised classification and labelling for reasons of carcinogenic, mutagenic, or reprotoxic effects, of respiratory sensitising effects, or of other effects;
- a proposal aimed at identifying titanium dioxide as a Substance of Very High Concern (SVHC);
- a proposal aimed at restricting manufacture or use of titanium dioxide;

- actions not coming under the REACh Regulation, such as a proposal for an occupational exposure limit value at European level.

Hypotheses

Hypothesis 1. Development of some top-of-the-range cosmetic products incorporating nanomaterials in France

In an ageing society where a cult of youth or indeed infatuation with youth rules, demand for cosmetics and care products grows, investment in research and development concerning the use of nanomaterials in France is targeted selectively (because of the high costs), some top-of-the-range products incorporating manufactured nanomaterials are developed and marketed in limited quantities, and the French cosmetics industry reinforces its supremacy in the field of luxury cosmetics.

Hypothesis 2. Very limited development of cosmetic products incorporating nanomaterials in France

In an ageing society where a cult of youth or indeed infatuation with youth rules, demand for cosmetics and care products grows, investment in research and development concerning the use of nanomaterials in France is very limited, the cosmetics industry turns to developing natural cosmetics and few products incorporating manufactured nanomaterials are marketed, and the French cosmetics industry nevertheless remains competitive.

Hypothesis 3. Development of a wide range of cosmetic products incorporating nanomaterials in France

In an ageing society where a cult of youth or indeed infatuation with youth rules, demand for cosmetics and care products grows, investment in research and development in France is substantial, numerous innovative products incorporating or not incorporating manufactured nanomaterials are developed and marketed, and the French cosmetics industry remains one of the world leaders.

The food industry

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Definition

This datasheet addresses the design, production, and use of nanomaterials in the food industry, which may also be termed the "food and agriculture" sector.

This datasheet includes not only uses of nanomaterials in foodstuffs (e.g. as a technological auxiliary), but also in food packaging (e.g. as an active biochemical agent).

Retrospective analysis

A market that is growing fast at global level

A document recently published by Friends of the Earth presents a very exhaustive review of the applications of nanotechnologies/nanomaterials in food and agriculture[1].

According to that report, the number of food or food packaging products containing nanomaterials is going to increase rapidly. On the basis of work done by the Food and Agriculture Organization of the United Nations (FAO) and by the World Health Organization (WHO), food will increasingly be produced using nanotechnology[2].

1 "Way too little - Our government's failure to regulate nanomaterials in food and agriculture" May 2014, Friends of the Earth, http://emergingtech.foe.org.au/wp-content/uploads/2014/05/FOE_nanotech_food_report_low_res1.pdf (consulted on 30 May 2014)

2 FAO/WHO (2010) Expert meeting on the application of nanotechnologies in the food and agriculture sectors: potential food safety implications, http://whqlibdoc.who.int/publications/2010/9789241563932_eng.pdf

Economists estimate that, by 2015, 40% of all companies in the food industry will be using nanotechnologies, the Asian markets leading, followed by the United States[3].

At global level, many large food companies, in particular Heinz, Nestlé, Unilever, and Kraft, are exploring nanotechnologies for food processing and packaging, as indicated in Table 1. According to Friends of the Earth – Australia, agrochemical and seed companies are also running nanotechnology research & development programmes.

• Altria (Kraft Foods) • Associated British Foods • Ajinomoto • BASA • Cadbury Schweppes • Campbell Soup • Dupon Food Industry Solutions • General Mills • Glaxo-SmithKline • Goodman Fielder • Groupe Danone • John Lust Group Plc • H.J. Heinz	• Hershey Foods • La Doria • Maruha • McCain Foods • Mars • Nestlé • Northern Food • Nicherei • Nippon Suisan Kaisha • PepsiCo • Sarah Lee • Unilever • United Foods

Table 1. List of food industry companies engaged in nanotechnology research & development programmes[4].

Use of nanomaterials in foodstuffs

Nanomaterials as technological auxiliaries

Synthetic amorphous silica

Used most commonly as a technological auxiliary, in particular as a "trickle and flow" processing aid, synthetic amorphous silica (E551) is added to foods that are in powder form (e.g. salt, whey powder, egg powder, instant drink powder (coffee powder), seasoning blends (chilli, garlic powder, etc.), powdered sugar (icing sugar), and soup powder[5], etc.).

Synthetic amorphous silica is also used as an anticaking agent, as a thickener, or as a carrier of flavours. Consumers are thus exposed to it on a daily basis.

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3 LGL Bayern (Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit) (2012) Nanomaterialien in Lebensmitteln und Verbraucherprodukten. Anwendungsbereiche, Analytik, rechtliche Rahmenbedingungen, http://www.lgl.bayern.de/publikationen/doc/nanomaterialien_lebensmittel_produkte.pdf

4 Kraft position on nanotechnology http://www.kraftfoodsgroup.com/DeliciousWorld/food-safety-quality/nanotech.aspx

5 "Evonik, Selective Studies on Fumed Silica" http://nano.evonik.com/sites/nanotechnology/en/responsibility/safety-research/studies-on-fumed-silica/pages/default.aspx

Trade names of amorphous silica nanoparticles designed to be used in food include: Evonik's Aerosil 200F and Aerosil 380F[6].

Titanium dioxide

Titanium dioxide (E171) is a common additive in many food products. It is used, in particular, to bleach and brighten confectionery, cheese, and sauces.

A 2012 study looking at adding titanium dioxide in particulate form to food calculated that about 36% of the titanium dioxide particles used in food were nanoparticles[7]. That study revealed the presence of titanium dioxide particles in a wide variety of foods, including doughnuts, lollipops, chewing gum, and chocolate. Some of the quantities detected by that study were relatively large (Figure 1).

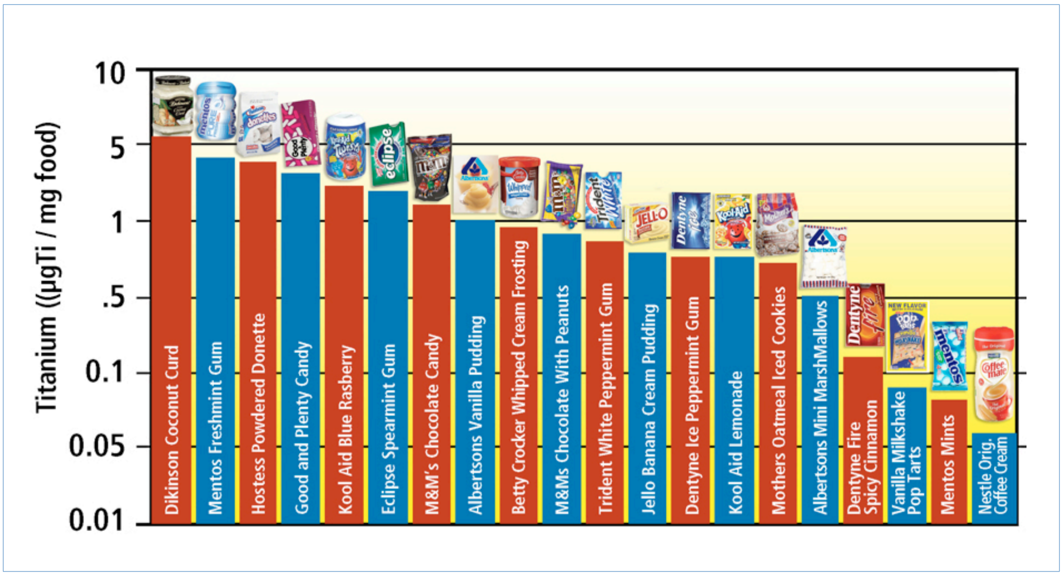

Figure 1. Titanium content (Ti in micrograms per milligram of weight of food)[8].

Tests conducted by Friends of the Earth – United States in 2013 also established the presence of titanium dioxide nanoparticles in fresh pear, capsicum (peppers), and apple samples.

A study conducted by As You Sow, published in 2013, also found titanium dioxide nanoparticles[9] in processed food, in particular in doughnuts.

Silver nanoparticles are also used in many food products as technological auxiliaries[10,11].

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6 "Presence and risks of nanosilica in food products", Dekkers S, Krystek P, Peters RJ, Lankveld DX, Bokkers BG, van Hoeven-Arentzen PH, Bouwmeester H, Oomen A.G. Nanotoxicology, 5 (2011), pp 393–405

7 "Titanium dioxide nanoparticles in food and personal care products", Alex Weir, Paul Westerhoff, Lars Fabricius, Kiril Hristovski and Natalie von Goet, Environmental Science and Technology 46 (2012), pp 2242-2250

8 http://grist.org/food/nanoparticles-in-your-food-youre-already-eating-them/

9 "Slipping Through the Cracks: An Issue Brief on Nanomaterials in Food" – As You Sow – Feb. 2013, http://www.asyousow.org/ays_report/slipping-through-the-cracks/ (consulted on 30 May 2014)

10 http://www.sciencedaily.com/releases/2013/08/130822194530.htm?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+sciencedaily%2Ftop_news%2Ftop_science+%28ScienceDaily%3A+Top+News+–+Top+Science%29

Functional foods

The food industry is investing in developing "functional" foods that should, for example contribute to:

- strengthening the immune system;
- improving digestion; and to
- lowering cholesterol.

Vitamins, minerals (such as iron, magnesium, or zinc), probiotic substances, bioactive peptides, antioxidants, etc. are added to dairy products, cereals, bread, and drinks. Some of these substances are added in the form of nanoparticles. The global market for functional food in 2005 was about US$ 73.5 billion[12]. That market is growing at 4% per year, which is much faster than the growth in the market for "conventional" food. From 2003 to 2010, the market for those products more than doubled[13]. A few functional foods containing nanomaterials are already on the market, e.g. yoghourts and drinks containing nanocolloidal platinum or gold[14].

Food packaging

Conventional packaging

One of the earliest commercial applications of nanotechnologies and of nanomaterials in the food industry was packaging[15,16]. Packaging using nanomaterials is of three types: barrier packaging, antimicrobial packaging, and sensor packaging. It is estimated that 400 to 500 packaging products containing nanomaterials are currently in commercial use across the world (it is predicted that 25% of all food packaging will contain nanomaterials by the end of the next decade[17]). According to Visiongain, the global market for packaging

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[11] *"Detection of engineered silver nanoparticle contamination in pears*", Zhang Z, Kong F, Vardhanabhuti B, Mustapha A, Lin M. J Agric Food Chem. ; 60 (43) (2012 Oct 31), pp 10762-7. doi: 10.1021/jf303423q. Epub 2012 Oct 19

[12] "*Out of the Laboratory and onto our Plates: nanotechnology in food and agriculture"*, Miller, G. & Senjen, R. (2008) Friends of the Earth Australia, p. 13 http://www.foeeurope.org/activities/nanotechnology/Documents/Nano_food_report.pdf

[13] Leatherhead Food Research (2011) Long may the growth in functional foods continue, http://www.leatherheadfood.com/ long-may-the-growth-in-functional-foods-continue

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containing nanomaterials was worth 20 billion US dollars in 2013[18]. A key objective of such nano-packaging is to offer longer shelf-life to the foodstuffs it contains[19].

Ingestible packaging

A practice that is emerging in the fruit and vegetable growing sector is treatment with nanoparticles either during growing or during storage. In particular, such treatment involves use of a synthetic clay (Laponite) known under its trade name Surround. Such treatment should make it possible to increase yield by nearly 20%, to reduce the quantity of pesticides and insecticides used, and to obviate the need for multiple packaging during storage.

Apparently, food coatings containing manufactured nanomaterials are already used on fruit and vegetables in the United States and in Canada.

Pesticides, insecticides

Nanostructured silica or Supersil, having a specific surface area of over 100 m^2/g, is typically used as a medium for carrying the active ingredients of pesticides, fungicides and insecticides. This nano-silica has greater absorption, facilitated wetting, better compatibility with most toxic substances and better chemical stability.

Using such nanoparticles as media for pesticides, insecticides, fungicides, etc. can also potentially lead to exposure of farmers during the operations of spreading and spraying those products, and also to exposure of neighbouring residents during those operations.

The determinants of this variable are constituted by the societal acceptability of the use of nanomaterials in the food industry.

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Hypotheses

Hypothesis 1. Nanomaterials develop in line with current trends

The toxicity and ecotoxicity studies show the innocuousness of the nanoproducts involved, their manufacturing costs are low, and their utility is demonstrated. Therefore, nanomaterials continue to be used in the food industry.

Hypothesis 2. Moderate or slower development

The toxicity and ecotoxicity studies show the innocuousness of the nanoproducts involved, their manufacturing costs are high, but their utility is demonstrated. Therefore, use of nanomaterials in the food industry becomes selective. Only a few uses are developed.

Hypothesis 3. Development is stopped

The toxicity and ecotoxicity studies show that the nanomaterials involved are clearly dangerous. Regardless of the manufacturing costs and of the utility of nanoproducts, their development in the food industry is stopped.

Energy

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Definition

The energy sector covers production, transport, distribution, and consumption of all forms of energy products, fuels, or heat, be they of nuclear, fossil, or renewable origin (Eurostat).

Retrospective analysis

At global level, in spite of a few downturns due to the oil crises, or to the financial crisis of 2009, the underlying trend of the energy market has been for high growth. Fuelled by demographic growth and economic growth, driven mainly by emerging markets[1], in particular the Asian markets (China and, in the medium-term, India, given its demography), the energy market could double by 2050 ("*Énergies 2050*" Report). Having already grown from 5.5 to 13.1 billion tonnes of oil equivalent (toe) between 1971 and 2011 (i.e. with an average yearly growth of 2.2%), energy consumption could, by then, reach more than 25 billion tonnes of oil equivalent (25 gigateo (Gteo)).

Fossil fuels, the leading example of which is oil, currently generate 80% of the energy supply[2]. This situation highlights the world's carbon energy dependence, and raises the issue of the sustainability of this dependence, both environmentally and as regards raw material procurement. At the environmental and raw material procurement levels, Europe has specific dynamics. As of the nineteen nineties, it started leading a movement to combat

[1] The four major emerging markets constituted by the "BASIC" group of companies (Brazil, South Africa, India, and China), and also those of the Middle East, much more than the OECD countries, will tomorrow "determine" the energy markets and the prices (*Energies 2050* Report, 2012).

[2] In 2010, global primary energy demand was over 80% satisfied by fossil fuels. Oil was the leading energy source, satisfying 33% of global needs, followed by coal, (27%) and gas (21%). Renewable energies satisfied 13% of demand, including 10% by hydroelectric power. The share of nuclear power in primary energy consumption was 6%.

climate change. Although its energy consumption has remained relatively stable since the first oil crises, it has launched an ambitious energy transition programme. Since 2008, the European Union (EU) has been implementing the "Climate and Energy Package" that has set stringent objectives to be achieved by 2020, in particular the famous "20-20-20" aligned on the Kyoto Protocol: to reduce the EU's greenhouse gas emissions by at least 20% compared with 1990 levels; to reach at least 20% of renewable energies in the gross final energy consumption of the EU; and to reduce primary energy consumption by 20% compared with the predicted levels, by means of improved energy efficiency.

In this context, although concerned about its energy independence, which is increasing[3], France is not an "energy island" ("*Énergies 2050*" Report). It is on the global markets both at procurement level and at production level, and it takes part in European policy with specific objectives. Although its singularity lies in the share of nuclear power (accounting for 85% of production and for 44% of energy consumption), recent plans driven by political will[4] have increased the share of renewable energy in energy production from 9.7% in 2005 to 13% in 2013 (18.1 million teo (18.1 megateo or "Mteo") out of a total of 139 Mteo) [5], with a target of 23% by 2020.

In 2014, the European Commission even produced an "Energy Roadmap 2050" which has reinforced the targets for 2030: the target for reduction in greenhouse gas emissions now being set at 40% (80% by 2050), and the target for renewable energies development being increased to 27%. Already, by 2013, the increase in wind turbine and photovoltaic solar generation resources had taken renewable energies to a level comparable to coal and nuclear power in the electricity mix in the 28-country EU (Figure 1).

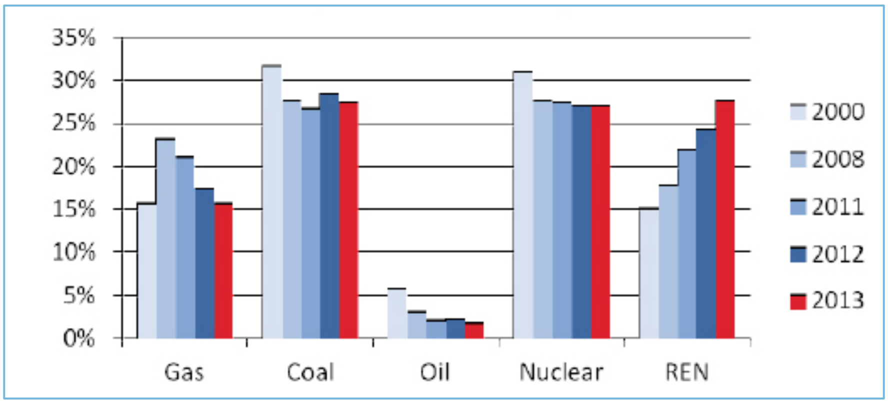

Figure 1. Electricity mix in the European Union.
Source: http://sciences.blogs.liberation.fr

[3] For the first time in 2013, the energy independence rate of France exceeded 50%, with national output covering 53.1% of the primary consumption of the country (*Commissariat Général au Développement Durable* (General Commission for Sustainable Development), *Chiffres et statistiques* (Figures & Statistics), No. 539, July 2014).

[4] See the latest bill debated in the French Parliament in 2014 following the national debate on energy transition and the national plan for action in favour of renewable energies.

[5] *Commissariat général au développement durable*, "*Le bilan énergétique de la France en 2013*" ("The Energy balance of France in 2013"). *Le point sur* (Focus on), No. 192, July 2014.

At global level, renewable energies (REN) now supply nearly one fifth of the energy consumed, and account for more than 22% of the electricity produced, representing 1.560 gigawatts (GW) (Report by the REN 21 network, UN, *Renewable Energy Network for the 21st Century,* June 2014). According to that report, in 2013 renewable energies accounted for more than 56% of the new electricity generating capacities at global level. China, the United States, Brazil, Canada, and Germany remain among the leading countries in terms of installed capacity. Hydroelectricity grew by about 4% to about 1000 GW in 2013, i.e. nearly one third of the renewable electricity generation. The other electricity generation renewables combined grew by nearly 17%, to 560 GW, according to estimates. Installed photovoltaic solar power overtook installed wind power for the first time, the report notes. New photovoltaic capacities grew by more than 27% compared with 2012, to reach about 138 GW installed in all. Nearly one third is from China. The onshore wind power capacities now account for more than 318 GW. The report observes, however, that that market has declined by nearly 10 GW compared with 2012, mainly due to the major reduction in the US market and to changes in public policies on subsidies. On the other hand, it points out that offshore wind power has enjoyed a record year, with 1.6 GW of new capacity, mainly coming from the EU.

The development of wind power and also of photovoltaic power suffers, however, from the problem of intermittence or non-continuousness of generation, which requires a rethink of technical solutions for storage and supply. The entire market for renewable energies and renewable fuels was, at global level, worth 249.4 billion US dollars in 2013.

In France, the energy industry is estimated to account for 200,000 to 400,000 jobs (in full-time equivalent (FTE) terms), i.e. 1% to 2% of the working population (2010 figures): 127,165 people work in production, transport, and distribution of electricity, 20,705 in production, transport, and distribution of gas, and 17,611 in refining (Energies 2050 Report, Appendix 9, 2012). In these sectors, France has major companies in international leader positions (Areva, EDF, GDF-Suez, Alstom, Total, etc.). In the renewables sector, according to the report published in 2010 by ADEME (French Environment and Energy Management Agency), there were 80,873 jobs in FTE terms. The vast majority of the jobs lie outside equipment manufacturing. According to Ademe, the job figures broke down as follows in 2009: 15,849 in equipment manufacturing, 24,195 in research, design, engineering, and installation, 12,683 in distribution, and 28,145 in operating and maintenance.

Applications of nanotechnologies to energy

In this buoyant sector[6], the issues of the use of nanomaterials concern above all energy savings, improvement of the performance of energy systems, and development of renewable energies.

As regards helping to exercise restraint in energy use, nanotechnologies already have numerous applications: glazing that regulates heat exchange, nanostructured materials that contribute to reducing consumption of raw materials and of energy by means of their lightness or efficiency, in the fields of electronics, of building and construction,

[6] *L'Energie, nouveau moteur de la guerre économique ?* (Energy, the new driving force of the economic war?) IFRI, 2014.

transport, etc. The highest added value use of nanotechnologies is in optimising the production of existing energy resources (crude oil, and thermal energy, for example), in using new energy sources (heavy oils, solar energy, etc.) and in improving the energy transmission and storage capacities, in particular for electricity and hydrogen. More precisely, on these points, the applications for nanotechnologies relate to more economical lighting, to developing materials for storing hydrogen (in particular carbon nanotubes), to use as nanostructured thermal barriers (such as aerogels), to new generations of photovoltaic cell, to electrical storage cells and to compact fuel cells with large inside surface areas, to quantum well lasers, etc.

In these fields, nations are rivalling with one another in terms of the strategic programmes they are developing. Unlike other sectors in which more conventional nanomaterials are used, energy requires a reinforced level of maturity in order to market these new materials or processes. The objectives of national programmes like those of the United States are thus to develop the share of solar energy and, by 2020, to make it as competitive in terms of production prices as the other forms of electricity (Sunshot Initiative, US DOE Office). In Europe, the research programme Horizon 2020 gives significant importance to a call for development of nanotechnology and advanced materials for low-carbon energy technologies and energy efficiency (European Commission Decision 4995 of 22 July 2014, p. 24 *et seq.*). In France, among the furthest advanced work is, for example, the production of multi-junction photovoltaic cells that offer performance in terms of efficiency of about 30% to 40%, which is much higher than the previous generations of cells. In addition, that level of efficiency is achieved with active surface areas that are much smaller.

As regards energy storage, applications have already been developed. They take up two major challenges: firstly, to reinforce the range of electric vehicles, and secondly to find solutions to the problems of intermittence raised by wind or solar powered electricity generator systems. Like other countries, France is thus developing "supercapacitor" components (combining high power density and high energy density) to increase the thermo-electric conversion levels or energy recovery (e.g. during braking) and also to increase the fast recharge capacity and the lives of batteries, or indeed to smooth out production from photovoltaic fields while clouds are going past, etc. Finally, metallic hydrides and other nanostructured membranes are already making commercial applications possible for systems for storing hydrogen in solid form (by adsorption) (Report of December 2013).

To sum up, many nanomaterials are used for applications in the energy sector. In particular:

- Quantum dots (cadmium selenide, cadmium sulphide, etc.) or aluminium oxides for lighting;
- Silicon, indium, gallium, or selenium, titanium dioxide, zinc oxide, or carbon nanotubes for photovoltaic cell efficiency;
- Rare earths (lanthanum, cerium, neodymium, etc.), lithium titanate, carbon black, or carbon nanotubes for battery and storage cell performance;
- Carbon nanotubes for fuel cell efficiency.

Dissemination of applications of nanomaterials in the energy sector

The energy sector is one of the five leading sectors in terms of use of nanomaterials in France. This sector is not traditionally a user of "historic" nanomaterials, but it does use recent nanomaterials that have high short-term maturity (DGCIS (French Directorate-General for Competitiveness, Industry, and Services), 2012 report). Only about fifteen companies have been identified as integrating nanomaterials, but, upstream, other producer companies have been identified, who are mainly SMEs, in particular from the microelectronics sector, and the overall situation could develop rapidly. This sector is among the ones that are likely to use large quantities of manufactured nanomaterials in the future (*Académie des technologies* (French Academy of Technologies), report 2012). As regards nanomaterials, applications that serve the development of solar energy and of energy storage are the ones that are the most eagerly awaited.

At global level, the growth forecasts for the various energy market segments are all in two figures; they range from 10% to 70% per year! The batteries market alone (batteries optimised by nanomaterials for improved power and improved lifespan), already close to several billion US dollars (USD), could reach 43 billion USD by 2020. Applications for superconductivity and for supercapacitors are showing growth between 10% and 20%. Distribution of photovoltaic cells is showing growth of about 40%, suggesting a specific market of 7 billion USD in 2020. In comparison, the photovoltaic energy market as a whole is apparently going to double in ten years: close to 30 billion USD in 2010, it could reach 70 billion USD by 2020 (IEC, 2013 report). Thus, in 2030, one third of the new electricity generating capacities could be provided by renewable energies, with them generating nearly 3,000 GW (instead of 1,500 GW today).

France, which is investing in these technologies, is already rich in renewable energy resources: it has the fourth largest amount of forest area in Europe, behind Sweden, Finland, and Spain. It also enjoys high hydroelectric, wind, and geothermal potential, making it the second largest producer of renewable energies after Germany. In 2012, the primary production of renewable energies totalled 22.4 Mteo. Energy from wood accounted for 45%, hydroelectric power 22%, biofuels 11% and heat pumps 6%.

In order to remove obstacles to marketing, and in order to guarantee attainment of development targets, certain challenges sometimes remain to be taken up; they can be scientific (involving fundamental sciences on the properties of nanomaterials), technical (to increase the efficiency of the materials from which photovoltaic panels are made for solar energy, for example), or indeed economic and organisational for having industrial processes that are stable and low-cost, such as for nanomaterial-based coatings and coverings.

Prospective analysis

Be they in the form of powders, composites, or nanostructured films, nanomaterials have a multitude of applications to the energy industry. Their future development will depend, in particular, on changes in energy demand and on changes in the industrial sectors. On these two levels, international scenarios have been developed. They outline roadmaps that it is interesting to combine. Regarding energies in France, the *Débat*

National sur la Transition Énergétique (National Debate on Energy Transition) has led to four paths (families of scenarios) relating to energy consumption, in relation to the 2013 edition of the World Energy Outlook (WEO) Report by the International Energy Agency (IEA). They justify the French action programme and its targets for 2035 and 2050. As regards nanomaterials applied to energy, international prospective analysis exercises have also been conducted specifically (cf. IEC and BBC reports). They describe futures or "horizons" at dates ranging from 2012 to 2030, such horizons being foreseeable, probable, and likely for the influence of nanotechnologies in the sectors of solar energy and of energy storage.

While, at demographic level, the world's population is growing and while 20% of that population still has only limited access to energy, the development of the energy market should benefit nanotechnologies. The levers for such development will be firstly social and economic, relating to social demand for clean energies and sustainable development, in conjunction with the available natural energy resources (oil, gas, water, etc.) and with the market prices. They will also be technical, given the length of the technological cycle and of the time scale of approximately a few decades for the technologies to reach maturity. Finally, the levers will also be ecological and political, related to potential major climate events and to possible international crises acting on the funding and on the regulation of the markets. All this will thus weigh on the time required to make available high-performance applications that are produced industrially in a standardisation context that is not particularly clear.

Hypotheses

Hypothesis 1

In line with the current situation, the development of nanotechnologies for energy takes place in all segments of the energy market: photovoltaic solar energy, batteries and electricity generators, hydrogen reservoirs, refining of petroleum products, production of ethanol, additives, etc. This gradual development is slow and, although it is of potential benefit to all technologies, development of those technologies is governed by fluctuations in the markets and in the policies. This situation is illustrated by the case of the photovoltaic sector which enjoyed major public subsidies that were then limited and became less advantageous for private individuals, resulting in a movement of enterprise creation followed by enterprises being wound up or merging in the sector, pending other profit opportunities and other public markets… Although public grants serve as temporary accelerators of technologies, development is nonetheless erratic.

Hypothesis 2

The development of nanotechnologies for energy is limited to certain energy markets depending on national policies that are not necessarily very coordinated and that structure the regulatory contexts. The future superiority of the renewable energy sectors in economic terms and in employment terms is demonstrated, and thus accelerates the decline of the fossil energy sectors. On this basis, preference is given to applications in photovoltaic solar energy and in energy storage. Conversely, enzymes for producing ethanol are neglected given the limitation of agro-fuels for ecological reasons. The applications for oil refining or for oil additives are limited to a few simple products having high cost-benefit ratios.

Hypothesis 3

The occurrence of a climate crisis or of an international conflict reinforce the issue of energy restraint and of energy independence in France. Nuclear power retains its rank as priority sector both due to its safety and due to its production capacity, but procurement for it is threatened or complicated. The need to have local procurement sources available and to reduce energy spending leads to an accelerated development in nanotechnology applications in all fields (fossil and renewable energies, energy savings, etc.) depending on authorised international co-operations. Energy storage thus becomes a key development sector; developments are preconditioned by access to certain rare raw materials.

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The environment

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Definition

The Environment sector as presented herein corresponds to eco-activities involving green jobs. This covers the activities that produce goods and services whose purpose is to protect the environment or to manage natural resources[1].

According to the currently applicable definitions (international definition by OECD and Eurostat), environmental protection aims to prevent and reduce pollution and other degradation of the environment. It includes: protection of the air; management of wastewater, of waste, and of radioactive waste; rehabilitation of soil and of water; combating of sound pollution; and protection of biodiversity and of landscapes. Management of natural resources aims to reduce the tapping of natural resources: in addition to keeping energy consumption under control, and to recovering and sustainably managing water, it includes, *a priori,* developing renewable energies. However, this sector of activity is also sometimes associated with the energy sector. This is what has been chosen in this work, with, for example, the application of nanotechnologies to solar electricity generation being incorporated into the datasheet on the Energy market.

To sum up, the environment market concerns goods and services designed to measure, prevent, limit, or correct environmental damage to water, air, and soil, as well as problems related to waste, noise, and ecosystems. These eco-activities constitute the core activities of the green economy, which is a growing economy both in France and in the world. In France, in 2012, jobs (in Full-Time Equivalent (FTE) terms) in the green economy were up by +4% compared to 2004; they were more dynamic than the economy as a whole (+0.3%). Estimated at nearly 500,000 in 2011, they account for

[1] This datasheet does not consider the environmental impacts of nanomaterials in terms of consequences of the development of nanotechnologies for the environment (consumption of natural resources and discharges and emissions related to producing nanomaterials). It would seem, for example, that the environmental balance of certain nanomaterials is particularly questionable (e.g. carbon nanotubes, manufacture of which requires particularly high water and energy consumption). Similarly, bio-accumulation or persistence of nanomaterials in the environment, with them being difficult to detect and present in the food chain, is an eventuality that is arousing much discussion among insurers (International Risk Governance Council, IRGC, 2011).

about 2% of total employment[2]. Among those activities, waste management (84,900), wastewater management (69,800), and renewable energies (68,700) accounted for one half of environmental jobs in France (*Commissariat général au développement durable* (General Commission for Sustainable Development), *Observatoire national des emplois et métiers de l'économie verte* (National Observatory of Jobs and Trades in the Green Economy). *Le marché de l'emploi de l'économie verte* (The green economy job market), *Études et Documents* (Studies and Documents), No. 110, August 2014).

Retrospective analysis

Applications of nanotechnologies to the environment

The increasing cost of natural resources and of energy, combined with a growing environmental awareness, is driving marketing of new products and processes that bear promises for climate and environment protection. Indeed, it was in this field that, historically, the hopes for nanomaterials were initially placed. In France, as regards nanotechnologies, environmental engineering is beginning to roll out techniques, mainly nanofiltration for water treatment, catalysis for remediation of pollution, and use of nanosensors for detecting pollutants (*Le déploiement industriel des nanotechnologies et de la biologie de synthèse sur les territories* (Industrial deployment of nanotechnologies and of synthetic biology across the country), *Rapport* (Report), December 2013).

More generally in matters of the environment, the use of nanomaterials is being considered for reducing emissions of pollutants, treating effluent, in particular by photocatalysis, and purifying gas, sequestrating greenhouse gas, producing ultra-pure water from seawater, making better use of, recovering, and improving recycling of existing resources, real-time specific chemical and multi-substance analysers (e.g. for detecting and neutralising micro-organisms and pesticides), etc. These applications are sometimes grouped together under the term “ecotechnologies" or “green nanotechnologies”. Nanomaterials could be developed, in particular in the form of non-functional organic membranes, catalysers, filters, nanoporous ceramics, and aerogels.

The emblematic examples of the use of nanomaterials for the environment concern depollution of soils and of water, and capture of CO_2. For depollution, iron nanoparticles can be injected into contaminated sites or groundwater: on the basis of a redox (oxidation-reduction) reaction that makes them rust, the metal particles can reduce the organic and inorganic compounds. These nanoscale iron particles are from 10 times to 1000 times more reactive than conventional metal powder. Treated in this way, pollutants such as chromium (VI) find themselves in less toxic (chromium (III)) and precipitated forms. Iron nanoparticles can also be used to remove pollutants such as arsenic, which is

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[2] These jobs that are directly for environmental purposes can appear limited, the green economy in the sense of activities related to the environment would appear to concern in all nearly four million people in jobs (C*ommissariat général au développement durable* (General Commission for Sustainable Development), *Comprendre l'emploi dans l'économie verte par l'analyse des metiers* (Understanding employment in the green economy by analysing the trades), *Le point sur* (Focus on) No. 188, June 2014).

present in drinking water in numerous countries: arsenic can be captured by nano iron oxides that are magnetic and that can be isolated, then making it possible to recycle these components.

For capturing CO_2, i.e. for Carbon Capture and (geological) Storage (CCS), the processes consist in trapping the molecules of CO_2 before, during, or after the combustion stage so as to prevent them from being released into the atmosphere. Capture before combustion is known as "pre-combustion capture", capture after conventional combustion (in air) is called "post-combustion capture", and capture after combustion in pure oxygen is known as "oxy-fuel combustion capture". Nanomaterials are particularly suitable for post-combustion capture in existing facilities. While this capture is currently mainly performed by cooling and chemical reaction on solvents, capture by membrane separation uses the properties of the nanomaterials: the process involves physically separating the CO_2 from the other components of fumes by means of a selective porous membrane. The CO_2 extracted is, in any event, in gas or liquid form. The plan is then to store it in underground geological formations, enabling it to be sequestrated over the long term, at least for several centuries.

Desalination of seawater is also a key challenge in the arid zones of the planet. There is already a technology that is simple to implement, and that is known as "reverse osmosis". The principle used is filtration based on porous membranes that currently suffer from the problem of requiring very high pressures and thus of consuming enormous amounts of energy. The challenge for nanomaterials is to enable water to be purified with membranes that are less thick than the ones used today and that therefore need less energy. Graphene, a strong material, in the form of a layer whose thickness – the thickness of one carbon atom – is one thousand times finer than the thickness of existing membranes, appears to be capable of taking up the combined challenge of achieving both development and also improved energy efficiency.

Numerous nanomaterials could be used for environmental applications. We might mention the following:

- silver, titanium dioxide, iron oxide, palladium, carbon nanotubes, and amphiphilic polyurethane as agents for depolluting water and soil due to their properties of degradation and absorption of contaminants such as arsenic, pesticides, polynuclear aromatic hydrocarbons, etc.;
- gold for detecting mercury;
- graphene, silver, titanium dioxide, aluminium dioxide, zirconium dioxide, aquaporin and polymer nanofilaments used in filtration membranes for filtering liquids and gases;
- cerium dioxide, gold, and iron oxide as additives to diesel or as components of catalytic exhausts due to their functionality as combustion or oxidation catalysts serving automobile depollution;
- quantum dots and fullerenes as sensors and components of measurement or monitoring tools, because of their luminescence properties;
- etc.

Dissemination of applications of nanomaterials in the environment sector

The sector of eco-industries is ranked among the sectors that use nanomaterials least in France, with only 5 or 6 user companies having been identified in the sector in the DGCIS (French Directorate-General for Competitiveness, Industry, and Services) survey of 2011. It is true that eco-industries are among the user sectors in which the level of maturity of the marketed products that incorporate nanomaterials is the lowest. Unlike the sectors that incorporate "conventional" nanomaterials, they propose a range of new nanomaterials for products or services that are innovative but whose development potential is currently being studied. In these sectors in which the products are currently at the test stage or at the pre-industrialisation stage, obstacles remain to be overcome that are related to scientific recognition and to industrial feasibility or profitability.

However, in this sector, France has high-calibre companies who are international leaders in the fields of water or of waste, and they are capable of making use of the potential of nanotechnologies. Of the 140 major applications of nanobiotechnologies identified in France by the NanoThinking Report (2013), 11%, i.e. about fifteen, concerned the environment.

The environment has the advantage of being a major political issue, in particular in France. Therefore, it is important to consider the national policies. For instance, in the summer of 2014, the French Ecology Minister presented a bill on energy transition for green growth. That bill is for a major law of the current government's five-year term, setting precise targets and putting tools in place for lowering the amount France spends on energy, and for combating climate warming.

Among the goals is a reduction in greenhouse gas emissions by 40% from 1990 to 2030, and a reduction by a factor of 4 (75%) by 2050. French greenhouse gas emissions are monitored under the Kyoto Protocol. The signatory countries of the United Nations Framework Convention on Climate Change have set themselves the goal of containing the rise in temperatures to within 2°C compared with the pre-industrial era. To achieve that target, the global emissions must be reduced by half by 2050, relative to 1990 emissions. In this context, according to the French Ministry for Ecology, Sustainable Development, and Energy, reducing the risks related to climate change requires actions in two complementary fields: firstly it requires efforts to reduce greenhouse gas emissions produced by human activities, and secondly it requires adaptation to climate change. Those two fields are the subjects of international, regional, and national policies, making it possible to reduce emissions and to prepare as well as possible for the climate of tomorrow.

In 2015, Paris is to host the next world conference on climate change, in the absence of an international environment agency. However, will does seem currently to exist to find an agreement on a European framework for energy and climate for the horizon of 2030.

A key element of the European climate policy is to continue the trading system for CO_2 emissions allowances, known as EU ETS (European Union Emissions Trading Scheme), put in place in 2005 on the same principle as the international market under the Kyoto Protocol. Since 2005, the EU ETS has been limiting emissions from about 11,400 industrial facilities, responsible for nearly 50% of the CO_2 emissions of the European Union. Those industrial facilities have to surrender, every year, as many allowances (1 allowance = 1 metric ton (tonne) of CO_2) as their verified tonnes of emissions for the previous year. Since 2008, they have been authorised to use a quantity of Kyoto credits (Certified Emission Reductions (CERs) or Emission Reduction Units (ERUs)) limited to 13.5% of their allowances on average. Initially, the EU ETS covered CO_2 emissions only. Since 2013, N_2O and SF_6 emissions from the chemicals and aluminium production sectors have also been covered. The energy sector (electricity and heat production, refining, and coking plants) is the main sector of the EU ETS. Energy producers alone have received about 50% of the total allowances. The greenhouse gas market may be considered as a lever for direct applications of nanotechnologies in the field.

On the international stage, France sees itself as a major financial backer for helping developing countries to reduce their emissions and to adapt to the impacts of climate change. It thus supports its own industries to do likewise. From an economic point of view, in 2012, output in the sector of eco-activities reached 85 billion euros, i.e. 2.3% of the value of total output. The amount of the added value totals 32 billion euros, and the amount of exports has reached 9.1 billion euros, i.e. 2.1% of total exports. Exports in eco-activities increased by 0.6% from 2011 to 2012. The balance of trade in eco-activities showed a surplus of 3.2 billion euros, i.e. a sharp increase compared to 2011 (1.2 billion euros) following a large drop in imports (*Les éco-activités et l'emploi environnemental en 2012: premiers résultats* (Eco-activities and environmental employment in 2012: initial findings), *Chiffres & statistiques* (Figures & Statistics) No. 523, May 2014).

Prospective analysis

Numerous developments of nanomaterials are expected for the future in order to take up the environmental challenges. They need to be in tune with the changes in demand and in production that are emerging in the sector. In the course of the *Débat National sur la Transition Énergétique* (National Debate on Energy Transition) four paths or trajectories (families of scenarios) were studied in order to predict energy consumption and pollutant emissions and in order to underpin French policy. Those scenarios were discussed again in 2014 in relation to the 2013 edition of the World Energy Outlook (WEO) Report by the International Energy Agency (IEA). In over 500 pages, that annual report presents various scenarios for energy policies up to 2035, making it possible to analyse the major energy changes in progress or to come, and the issues and the limits for combating climate change.

The WEO is a reference document for analysing the energy trends and the impacts of the policies conducted. It compares the central "New Policies" scenario, which takes account of the commitments and pledges made to reduce greenhouse gas emissions, in particular pursuant to the Cancun Agreements, with the "Current Policies" scenario, which describes how the world energy markets are changing based on the implementation of the policies and measures that had been enacted by mid-2013. The WEO develops a third scenario, known as the "450 ppm" or "450" scenario, proposing a change in the world energy system enabling the greenhouse gas concentration in the atmosphere to be stabilised at or limited to 450 parts per million by reducing the emissions of CO_2 due to energy combustion in order to limit global warming to 2°C (compared with the pre-industrial era).

The WEO restates, as in the previous years, that the current pathway or trajectory for greenhouse gas emissions is not consistent with the climate target of +2°C: the central "New Policies" scenario is taking us on a trajectory leading to a long-term temperature rise of at least 3.6°C.

The IEA updates its scenarios every year and sheds light on various determinants of the global energy system. Thus, in 2013, the IEA emphasised the new energy world that is tending to emerge, characterised by new production and consumption zones, and by new resources. However certain key trends persist, in particular the predominance of fossil energies, and the regional disparities in gas and electricity prices. These disparities have led the WEO 2013 to raise the question of the link between energy and economic competitiveness, and to conclude that energy efficiency is a major lever for action.

The energy transition levers consist, in particular, in keeping energy demand under control, in increasing carbon prices to an incentive level, and in mobilising public and private banks for creating specific funding circuits (IEA-IFRI (French Institute for International Relations) conference, 5 March 2014). Development of patents relating to applications of nanotechnologies to the environment, dissemination of such applications, and improvement of the efficiencies of the technologies and of the operating costs all depend on this national and international context on climate and sustainable development.

Thus, the uncertainties about the future changes in the variable can be outlined:

- improvement in the efficiencies and in the costs of these technologies with high-performance and industrially produced applications being made available;
- available natural energy resources (oil, gas, water, etc.) and market prices;
- major climate events;
- international crises weighing on the funding and on the regulations of the markets;
- knowledge of risks related to releasing nanostructures into the environment;
- control of markets (water, etc.) by private groups having command of the technologies and limiting access to markets to certain populations due to the prices;
- stabilisation of the regulatory context relating to the environmental applications of nanotechnologies.

Hypotheses

Hypothesis 1

Applications of nanomaterials develop erratically due to difficulties with global governance and with international co-ordination. Certain markets develop but in slow and limited manner depending on the supporting policies and/or on the local environmental risks (e.g. purification or filtration of groundwater, acceptance of locations of geological storage of CO_2, etc.). This context is conducive to periods during which progress is stimulated followed by periods during which progress is checked, as experienced in the photovoltaic sector with the discontinuation of national subsidies, with companies failing and merging on that market. This situation could repeat itself with CO_2 capture if the European Union Emissions Trading Scheme (EU ETS) does not manage to attract sufficient investment in low-carbon technologies, the risk being that this leads to new national policies being adopted that call into question the conditions for fair competition that this system was supposed to create.

Hypothesis 2

Certain applications develop rapidly, taking advantage of international political co-ordination. Opening up of markets controlled by private investors encourages massive investment for certain applications of nanotechnologies (depollution, desalination, etc.), but, at the same time, limits access to such technologies to certain populations or countries, fuelling tensions over resources. For example, the problem of access to water cannot be solved by technological development alone, without appropriate political and economic regulations.

Hypothesis 3

The environment sector develops in accelerated manner because it becomes a priority due to a climate crisis and/or to international conflict. The will of countries to be nationally independent accelerates the mobilisation of the local players, but without benefiting from all of the possibilities of international scientific co-operation.

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Textiles

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Definition

The textile industry covers the activities of design, manufacture, and marketing of textiles: making artificial or synthetic textile fibres, spinning, making ropes, twine and netting, weaving, finishing, manufacturing finished products, and distribution. According to the *Union des Industries Textiles* (the French Textile Industry Association), in France this sector accounts for 2,300 businesses, which are often of small size (average size: 40 employees), and employs over 65,000 salaried workers. The textile industry experienced very considerable internationalisation during the XIXth and XXth Centuries, with the rise of developing countries, in particular China. In spite of this competition, the French textile industry remains dynamic in the segments of technical textiles and luxury textiles.

Clothes and upholstery account for the largest and most well-known share of textile products. Beyond these traditional sectors, there are also technical textiles that have multiple applications and that are used in almost all industrial sectors: from the automobile industry to the medical sector, including civil engineering and the building trade, electronics and the aircraft industry, etc. A "technical textile" can be defined as any textile product or material whose technical performance and functional properties prevail over aesthetic or decorative characteristics.

"Smart textiles", also known as "electronic textiles" or "e-textiles", are capable of picking up or of analysing a signal in order to respond to it appropriately. They can be produced by incorporating detectors, electrical power supplies, or electronic components into and onto the textiles, but also by adding smart materials and fibres to the textiles so as to offer a response to a stimulus or to an excitation coming from the outside (temperature, or mechanical stress, for example).

France is a major consumer of technical textiles for the transport sector (42% of consumption in 2005). The industry sector is ranked second in terms of consumption, followed by the sports and leisure sector. The French companies who are specialised in technical textiles are spread mainly across 5 sectors: industry, transport, medical, sports & leisure, and home furnishings.

Global consumption of technical textiles has been growing continuously since 1995. In 2005, it was estimated at 19.7 million tonnes, including 4.8 million tonnes in Europe. Euratex (2003 data) gives the following estimates for France:

- turnover for the technical textiles sector: 4 billion euros;
- share of technical textiles in the textile industry: 17%;
- number of technical textiles companies:300;
- number of companies exclusively dedicated to technical textiles: 120;
- number of employees: 20,000.

The development of technical textiles is based on research work on materials (development of new generations of fibres), implementing the fibres (development of new processes), treatment of textiles (optimisation of the chemical treatment or development of new technologies), and addition of new features and functions. In this sector, as in many others, nanotechnologies are opening up new prospects.

Relevant indicators

- Number of patents for this use.
- Number of products identified for this sector (Wilson Center database).
- Quantity of substances in the nanoparticulate state declared in R-Nano database (for use in textiles).

Retrospective analysis

Production of multi-function textiles constitutes a promising application for nanotechnologies. Nanomaterials can be incorporated into the textile in two different manners during the production process:

- either integrated into the thread prior to extrusion (nanocomposites);
- or added to textile coatings and coverings (coating, or nanofinishing).

Depending on the developments in nanoelectronics, nanomaterials can be included in the electronic components that are incorporated into smart textiles.

The literature describes numerous properties that can be imparted or improved by using nanomaterials: mechanical strength, reduction in shrinkage, fire or flame resistant or retardant capacity, UV stability, electrical conductivity, anti-soiling properties, antistatic behaviour, anti-microbial properties, greater resistance to traction, better resistance to ageing, etc.

The nanomaterials selected for these applications are essentially nanoclays, metal oxides (titanium dioxide, alumina, synthetic amorphous silica, zinc oxide, and magnesium oxide), and nano-silver. Great hopes are being put in carbon nanotubes due to their robustness and their electrical conductivity, but technical difficulties and their cost appear to be holding up their development.

Here are a few examples of potential applications of nanotechnologies to the textile industry:

- treating wool with silver nanoparticles having bactericidal properties for carpets and rugs, upholstery for public transport, socks, sports clothing; treatment with gold nanoparticles has also been proposed, but only for luxury articles in view of the price;
- antibacterial coating (zinc oxide) for textiles used in the medical sector;
- coating improving resistance to UV radiation for sports clothing or for textiles used in construction (tarpaulins, for example);
- improvement of the resistance to heat of protective clothing for fire fighters (e.g. by inserting an inner composite layer based on aramid fibre and on carbon nanoparticles);
- organic nanofibres having piezoelectric properties enabling clothing to generate electricity for pocket electronic equipment through movements of the body;
- incorporating chips and sensors into clothing in order to monitor the state of health of the person wearing it, or the external risks.

In view of the attractiveness of these applications, it is expected that the use of nanomaterials in textile products will enjoy major growth in the coming years. Currently, little information exists on the products that are already marketed:

- the Hohenstein Institute (the renowned textile research and testing institute) has begun developing a quality label (the Hohenstein Quality Label) in order to prevent the term “nanotextile” from being used in situations that are not directly related to the use of nanotechnologies. In September 2009, four textile products had been awarded that label;
- an inventory taken from 2009 to 2012 over the Internet by the European Consumers’ Organisation (BEUC) and the European Consumer Voice in Standardisation (ANEC) identified 21 products (or ranges of products) containing nano-silver: essentially clothes, underclothes, or household linen;
- in the database of the Woodrow Wilson International Center for Scholars in the United States, consulted early in 2014 (www.nanotechproject.org/cpi), 156 products are identified in the Clothing category. Most of those products are presented as having water-repellent, anti-soiling, anti-odour, or antibacterial (nano-silver);
- in the first assessment, established at the end of 2013, of the declarations of substances in the nanoparticulate state (R-nano database), use in Manufacturing

textiles, leather, and fur is mentioned for 11 substances, including synthetic amorphous silica, titanium dioxide, and carbon black (but not nano-silver).

Those databases are not exhaustive and they do not make it possible to have a clear vision of the reality of the development of nanomaterials for use in the textile sector. However, they do show that use of nanomaterials is still at an early stage.

Prospective analysis

It is firstly the innovation and research capacity of the textile industry that should determine the progress of nanotechnologies in this sector. The most dynamic fields in terms of research and development are the medical sector, the transport sector, and, to a lesser extent, civil engineering and personal protection. However, before production and marketing can take place on an industrial scale, certain obstacles need to be overcome:

- the many scientific and technological obstacles; for example, the difficulty of uniformly dispersing nanomaterials in coating pastes and polymers, or of manufacturing products that are durable and that offer long-term strength;
- the global issues of environment protection (recyclability, and biodegradability of the products) and of reduction in energy consumption;
- cost-benefit performance; even though use of nanomaterials improves the products, they often remain too costly;
- industrial feasibility: going from the laboratory scale to the industrial scale;
- consumer habits: consumers may, for example, prefer to continue to wash their clothes regularly in the conventional manner, rather than trusting a new anti-soiling technology.
- the regulatory and societal environment, in particular consumer acceptability of products incorporating nanomaterials.

A study on the maturity of applications of nanomaterials to the textile industry that was published in 2007 did not foresee any real penetration of nanotechnologies in this sector until beyond the 2015 to 2020 period.

Hypotheses

Hypothesis 1. Some innovations and marginal use

The research laboratories seek to develop new processes, but the innovations they propose remain limited or do not offer sufficient added value to go on to the industrialisation stage. Use of nanomaterials in textiles remains marginal at global level.

Hypothesis 2. Intensive development in France in technical textiles

The French textile industry seeks to reinforce its competitiveness by specialising in emerging high-technology activities. Major investment is devoted to nanotechnologies, with the main results being in the field of technical textiles.

Hypothesis 3. Development in technical textiles, but not in France

The French textile industry limits its investments and this sector of activity declines. However, technological progress takes place in other parts of the world and numerous textile products incorporating nanomaterials are imported and come onto the European market with multiple applications.

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Transport

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Definition

Transport designates movement of objects, goods, humans, or animals from one place to another. A distinction is generally made between three modes of transport:

- land transport (road and rail);
- water transport (sea and inland-waterway);
- air and space transport.

The sector of transport and logistics (all of the services for managing flows of goods and materials) is one of the main sectors of the global economy. In France alone, it employs over one million people. The growth in international trade is putting this sector at the very top of the rankings.

This market variables datasheet addresses more particularly current and future applications for nanomaterials in the boat-building, shipbuilding, automotive, and aerospace sectors.

Retrospective analysis

According to a report dating from 2012 by the *Direction Générale de la Compétitivité de l'Industrie et des Services* (DGCIS, French Directorate-General for Competitiveness, Industry, and Services) of the *Ministère de l'Économie, des Finances et de l'Industrie* (MINEFI, French Ministry for the Economy, Finance, and Industry), the transport market is one of the markets for nanotechnology applications that is the most buoyant and competitive for France, together with building & civil engineering, healthcare, luxury goods, and defence. The number of companies in the transport sector apparently accounts for 15% of the total number of nanomaterial user companies. This is partly due to the use of products that incorporate "conventional" or "historic" nanomaterials.

Boat-building and shipbuilding sectors

France is open to four sea areas, representing 10% of the European coastline (7,000 km). These areas, conducive to yachting and boating activities, are the playground for 4 million yachting and boating enthusiasts, with over 500,000 craft in service in 2012.

The yachting and boating sector, within which a distinction can be made between boats for the general public and activities specifically related to ocean racing (boats for sports use), accounts for about 5,000 companies and over 41,000 employees; it is structured depending on the various segments of activities. The segment of boat-building proper represents 25% of the 4.5 billion euros of turnover of the entire sector (2012 figures); it is on a par with trading & brokerage. Then come the repair segment (15%), the equipment market (15%), motors & engines, marinas & harbours, and chartering & hire (10%). The sector is built essentially on SMEs (Small and Medium-sized Enterprises) and VSEs (Very Small Enterprises), since about 75% of the companies employ fewer than 20 people.

In 2011, the French boat-building output was produced by 223 boatyards employing a total number of staff of nearly 8,000. With an export rate for 2011/2012 of nearly 68% (multiplied by 4 in 10 years), the French boat-building industry is one of the sectors in which France is among the leaders: Ranked 5th in the global recreational boat building industry in 2010 (3rd in Europe behind Italy and Germany); ranked 1st on the sailing yacht market (with 29% of the market); leader in inflatable boat building; and ranked 4th in motor boat production. Although the financial crisis has had an impact on the sector, exports were not affected very much, thanks to the emerging markets that kept the sector going. In 2011/2012, after having withstood the crisis well compared with its European neighbours, the French market suffered a marked downturn, despite sustained interest from French clients who have continued to turn out in large numbers at the major yachting and boating events in France, be they sporting or business events.

The boat-building or yachting & boating sector should be distinguished from the shipbuilding sector that can be subdivided into two sections: firstly the section of building, equipping, repairing, and refitting or converting ships, serving what the French call the “five navies” (defence, merchant, fishing, recreational, and research), and secondly the section that covers the activities of building specific vessels designed for developing offshore extraction and exploitation activities.

Structured around major decision-takers (seven main groups structure the sector), the shipbuilding sector is underpinned by a network of equipment manufacturers and of subcontractors who are small in size. It constitutes a full industrial chain covering all of the trades necessary for building the most complex civilian and military ships. The building, equipping, repairing, and refitting or converting section of the French shipbuilding industry is ranked 6th in the world and 2nd in Europe on the global civil and military market. In 2012, France had 69 shipyards, 9 of which employed staffs of over 100 people. The success of France in this sector is due to its industrial stakeholders continuously repositioning to focus on ships that are highly complex, requiring multiple skills, cutting-edge technology development, and use of numerous suppliers for the components and sub-systems. This enables it to remain a high-export activity: 50% of what was on the order books in France in 2010 was for export; 80% of the French output of civilian ships was exported. This development has been made possible, in particular, by the capacities for innovation (a field in which the French shipbuilding industry is at the cutting edge).

Although these two sectors of shipbuilding and boat-building (yachting & boating) are, in theory, distinct, it transpires that, for certain types of market, skill in both is an asset or indeed a necessity. This applies to building and repairing or refitting large pleasure vessels for which the hull skills are more shipbuilding skills while the fittings and equipment skills are related more to the field of boat-building for yachting and boating.

Currently, there is no clear information about the actual use of nanomaterials in the boat-building and ship-building industries. However, alongside issues of eco-design, emissions reduction, energy efficiency, on-board electronics, and appropriate design tools, nanomaterials are currently considered as differentiating factors, e.g. in the following fields:

- high-performance and large-size composite parts. For example, incorporating carbon nanotubes into resins procures very significant improvements (200% to 300% compared with conventional composites) in fracture toughness, without increasing the weights of the manufactured parts;
- materials based on nanofibres or surface treatments offering super-hydrophobic properties. These coating technologies aim to produce surfaces that have very low friction, thereby making them super-slippery;
- antifouling. Made up of marine organisms, bacteria, and seaweed, biofouling covers the immersed portion of the hull and, within a few months, reinforces the resistance through the water and the weight of a boat or ship, thereby giving rise to increased fuel consumption. A recent European project has shown that a coating based on vanadium pentoxide inhibited the formation of biofouling. In addition to be effective, this type of coating (in the form of paint) would make it possible to limit the use of biocides, which is currently the only really effective solution.

Automobile sector

The automobile industry covers manufacture of motor vehicles and manufacture of various supplies for such vehicles. In terms of employment, the French vehicle manufacturing branch employed 215,000 people directly in 2012 (excluding temporary workers, who can account for up to 10% of the staffing requirements), i.e. 7% of the salaried employment for industry as a whole.

According to the figures published by the *Fédération des industries d'équipements pour véhicules* (FIEV, French Federation of vehicle equipment industries), the automobile suppliers industry employed nearly 240,000 people in 2012, of whom one third worked for equipment manufacturers, 27% worked in mechanical engineering, 14% in tyres and rubber, 10% in plastics, and 8% in electronics. In France, equipment manufacturers are located on 375 sites, the size of which varies from the multinational group to the SME specialised in a particular industrial process. 70% of the French output from automobile equipment manufacturers feeds the production sites of the automobile makers, in France or elsewhere.

Also in 2012, while the global output of light vehicles from French automobile makers totalled 5.6 million, a little less than 30% were produced by French automobile makers in France. Compared with the level prior to the financial crisis of 2008, the output from

French vehicle manufacturers has fallen by 9% in a global economic context marked, since then, by continued high growth in the emerging countries. While, for a long time, it was the second largest producer in Europe, behind Germany, France, the land of automobile production, is now third behind Spain.

In order to withstand recessions, the French automobile sector has become structured. Thus, in October 2012, a sector contract was signed, one of the four focuses on which it has been decided to work is innovation and R&D. Through automobile competitive clusters, cross-cutting actions are being conducted to take up the challenges of industrial excellence and of sustainable mobility; they involve vehicle manufacturers, equipment manufacturers, innovative SMEs, research laboratories, and training bodies.

Innovation is at the core of the development strategies of equipment manufacturers, who devote an average of 6% of their turnover to Research & Development for systems making it possible to improve passenger safety and comfort, and preservation of the environment.

An automobile is a product that has to satisfy numerous regulations mainly relating to safety upon impacts in various configurations, to the environment regarding pollution by exhaust gases and greenhouse gases (CO_2), to noise emissions, and to "recyclability" of end-of-life vehicles (recovering/reclaiming, converting, or recycling/reusing component materials).

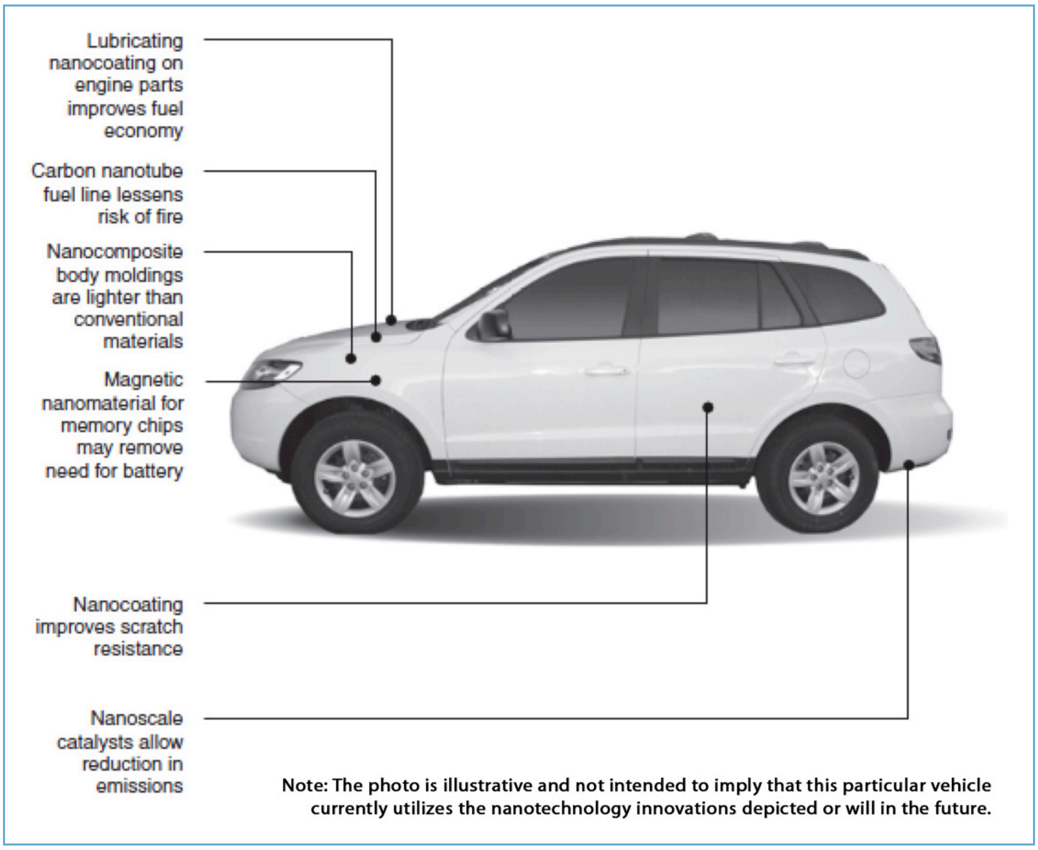

Figure 1. Example of current and future innovations.
Source: Adapted by GAO from materials produced by Lux Research, GAO Report, 2010.

In order to satisfy these various requirements, and as shown in Figure I, the automobile sector has, for several years now, been investing in nanomaterials so as to develop, for example:

- composite materials that are lighter in weight but that are ever stronger for the structures of the vehicles;
- materials having improved fire/flame resistant/retardant properties for the interior parts;
- materials limiting the accumulation of electrostatic loads;
- textiles having antibacterial, antimicrobial, and anti-odour properties;
- catalysts, additives for fuels, lubricants, and coolants making it possible to improve engine efficiency and fuel consumption;
- coatings for glazing that improves vision comfort, or for increasing the wear resistance of heavily used parts (actuators, distributors, etc.).
- paints that are more scratch-resistant and corrosion-resistant;
- high-performance tyres combining grip, wear resistance, and low rolling resistance;
- energy storage devices (batteries, supercapacitors, and fuel cells);
- devices capable of adapting shock-absorber force continuously, based on magneto-rheological fluids;
- electrical and electronic components.

In the future, nanomaterials could contribute to making even more significant improvements to the performance of existing technologies and materials for motor vehicles. By way of example, automobile manufacturers are already working on:

- designing structural batteries having high capacities, based on using nanomaterials, and in which the outer panels forming the bodywork of the vehicle act as storage cells. If this structural battery concept is developed to its maximum, such batteries should be able to replace the batteries of the electric cars of the future;
- implementing nano-structured polycarbonate or acrylic parts for all the glazing of a vehicle. 50% lighter than glass, these new glazing products combine strength and transparency, regardless of temperature, and facilitate complex design shapes;
- designing thermoelectric devices making it possible to use heat losses inherent to engines and to convert them into electrical energy.

Aerospace sector

The aerospace sector covers the industries from the aviation and the space sectors, and also the arms industry[1]. Technologically and industrially, the aviation, space, and military industries are very similar.

[1] The latter sector is the subject of a specific datasheet and is therefore not addressed here.

The aerospace sector is driven by various types of demand: demand from states (key sector), from people (travel), from companies (goods transport), or from organisations of all types who work in space exploration.

To satisfy those types of demand, aircraft manufacture is structured around three trades, namely:

- manufacturers of aircraft (aeroplanes and helicopters);
- manufacturers of structures (fuselages, wings, jet engine pods) and of engines;
- equipment manufacturers who manufacture the subassemblies constituted by undercarriages, rudders, electronic flight systems, seats, evacuation slides, etc.

These three trades are performed by more than 260 companies in France, and, in addition, there are several thousand companies (about 4,500 SMEs) who are suppliers to the aerospace industry.

The leading French export sector (75% of turnover is for exports), the aerospace industry generated, in 2012, 170,000 jobs (and over 310,000 jobs with subcontractors) for a turnover of 42.5 billion euros. This industry, which looks out onto the world, has strong roots located mainly in the regions of Midi-Pyrénées, Aquitaine, and Île-de-France (Paris Region).

The aerospace industry has undergone major transformations over the last thirty years. Since 2000, the European Aeronautic Defence and Space Company (EADS) has taken over the activities of several manufacturers (the French company Aérospatiale-Matra, the German company DASA, and the Spanish company CASA). The group is today the world leader in the aviation, space, and defence sectors.

In the helicopters segment, Eurocopter, born out of a Franco-German merger, is the world's leading manufacturer of civilian helicopters.

With Astrium, EADS is also at the cutting edge in building space launch vehicles (carrier rockets) and telecommunications and Earth observation satellites; Astrium is also one of the main shareholders of Arianespace (the world’s leading satellite launch company).

Currently, we do not have any clear information on the actual use of nanomaterials, be it in the aviation or space branches, even though it is clear that those branches are increasingly seeking:

- composite materials that have ultra high performance in terms of lightness, strength, and longevity, for the structures;
- electronic systems that meet specifications that are ever more stringent as regards reliability, electromagnetic compatibility, immunity to interference, consumed power, and safety;

- propulsion systems making it possible to achieve considerable reductions in propulsive energy consumption and in emissions, as well as in the noise footprints of the aircraft.

The challenges, uses, and opportunities for nanomaterials in the aerospace sector are close to those of the automobile or boat-building sectors, with, however, inherent constraints that require tough specifications as regards reliability, electromagnetic compatibility, immunity to interference, consumed power, and safety.

In the future, nanomaterials should contribute to making air and space transport means lighter and capable of carrying larger payloads while also consuming less energy and polluting less.

Among the technologies that are at various stages of maturity, mention might be made, by way of example, of developing:

- a de-icing system for aircraft wings that is based on non-metallic nanomaterials, also improving lightning protection and increasing fatigue resistance;
- a coating based on super-black carbon nanotubes capable of absorbing nearly 99.96% of light for sensitive systems, such as infrared cameras, Earth observation satellites, or anti-missile detectors;
- nano-sensors for flexible technology;
- wireless communications architectures that are reconfigurable, low-consumption, and highly immune to interference.

Hypotheses

Hypothesis 1. No innovation, *status quo*

Through national and European funding, R&D proposes innovations but, in France, because of the obstacles of industrial feasibility, regulations, and acceptability by the consumer, use of nanomaterials remains marginal. Only the "conventional" or "historic" nanomaterials remain present. However, the boat-building/shipbuilding sector remains competitive due to other innovations and factors. The same applies for the aerospace sector. The French automobile industry stagnates, as do the automobile industries elsewhere.

Hypothesis 2. Innovation and development in certain sectors

Through national and European funding, R&D proposes innovations, the boat-building/shipbuilding sector is mobilised and enriches its know-how: the industry becomes the world leader. The same applies for the aerospace sector. As regards the automobile sector, through lack of investment from the manufacturers, materials engineering still faces numerous challenges, such as, for example, shaping products having elaborate architectures for improved mechanical performance combined with significant reduction in weight. The automobile industry declines in France while manufacturers elsewhere have managed to change course effectively.

Hypothesis 3. Innovation via the suppliers

Due to national and European funding, R&D proposes innovations, and the automobile, aerospace, and boat-building/shipbuilding sectors mobilise their efforts effectively (including in cross-cutting manner) to improve performance and to enrich French know-how. As regards the boat-building/shipbuilding sector, due to ever increasing exports, the French industry becomes the world leader. After several years of falling output, the French automobile industry turns the situation around. Design, integration, and assembly therefore take place in France.

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Electronics

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Definition

Electronic components and systems are currently involved in almost every industrial and commercial activity, and are to be found in numerous objects used in our daily lives. It has become impossible to give an exhaustive list of such activities: communications, computing, traceability (RFID chips), automatic control, robotics, security and safety of property and of people, healthcare, transport, etc.

In 2010, Laurent Malier (in his assignment report to the French Ministry for Industry) considered that France was in a solid industrial position in the field of micro- and nano-electronics, and was capable of seizing "the opportunities for growth in the field of semiconductor components and in the related sectors of application, in particular energy, transport, and healthcare, which are sectors in which the economic and sovereignty challenges are going to become much bigger over the coming decades". Worthwhile reference can be made to that report for its map of the French industrial production sites. The report also considered that, on the whole, the French industrial sites were of a global state-of-the-art calibre in terms of the competitiveness.

The current research & development trend is for miniaturising microelectronic components down to nanoscale sizes while also remaining within the conventional limits of physics: transistors are currently being manufactured using technologies of 32 nm or less. Below that, nanoelectronics will emerge, making it possible to achieve further miniaturisation and to use new physical effects when certain components of electronic systems are of nanometre size. Nanoelectronics represents a major technological and commercial challenge looking forward to the horizon of 2020-2030, i.e. it is a major challenge in research laboratories today.

Relevant indicators and data on changes in the variable

At global level, the turnover from the micro- and nano-electronic sector was about 230 billion euros in 2012 and the value of the products from the sector stands at about 1,600 billion euros (EESC, 2013).

European Union (EU) level is the appropriate coordination level for organising a cross-cutting approach, avoiding duplication of research, mobilising value chains, and commercialising the results of the research in the best conditions. Since this sector is an area crucial to the European economy, micro- and nanoelectronics deserves a genuine common industrial policy benefiting from a critical mass, so as to turn research into marketable products. This will enable Europe to catch up and keep pace with the United States and Asia (EESC, 2013).

According to the European Commission, it is strategic to bring the missing links in the micro- and nano-electronic technologies value chain back into Europe after 10 years of stagnation in the European R&D&I budgets that has prevented the European Union from taking its place on the world market (production has moved massively to Asia). The Commission proposes to develop a new European industrial strategy for electronics and recommends coordinated public and private investment in "advanced technologies". The Commission is thus urging the private sector to step in: the race for markets requires investments that the Member States, in the grip of the crisis and the budget cuts demanded by the EU, are no longer able to provide. Nine main product categories contribute, in particular, to innovation and competitiveness:

1. computers;
2. computer peripherals and office equipment;
3. consumer electronics;
4. server and storage devices;
5. networking equipment;
6. automotive electronics;
7. medical electronics;
8. industrial electronics;
9. military and aerospace electronics.

In the first four product categories, there is only one European company up among the world leaders. There is a greater European presence in the other sectors, but in no sector does Europe have a dominant position (EESC, 2013).

In France, over the last twenty or so years, microelectronics plans have been launched, focussed mainly on the Rhône-Alpes region (Crolles in the *département* of Isère). Since 2003, the "Renatech" Network of large technological facilities for basic technological research, in which CNRS, universities, and CEA Leti have joined forces, has been playing a big part for the benefit of French laboratories in the research fields of micro- and nano-technologies and of nanosciences. The French scientific community, covering a broad range of skills, is in a good position at European level and is heavily involved in the main programmes of the 7th Framework Programme for Research & Development (FP7). Around the major players, namely STMicroelectronics on an industrial level and CEA Leti for "pre-industrial" integration, the research laboratories can take up the challenges of coping with the end of Moore's Law (CNRS, 2011).

The French national strategy for research and innovation (SNRI), which was developed in 2009, identified nanotechnologies and biotechnologies as priorities. The SNRI has served as a guide for defining the funding programmes and the prioritisation of the investments. In July 2013, a vast industrial research & development programme worth 3.5 billion euros and called “Nano2017” was launched for developing nanoelectronics, with the French State contributing 600 million euros to it. That project is being led by STMicroelectronics, the “Leti” Laboratory of the CEA (France's Alternative Energies and Atomic Energy Commission) in Grenoble, and their local partners. The nanoelectronics plan is one of the 34 industrial plans that, in 2013, the French Government decided to implement (http://www.redressement-productif.gouv.fr).

Despite the economic recession, R&D spending in companies in the nanotechnologies sector has been increasing steadily. The analysis conducted by the Information and Statistical Studies Department (SIES) of the French Ministry for Higher Education and Research (MESR) shows that most R&D in nanotechnology in France (about 67%) is focused on manufacturing components, electronic cards, and peripheral equipment (CGEIET, 2014 (report by France’s General Council for the Economy, Industry, Energy, and Technologies)).

Retrospective analysis

The invention of the transistor (1947), and then of the integrated circuit (1958), triggered the electronics innovation of the early 1960s with the advent of integrated circuits using Complementary Metal Oxide Semiconductor (CMOS) technology (the MOS transistor is the basic element of integrated circuits). Since then, applications for microelectronics have been preconditioned by the reduction in the size of the components, enabling them to be integrated to an even greater extent and enabling the power and the scope of the functions to be increased. This preconditioning is even more true today. This reduction in size has been accompanied by a considerable reduction in the unit cost of transistors, and by an increase in their number per unit area in line with the “law” or rather the “conjecture” that Gordon Moore, an engineer at Intel, put forward in 1975: the number of transistors integrated into a chip doubles every 18 months. The applications are extended to all of the main economic sectors: information processing, communications, energy, healthcare, industrial control, transport, defence, the environment, etc.

Progress in the technologies used for manufacturing integrated circuits on silicon has made it possible to produce microelectronic systems integrated into the same chip by using SoC (Silicon-on-Chip) technology, it being possible for such a system to integrate several billion transistors with grid lengths of from 28 nm to 22 nm onto an area of a few square centimetres by using CMOS technology. Currently, these technologies are present in all equipment related to information and communications technology: personal computers, mobile phones, personal digital assistants, GPS navigators, etc.

Organic electronics uses semiconductors based on carbon chemistry. Its applications include Organic Light-Emitting Diodes (OLEDs), Organic Photovoltaic devices (OPVs), Organic Field Effect Transistors (OFETs) and organic sensors. According to IDTechEx, in its report entitled *Organic & Printed Electronics Forecasts, Players & Opportunities 2007-*

2027, "…few other technologies will have such an impact on industry in the next twenty years. Organic electronics in the form of smart packaging, electronic billboards, posters, signage, and electronic books will impact the conventional printing and publishing industry. Organic lighting will severely dent sales of both incandescent and fluorescent lighting". Organic electronics also offers the advantage of being producible by small production units using low-cost production means.

A large part of current research is focused on the operating time between charging and the energy consumption of electronic systems, on their reliability, etc.

Trends for changes in the variable

The EESC (2013) believes that "*micro- and nanoelectronic components and systems can provide the basis for a new industrial revolution. In this context, the system of state aid and (European) subsidies needs to be revised because the issue faced by the EU in high-tech industries is not competition between EU firms, it is rather the absence of globally competitive leader firms in many high-tech sectors. The real weaknesses of Europe are the lack of products and of market presence, and the paucity of global leader companies."*

Prospective analysis

The determinants of future changes in the variable depend for the most part on the availability for application of the current and future nano-electronics research in the following sectors (AENEAS, 2012):

- health, demographic ageing, and well-being: early screening and diagnoses, therapeutic and post-therapeutic monitoring, remote monitoring networks collecting information from body nanosensors, etc. (improving the prognosis of patients, and reducing or stabilising health costs);
- food safety and sustainable agriculture: nanosensors
    - guaranteeing that foodstuffs are comestible, and securing quality, reliability, and traceability for manufacturing operations;
    - enabling plant strains to be developed that withstand diseases and unfavourable climatic conditions;
    - making it possible to check the presence and the degree of biodegradation of pesticides, herbicides, and fertilisers;
- safe, clean, and efficient energy: nanoelectronics will make it possible to reduce energy consumption in many sectors, to make energy distribution smarter (through smart grids) in public and private spaces and in industrial automation, and to reduce the costs of renewable energy sources;
- smart, green, and integrated transport: systems making it possible to control speed automatically, to prevent collisions, to optimise fuel consumption, etc.

- optimisation of resources and action for climate: energy production and energy efficiency; waste recycling and reduction; emission checks and environmental checks;
- information and security & safety: dedicated information systems, control and check systems for personal safety and security, and monitoring and control of domestic environments;
- defence.

Further upstream, it will be necessary to facilitate research into:

- unified tools for modelling, simulating, and designing nano-electronic systems;
- tools for nano-manufacturing, including coping with industrial issues such as reproducibility, process control, and possibilities of co-integration with the existing technologies (CNRS, 2011);
- recycling (or replacing) the strategic metals necessary for manufacturing the systems (European Commission, 2014): rare Earths, platinum, gallium, indium, etc. It should be noted that, in France, the Ministry for Industry set up a Committee for Strategic Metals (COMES) by a Decree dated 24 January 2011. That committee for analysis and dialogue on strategic metals brings together representatives of various ministries and of the relevant public establishments, of the industry associations and of certain companies related to the mining sector.

It is also important not to forget the research on the impact of nanotechnologies in society: social, ethical, legal, and economic repercussions on employment, on the environment, on health, on safety, on security, on teaching methods, and on consumer information (CNRS, 2011).

Hypotheses

The hypotheses for how the variable will change depend to a large extent:

- on European cooperation being reinforced between research laboratories and manufacturers in each sector with multi-disciplinary research groups being set up, bringing together researchers and academics, and also industrial R&D staff;
- on the economic and financial context that might influence funding of European or national policies for backing private or public research and industry, with, as a consequence, greater or lesser dependence on foreign patents and on imports;
- on wealth-generating products (productivity gains, economies of scale, etc.) that incorporate nano-electronics in the above-mentioned sectors;
- on social acceptability.

Hypothesis 1. Massive investment in research

Europe and the States that make it up draw most of their growth from nanotechnology components enabling it/them to come out of recession through two complementary aspects:

- the patents from research that is highly stimulated by public policies make it possible to manufacture products with optimum profit (no payment of royalties);
- the devices that contain nanotechnology make it possible to achieve an overall improvement in profitability in all of the conventional economic sectors (health, transport, security, safety, information, resource optimisation, etc.).

This hypothesis assumes, in particular, that (unrestricted) access to strategic metals is possible.

Hypothesis 2. Little research in France

No improvement in the economic and financial context associated with insufficient cooperation in terms of public and private R&D with, as a result, an increase in the dependence on foreign patents. The share of growth related to nanotechnologies is suboptimum compared with what is observed in countries devoting high stimulation to this sector: it is limited to development of applications (optimisation of what already exists), and to use of electronic systems that incorporate nanotechnology.

Hypothesis 3. Limitation of the uses of nano-electronics

Low social acceptability establishes itself, related 1) to the uncertainties associated with the effects on health and on the environment or 2) to the risk of use of information gathered by nanotechnology devices. Such devices are liable to become generalised to all human activities with, as a result, the risk of information being collected and kept to a much larger degree than was planned for the device: the current example of this being Radiofrequency Identification (RFID) chips/tags, with product labelling for going through shop check-outs faster versus keeping histories of consumer data per individual. This can lead to social rejection due to (legitimate) fear of making the boundaries of private life permeable (a recent example: the NSA phone-tapping case). Development of this hypothesis is highly dependent on the regulatory framework for traceability data and on the parameters for keeping the collected personal data.

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Defence

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Definition

This datasheet addresses the design, production, and implementation of nanomaterials (including components of sensors, devices, and actuators) in the defence sector.

The fields of defence and security have always been precursors in terms of implementing new technological and scientific progress and breakthroughs. Whether it be for "smart dusts" making it possible to perform passive surveillance over a particular geographical area (monitoring ground movements, changes in temperature, and alterations in the chemical composition of the ambient air), or for robots, in particular drones (land, air, and water drones) capable of carrying out their missions almost on their own, developments in nanotechnologies and in nanomaterials are inescapable. Nanomaterials are already in use for active and passive protection for the armed and/or security forces.

Nanotechnologies are going to revolutionise the arms world in the coming years[1]. Miniaturisation, integrating humans into weapons systems, and robotisation are being considered in order to enhance the performance of military hardware. In this perspective, combatants are going to become one of the elements of the weapons system: they are no longer going to be kitted out or equipped; instead they will be "integrated" as is being considered in France with the FELIN future integrated soldier technology. Thus, it looks likely that the integrated infantry soldier known as "FELIN" will be the French soldier of the future, with electronics, sensors, detectors, nano-structured fibres, and lightwave-absorbing active camouflage clothing (the first FELIN systems were delivered to the French Army in 2010, to the 1st Infantry Regiment located in Sarrebourg).

1 Institute for soldier nanotechnologies - http://isnweb.mit.edu/ (consulted on 15 May 2014).

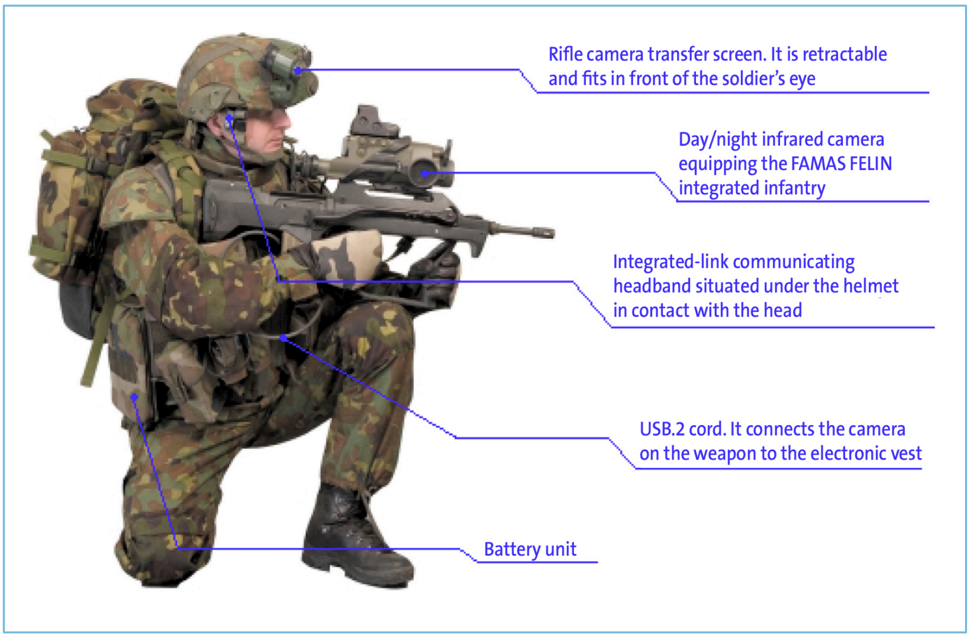

Figure 1. "FELIN", the foot soldier of the future.

In France, most of these technological innovations have been made by private companies such as Thalès or STMicroelectronics, the global leader in semiconductors and systems on chips.

To co-ordinate and steer research in these fields in France, the *Délégation Générale pour l'Armement* (DGA, France's Armament Procurement Agency) has invested in "upstream" research[2].

The DGA is a directorate of the French Ministry of Defence, acting with the aim of securing the final defence of the vital interests of the Nation against any threat regardless of its origin, the defence of the strategic interests of the country and those corresponding to its international responsibilities and its position in the world.

The three essential missions of the DGA are as follows:

To equip the armed forces

As the contracting authority for arms programmes, the DGA is responsible for design, acquisition, and assessment of the systems that equip the armed forces. Its action covers the entire life of each of the programmes:

- The DGA is France's top State investor;
- It runs 80 armament programmes;
- It paid 10.835 billion euros to industry for the programmes in 2013.

To prepare for the future

Imagining the possible futures, anticipating the threats and the risks, and preparing the technological and industrial capacities, within a resolutely European framework:

- The DGA is Europe's top defence research player;
- It awarded 776 million euros of design contracts to industry in 2013.

[2] *L'armement du futur : pression sur la recherche. Présence militaire dans le secteur des nanotechnologies*, Antonin Reigneaud, Observatoire des transferts d'armements/CDRPC, juin 2006. http://www.obsarm.org/news/2006/Dossier%20nanotechnologie.pdf

To promote armament exports

Contributing actively to this major part of industrial policy both on the overseeing and inspection aspect, for ensuring France complies with its international commitments, and also on the economic aspect, for developing defence companies:

- The DGA is a major partner for the international development of French companies;
- Arms exports represent 1/3 of the activity of French companies in the sector over the last ten years;
- 6.3 billion euros of export orders were taken in 2013 (this figure is an estimate, and the final amount of the orders taken will be published in 2014 in the report to the French Parliament on arms exports from France).

Utility of nanotechnologies for the DGA[3]

- Lightening and reducing the vulnerability of equipment by using materials that are lighter in weight, stronger, and "smart".
- Developing innovative energetic materials.
- Augmenting human performance through physiological monitoring systems or through integration of biological microsystems.
- Improving command of information by using abandoned sensors (sensors for detecting, acquiring, and processing information, etc.).
- Increasing robotisation on the battlefield.
- Improving medical care in close collaboration with the field of biotechnologies: artificial blood, treatment for burns, biomaterials, neuroprotection, etc.

Thus, the field of nanotechnologies offers a broad spectrum of potential applications that extends over almost all of the technical fields.

The DGA thus gives the following list of the technological changes that will structure the future of armament:

- **miniaturisation:** development of micro-nanosystems should make it possible to develop innovative architectures for weapons systems;
- **robotisation:** with the aim of sparing human lives, efforts to make systems increasingly autonomous, i.e. increasingly able to operate without human intervention, will be continued (land robots, drones, etc.);
- **design of metasystems:** generalised interconnection of systems (for communications, information, decision-making, etc.) will lead to the development of systems of systems, in particular using the concept of network-centric operations;

[3] DGA website: http://www.defense.gouv.fr/dga (consulté le 15 mai 2014) and http://www.defense.gouv.fr/dga/innovation2/prospective/le-plan-prospectif-a-30-ans-pp30

- **electrification:** the general trend for using electricity for all of the functions of weapons systems will require major progress to be made in the field of generating and storing the energy needed;
- **generalised use of digital technologies:** extension of the field of information technology with the development of automatic digital-signal reconfiguration, and of resilience or fault tolerance;
- **integration of humans:** soldiers will be part of systems, by means of sensors and computers being integrated as close as possible to them, and by means of miniaturised energy sources (convergence of biotechnologies and nanotechnologies, and sensory prosthetics, etc.);
- **networking:** the generalisation of wireless communications will have a major impact on the management of radio frequencies and on the information security of such communications (defensive cyber warfare, encryption technique, etc.);
- **use of space:** the specificities of space (global coverage, use with full sovereignty and without breaking the laws of other countries, etc.) accentuate its utility.

Retrospective analysis

Development of applications

From passive surveillance to smart dusts

The use of passive sensors for surveillance of the surrounding environment was implemented intensively by the US Army during the Vietnam War[4]. The idea was to set up the "McNamara Line", named after the American Secretary of Defense Robert S. McNamara. That line was made up of nearly 20,000 sensors (detectors) dropped by aeroplane or helicopter. Most of them were seismic sensors, making it possible to detect ground vibration induced by movements of North Vietnamese troops and their vehicles. Some of the sensors looked like plants so as to avoid them being spotted by the enemy.

Figure 2. Seismic detector on the McNamara Line (1966).

In the mid-2000s, RFID chips, of particularly small size, were developed and marketed. In the field of marking and identification, it is important to emphasise the applications that are already operational. By way of illustration, in 2007, Hitachi

[4] http://www.afa.org/magazine/Nov2004/1104igloo.asp

presented the smallest RFID chip ever produced. Its vital statistics (0.05 mm x 0.05 mm) earned it the name of "powder" or "smart dust". It contains a 128-bit ROM capable of storing a 38-digit identity number, and it can easily be embedded in a sheet of paper. A Radiofrequency Identification (RFID) chip (often in the form of a tag) makes it possible for the contents it carries to be identified automatically. RFID chips can contain all sorts of information and are to be found on a multitude of media ranging from passports to labels or tags on products sold in supermarkets, and including concert tickets. The emergence of RFID powder is enabling them to be integrated into an increasing number of media. Alongside these developments, a British company has developed a device making it possible to locate such RFID tags from as far away as 180 metres[5] and within a three-dimensional volume, with precision of 2 cm. Such miniaturisation is leading to concern among some people about the possibilities of tracking a person and of monitoring them without them knowing.

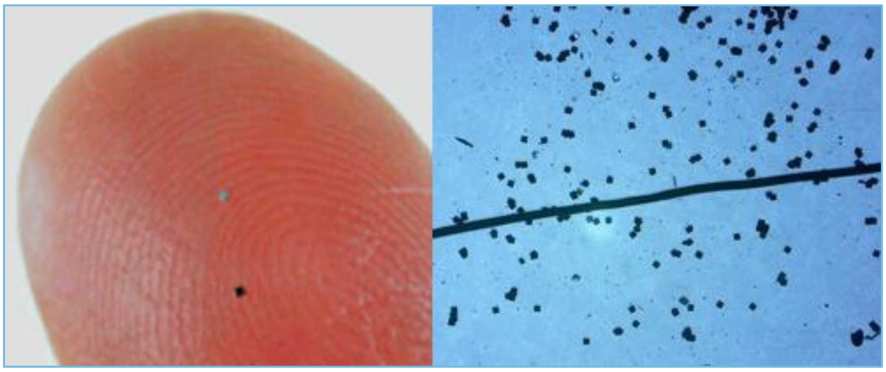

Figure 3. http://www.presence-pc.com/actualite/RFID-poudre-Hitachi-21816.

- **A RFID chip having sides of 0.15 mm and thickness of 7.5 μm**
  In February 2006, Hitachi succeeded in marketing a RFID chip that measured 0.15 mm x 0.15 mm and had a thickness of 7.5 μm. In 2007, a team from the University of Tokyo developed a very small visual sensor capable of instantly analysing fast-moving objects and determining their sizes, positions, inclinations, and shapes. The chip in that peripheral contained a 16,000-pixel image sensor and a hard-wired algorithm making it possible to process 1,000 images per second. It measured 3.3 mm x 3.5 mm and could be embedded in a printed circuit of a mere 5.5 cm^2. Its small size enabled it to be manufactured for a low cost of 1,000 yen (about 6.17 euros). Compared with a CCD (Charge-Coupled Device) sensor, the resolution was much lower (16,000 pixels as against several million), but the image processing was performed instantly on a small surface whereas with a CCD, the sensor is often connected to a larger machine capable of performing processing. Sensors that instantly analysed position and size already existed, but this new sensor was also capable of determining shape and inclination[6].

- **A microchip as tiny as a grain of rice[7]**
  Hewlett Packard's Bristol laboratories took four years to develop a microchip measuring 2 mm x 4 mm and capable of containing up to 512 kilobytes of data, i.e. approximately the equivalent of about one hundred pages of text. Data could be transmitted to and from the chip via a wireless network at a speed of 10 megabits

[5] http://thefutureofthings.com/5332-rfid-loc8tor/
[6] Nikkei - 23/08/2007 : http://www.nni.nikkei.co.jp/AC/TNKS/Nni20070919D18JS
[7] Source: BBC, press release 17 July 2006 http://news.bbc.co.uk/2/hi/technology/5186650.stm

per second. That chip could be easily embedded in objects and be used, for example, to identify pharmaceutical compounds, and, in hospitals, to log the medicines that a patient had received. It could also be incorporated into books in order to facilitate printing the pages of the books. In addition, that chip would not need any batteries because the devices for reading data from the chip would provide power by induction.

- In 2007, Hitachi presented the tiniest RFID tag ever made[8]
  Its vital statistics (0.05 mm x 0.05 mm) earned it the name of “powder”. 150 micrometres x 150 micrometers x 7.5 micrometres! This chip is 64 times smaller than the smallest chip before it and 9 times smaller than the prototype presented by Hitachi in 2006. It contains a 128-bit ROM capable of storing a 38-digit identity number, and it can easily be embedded in a sheet of paper.

Robotisation, and drones

The latest American interventions in Afghanistan and Iraq have shown the extreme sensitivity of public opinion to combatant deaths, making it necessary to seek means of reducing commitment of troops in favour of robotised devices.

In 2011, in Afghanistan, there were already over 2,000 robots, including robots for detecting improvised explosive devices (War Machines: Recruiting Robots for Combat. New York Times, Nov. 2010) and for deactivating them.

Also in April 2011, the US Navy unveiled an unmanned bomber (the X-47B) capable of seeking and finding its target without human assistance, whereas conventional drones still need to be flown by a remote human pilot (Source: War of the machines? April 6, 2011 - CNN, April 4, 20011).

Nanomaterials and weapons[9,10]

It should also be emphasised that the development of nanotechnologies and nanomaterials includes development that is clearly dual-use (for both military use and civilian use) rather than being limited to integration into specifically defence applications. This applies to individual protection (bulletproof vests or helmets based on carbon nanotubes), very fast and ultrasensitive detection devices, chemical and bacteriological vectors, exoskeletons (external prostheses controlled by the movements of the combatants that should enable them to carry 80 kg for 80 km at more than 50 km per hour (target of the Defence Advanced Research Projects Agency (DARPA), USA), and also to the development of thermobaric bombs[11] implementing pyrophoric nanoparticles and developing blast effects that are locally equivalent to those of a nuclear

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8 Source: BBC, press release, 23 February 2007, http://news.bbc.co.uk/2/hi/technology/6389581.stm

9 *Nanomatériaux : différentes voies de synthèse, propriétés, applications et marchés.* E. Gaffet, adsp n° 64 septembre 2008, pp 18–23.

10 *Augmentation des performances humaines avec les nouvelles technologies : Quelles implications pour la Défense et la Sécurité ?* Jean Didier Vincent, Arnaud de la Lance, Bernadette Bensaude - Vincent, Éric Gaffet, Xavier Bigard, Louis Laurent, Michel Detilleux, Michel Peres, Régis Guillemaud, Virginie Tournay, Yann Perrot, Agnès Colin – DGA / Club de réflexion et de recherche de l'IRSEM, Institut de recherche stratégique de l'École militaire, mars 2010.

11 A thermobaric weapon is an explosive weapon that combines thermal, shockwave, and pressure effects.

weapon[12]; the first tests were conducted by the USA and Russia as of 2007. This pervasive dual-use aspect of nano-applications is leading to concerns at international level about the need to update the treaties and schemes relating to non-proliferation of weapons of mass destruction.

Dual-use technology, R&D, and industrialisation

The defence sector would like all fields to take advantage of the dual-use (civilian-use and military-use) possibilities. In view of the increasingly high technology of civilian-use products and in view of their short development lead times compared with those of products for military applications, the civilian sectors have, today, become drivers of innovation. It is thus by focusing on using civilian applications as far upstream as possible that the defence sector hopes to obtain better performance, and to cut costs and lead times, while also guaranteeing that the best technologies are available[13].

The French Prime Minister, Jean-Marc Ayrault, the French Minister for Industrial Renewal, Arnaud Montebourg, the French Minister for Higher Education and Research, Geneviève Fioraso, and the French Minister for SMEs, Innovation, and the Digital Economy, Fleur Pellerin, as well as various representatives of the national, regional, and local authorities, and the managers of STMicroelectronics met on 22 July 2013 on ST's site of Crolles, near Grenoble (Isère), to launch the programme R&D Nano2017[14].

The French Prime Minister announced that the State would be contributing 600 million euros to the Nano2017 programme, which would have a total cost of 3.5 billion euros. It should translate into major high-technology industrial investment in France by STMicroelectronics, in particular in its Crolles factory. STMicroelectronics will itself invest 1.3 billion euros that should enable it to double the production capacity of that factory. That capacity will grow from 3,500 silicon wafers per week to 7,000 ultimately, with an intermediate stage at 5,700 wafers per week.

The project will be supported by the European Union through the Joint Technology Initiative (JTI) of the European Nanoelectronics Initiative Advisory Council (ENIAC).

The Nano2017 programme should reinforce STMicroelectronics's leadership in the key enabling technologies: FD-SOI (Fully Depleted Silicon on Insulator technology for high-performance and low-consumption processing), new-generation imaging (image signal sensors and processors), and new-generation embedded non-volatile memories. Those technologies are at the core of ST's embedded processing solutions, such as microcontrollers, imaging solutions, consumer digital products, application processors, and digital Application-Specific Integrated Circuits (ASICs).

Nano2017 is part of a European vision, together with the Airbus of Chips programme for 10 billion euros over 7 years launched by the European Commission and aimed at doubling the production of cheaper and smarter chips to reach 20% of global output. The Grenoble-Crolles site will be one of the three pillars of this ambitious

[12] http://news.bbc.co.uk/2/hi/europe/6990815.stm
[13] http://www.challenges.fr/entreprise/20140415.CHA2751/comment-la-recherche-militaire-irrigue-l-industrie-francaise.html
[14] http://rpdefense.over-blog.com/tag/Nanotechnologie

microelectronics strategy, together with the innovation clusters of Dresden in Germany and Eindhoven-Leuven in the Netherlands and Belgium.

The determinants of this variable are societal acceptability of the use of autonomous devices capable of taking final decisions without human intervention (raising issues of combatant ethics), the costs of the devices, and, finally, the issue of improved/augmented humans.

Hypotheses

Hypothesis 1. Development of nanomaterials in line with current trends

Depending on the conflict model (spread-out; localised in urban areas), and the scale of the conflicts (long distances; immediate intervention), nanomaterials (armouring; smart dust sensors; robots and drones) and electronic nanosystems (autonomous drones; satellite communications and observations) will become inescapable, and therefore increasingly conventional and integrated into current military equipment.

An important point is implementation of such nanotechnologies for "repairing" wounded combatants. The US armed forces are among the biggest supporters of the development of "repaired humans" with a good number of associations of war veterans being proactive in this field.

Hypothesis 2. Moderate or slower development

This hypothesis can be encountered with the conjunction of the impact of three parameters: manufacturing cost, the risk level, and utility:

- high manufacturing cost, few risks, and high utility;
- low manufacturing cost, possible risks, and high utility;
- low manufacturing cost, possible risks, and low utility;

If the nature of the conflicts remains regional, or indeed highly localised, with little impact on the major Countries and on public opinion, the need for committing to them will remain low. The extra cost related to using nanotechnologies and nanomaterials will not be justified from an economic or strategic viewpoint.

Hypothesis 3. Development is stopped

This hypothesis assumes a high cost, possible risks, and low utility.

Depending on the countries and on their funding capacity (dual-use industry R&D), this hypothesis will have greater or lesser relevance.

Typically, development for defence and security will be possible only if civilian applications having dual use are capable of bearing the cost of developing military applications. This assumes that a strong industry is present in the fields of consumer electronics and materials (typically, in France, Thalès or Airbus, and other aerospace or aircraft manufacturers), or indeed in the automotive field for land drones (cf. the accelerated development of autonomous/driverless vehicles). As a corollary, the disappearance of a national civilian industry in such essential fields will necessarily lead to discontinuation of the development of nanotechnologies in those sectors. This means that the various hypotheses are heavily dependent on a context external to the field in question, as is typical of sectors having dual-use applications.

The dissemination of information and knowledge

Nathalie Dedessus-Le Moustier, Université de Bretagne-Sud, and Michaël Koller, Suva

There is little sharing of knowledge about nanomaterials[1] and their potential health effects, although they are manufactured, handled and sold to a large extent. Could more information about nanomaterials make them better accepted?

Definition

An analysis of the dissemination of knowledge and information about nanomaterials must cover, on the one hand, sources of information and dissemination channels, and on the other hand, the target public. The main sources of information are the State, particularly through its agencies, and companies and their representatives (trade associations, etc.). The target public includes the general population comprising citizens and/or consumers and employees of companies that manufacture or use nanomaterials. The present sheet is based on this distinction.

Moreover, a distinction must be made between information and knowledge. Information is a source of knowledge. Knowledge is a human process that involves transforming raw information to give it meaning. It has to be integrated and interpreted.

[1] 54% of Europeans have not even heard of nanotechnologies and 75% of workers and employers in the construction industry are unaware that they use such materials (Eurobarometer, 2010).

Retrospective analysis

Dissemination of knowledge and information on nanomaterials to the general population

This generally means the spread of information coming from the State or industry targeted at citizens and consumers. However, many other bodies provide information on nanomaterials and adopt a position, such as consumer associations, environmental protection associations, agencies such as Anses (French agency for food, environmental and occupational health and safety), INRS (French institute for prevention of occupational accidents and diseases), Appa (association for the prevention of air pollution) Afnor (standardisation agency) and public research centres: Inserm (for medical issues), CNRS (French national research center), CEA (for atomic energy), Ineris (industrial risks), etc. There is also C'Nano which brings together the research centres working on nanosciences and which aims in particular to promote scientific communication on the subject.

Today, internet is the most important and richest source of information. A host of companies, public and private research institutions and bodies working in the field of nanotechnologies upload information about those technologies. It is not always easy to assess Internet content and caution is thus recommended. Here, we shall not attempt to inventory Internet pages, since this is a very volatile area.

The other vectors of information are in particular printed media (journals, books and other publications), television, radio, podcasts, safety data sheets, oral communication, discussion meetings, etc.

Other possibilities for French citizens to express their opinions and gather information about a topic are through consensus/citizen conferences. Such conferences were held on nanotechnologies in 2006 and 2007. They were organised by the association for the prevention of air pollution (Appa) and Entreprises pour l'environnement (EpA) and the Conseil régional d'Île-de-France. In 2011, Anses created a nanomaterials dialogue committee. The CNDP (Commission nationale du débat public), which, for roughly 20 years has organised discussions on environmental protection attended by the general population, launched a series of public debates in 2009 on general nanotechnology development and regulation options. Seventeen such debates were held in different cities in order to obtain the general public's point of view. Lastly, the Nanoforum aimed to promote exchanges and discussions on the health, environmental and social aspects of the development of nanotechnologies and nanomaterials through the organisation of meetings between scientists, manufacturers, professional organisations, journalists, etc.

An international technical document ISO/TS 13830 is intended for all manufacturers that would like, on a voluntary basis, to indicate the presence of nano-objects in their consumer products.

Legal information requirements fall primarily under the REACH regulation. In general, all chemical substances sold in the European Union, whether or not they are nanomaterials and regardless of the quantity placed on the market, must bear information on the potential health and environmental risks. Specifically regarding nanomaterials, since 1 January 2013, all manufactured nanoparticle substances, imported or placed on the market in France must be declared (Grenelle environmental laws). However, these declarations are especially intended to inform the State, rather than the public. Nevertheless, there are specific consumer information requirements: the term "nano" must be included in the composition of foodstuffs containing manufactured nanomaterials (Regulation 1169/2011/EU). Cosmetics labels must also signal the possible presence of nanomaterials (Regulation 1223/2009/EC).

With regard to public authorities, the precautionary principle goes hand in hand with a requirement to continuously search for information. This involves following the development of knowledge about risks and assessing the actions carried out to obtain information about those risks. The State therefore has an obligation to actively obtain information on the possible risks.

The existence of multiple sources of information, however, does not lead to better acceptance of nanotechnologies, as showed by a study conducted in 2011 by the national agronomic institute (Inra). According to a Eurobarometer survey, people's trust in information depends rather on the source of that information: physicians and health sector experts are the most trusted sources of information, followed by consumer organisations, scientists and environmental protection groups. The least trusted source is the agro-food industry and retailers.

Dissemination of knowledge and information about nanomaterials to workers

In companies, workers have a fundamental right to information. The Community Charter of 9 December 1989 even considers information, consultation and participation for workers as a fundamental right, on the same level as equal treatment and occupational health protection and safety. However, information sharing often comes across certain difficulties. Given the importance of information in the dynamics of power relations in the corporate world, it is the source of claims and demands and a factor of empowerment for workers. Companies, on the other hand, may argue that the transmission of information must not jeopardise their interests, and set discretion and secrecy requirements against information requests.

Directive No. 391/EEC of 12 June 1989 contains several provisions on information for workers. The recitals state that "in order to ensure an improved degree of protection, workers and/or their representatives must be informed of the risks to their safety and health and of the measures required to reduce or eliminate these risks". Article 10 provides that "the employer shall take appropriate measures so that workers and/or their representatives […] receive […] all the necessary information". Specific directives concerning specific risks state the same individual and collective information requirements for workers.

In domestic law, organising this information is one way for employers to comply with their prevention obligation. The French Labour Code requires them to set up and provide information to employees about their safety and health risks and the measures taken to counter those risks. This information was improved by the decree of 17 December 2008 which states that information must be given to workers in a comprehensible manner for all, when the workers are hired and as often as necessary. In addition, the *document unique* (occupational risk assessment document that must be updated at least annually) must be available to all employees. This general information requirement is complemented by specific information on certain types of risks, particularly with regard to dangerous chemicals (Labour Code, Article R. 4412-38).

Companies typically have several methods of informing their personnel about risks: safety data sheets, posters, training, etc. Today, safety data sheets are the main means of information, but their content is not always satisfactory. A study of 30 nanomaterial safety data sheets available on the market, based on instructions from European directives, showed that the quality of information varied greatly[2]. Safety data sheets are vague about risks in addition to being more or less suitable communication tools. Against a lack of information about nanomaterial-related risks, employees' knowledge also appears to be extremely limited. Among workers, experts, researchers and scientists are apparently the most sensitive to risk, twice as much as other workers[3]. The occupational risks that are most well-known concern nanoparticle inhalation and skin exposure. But not all professional groups have this information. Information about risks is therefore a critical topic for the development of activities involving the handling of nanomaterials.

In companies, the occupational physician and the CHSCT contribute to informing workers. The CHSCT, which represents the personnel, has an extended right to information. The French labour code imposes numerous information obligations on employers specific to certain risks, but they also have a general information obligation covering all matters related to occupational safety and health. Confidentiality, for example, about a manufacturing procedure, cannot be used to restrict information to the CHSCT, since its members are required to comply with discretion and secrecy obligations.

In addition to the difficulties related to access to information, there may be problems with managing or understanding information about topics that are sometimes complex such as nanomaterials. The CHSCT can provide, in addition to knowledge about the risk, assistance with understanding the risk, by calling on experts. Two situations justify the use of experts: a serious risk observed in the establishment or a major project to change the health and safety conditions or the working conditions (French Labour code, Article L. 4614-12). However, for the time being, no consulting firm that assists union representatives or helps the CHSCT to formulate an opinion has the training or equipment to handle topics on nanomaterials.

With employers being responsible for providing information, in a context where different points of view co-exist and require them to make choices based on their resources for monitoring scientific and documentary developments, employees find themselves on unequal ground as regards information. Certain employees, on seeing a new pictogram or the term "nano" in a composition, wonder about the risks involved. It is not a problem of dependency, but rather what economists term "moral risk" generated by this situation of uncertainty. Against the current context, many employees, taking advantage of information technologies such as Internet, seek the information themselves, even if what they find is different to the information transmitted by the employer.

[2] Scheider T et al, 2007 , Evaluation and control of occupational health risks from nanoparticles, http://www.norden.org/da/publikationer/publikationer/2007-581

[3] Cheng et al, The Risk Perception of Nanotechnology in Taiwanese General Population, Workers, and Experts, Epidemiology: November 2009 - Volume 20 - Issue 6 – p.227

Prospective analysis

Given the development potential of nanomaterials, the matter of disseminating related information remains relevant for the upcoming years.

What determines the evolution of the variable?

- Information providers: number of informants, credibility, means of communication volume of information, complexity of the information.
- Target public: interest, level of training, age, socio-professional category.
- Development of nanotechnologies: benefits, risks, hazards.

Can past trends continue?

Never has access to information been so fast and easy for so many topics. Where in the past hours of research were required for complex matters, today answers can be found with a few clicks on the Internet. This, in addition to the flow of information from all over that we receive passively whether we want to or not. It is not easy, given the volume of information and number of media that exists, to separate the wheat from the chaff, to stand back and keep it in our long-term memories. For laymen, it is often impossible to distinguish duly validated information from information that is less sound. We do not always devote the necessary time to new information, because we lack the time, but also because of many factors that distract us and divert our attention. Tendentious presentations evidently draw more attention and sensational news are more captivating than less spectacular information. This is a profoundly human phenomenon observed not only in laymen, but in experts and researchers, since unfortunately, we tend to publish only positive research results, and overlook or ignore negative results. All of this gives rise to biased information which should be taken into account by information providers.

To reach citizens, in the jungle of data, neutral, objective information is required, coming from a trustworthy institution, in the form of brief, attractive and simple messages. The main institutions that are competent in this field should pool their resources and create a common platform. Similarly, the main industries using nanotechnologies should do the same and harmonise their labelling systems, etc. A common approach by information providers makes it simpler to inform citizens.

With regard to workers, despite recent developments, their access to information could be enriched further. The law of 3 August 2009 scheduling the implementation of the Grenelle environment law provided for the improvement of information due by employers to their employees on emerging risks, particularly with regard to nanoparticles and electromagnetic waves (Article 42 of the act). This provision has not yet been translated into obligatory measures. The law of 16 April 2013 on the independence of health and environmental assessment and the protection of whistleblowers improves workers' access to knowledge through information on the risks that manufacturing products or processes can pose to the environment or public health, and on the measures taken to counter this. In that same vein, the obligation for listed companies to communicate environmental and social information in the annual management report was extended to certain non-listed companies, and specified with respect to the information content to be provided, in particular by the law of 12 July 2010, known as Grenelle 2. The information to be provided includes work organisation, social relations, and aspects on health and safety (Decree No 2012-557 of 24 April 2012).

Considering that existing directives and regulations are not appropriate for nanomaterial regulation, European worker unions, such as the European Trade Union Confederation (ETUC), and national unions, turn to public authorities and demand changes to the current legal framework, particularly by improving information provided to workers. The French CFDT has just published a guide titled "Nanotechnologies", demanding responsible development, in order to assist activists and employees concerned in voicing their opinions knowledgeably on the options taken regarding nanotechnology development.

In Brazil, the chemical industry agreement concerning nanotechnologies and nanomaterials contains an obligation to inform workers. Moreover, this country organised, on 5 and 6 September 2013, the International Workshop on Nanotechnology and Society in Latin America: Nanotechnology, Labor and Regulation, which implemented a declaration based on transparency and prevention in the field of nanotechnologies[4]. Voluntary signatories (companies, government, institutions, trade unions, etc.) commit to promoting information and precautionary approaches concerning nanotechnologies.

Are there factors that could break past trends?

Companies conveying that the transmission of information must not jeopardise their interests and setting secrecy and confidentiality requirements against information requests put pressure on public authorities to restrict the right to information about nanomaterials.

Hypotheses

Hypothesis 1. Major reinforcement of information and communication to the wider public and in the working world

Hypothesis based on a strong demand for better dissemination of information by pressure groups such as consumer associations, non-governmental organisations, but also employee unions, as in Brazil currently, with research highlighting the toxicity of certain nanomaterials.

Hypothesis 2. Reinforcement of information and communication in the working world

This hypothesis uses the division adopted in this sheet between the categories of audiences targeted for information about nanomaterials. For example, it can be envisaged that labour law, which protects the interests of employees, strengthens the

[4] The declaration form is available on the website of the CIEL association: http://action.ciel.org/p/salsa/web/questionnaire/public/?questionnaire_KEY=1495&key=677816

right to information of those that make and handle nanomaterials while the dissemination of knowledge to the wider public does not improve because of the economic stakes related to the development of nanotechnologies.

Hypothesis 3. Information without communication

In this case, information is simply given by the company to employees and the larger public, but no real sharing of knowledge or debate is desired. The public might not accept the development of nanomaterials and remain sceptical or even hostile, because the approach is not participatory and not open to discussion.

Hypothesis 4. Passivity regarding nanomaterials (lack of interest by the public and demotivation in experts, journalists, etc.)

This attitude does not prevent communication about specific nanomaterials such as graphene.

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The stakeholders

Myriam RICAUD, INRS

Today, manufactured nanomaterials have major economic, technological and societal importance. They have an increasing impact in strategic sectors such as health, energy, the environment and transportation and enable more traditional industries (textile, agrifood, chemistry) to increase their market opportunities thanks to more technically complex products. But manufactured nanomaterials also generate many questions particularly regarding the health and environmental hazards environment as well as ethical and societal concerns.

There are numerous, more or less organised groups that exert pressure or influence on power-wielding persons or institutions in France and Europe, to defend their particular interests as regards manufactured nanomaterials, be they economic, financial, moral, etc. These groups seek to promote developments in legislation, to encourage political, economic, change, etc.

Their approaches may be discrete (participation in consultative bodies, networks, etc.) or public (declarations, petitions, protests, etc.).

Retrospective analysis and current situation

The term "lobbying" originated in Great Britain. It designated the corridors or the halls in the House of Commons. It was around 1830 that the term "lobby" came to refer to a pressure group. Lobbying developed in connection with the diversification and specialisation of industrial and commercial sectors. Lobbies are present at all levels. The complexity of public affairs, the need for reliable information ahead of all political decisions, the preparation of the European market, etc. are all factors that have made pressure groups essential in the political arena.

Types of pressure groups

In France, there are many various pressure groups or interest groups associated with the development of manufactured nanomaterials:

- professional organisations: Union of chemical industries(UIC) (and its European counterpart, European chemical industry council, Cefic), paint federation, cosmetics association, etc.;
- non-governmental organisations (NGOs): environment and consumer associations;
- employer associations and trade unions;
- citizen groups: e.g. science and nanotechnology associations;
- specialised firms mandated by industrial companies or financial groups, etc.;
- consulting firms: Lux Research, Boston Consulting Group, etc.;
- chambers of commerce and industry;
- think tanks;
- etc.

Most of these entities have exerted their influence on political and economic decision-makers for roughly 15 years.

Certain groups, and in particular, certain citizen associations and NGOs are devoted exclusively to matters concerning manufactured nanomaterials. These bodies, often small in size, are active only in French territory. Other larger associations and NGOs exert their influence at international level, such as Friends of the Earth International, which is represented in 72 countries with over 1.5 million members.

French trade unions have been addressing the development of manufactured nanomaterials for roughly five years now. A national public debate on nanotechnologies, which started in October 2009 forced French trade unions to take a position on a topic they had considered thus far technically complicated and not a very tangible industrial activity[1]. The European Trade Union Confederation adopted an initial resolution on this topic in June 2008.

These groups often have diverging opinions and interests. Generally, NGOs, citizen associations and trade unions are in favour of a controlled and cautious development of manufactured nanomaterials; some are even opposed going so far as to request a moratorium on them, while professional organisations and employer unions support a massive development of nanomaterials.

[1] Syndicalisme et nanotechnologies. De l'espace des relations professionnelles à l'espace public des risques, Patrick Chaskiel, Sociologie du Travail, Volume 55, Issue 4, octobre - décembre 2013, pp. 454-474.

Means of action of pressure groups

Interest groups take action to directly or indirectly influence the elaboration, application or interpretation of existing legislative measures, standards, regulations and more generally, any operation or decision by public authorities relating to the development of manufactured nanomaterials.

These entities participate in and even organise debates, conferences, discussion forums, etc. covering the challenges associated with the development of manufactured nanomaterials at local, national and international level. These initiatives include the cycle of debates proposed since 2006 by the association VivAgora[2] and the discussions held regularly since 2010 by a citizen association[3]. There is also the Nanoforum[4], which were eight discussion sessions held in Paris between June 2007 and April 2009. Following this forum, a national public debate was announced by a joint letter from eight ministries dated 23 February 2009. The national public debate commission (CNDP) organised 17 public meetings in 17 towns in France on specific topics up until February 2010. The goals of these consultations were to inform the population about the main controversies surrounding the topic and to enable it to understand the positions of the different actors and to clarify the State's policy. Trade unions, NGOs and professional organisations expressed their views during these discussions, which often occurred amidst tensions. They were also invited to draft "actor specifications", a summary presenting their reasoned point of view on nanotechnology and nanomaterials. The government made different commitments[5] following the review sent by the CNDP. Pressure groups are also active in many bodies in France such as the Nanomaterials and health discussion committee set up by Anses in 2009 and which was designed as a place for discussion and to express concerns in order to provide matter for scientific research led or encouraged by Anses.

Pressure groups are also present in more technical and economic structures such as French, European and international standardisation bodies within which there are specific committees for manufactured nanomaterials. The French standardisation committee X 457[6] has been chaired by a representative of the union of chemical industries (UIC) for several years now. Its members include representatives from NGOs, professional organisations, major industrial groups, ministries, etc. The goal of this committee is to "favour the development of nanotechnologies in order to take advantage of their progress while guarding against their potential negative effects". ISO's technical committee 229 is currently chaired by a British pharmaceutical company.

Interest groups are also heavily represented at the European Commission and the European Parliament, whose powers have been strengthened these past few years. They are frequently present in the decision process in Brussels, in order to consolidate their requests and validate their interests. Their goal is to influence, direct, or oppose community decisions taken on manufactured nanomaterials.

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[2] The VivAgora association no longer exists since end of 2013.

[3] http://www.collectif-nanosaclay.fr

[4] http://securite-sanitaire.cnam.fr/nanoforum

[5] http://www.developpement-durable.gouv.fr/IMG/pdf/Les_engagements_du_Gouvernement_sur_les_suites_a_apporter_au_debat_public_relatif_au_developpement_et_a_la_regulation_des_nanotechnologies.pdf

[6] http://www2.afnor.org/espace_normalisation/structure.aspx?commid=59942

The current version of REACh (Registration, Evaluation, Authorization and restriction of Chemicals), in effect since 2007 in Europe, does not include any specific nanomaterial-related provisions; therefore, it is considered that nanomaterials are covered by this regulation in the same regard as other chemicals. In 2012, the European Commission announced that the REACh annexes were going to be amended in order to better take into account certain particularities of nanomaterials. For that purpose, the European Commission ran a public consultation open to all until mid-September 2013. Comprising 41 pages and 38 questions, this consultation proposed, in addition to the option which is the current situation, five options aimed at clarifying the procedure for registering nanomaterials in the registration files. Professional organisations, NGOs and citizen associations answered this consultation; some even published their responses on their website or in press releases. Among the different options proposed, the most flexible was chosen by industry federations, and the most demanding option in terms of information and guarantees regarding the safety of nanomaterials was adopted by the French authorities and several NGOs. The final report of this consultation will be formalised in the coming months by the Commission.

In autumn 2010, the European Commission submitted a draft recommendation for the definition of the term nanomaterial. Two hundred responses were sent to the Commission by professional federations, citizen associations, unions, NGOs, etc. At the end of March 2011, the European Commission made it official that it would take several months to formulate a finished definition, which was generally met with dissatisfaction. This delay in the adoption of the draft recommendation was due to diverging opinions between the different stakeholders, which the Commission was unable to reconcile. Several departments of the European Commission were involved in this action, each subjected to intense lobbying from actors with opposing interests. The Commission's recommendation was finally published on 18 October 2011[7]. As soon as it was published it sparked strong reactions both from professional organisations and civil society actors.

Moreover, at European Union level, provisions specifically devoted to nanomaterials have been included, since 2009, in several sector-specific legislations. In December 2013, the European Commission proposed a draft delegated regulation on the labelling of foodstuffs which became mandatory in December 2014 as provided for by Regulation (EU) No. 1169/2011[8]. This delegated regulation aims to specify the provision of information to consumers about the presence of manufactured nanomaterials in foodstuffs. But while the initial regulation stated that "all ingredients present in the form of engineered nanomaterials shall be clearly indicated in the list of ingredients", the draft regulation takes a step backwards. The European Commission in fact intends to not make the indication [nano] necessary for ingredients already used for decades now in nanoform in foodstuffs. However, it is such food additives – in particular calcium carbonate, titanium dioxide and silica – that raise the most concerns given the uncertainty concerning their harmlessness. Industry representatives such as the Federation of European Specialty Food Ingredients Industry (ELC) fervently supported the position of the European Commission, which was evidently not the case for consumer associations, or the French government, whose positions were finally taken into consideration. Early March, the European Parliament rejected the draft regulation, therefore, the Commission now has to submit a new proposal.

[7] Recommendation No 2011/696/UE published on 20 Octobre 2011 in the Official Journal, L 275/38.

[8] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:304:0018:0063:FR:PDF

In France, within the framework of the annual declaration of substances in nanoparticle form, entered into effect as at 1 January 2013 (Articles L. 523-1 to L. 523-3 of the environment code), the Ministry of Ecology, sustainable development and energy formed a working group comprising professional organisations (UIC, Fipec, Ania, etc.) and NGOs (VivAgora, Avicenn). The group meets once per year in order to review this regulatory mechanism. These entities were also consulted during the very preparation of the founding texts of this declaration obligation.

Pressure groups also publish a host of documents (press releases and articles, websites, summaries, books, etc.) proposing well-founded arguments to raise their profile, promote their opinions and interests, draw the attention of economic and political decision-makers, propose actions and rally supporters. In November 2012, three NGOs - the Center for international environmental law (CIEL), ClientEarth and the German Friends of the Earth (BUND)- published a report entitled "High time to act on nanomaterials - Proposal for a 'nano patch' for EU Regulation"[9] in which they defend the implementation of a specific nanomaterial regulation. In 2013, the European Trade Union Institute (Etui) published a booklet "Nanomaterials and workplace health & safety. What are the issues for workers?". The union of chemical industries has a webpage[10] devoted to nanomaterials.

Prospective analysis

Pressure groups have acquired major importance over the last few decades and their actions are carried out at the forefront of the national and international stage.

Given the economic, technological and political challenges associated with the development of manufactured nanomaterials, pressure groups representing the interests of large industrial and financial companies can only develop their influence strategies with people and institutions that have power in France and Europe in this matter.

Similarly, the many societal and ethical questions raised by the development of manufactured nanomaterials can only strengthen the role of interest groups representing civil society. Not to mention trade unions that make themselves heard in order to avoid the errors of the past, i.e. those relating to asbestos.

[9] http://www.ciel.org/Publications/Nanopatch_EU_Nov2012.pdf
[10] http://www.uic.fr/Activites/Innovation/Nanomateriaux

The importance of these pressure groups with diverging interests, with regard to French and European political and economic decision-makers, is difficult to estimate and extrapolate. It would appear that the French government, just like the European Commission, generally wishes to show consideration to all stakeholders by organising for example, consultations or public discussions. Nevertheless, according to the European Commission, among the 15,000 to 20,000 interest groups active in Brussels, approximately 1/3 are associations that defend “citizen interests” and just over one half protect economic interests. Similarly, in France, there are many citizen associations and NGOs active in the field of manufactured nanomaterial development but they sometimes have limited human and financial means, as opposed to professional organisations, large industrial and financial groups and employer associations, which are better organised and therefore exert greater influence.

Moreover, for several years now, it appears that the European Parliament has been reflecting on regulating lobbying inside parliament. The first attempts at regulation date back to the 1990s. Inspired by legislation in the USA, the European Parliament adopted the Ford report in July 1996, which establishes a register for lobbyists that wish to enter Parliament and which proposes a code of conduct. In parallel, the Nordmann report requests parliamentarians to provide information on their professional affiliations and sources of income. For those who criticise lobbying culture in Brussels, these promises are hardly sufficient. For ten years now, the Corporate Europe Observatory and other NGOs have opposed the influence of economic groups in the European Union and demand stricter regulation in vain.

Hypotheses

Hypothesis 1. Actors have the same influence

The different pressure groups, regardless of the interests that they defend, maintain the same influence on political and economic decision-makers. The French government and the European Commission continue to carry out consultations and listen to and give consideration to all stakeholders.

Hypothesis 2. Economic interests dominate

The economic importance and opportunities (especially in terms of jobs) of manufactured nanomaterials are considerable. Pressure groups representing the interests of industrial companies and financial groups are very active and organised and significantly increase their influence. The political weight of groups defending economic interests far exceeds that of trade unions, NGOs and citizen associations.

Hypothesis 3. Influence of certain civil society actors dominate

The concerns particularly about the hazards posed by manufactured nanomaterials to health and the environment persist. Civil society is increasingly worried. There is an increasing number of NGOs, employee federations and citizen associations which are more organised and active at international level, and therefore draw closer attention from decision-makers. The influence developed by representatives of industrial companies and financial groups lessens.

Ethics and social values

Éric Drais, INRS

Definition

This variable covers different points:

- the acceptability of nanomaterials and associated technology to society, companies and opinion leaders (government, insurers, professional organisations, etc.);
- the concerns and fears of the general population that nanomaterials might infringe on the different values or principles considered important for people's lives or existence in society, such as respect of independence, justice, freedom, dignity, right to privacy, etc.;
- the relationship with science and new technology.

Nanotechnology and metaphysics: an ethical framework

Strictly speaking, ethics describes a set of values upheld by an individual, and by extension a group. Defined as such, ethics is enshrined in a given culture and is the product of learning. From an etymological point of view, the term "ethics" is formed from the Greek root *ethos*, meaning "character", "personal disposition" and also "custom". This same root designates, according to Vallet (1995)[1], a habit, behaviour that has become common practice and a reference (*op. cit.* p.106)[2]. Associated with the idea of "habit, custom, common practice", and "a way of being, disposition, character" (in the Aristotelian sense of the word), ethics refers to principles that steer actions.

[1] Odon Vallet, Discours sur la bioéthique, L'éthique ou la morale défroquée, volume 44, numéro 1, p. 106-107

[2] This same author also writes that *éthos* comes from the Indo-European root *swedh*, meaning the independent existence of an invidual or group (*op. cit* p. 106).

The importance of the concept of ethics lies in the action that it authorises. For Fortin (1995), it designates a set of elements commonly accepted within a given social group that define what really matters, what makes sense: it therefore concerns reflection about the action and its foundations, its justifications. From a moral philosophy perspective, it could be seen as an attempt to answer Socrates' fundamental question: how should we live? (William, 1985).

From Greco-Roman antiquity[3] up to the present day, a number of reflections by philosophers to forge or assess universalist doctrinaire systems, have addressed ethics. However, while discussions devoted to ethical matters (and by extension, notions of justice, virtue, good, morality, etc.) have long been dominated by idealist concerns (in the philosophical sense), it appears that they gradually took a more contextualised turn among modern contributors (from the 20th and 21st centuries). In other words, ethical matters tended to become less abstract, and revolved more around diverse and well-defined situations in our social environment (medicine, politics, economy, the corporate world, labour). Evidently, it is this more finalised, and to a certain extent, more pragmatic configuration that is of interest to us in our analysis of ethics as regards nanosciences and nanotechnologies.

Today, ethics has a double role to play in the development of nanomaterials: on the one hand because this development depends on society's incorporation of nanotechnologies into its cultural heritage, and on the other hand, because it is necessary to equip our societies with guiding principles (ethics) in order to set socially acceptable limits on the use of nanotechnologies. This is why ethics is advocated both by nanotechnology opponents and supporters alike.

Ethical questions are more pressing in the case of nanomaterials. Although there is great uncertainty surrounding them, these materials with new properties are presented as the solution to most of the challenges society faces currently: climate, health, ageing, pollution, energy, etc. In fact, in 2002, the promoters of the American programme on converging technologies promised nothing short of "world peace, universal prosperity and evolution to a higher level of compassion and accomplishment". This is because convergence between nanotechnologies, biotechnologies, information technologies and cognitive sciences (called NBIC convergence) ushers in a new era which, for J-P. Dupuy, has been a source of original ethical questions since the 2000s ("*Les nanotechnologies: éthique et prospective industrielle*", 2004) that might even require epistemological and ethical change (Kermisch and Pinsart, 2012) because of their metaphysical project to "reconceptualise nature". At nanotechnology level, the boundaries between disciplines have become blurred. The handling of nanomaterials at atomic scale interconnects biology, physics, chemistry, medicine, information sciences, etc. It makes it possible to "connect the inert and the living, the natural and the artificial, the human body and machines" (CNRS, French national scientific research body).

[3] In particular the very famous *Nicomachean Ethics* by Aristotle, but there are many other classical references (not only ancient, but also medieval, renaissance, early modern) worth mentioning (see the very complete historiographical and thematic bibliography established by Wunenberger, 1993): Plato, Aristotle, Seneca, etc. for the Age of Antiquity; the great thinkers of Medieval Christianity (Plotinus, Saint Augustine, Saint Thomas Aquinas, etc.); Renaissance authors (Erasmus, la Boétie, Montaigne, etc.); those of the Classical Era (Bacon, Malebranche, Spinoza, etc.); those of the Enlightenment (Locke, Hume, Kant, etc.); thinkers of the early modern period (Bentham, Mill, Fichte, etc.); lastly, modern thinkers (Shopenhauer, Nietzsche, Bergson, etc.).

Since they are a generic technology paired with major stakes, nanotechnologies raise numerous questions (document on the French government's website www.santé.gouv.fr on the concerns of public authorities with regard to the health impact of nanomaterials). In addition to health and environmental concerns, the diffuse and invisible integration of nanomaterials challenges, for example, personal freedoms because of the possibility of checks and traceability, as well as human dignity because of interventions on living organisms and potential human transformations (post and transhumanism). As reality meets fiction[4], the perspectives, which are fascinating and worrying in equal measure, require consideration of ethics.

The challenge related to ethical regulation of nanotechnologies

Several countries investing in nanotechnologies have set up programmes to analyse the environmental, social and legal impacts or aspects of nanosciences and nanotechnologies. From an ethical point of view, the public must be informed ahead of or together with scientific or technical development, and allowed to debate, but not manipulated or simply prepared for what others want to impose on it (Bensaude-Vincent). However, the difficulty in agreeing on a shared definition of nanotechnology complicates the task, and also makes it difficult to delimit the areas of application of regulation.

In Europe, many discussions have taken place since the 2000s, associated with regulatory development and deontological recommendations[5] on nanosciences and nanotechnologies. Great Britain, the Netherlands and Denmark were the precursors. In France, the matter of ethics was raised in 2004 by J-P. Dupuy and F. Roure in their outlook report on ethics and the industrial future of nanotechnologies in support of public action. Then in 2006, a report drafted in conjunction with the ministry of ecology and sustainable development on the hazards and risks of nanotechnologies was published. At the end of the year, the ethics committee of CNRS published an opinion on the ethical challenges of nanosciences and nanotechnologies shortly before the parliamentary technology evaluation office published its report on the same subject. In 2007, the advisory committee on bioethics issues published its opinion on the ethical matters raised by nanosciences, nanotechnologies and their health consequences, at the same time as an opinion was published by the European group on ethics and new technologies on the ethical aspects of nanomedicine. In 2008, the first international ISO standards on nanotechnologies were published (first concerning definitions, then on other matters) and the European Commission released a recommendation concerning a Code of Conduct for Responsible Nanosciences and Nanotechnologies Research.

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[4] Combining these fields, the scenario of uncontrolled self-replication of nanorobots, imagined in 1977 by E.K. Drexler, an MIT engineer, is one of the scenarios featuring most often in literature and cinema.

[5] The term "deontology" was coined by English philosopher Bentham (1748-1832) to designate "the science of morality". It is derived from Greek "deon", meaning "that which is binding". Note however that nowadays the meaning of the term "deontology" is different to previous meanings (ethics and morality), not so much because of etymological reasons but because it is generally reserved to define a set of rules specific to a given professional activity, to a specific job.

The goal of these standards, reports and opinions was to provide a framework for the practices of those concerned, however, ethics is not limited to these official positions. In parallel, society heightened the debate on nanotechnologies. It became public when it appeared in the media in 2004. In France, the year 2005 saw the official organisation of the first citizen debates (in Grenoble for example) and the first citizen conferences (Vinck, Gallice, Jouvenet, Zarama). They were continued in Paris in 2006, then in 2007 and 2008 with the Nanoforum. In addition to institutional initiatives, there were public meetings promoted by civil society: Nanomonde (Fondation Sciences citoyennes, 2006), Nanovi (Vivagora, 2006), and Avicenn (Sciences et démocratie, 2013). These debates by society had different objectives. Nanoforum, for example, proposed a “technical democracy” aimed simply at exchanging and learning: its goal was to provide a free, transparent, pluralist and open space to respond to the uncertainty generated by nanotechnologies. These hybrid forums opened up spaces for discussion that could be used to manage controversies related to technical innovations (Callon et al. 2001) and to undertake ethical regulation, provided that the different interested parties, as well as citizens evidently, were represented(Vinck, Gallice, Jouvenet, Zarama).

In 2009, society’s debate about nanotechnologies showed the extent to which there were hardly any practical, credible and rational conditions for ethical regulation. A result of the environmental act of 2007, a public discussion on the development and regulation of nanotechnologies was held at national level. It responded to a commitment included in a draft law (law 2009-967 of 3 August 2009, Article 42). Commissioned by seven ministries, the discussion was entrusted to CNDP, a government body created to encourage public participation in major infrastructure projects (high-risk industrial sites, railways, etc.). This commission organised the discussion over five months (October 2009 to February 2010). Noting the public’s unawareness about this topic, the commission decided to approach the public in towns in which industries or laboratories working on nanotechnologies were set up. The main motivation was to inform citizens about the different industrial applications of nanotechnologies and gather their views. Seventeen towns were selected for as many thematic discussions, which combined both technical subjects in connection with local activities and a general topic. Information was given beforehand through a database with about 50 “actor specifications”, a collection of opinions and positions of the main nanotechnology stakeholders. However, out of the 17 meetings scheduled, 8 were disrupted or cancelled. Some NGOs blocked participation in the public discussion to denounce the useless debate about nanotechnology development, since decisions had already been taken. Certainly, the ministry of research had announced earlier in May 2009 the implementation of a funding programme for 70 million euros (Nano-Innov) and this public discussion was a bit late compared to the brief history of nanotechnologies in France. Access to meetings was therefore monitored and sometimes overseen by the police. But very few participants were satisfied with the conditions under which the discussion took place (limited and timed). A great many important issues (military, individual freedoms, etc.) were in fact overlooked (Jouzel, 2010). At the closing of the discussion in February 2010, 3,216 participants had attended the meetings (instead of the 10,000 expected) and the website had received 169,717 hits. Officially, the discussion had not had the desired success. Seen by its opponents as a promotional nanotechnology tour, the discussions were considered a failure.

The follow-up to the discussions took place in 2011, with the government acknowledging in a press release that the debate had highlighted the expectations of the French society in terms of information, transparency and long-term dialogue, and their concerns about the potential impact of these technologies on individual freedoms and ethics. This press release was coupled with commitments aimed at positioning France at community level with regard to the inclusion of specific nanomaterial properties in directives and regulations, with, for example, product labelling regulation made available to the wider public, but also the inventorying of substances in nanoparticle form placed on the market[6], and the creation of a specific interministerial web portal.

Though they may appear to be exemplary or proactive, these commitments in the long run are just the normal result of the application of the precautionary principle required of French public authorities when there is scientific uncertainty about the potential environmental damage. In fact, this precautionary principle, enshrined in the constitution, requires authorities to continuously search for information and assess health risks. The ANSES report dated April 2014 is part of this process. It includes a chapter on “Ethics and civil society”, and presents the uncertainties relating to manufactured nanomaterials. It reiterates that the most discussed points in the field of nanotechnology are related to three aspects: social surveillance (traceability), living things (nanobiotechnologies) and risks (nutrition-environment-health).
It summarises a few elements of the debate and especially concerns about the potential health damage related to the development of nanomaterials, calling for caution. In that regard, it cites discussions using the notion of “uncertain” risks, a paradoxical notion that has no meaning except in an attempt to obtain risk analysis against ongoing uncertainty about nanomaterials and their effects.

The situation and ethical prospects for nanotechnologies

The magnitude of nanotechnology applications explains the need for and the importance of the ethical debate on the topic. The elaboration and use of notions such as that of “nanomaterials” should contribute to delimiting and facilitating the debate. However, these generic notions – with debatable boundaries – structure the topic as much as they maintain uncertainty and difficulties to overcome. This could explain the contrasting and unstable values attributed to nanotechnologies.

Since their launch, nanotechnologies are the topic of much controversy. These controversies have been more or less intense and wide-ranging with time. The risks associated with nanomaterials are decisive elements in the debate. This is why the use of nanomaterials for cosmetics or nutrition for example, were discussed. While the properties of nanomaterials could have initially been used as a commercial argument, manufacturers today remain discrete about their presence in their products. However, knowledge about the risks is still limited. But the perception of risks generally depends on the risk/benefit ratio associated with the technology[7] and in these cases, the expected benefit does not outweigh the health concerns. This is why specific regulation with a generalised labelling, requested for a long time now by NGOs, was first elaborated in these sectors that are sensitive for the public.

[6] This obligatory notification mechanism (R-Nano) is promoted with a view to harmonised notification in Europe.
[7] OSHA report 2012, Risk perception and risk communication with regard to nanomaterials in the workplace.

Embedded in culture, ethics is associated with social standards and mental representations. In a context of uncertainty, these elements determine why certain applications are promoted and others contested. This is the case with medical nanotechnology applications (drug vectors in particular), which are generally trusted (and are based on organic, absorbable particles), whereas criticism is made of socks with silver nanoparticles (biocides) which are therefore odour resistant, but also harmful to the environment because of discharge into rivers after they are washed. To understand the foundations and movements of these positions in populations, health and government bodies have different quantitative survey tools[8]. Opinion panels for example, have been developed both at European level (European Commission's Eurobarometers) and at national level. It serves to measure the adoption of technology by the public in general or by certain stakeholders.

Concerning nanotechnologies, the latest surveys available show first of all poor knowledge of the topic at European level: despite major disparities between the north and the south in 2010, in Europe an average 54% of people did not know what nanotechnologies covered (some even asking if it was an Ipod Nano). And other surveys show that despite its development, the information available hardly changes this perception. In France, the results vary slightly. Only 46% of people surveyed were unaware about the topic (Figure 1).

[8] Identifying trends in the perception of technology is particularly important for those in authority given the effects of the public's responsiveness to the development and operation of techniques. This is particularly the case in a recent historical context marked by resistance to biotechnologies (GMOs, etc.) and the extraction of shale gas for example.

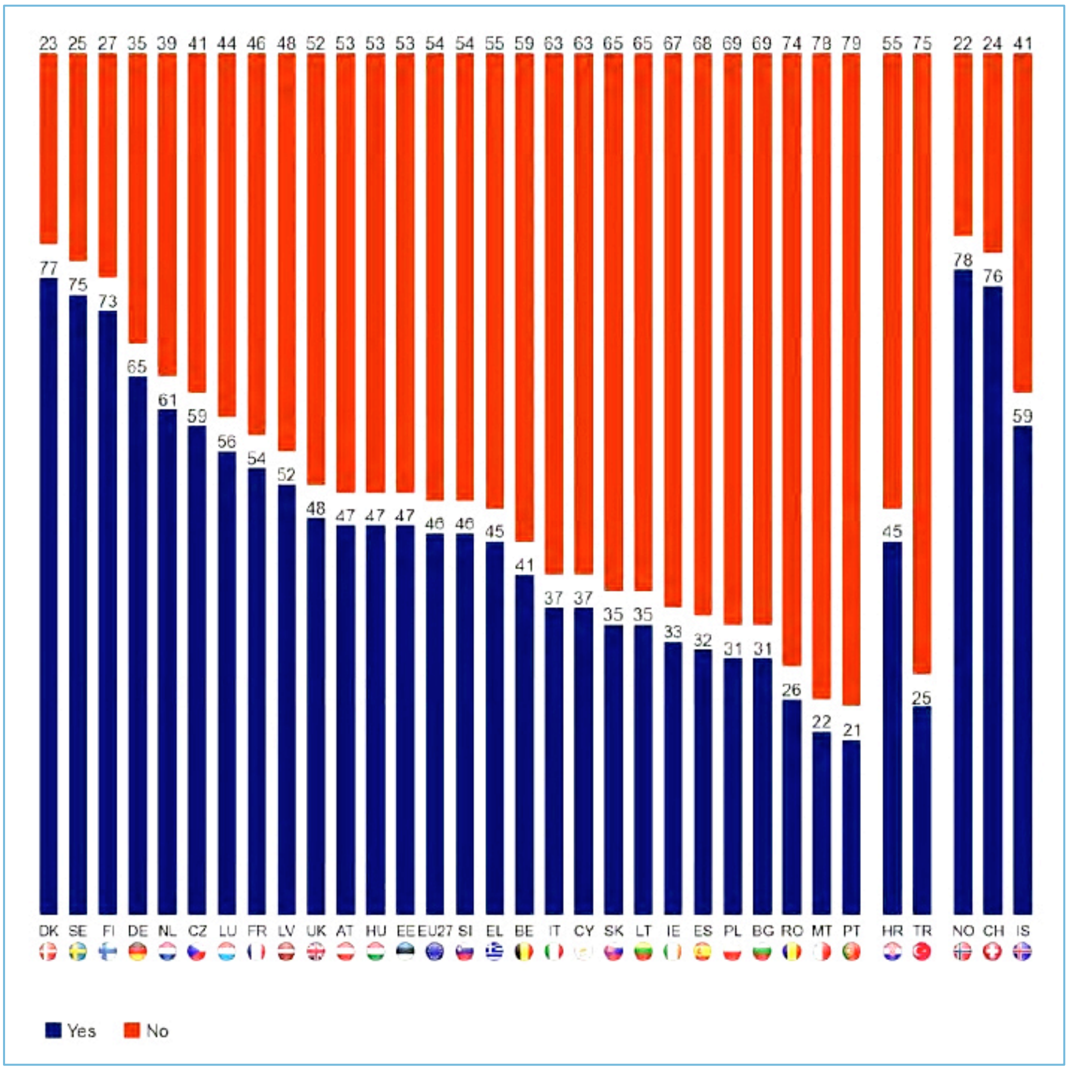

Figure 1. Have you ever heard of nanotechnology before?
Source: Bar chart from Eurobarometer no. 341

In addition to knowledge about technologies, risk perception and also the benefits associated with technology and trust in science are all useful measurement criteria that can be used to understand the reactions of populations. These matters are incorporated in France in an annual barometer managed by the nuclear safety institute (IRSN). IRSN adopted the survey practice to follow the opinions of French people on radioactivity-related risks. The results of surveys are reported annually in the IRSN barometer on the perception of risks and safety, created in 1990 in its current form. A comparison over time was carried out for about thirty topics. Nanomaterials were included in 2009 in the list of topics studied. Following opinions offers, to all actors that contribute to controlling and managing nuclear risk among other things, knowledge about the way in which the greater public puts the different risks into perspective, on its perception of the quality of their management and on its information expectations (Figure 2).

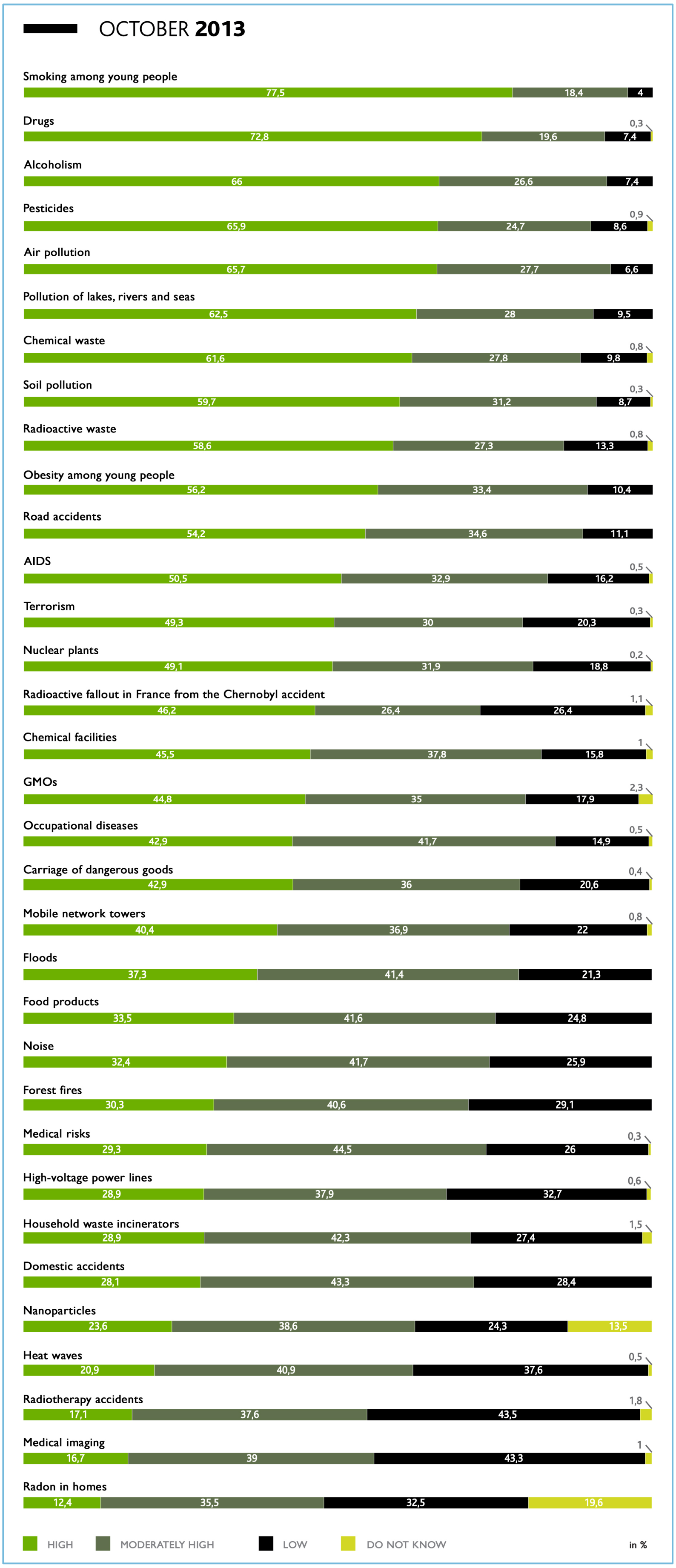

Figure 2. In each area below, do you consider that the risks for French people in general are …
Source: extract from the IRSN barometer 2014 p. 64-65

In the survey results, the subject of nanoparticles (as formulated in the questionnaire) was different to other risk situations for several reasons. First, it was among the topics raising the least concern from a risk perspective (29th out of 33 in 2013), which can be considered positive for the subject. However, for the majority of respondents, they represented a high risk or medium risk (64.2% in total) compared to 24.3% low risk. And with pesticides and soil pollution, it appears as one of the topics which garners the least trust in the French authorities for their protection of people (12% trust, 37.5% more or less and 36% no trust) and especially the greatest mistrust in the information on the hazards (almost 50% mistrust). Nevertheless, nanoparticles, together with residential radon, are the two risk situations which had the least responses about risks (13.5% and 19.6%
in 2013), revealing French people's unawareness about the topic and confirming the results of international surveys on the low level of information provided to the public.

These results are relatively constant across the years, reflecting little change in French people's perception of the subject. This is one of the particularities of nanomaterials, for which there has not been an increase in the information concerning them over time, because of their scientific complexity in particular. Moreover, other studies show that large portions of the population do not have an opinion on the risk/benefit ratio of nanotechnologies in general, a scale that can be tipped either in favour of or against nanomaterials depending on the applications proposed. Indecision therefore surrounds not only nanomaterials but also the ethical position on nanomaterials. Studies on risk perception however, show that the attitude towards ecology is the variable most closely linked to the positions defended with regard to nanotechnologies.

In this context, the uncertainty relating to the decisive factors in the ethical debate on nanomaterials and their regulation is due mainly to the type of nanomaterial applications that may circulate in society and whether they are visible, and also the standards and regulations put in place and the information available on the expected risks and benefits. These elements reveal two hypotheses for the development of ethical regulation and therefore of the future social climate with regard to nanomaterials.

Hypotheses

Hypothesis 1

The first hypothesis is that of a relatively continuous ethical regulation, which enables scientific debate, the expression of diverging opinions and generally recognises the value of the development of the production and use of nanomaterials. The application of the precautionary principle enables the State to maintain an active role in this regulation by regularly informing citizens. The very broad definition of the notion of nanomaterials is preserved thanks to which a balance is struck between the expectations of all stakeholders. Such stakeholders create regular occasions for expressing views and sharing information. Knowledge about nanomaterials, though not widely disseminated, is adopted by civil society actors. Latent controversy can resurge locally with certain investment or application development programmes, challenging individual freedoms (RFID chips and other trackers) requiring information production, but the debate makes way for technical or normative adjustments which provide a clear framework for the activity.

Hypothesis 2

The second hypothesis suggests sporadic ethical regulation, occurring with debatable nanoscience affairs or applications. This regulation leads to a massive rejection of certain products due to moral principles or concerns about their dangerousness. Rejection is based on a discontinuous scientific debate and a conflictive expression of the controversies that are difficult to arbitrate. This context regularly limits the development of production and use of nanomaterials, which intermittently halts research and investments. Mistrust of the State's application of the precautionary principle causes it to lose its traditional arbitration role. The excessively broad definition of the notion of nanomaterials is criticised, distorted; it requires renewals and specific sub-definitions in each field of nanotechnology applications (energy, health, environment, etc.) which calls for specific standards and regulations. The notion of nanomaterial is therefore discarded because it cannot be placed in a homogeneous category. Knowledge about nanomaterials is spread as the market sees fit and is not coordinated at society level given the multitude of characteristics and applications that have been discovered. Each controversy, which is taken up to a large extent by social networks, however fuels the international debate and condemns for a long time the actors of the sector concerned. The lack of coordination generates reservations by the population with regard to nanotechnologies. However, public opinion is less undecided and asserts itself more, both for opponents and defenders of certain applications. The ethical debate is finally resolved locally by arbitration of matters concerning labour, growth and resources associated with industrial processes and research.

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The health risks

Stéphane Binet, INRS and Nathalie Thieriet, Anses

Definition

This datasheet looks at the immediate or long-term risks for human health that are associated with the development of manufactured nanomaterials.

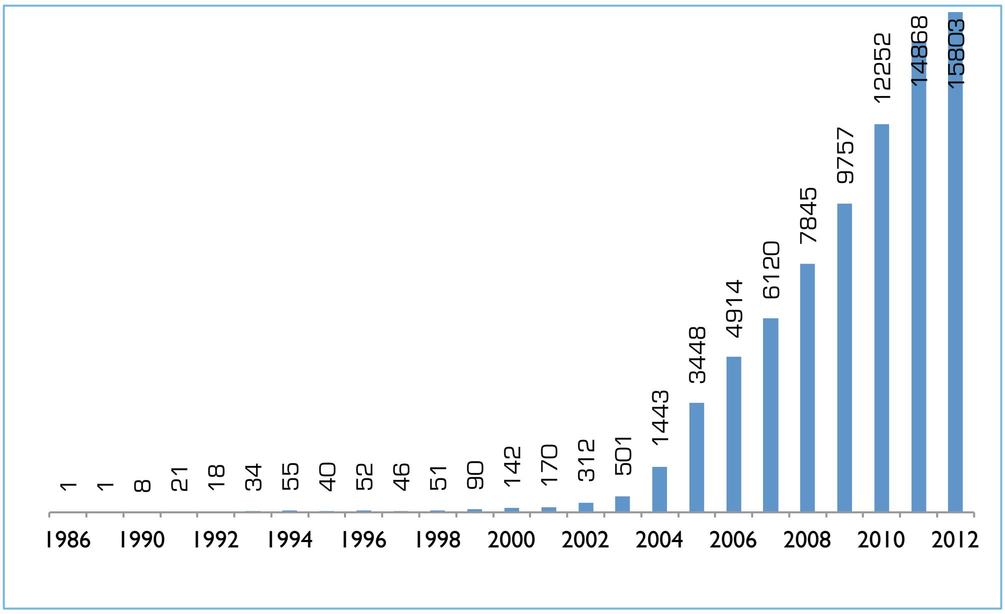
Regardless of the population in question (workers, consumers, etc), health risk assessment is conventionally based on identifying the hazards, defining dose-response relationships, identifying and assessing the exposures, and finally characterising the risks resulting from exposure to a hazard.

Nanomaterials represent a field of research and industry that is expanding rapidly both in France and globally. The potentially exposed population is therefore going to grow substantially, whether the people exposed are consumers or workers in such sectors as food, chemicals, pharmaceuticals, cosmetics, etc.

In France, it has been mandatory since 1st January 2013 to declare any substances in the nanoparticulate state, and, in its first annual assessment, that declaration system revealed that considerable quantities of substances in the nanoparticulate state were produced, imported, and distributed in France in 2012: the total quantity of such substances produced in France was 282,014 metric tons; the total quantity imported into France was 222,090 metric tons; and the total number of categories of declared substances in the nanoparticulate state was in the range 243 to 422.

Although the number of publications on nanomaterials counted in the US database PubMed[1], specialised in medicine and life sciences, is rising steeply (see figure below), studies relating to the effects of nanomaterials on health only account for about 8% of the total number of scientific publications available.

1 http://www.ncbi.nlm.nih.gov/pubmed/



Timeline showing the variation in the number of scientific publications found per year (with "nanomaterial" as the search term) on the website PubMed, which is specialised in medicine and life science publications
Source http://www.ncbi.nlm.nih.gov/pubmed/?term=nanomaterial

Retrospective analysis

Nanomaterials are made up of elementary structures of which at least one dimension is in the nanoscale. This dimensional characteristic can give the materials particular properties or behaviours, potentially offering numerous applications of varying degrees of innovativeness. In view of these possible scale effects, significant differences in assessments of health risks are also likely.

The physical and chemical properties and the biological effects of nanomaterials depend on a combination of parameters, including the chemical nature of the substance, and modulated by other characteristics, such as, for example, the size and shape of the particles. With this logic, the ISO, who set up a technical committee specific to nanotechnologies in 2005 (ISO TC229), identified eight key physicochemical parameters for manufactured nano-objects and their aggregates and agglomerates (NOAAs) to be characterised prior to any toxicological study. In view of the importance of all of these parameters for assessing the risks of nanomaterials, the simplistic paradigm consisting in assigning a single toxicity depending on a single one of these parameters, such as, for example, the chemical nature of the substance, is not acceptable for these objects.

Therefore, not only might the toxicological data available for a substance not necessarily be applicable to the nanomaterials of that substance, but also, following on from this reasoning, the toxicological information collected for a nanomaterial of a given substance (e.g. titanium dioxide) cannot be directly extrapolated to another nanomaterial of the same substance, if their physicochemical characteristics are not identical (for example, the knowledge accumulated in toxicology on gold particles, resulting from studies conducted with particles of dimensions of the order of the micron, cannot be used for gold nanoparticles[2]).

Thus, in order to assess the health risks related to nanomaterials and to their uses, it is necessary to collect a large amount of data, in particular relating to physicochemical characterisation of them. This requirement is even more important when a risk study covers various stages of the life cycle for a nanomaterial, because its physicochemical characteristics can change depending on the stages.

Data is complex to generate

Physicochemical characterisation of the manufactured nanomaterials upstream from any toxicological study is essential in order to identify the objects studied and then in order to make it possible to assess the results of the tests, to compare them with one another, and to help with interpreting them. Although there is currently a broad consensus about this need for characterisation, it remains, *a priori*, impossible to determine an order of precedence for the parameters (i.e. an order of significance or relevance), since such an order can vary from one nanomaterial to another. In practice, implementing this analytical step, and using the results remain sources of controversy.

The analytical methods currently proposed are not always appropriate for studying nanomaterials, and such technical limitations can give rise to research bias. Furthermore, it is impossible to determine a single characterisation technique for any given physicochemical parameter that is applicable to all nanomaterials. As a result, several characterisation methods (analytical technique and experimental protocol) co-exist and the results of the various characterisation methods can be difficult to compare.

Added to these technical complications is an issue of a more fundamental order: certain characteristics, of interest for characterisation, such as the surface charge of the particles or the state of aggregation/agglomeration depend on experimental factors. For example, over time, a sedimentation effect can appear and thus change the initial state of aggregation/agglomeration. Similarly, the surface charge of a nanomaterial can vary depending on the ion concentrations of the solutions used. Thus, for any given nanomaterial, it is impossible for one single value to exist for each of these parameters, but rather results are obtained under particular conditions (scenarios) that must be set in the manner that is most relevant for the biological study in question.

Beyond this difficulty associated with characterising nanomaterials, the guidelines used for toxicological tests on conventional chemical substances are not always appropriate for studying nanomaterials, in the same way as they are not for types of substance that are not soluble in water. Work initiated in 2006 at the OECD to adapt them is still in progress. Currently, there is therefore no commonly accepted experimental protocol that enables the toxicity of these objects to be evaluated with certainty and that is applicable to all manufactured nanomaterials. In order to produce scientifically acceptable results, the toxicological test protocols that are used need to be adapted on a case-by-case basis as pertinently as possible.

[2] Panyala, N. R., Peña-Méndez, E. M., & Havel, J. (2009). Gold and nano-gold in medicine: overview, toxicology and perspectives. *Journal of Applied Biomedicine*, 7(2).

The state of current knowledge does not make it possible to have a general method for extrapolating the toxicological data from one manufactured nanomaterial to another on the basis of the differences in their physicochemical characteristics: each case is specific and deserves to be analysed.

Finally, nothing makes it possible to say that all of the publications on nanomaterials use the same definition of what constitutes a nanomaterial, which adds further uncertainty. Although there is now an institutional definition of nanomaterials that is recommended by the European Commission, the scientific nature of its content is still a subject of debate.

Exposures are complex to quantify and to express

The work done so far in assessing the risks of nanomaterials (Anses 2010; Hunt and Riediker 2011; Kuhlbusch, Asbach *et al.* 2011; Maynard 2007; Olabarrieta, Zorita *et al.* 2012; Van Landuyt, Hellack *et al.* 2014) has highlighted various difficulties, starting with the considerable limitations at exposure assessment level (technical limitations of the existing instruments, distinguishing the specific contributions from manufactured nanomaterials in non-negligent background noise, rapid temporal dynamics, etc.). However, considerable progress in metrology applied to nanomaterials has been observed in recent years, and is tending to reduce these difficulties.

On a more fundamental level, determining a unit of measurement for quantifying nanomaterials that enables the results to be compared currently constitutes one of the major challenges. Although at international level, thought has been given to this subject in recent years, a harmonised system of units does not, for the moment, appear to be emerging that can fully satisfy the criteria of metrological feasibility and of biological relevance.

Thus, the use of mass concentration, which is usual for reasons of metrological simplicity, is being called into question as a means for defining biological effects. It now appears to be generally accepted that the effects of nanomaterials are associated to a greater extent with the developed surface area of those particles during the exposure and/or with the number of particles in question rather than with their mass (Oberdorster, Oberdorster *et al.* 2007). An increasing number of toxicology researchers are expressing and comparing the results of their studies by quantifying the doses used in the form of numbers of particles or indeed of biologically accessible specific surface area, which, however, presupposes that numerous calculation assumptions are made (homogeneous distribution of the nano-objects in terms of composition and morphology, which is rarely the case).

A nanomaterial can change over the life of the nano-product

Although major efforts are being made in terms of toxicological research in order to generate data useful for risk assessment, most of that work is being done on nanomaterials as originally manufactured.

However, nanomaterials are extremely reactive and they can therefore react with their environment and have their properties changed. Analysis of the risks related to a substance presupposes that such changes are taken into consideration.

Gaps in knowledge that hinder proper quantitative assessment of the risks

Proposed for the first time in 1983 by the United States Academy of Sciences (National Research Council), the quantitative health risk assessment method constitutes a tool that is now commonly used for assessing health risks (NAS 1983). Its principle, as defined by its designers, is based on using scientific facts to define the effects on health of exposure of individuals or populations to hazardous materials or situations.

For this assessment approach, expressing the risk is based on combining exposure to a substance with the intrinsic hazard of that substance.

Applied to the case of nanomaterials, the principle of this quantitative approach comes up against the difficulty of estimating the exposure as a function of the chosen scenario and up against the manifest insufficiency of the data, in particular toxicological data, that is specific to the nanomaterial being studied (Anses 2010). Implementing quantitative risk assessment can but lead to identification of gaps in knowledge.

In practice, since the establishment of the REACh European Regulation, any chemical substance put on the market (in quantities greater than 1 metric ton) must undergo hazard assessment by the producer, distributor, or importer. The regulations thus require manufactured nanomaterials to undergo hazard and/or risk assessments, and yet such assessments rarely meet the specificity requirements related to the product itself, and therefore do not guarantee that it is harmless.

In the course of work done for a European project called NanoImpactnet[3], the uncertainties inherent to nanomaterials and lying behind these assessment difficulties were analysed (Hunt and Riediker 2011). Beyond these considerations of availability of information, methodological limitations have been identified that limit application of the quantitative health risk assessment method to nanomaterials (Anses 2010; Boize, Borie *et al.* 2008; Hunt and Riediker 2011). Recent work on nanomaterials would suggest that the biological response could be non-monotonic, i.e. biological effects could be observed only at low concentrations of nanomaterials (Nanogenotox 2012). This observation could be explained by greater bioavailability for low doses of nanomaterials (elementary particles that are isolated at low concentration, but that are aggregated at higher concentrations). This contributes to making quantitative risk assessment even more difficult.

In response to the difficulties raised by nanomaterials as regards health risk assessment, various alternative risk assessment approaches and various tools designed to guide action (risk management) in such a context of uncertainty are currently available. Each method is designed to meet different objectives (e.g.: helping occupational risk prevention, prioritizing risks for nano-products, etc.). It is focused on distinct objects (e.g.: nanomaterials, nano–products, or nanoparticles only, etc.) and for specific targets (e.g.: consumers, general population, workers, etc.). For example, the Scientific Committee on Consumer Safety recently published a guide for assessing nanomaterials in cosmetic products[4]. Therefore, the operating principles and logics that are implemented for them are often heterogeneous.

3 http://www.nanoimpactnet.eu/

4 http://ec.europa.eu/health/scientific_committees/consumer_safety/docs/sccs_s_005.pdf

Prospective analysis

Despite the progress indicated above, knowledge on toxicity and exposure remains patchy and it is still very difficult to give an opinion on the health risk related to using a given nanomaterial in a given product that is used in everyday life.

Systematic case-by-case risk assessment is not possible for taking the current situation into account in the short or medium terms, given the time that would be needed and the extensive of use of laboratory animals that that would imply. Therefore, in order to go beyond the limitations imposed by that approach, it is opportune to develop and to assess the relevance of new, alternative risk assessment approaches, such as:

- risk management approaches based solely on graduated assessment of the risks; certain tools have already been published;
- categorisations by effects or according to physicochemical properties; being thought about but not ready for use;
- the *safe by design* / *safe by process* approaches look like promising alternative solutions that need to be assessed in order to demonstrate their effectiveness.

Furthermore, all these approaches should be systematically accompanied by assessment of the exposure throughout the life cycles of the nanomaterials.

Hypotheses

Hypothesis 1. Unanticipated serious health effects occur

This hypothesis assumes the tools have low predictivity as regards assessing the hazards (health) and the exposures (measurement). Certain nanomaterials (very widespread or accidentally released) whose potential hazards have been under-estimated or ignored cause, after several years, serious and very high profile health effects.

Hypothesis 2. Anticipated serious health effects occur

In this case, we assume the tools have good predictivity as regards assessing the hazards (health) and the exposures (measurement), but that the long-term risk assessment has predicted serious effects for humans (and the environment) for a significant proportion of nanomaterials (or indeed for all nanomaterials indistinctly = systemic risk related to the dimensional characteristics). Absence of political decision, one of the causes of which could be the fear of a major economic impact if use is banned, results in health effects occurring. Same consequences as above.

Hypothesis 3. The health effects are not specific relative to the other chemicals (no crisis)

This hypothesis assumes the tools have good predictivity as regards assessing the hazards (health) and the exposures (measurement). The health risks, which are assessed *a priori* (pre-marketing), are established as being very different from one nanomaterial to another and, generally, nanomaterials do not represent an overall risk for health or for the environment that is specifically higher compared with other chemicals. Each nanomaterial is thus placed in a continuum of effects anticipated by toxicological research: from the most serious to the most insignificant.

Hypothesis 4. Possible health effects without any crisis breaking out

Category-based restrictions on the use of certain nanomaterials used in very close contact with the consumer (food, cosmetics) because, even in the absence of objectively established health effects, it has been proved that those nanomaterials diffuse into our systems and build up in them.

Hypothesis 5. Health risks remain difficult to assess

Currently, the knowledge gap between technological progress and nanosafety research is estimated at about 10 to 20 years. Research is mainly aimed at developing new nanomaterials and nanotechnologies, while the means allocated (all sectors together, both public and private) to research on their potential health effects are insufficient. If high-throughput tools for assessing the hazards (toxicology, etc.) do not emerge, this gap will remain, or indeed widen.

The risks for the environment

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Definition

This datasheet looks at the immediate or long-term risks for the environment that are associated with the development of manufactured nanomaterials (MNs).

The subject of this datasheet is nanostructured particles coming from intentionally manufactured sources (nanomaterials, etc.) and not ultrafine particles in the environment that are also nanostructured but that come from environmental sources (volcanoes, etc.), and from urban or industrial pollution (diesel particles, welding fumes, fly ash, and Residual Oil Fly Ash (ROFA)).

The scope of this variable is suggested by two definitions:

- "the environment" means the ecosystems, i.e. the systems that are each formed by a habitat (biotope) and by a biological community (biocenosis) of all of the species that live there, feed there, and reproduce there (roughly as defined by Larousse);
- "ecotoxicology" is the branch of toxicology that, in a context integrated into the study of the toxic effects caused by natural or synthetic pollutants, looks at the constituent parts of ecosystems: animals (including humans), plants, and microbial life (Truhaut, 1977).

The use of nanomaterials, which is likely to become generalised in the coming years, due to their novel physical, chemical, or biological properties, represents a risk for humans and for ecosystems. A distinction therefore needs to be made, for this variable, between:

- the risks for the general population, through use or consumption of products containing nanomaterials (body hygiene products, medicines, food packaging, clothing, etc.), and through environmental contamination by exposure to waste, drinking water, air, soil (nanoparticles or nano-objects resulting from wear or end of life of nanomaterials contained in tyres, inks, or essences, or deposited on facades, glazing, solar panels, etc.); and

- the risks for the environment (ecosystems) through (1) contamination from nanomaterials dedicated to human use (medicines, packaging, objects, etc.) and (2) use of nanomaterials for any other purpose (decontamination of soil, etc.).

This datasheet only looks at the risks for ecosystems and not the risks related to the effects on human health resulting from environmental contamination:

- the impacts on air, soil, and water;
- the impacts on animals and plants.

When looking at how this variable might change, it is important to remember, as a starting point, that the research efforts concerning environmental fate and potential impacts of the waste generated by this technology are insufficient (less than 5% of the funding devoted to developing new MNs). In particular, the studies about the ecotoxicological consequences of nanomaterials do not include determination of the life cycle and the effects of the nanoparticles (NPs) themselves or those of the pollutants (organic or inorganic) that penetrate into the environment in association with MNs (Gao, 2008).

Retrospective analysis

Some context is given by the considerable quantities recorded in the 2013 assessment of the substances in the nanoparticulate state that were produced, imported, and distributed in France in 2012: the total quantity of such substances produced in France was 282,014 metric tons; the total quantity imported into France was 222,090 metric tons; and the total number of categories of declared substances in the nanoparticulate state was in the range 243 to 422.

Research into the environmental impacts of NPs began late, only beginning in 2006 judging by a bibliometric search on the ISI Web of Science (Kahru, 2010). The same bibliometric search made again in February 2014 also indicated that the growth in this type of research was slow: only 263 records were found with the search words "*nanoparticle* AND ecotoxicity*" [*field: topic*] and 574 after broader search terms were used (*"nano* ecotox*" [field: topic*]). It can also be noted that quantitative data on the ecotoxicological effects of NPs is still rare, be it for simple organisms, for simplified communities, or for entire ecosystems, even though such data is required for risk assessment and for regulatory purposes.

The urgency of the need to understand the biological effects of nanomaterials has produced a growing body of research on the hazards of human or environmental exposure, but, currently, we have very insufficient knowledge on the nature of the nanomaterials that are actually released, on their fate and on the effects of the degraded and aged nanomaterials. Assessment of the risk for ecosystems represents a challenge that is doubtless more diversified than the challenge of assessing human health risks because it involves numerous disciplines: physicists and materials specialists, and also environmental engineers, for quantifying the release of the particles, chemists, biologists, and toxicologists, in order to characterise the transformations of the initial products, the bioavailability and the toxicity in the various food webs (food chains interconnected within any given ecosystem) (Klaine, 2012).

Ecotoxicologists use standardised test methods (e.g. OECD methods), as do toxicologists, and, as a result, they mainly treat nanomaterials in the same way as they do the conventional products for which those methods were designed (Park *et al.*, 2014): they assume *a priori* that nanomaterials behave like soluble contaminants, and they adapt the tests for use within the context of nanoecotoxicology. This decision stems from the fact that (1) developing a test method can take several tens of years, and, in the meantime, nanomaterials are already here, and (2) research on environmental health and on the safety of nanomaterials receives less than 5% of the funding devoted to developing new nanomaterials!

It is now accepted that the biogeochemical processes involved in the fate and transport of nanomaterials after their release include, in particular, photochemical transformation, redox reactions, dissolution, precipitation, adsorption, desorption, combustion, biotransformation, and abrasion, not forgetting modifications in their agglomeration and aggregation properties (depending on surface modifications, and degradation of the coating), and sedimentation (Nowack, 2012). Knowledge of these geobiochemical processes is required for choosing the ecotoxicological tests to be conducted for assessing hazards on a case-by-case basis, and for adjusting these tests to enable them to predict hazards better (Park *et al.*, 2014).

Some examples

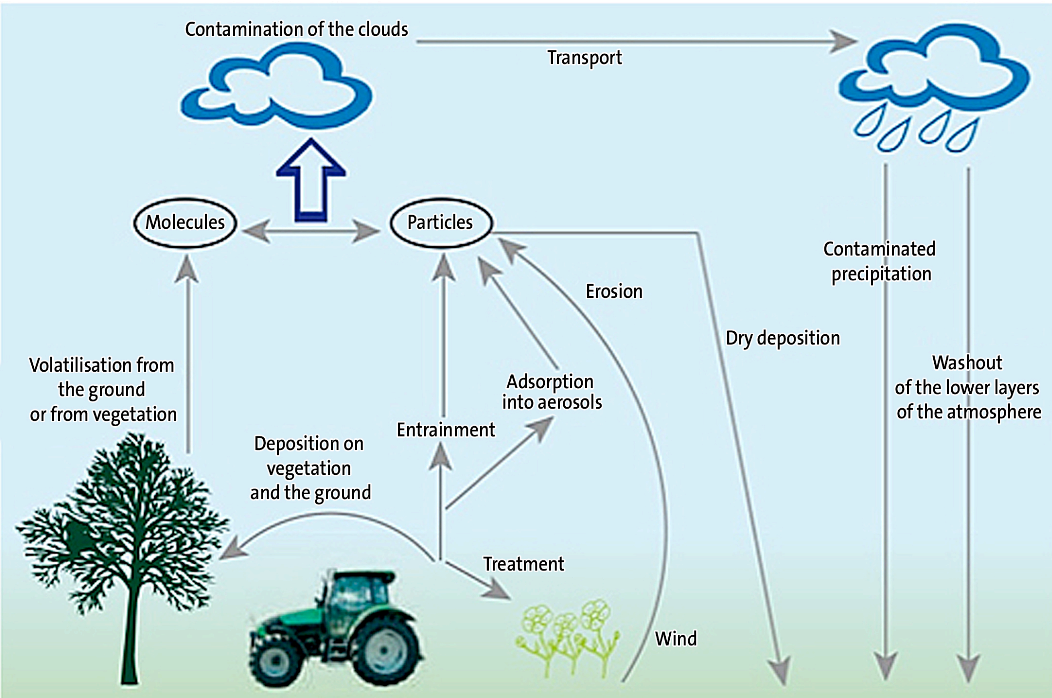
- According to Kahru *et al.* (2010), the test organisms that were most sensitive to NPs (TiO_2, ZnO, CuO, Ag, MWCNTs and C_{60}) were seaweeds and shellfish, revealing the vulnerability of the groups of organisms belonging to the aquatic food chain.

- Nanoparticulate nano-Ag can release the cation Ag+ over a period ranging from a few hours to a few days; secondarily, that cation can undergo transformation into insoluble or soluble Ag salts, influencing the toxicity depending on the redox state of the medium (Nowack, 2012).

- Assessment of the ecotoxicity of the original product is not representative of all of the effects that can occur (Gao, 2008). The mesoporous nanocomposites SiO_2-TiO_2 have large specific surface areas (> 300 m^2/g) and are better photocatalysts than TiO_2: on the basis of these properties, they could be used for purifying contaminated effluent containing organic substances (dyes, etc.; Siddiqa, 2013). Effluent can also contain other toxic substances such as metals (e.g. mercury) that can adsorb into the nanocomposite and then be released during the life cycle of the nanocomposite into natural systems (rivers and streams, etc.). This is an example of the advantages/disadvantages type for which the disadvantages require research to be done on the highly contaminated nanowaste that would need to be treated before it goes to landfill.

- The quantitative nano-ecotoxicological data that currently exists on simple organism models would appear to classify NPs from “very toxic” to “harmful”. None of the NPs studied in the literature review by Kahru and Dubourguier (2010) were classified as “non-harmful”. Currently, neither the life cycles of nanoscale materials nor their impacts on animals, plants, or communities of organisms in the soil have been studied *in situ* even though that would be necessary in order to validate the models proposed for assessing the environmental risks of NPs.

To conclude, nanoparticles are already being introduced into the terrestrial and aquatic ecosystems, and it is likely that the development of nanotechnologies will result in these additions growing, both in quantity and in diversity. Assessment of the future environmental consequences should take into consideration the nature and the scale of the sources, the transfer mechanisms and paths (atmosphere, runoff, direct discharge), the storage compartments (water, soil, sediment), the target species and their interrelations (prey-predator), and the effects on the different populations exposed. However, in view of the diversity and the complexity of the ecosystems in question, the knowledge necessary for the ecotoxicological approach remains insufficient.



The main modes of diffusion of nanoparticles into the environment.
Source: *Débat public* (public debate in France), 2009

Trends for changes in the variable

To enable the effects on ecosystems to be understood or predicted, it is therefore necessary not only to assess the predictability of the ecotoxicological methods, but also to acquire in-depth knowledge of the physicochemical changes undergone by nanos in the environment. The life cycles of nanoparticles, from production to use, and their ends of lives currently remain unknown, and therefore an issue for public health and the environment (OECD, 2013). Thus, various summary articles have highlighted the way in which environmental factors such as calcium concentration, pH, or effects of organic ligands change the behaviour of colloidal nanomaterials and influence their biological effects.

The trend that currently looks most likely is for a widening of the gap between the number of MNs developed and the characterisation of the ecotoxicological risk (to a greater extent than for human health because the related research staffing and budgets are lower), this widening being associated with:

- the inappropriateness of some of our ecotoxicological models for coping with the issues of the initial nanostructured particles and with the degradations they undergo in the environment that worsen or diminish the biological effects of the initial particles;
- the possibility of sudden changes of scale in the way NPs interact with biological systems.

Prospective analysis

What are the determinants of future change in the variable?

To sum up, and in order to make it possible to perform quantitative assessment of the risks, the challenges for environmental nanosafety include (Klaine, 2012): (1) detection and quantification of these materials in biological and environmental matrices, (2) the capacity to predict their fate in the environment, (3) assessment of the risk (ecotoxicity x values of the contaminations including knowledge on the toxic effects of the starting nano, of the nano degraded by staying in the environment, and of several nanos, degraded or otherwise, acting in synergy).

This presupposes:

- developing and validating protocols for assessing the environmental contaminations;
- developing and validating test methods for assessing the ecotoxicity of NPs throughout their life cycles;
- developing and validating models making it possible to predict the potential impact of NPs on ecosystems.

What are the major uncertainties relating to constructing hypotheses?

- Uncertainty 1 concerns the fact that the risks associated with exposure to nanomaterials will be determined only based on our knowledge about the fate of nanomaterials or of materials containing them, i.e. about how nanomaterials will be transported, degraded, and transformed in ecosystems.
- Uncertainty 2 concerns change in the predictivity of the tools for assessing the hazards (ecotoxicology) and the exposures (measurement) of original and transformed nanomaterials.

- Uncertainty 3 concerns the state of research on (1) safe-by-design MNs and (2) optimisation of technological innovations and processes via nanotechnologies.

Hypotheses

Hypothesis 1. Serious ecological health risks (anticipated or established)

Certain nanomaterials that are potentially highly dangerous have had their risks underestimated or ignored, and after several years, cause serious environmental effects to occur (widespread or global dissemination or accidental release, the massiveness of which can vary). This hypothesis is associated either with:

- **low predictivity** of the tools for assessing the hazards and the contaminations (measurement). In general, the knowledge gap between the technological progress and the state of nanosafety research, currently estimated at 10 to 20 years for human health, and probably much greater than that for environmental risks, is not narrowing. Research is mainly aimed at developing new nanoparticles and nanotechnologies, while the means allocated to research on their potential effects are insufficient (all sectors together, both public and private). Harmful consequences are to be expected between the moment of dissemination of certain nanomaterials and the regulatory decision to ban use of them;

- **good predictivity** of the tools for assessing the hazards and the contaminations. Despite an assessment of the long-term risks that predicted serious environmental effects for a significant proportion of nanomaterials (or indeed for all MNs indiscriminately = systemic risk related to the dimensional characteristics), absence of political decision, one of the causes of which could be the fear of major economic impact in the event a ban is put on use, causes serious environmental effects to occur.

Hypothesis 2. Limited ecological health risks, thanks to responsible risk management

The ecological health risks are limited thanks to responsible risk management based on the good predictivity of the tools for assessing the hazards (health) and the exposures (measurement).

Despite widespread or global dissemination of MNs in terms of industrial products, they do not represent an overall risk for the environment that is specifically higher than the overall risks of other chemicals: each NM is placed in a continuum of effects anticipated by ecotoxicological research, from the most serious to the least significant. Knowledge of the environmental risks, assessed *a priori* (before marketing) makes it possible to decided wither to authorise the dissemination of nanomaterials, on a case-by-case basis, depending on the result of the initial assessment of the hazard: in the absence of expected risk or if the potential benefit far outweighs the expected risk (e.g. purification of water, rehabilitation of soil, etc.). If the tools for assessing the hazard *a priori* are predictive, the occurrence of harmful consequences will be limited.

Hypothesis 3. Ecological health risks limited by a safe-by-design approach

Development of MNs that are safe-by-design: e.g. MNs that are stable relative to their use (by humans) but that become degraded or inactive very quickly under environmental conditions. This possibility is preconditioned by knowledge of the physicochemical conditions of exposure of the MNs during their life cycle, after human use.

Hypothesis 4. Nanomaterials as a solution for improving the quality of the environment

Optimisation of technological innovations and processes via nanotechnologies.
The advantages of using MNs easily offset their intrinsic ecotoxicity: for example, clean, sensible, and inexpensive technologies appear that make it possible to save fluids and materials at source, and that limit production of hazardous waste; the technological innovations can concern sectors such as water purification, soil rehabilitation, etc.

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Risk control

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Definition

This variable designates the methods for controlling contamination of the process environment. This can involve:

- protecting the process from external contamination in order to secure the quality of the process and of the products manufactured;
- protecting the workers from dangerous substances emitted by the process;
- protecting the environment from dangerous substances resulting from the process.

All three of these functions are considered simultaneously because, in general, they correspond to the specifications required for the environment of a process. They are often provided by a single (complex) system, e.g. an air treatment system.

Personal protective equipment lies within the scope of this variable.

Relevant indicators

1. Existence of standards specific to nanomaterials or of assessment methods relating to personal and collective protective equipment.
2. Market, number of nano-type facilities installed in France.

By way of indication, the ventilation and air treatment sector is represented in Europe by the industry association Eurovent that represents over 1,000 companies in 13 European countries, those companies employing about 150,000 people and having a combined turnover of over 20 billion euros.

Retrospective analysis

The development of clean room technology resulted from a convergence of needs from military applications, from the manufacturing industries, and from the healthcare sector.

The need to make complex and extremely reliable miniaturised objects (gyroscope, radar, radio, etc.) emerged during the Second World War. In particular, making high-precision miniaturised bearings was made difficult by the presence of dust and of aerosols in workshops. It was during the nineteen fifties, in the United States, that the first micromechanics production lines appeared, maintained in atmospheres in which dust was controlled. The first basic concepts were to be found in those facilities: filtered air, premises maintained under positive pressure, laboratory coats, hats and overshoes to be worn by the workers, etc.

At the same time, some British researchers from the National Institute for Medical Research developed a basic laminar flow system for reducing infection in operating theatres.

Another major contribution was made by AT & T's laboratories when they developed the transatlantic telephone cable. In order to combat attenuation of the signal, they developed repeaters based on electron tubes: 51 repeaters and 306 tubes were necessary. The tolerated failure rate was one failure out of the 306 tubes in 20 years! The tubes were manufactured by workers wearing special clothing to avoid generating dust in rooms that were fed with conditioned clean air.

High-Efficiency Particulate Air (HEPA) filters appeared during the Second World War (to protect the air in rooms at the front) but above all later on and immediately after the War with the Manhattan Project, for protecting the researchers and technicians involved in developing "the bomb". Those filters used asbestos paper and then glass fibre paper. For improved reliability, the military developed test methods and standards in the early 1960s. Those rigorous test methods made it possible to improve performance, and to develop Ultra-Low Particulate Air (ULPA) filters.

A research group from Sandia National Laboratories in Albuquerque, led by Willis Whitfield, was assigned the task of developing a method for maintaining unparalleled levels of cleanness on production lines for nuclear weapons. That is how the concept of laminar flow was developed, and, in 1961 it solved the problem of clean rooms. The team developed a room that was 2.5 m x 3 m; the air filtered by HEPA entered the room from the ceiling and was removed via the floor; the walls of the room were made of metal. The dust level was 1,000 times lower than what had been achieved previously.

A US Federal Standard was developed in 1963 with military personnel and subcontractors in order to standardise the methods of designing, building, and testing clean rooms. Standard FS209, which serves to classify the cleanness of rooms on the basis of their dustiness, enabled the know-how to be disseminated broadly to all industrial sectors across the world. It had repercussions in unexpected sectors, and, for example, by adopting clean-room technology in one of its transmission manufacturing plants, Chrysler was able to offer a 50,000-mile warranty on its transmissions, for the first time.

Prospective analysis

This brief history of the development of clean rooms is based on a publication by Daniel Holbrook in 2009. It shows the speed at which the innovative technology for low-dust environments was developed, and the huge industrial and military repercussions that it had. This technological revolution took place in the space of about fifteen years (from just after the war to the nineteen sixties). Naturally, the military stakes of the Cold War and the related industrial needs were an unparalleled driver of development.

However, it is not unrealistic to make a parallel with the current stakes and potential of nanotechnologies, and to imagine, on a favourable hypothesis (H1), that similar developments might be achieved in mastering the development environments and processes for nanomaterials over the next fifteen years. To illustrate this hypothesis, we transpose below the most significant lessons to be learnt from the history described above.

- The development of nanotechnologies in the industrial, military, and medical sectors requires reinforced control of the processes and of their environments both for reasons of quality and reliability and also for reasons of staff safety.
- New airflow device concepts are developed to attain new levels of cleanness hitherto unparalleled.
- These new classes of cleanness are defined using measurement instruments that offer more precision and that are appropriate for nanomaterials.
- New standards make it possible to codify these environments and these measurement instruments; they contribute to dissemination of know-how and of technologies.
- Conventional industrial applications also benefit from them and this results in an increase in reliability of the processes, of the equipment, and of the products manufactured.
- Occupational safety and health problems are controlled by using robotics and by the positive spin-off from controlling the contamination of process environments.

However, technological obstacles can still exist. For example, due to nanoparticles having specific physical properties, the smaller their diameters the greater their propensity to be deposited on surfaces. Using them can then give rise to serious problems of surface contamination/decontamination.

When they are emitted at high concentrations (e.g. at the end of a manufacturing process), nanoparticles can agglomerate to form complex structures of the fractal type, or be deposited on micron-scale particles. In that case, they acquire the dynamic behaviour of micron-scale particles, which complicates the methods of detection or capture.

It might therefore be considered, in a less favourable hypothesis (H2), that certain nano-aerosols appearing during processes for manufacturing particular nanomaterials could be very toxic with occupational exposure limit values (OELVs) that are very low. The collective and personal prevention means to be implemented should have performance levels that are significantly greater than hitherto.

The manufacturing processes should be implemented under confinement conditions of the nuclear type. Specific sectors are set up, and spin-off at industrial level is very limited.

It is likely that the two hypotheses could co-exist depending on the types of nanotechnologies or nanomaterials in question.

Hypotheses

Hypothesis 1. Risks controlled in all sectors

Risks are controlled in all sectors through development and optimisation of prevention equipment (for confinement, ventilation, filtration, personal protection, etc.). Technical prevention develops in such a manner as to limit exposure in view of the intrinsic dangerousness of nanomaterials.

Hypothesis 2. Risks controlled in some sectors only

Certain nanomaterials require stringent and costly prevention means to be put in place. Technical prevention does not make it possible to achieve exposure levels that are low enough in view of the dangerousness of certain nanomaterials. Risk control is insufficient in numerous enterprises.

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Life cycle and management of waste

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Definition

This datasheet addresses management of waste from products containing nanomaterials over their entire life cycles with a view to reducing contamination of the workplace and of the environment.

Relevant indicators

1. Assessment of the volume of waste produced annually from nanomaterials.
2. Regulations and standards relating to management of waste containing nanomaterials.

Retrospective analysis

Current situation

There are no specific regulations concerning waste containing nanomaterials. In particular, the fact that waste contains nanomaterials is not sufficient to classify it as hazardous waste.

There is therefore no specifically organised channel for collecting and treating such waste.

European Parliament and Council Directive 2008/98/EC on waste defines an order of priority or "hierarchy" in managing waste: prevention of the waste, preparing waste for re-use, recycling, other recovery, in particular energy recovery, and disposal. Naturally, that hierarchy applies to waste containing nanomaterials.

Sorting of waste

Sorting of waste containing nanomaterials is left to the discretion of users (laboratories, industry, private individuals). A survey by the Regional Observatory of Industrial Waste (*Observatoire régional des déchets industriels*) in the Midi-Pyrénées Region of France has shown that certain laboratories or manufacturers have put in place systems for managing this waste that are based on specific packaging of the products, labelling of the packaging, and collection in the same way as for hazardous waste.

Many nanomaterials from domestic use (food products, packaging, cosmetics, medicines, etc.) follow the same path as household refuse.

Air pollution: research work

Ineris (a French national institute working in the fields of industrial safety and environment protection) has been coordinating a 3-year project called "NANOFlueGas", co-funded by Ademe (the French Environment and Energy Management Agency), the aim of the project being to assess the risks related to incinerating nanomaterials and to propose improvements for effluent treatment and incineration processes. The project is seeking to acquire better understanding of the mechanisms whereby nanomaterials might be emitted during combustion, and, through an experimental prototype, should assess the feasibility and effectiveness of effluent treatment and incineration processes for nano-waste.

The project INNANODEP: funded by Ademe, this project is being conducted by the LNE (French National Laboratory for Metrology and Testing) in partnership with the Armines centre (run jointly by the *Centre des matériaux de grande diffusion* (CMGD, a laboratory studying widely used materials) and by the *École des mines d'Alès*) and with the collaboration of the manufacturers Arkema, Nanoledge, and Plasticseurope. It plans to assess the effectiveness of incineration for treating waste containing manufactured nanomaterials. The work will consist in determining the impact of incinerating nanocomposites having polymer matrices on the composition and on the microstructure of the ultrafine particles present in the aerosols produced, in order to determine whether the current fume-treatment means of the incinerators remain appropriate for treating these new types of waste.

Water pollution: research work

Nanomaterials in suspension in water or in other liquids can be discharged into the environment by domestic, urban, or industrial use. The nanomaterials are then transported towards wastewater treatment plants (WWTPs). The sludge from wastewater treatment in WWTPs is generally spread onto the soil. WWTPs therefore play an important part in controlling the dispersion of nanomaterials into the environment. One study predicts that, in the space of four years, the concentrations of manufactured nanomaterials in the soil treated with WWTP sludge in the United States will triple.

Questions arise about the nature of the interactions between the nanomaterials arriving in a WWTP and the bacterial communities constituting the activated sludge, because numerous nanomaterials have cytotoxic effects on the bacteria. Such effects would reduce the efficacy of biological treatments and would, potentially, cause pollutants to be released into the environment.

The conclusions of an expert assessment conducted in the Netherlands in 2011 on the subject are interesting:

- it is plausible that nanomaterials be discharged into the air downstream from the incineration plants;
- for wastewater treatment plants, it is probable that nanomaterials be discharged into the surface water. In addition, there is a risk that sewage plants might be contaminated by nanoparticles that have cytotoxic effects, with, as a consequence, pollutants being potentially discharged into the environment.

Hypotheses

Hypothesis 1. Control of discharge of nanomaterials into the air and into the water

Research & Development progress is making it possible to control the risks of nanomaterials being discharged into the air and into the water, and a channel for treating waste containing nanomaterials is being put in place in various industrial sectors.

Hypothesis 2. Waste management controlled in certain sectors only.

Only certain industrial sectors enable waste to be managed in controlled manner. The ageing of the products containing nanomaterials is generating such a large flow of nanoparticles that it is not possible to prevent air and water pollution (runoff on concrete or glass, for example).

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The scenarios

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Scenario 1. Strong and successful commitment from both State and Industry: massive development

The new driver of the technological revolution

The 2020s have been marked by a succession of major scientific and technical innovations in various fields that have boosted research and production, and have given renewed dynamism to the industrial fabric, in particular in France.

During this period, public and private investment in new and promising technologies has shot up. That investment has contributed to a clear and sustainable improvement in the economic situation, of which industry has taken full advantage.

Among these innovative technologies, nanotechnologies and nanomaterials have already, for some years now, been identified as Key Enabling Technologies (KETs), i.e. technologies essential to the development of a vast range of high added value applications.

The French State, followed closely by French Industry, has thus invested massively in research and development for nanomaterials and associated applications, rapidly removing the majority of the technological and scientific obstacles. The knowledge and know-how acquired has made it easy to succeed in implementing the 4th generation of nanomaterials (custom molecules, scalable systems, etc.).

Sustained support has also been given, in particular by the State, to developing and transferring the results of research by facilitating exchange, bridges, gateways and links between industry and academia. For example, laboratories have been set up that are run jointly by major public research bodies and certain companies.

A highly qualified, though ageing, workforce is available for those laboratories. Strong public policy has led many universities and engineering schools to propose initial and further training in nanoscience and nanotechnology. At the same time, the number of PhD and post-doctoral grants devoted to work related to nanomaterials has also

NANOCONCRETE TO PROTECT THE PLANET *

Concrete is the most widely used building material in the world. Manufacturing cement, which is the main ingredient of concrete, apparently accounts for from 5% to 10% of human-induced carbon dioxide emissions. The minerals going to make up cement have to be baked (clinkered) at temperatures close to 1500°C, which makes cement manufacture an industrial process that consumes particularly large amounts of energy.

On reacting with water, cement creates hydraulic calcium silicate, which is the "glue" that holds together the mixture of gravel, stone, and sand. Hydraulic calcium silicate is a mystery for scientists because its properties, and therefore also the properties of concrete, would appear to be related to its structure, and more precisely to its nanostructure, about which little is yet known.

Research now offers new techniques for studying and understanding the surprising structure of concrete at the scale of the particle. A team of researchers from MIT (Massachusetts Institute of Technology, USA) has discovered that the arrangement of the nanoscale particles making up the cement directly influences the mechanical properties of the concrete, and thus its strength and stability. It would therefore seem possible to obtain different, or indeed improved properties by changing the composition of the cement, provided that the arrangement of nanoscale particles remains unchanged. One idea that is currently being explored is to use magnesium as a substitute for calcium, so as to reduce the energy consumed by cement manufacture.

The possibility of adding other nanoscale objects, such as carbon nanotubes, is also being studied with a view to strengthening the concrete, and, ultimately, to reducing the quantity of concrete used.

With several billion metric tons of cement produced worldwide every year, and constantly increasing needs for concrete, in particular in developing countries, nanomaterials would appear to offer possibilities for reducing carbon dioxide emissions and for slowing down global warming.

* This and the following boxed texts were written by Jan Irmer, journalist.

increased. In order to promote these cutting-edge university courses, recognised both nationally and internationally, awareness-raising actions have been put in place in secondary schools.

This dynamic policy has led to the birth of a multitude of innovative businesses (mainly small or medium-sized structures), partly thanks to subsidies and orders from the State contributing to transforming discoveries rapidly into industrial success stories, and therefore into jobs and growth. Large companies, which have themselves already developed applications that are distributed more widely, thus coexist with a myriad of smaller structures.

Manufactured nanomaterials have thus, for about ten years, been one of France's fields of excellence, boosted by strong involvement from the Government. Public and also private investment has been abundant, conducive to ambitious innovation. The French companies also have genuine reaction capacity through the know-how acquired and mastered over many years. No shortage of raw materials or of energy has been a limiting factor.

The rapid development of nanomaterials, based on a close succession of key technological innovations, themselves resulting from technology transfers from the academic world, has thus translated into a return to pre-eminence for western countries, and in particular for France, in this very cutting-edge field, to the detriment of the emerging economies. Only a few nanomaterials having very low added value and that require little technical knowledge and know-how are produced in the emerging countries, where labour remains cheaper.

Multiple applications in all industrial sectors

Both industry and the authorities in France and Europe quickly understood that, due to their very often unprecedented properties, nanomaterials offered a very wide range of potential applications, and use of them opened up multiple prospects.

Nanomaterials were thus quickly perceived as vehicles of growth and employment in the majority of industrial sectors.

They have led to incremental and disruptive innovations being developed in the sectors of food and agriculture, building, pharmaceuticals, electronics, energy, the environment, transport, cosmetics, textiles, defence, plastics, and packaging.

Through its command of some cutting-edge technologies and know-how, the French chemical industry has been able to meet this pressing demand, which has contributed substantially to its prosperity.

Nanomaterials have therefore swarmed into most markets, also buoyed up by development and manufacturing costs that have remained affordable.

Health and environment risks under control

The health and environment risks associated with manufactured nanomaterials have been issues that the authorities have been addressing since the 2000s. Both the State and Industry very quickly understood that this crucial point could be a real obstacle to the development of manufactured nanomaterials in France. The funding devoted to research, in particular into the toxicity and ecotoxicity of manufactured nanomaterials has grown considerably over the decades, and it has been raised, among other ways, by setting up a tax paid by companies having activities related to nanomaterials and used to set up a fund allocated to independent laboratories.

The many research projects that have resulted have shown that the tools used offer good predictivity not only in assessing the dangers of nanomaterials for human health and for the environment, but also in characterising exposure of the population, of animals, and of plants.

The health and environment risks are thus assessed by companies *a priori*, i.e. before the products are put onto the market, and on a case-by-case basis, the hazards both for human health and for the environment differing widely from one nanomaterial to another. Each nanomaterial is thus placed in a continuum of effects anticipated by toxicological and ecotoxicological research: from the most serious to the most insignificant.

This *a priori* awareness of the risks for human health and for the environment enables companies to put new nanomaterials onto the market when there is no expected risk, or when the expected benefit outweighs the risk run.

It also enables companies, where necessary, to put in place suitable risk prevention, in order to limit the exposure of their employees. In view of the multiplicity of applications for manufactured nanomaterials across most industrial sectors, the salaried population potentially exposed is large (as is the general population). Prevention is achieved through optimisation of conventional prevention equipment (confinement, ventilation, filtration, personal protection, etc.) and thus remains accessible to all companies. It is also accompanied by keeping discharges into air and water under control, and by special-purpose waste management through a specific waste treatment channel.

The regulations, in particular labour regulations, have incorporated a few specificities related to nanomaterials, such as, for example, the relevant metrics for estimating exposure of the general population and of the salaried population.

New technologies well integrated into society

The accelerated development of nanomaterials has not put society off them. On the contrary, after some difficult beginnings, a calm debate established itself between society, experts, scientists, political authorities, and industry.

Against a backdrop of new-found growth, the French State and the European Commission initiated consultation, dialogue, and negotiation with all of the stakeholders, e.g. by organising public consultations.

In particular by publishing a multitude of documents (press articles, websites, executive and summary reports, works, etc.) and by organising stakeholders (employer and employee associations and unions, non-governmental organisations, citizens' associations, etc.) have participated actively in significantly increasing the dissemination of information and knowledge both to the general public and to the working world.

Society has thus readily integrated the technological transformations that have contributed to the development of nanomaterials, as well as the nanomaterials themselves and the associated applications. All the more so since this progress was rapidly identified as bringing significant aquality of life. Nanomaterials have thus enjoyed a steady and consensual rise in society.

NANOMATERIALS TO FEED THE WORLD

To feed an ever-growing population while the availability of natural resources becomes increasingly critical, numerous international organisations, including UN bodies, are recommending sustainable intensification as the future model for global farming production.

The use of nanomaterials in fertilisers and pesticides is one of the paths being proposed to achieve this development.

Incorporating nanomaterials into fertilisers and pesticides could considerably increase their efficacy, and thus reduce the quantities necessary for guaranteeing optimum results. While fertilisers account for 35% to 40% of the productivity in intensive and industrial farming, a non-negligible proportion finds its way into the environment, polluting groundwater, in particular with nitrates and phosphates, and creating chronic eutrophication that causes algal blooms capable of giving rise to dead zones by asphyxiating the biosphere.

Administering nutrients in the form of nanoparticles is also being explored because, since the size of the particles would then be better suited to the pores of the plants and roots, they would be more readily assimilated.

Encapsulating fertilisers and pesticides in nanostructures would also make it possible to improve their efficacy due to it then being possible to control their diffusion and gradual release in the plants depending on needs, and thus to reduce the quantities spread over farmland.

However, although nanomaterials offer numerous possibilities for intensive, high-yield farming, like genetically modified (GM) crops, use of them raises numerous uncertainties about the long-term consequences. And, while the development of these new products has accelerated, in-depth studies and trials remain necessary in order to ensure that all of these innovations are harmless.

Scenario 2.
Informed rejection by society: development in a few strategic sectors

A difficult political and economic context

Since the mid-2000s, the world has been marked by a succession of economic and political crises. In a difficult international and European context, the financial and economic situation of France has deteriorated.

Through lack of will and of means, political support for the development of nanomaterials has been very limited. The public initiatives have only concerned a few rare sectors considered to be strategic. Companies have also come up against major financial difficulties, considerably limiting their research and development efforts. Furthermore, due to increased competition from emerging countries, relocations have become more numerous and have even concerned certain sectors of activity that were hitherto spared, such as the luxury goods industry. Many small structures have not survived.

In this very gloomy context, public and private players have not managed to agree and to organise themselves collectively to react and bounce back. As a result, governance has become very fragmented. Markets are generally not very structured, and poorly organised, which has a negative impact on the profitability of the few rare sectors of activity concerned by manufactured nanomaterials.

The development model called into question

The economic debacle has been accompanied by society calling into question the whole political and economic development model, marked by clear mistrust of anything new. The societal debate is thus unable to advance, in particular on the subject of new technologies.

Various crises (food scandal, medicines having serious adverse effects being put on the market, explosion of a chemicals plant, invasions of privacy, etc.) have led to a loss of trust in the authorities and in industry. Certain companies, in particular in the chemicals, pharmaceuticals and food sectors, have highly degraded images in society. In addition, environmental awareness and the associated concerns have never been so strong in the population.

Civil society is active in speaking out against any discovery considered to be suspicious, through citizens' associations, trade unions, and non-governmental organisations at national and international levels. Each new technology systematically arouses suspicion and is carefully weighed up. It is then the subject of intense communication targeted on both the general public and also the working world. The influence developed by the representatives of industrial firms and financial groups has considerably diminished over the years, in favour of civil society, who is increasingly listened to and followed by political decision makers.

NO NANOMATERIALS ON MY PLATE?

Using nanomaterials in food often raises a fundamental issue of defining what is meant by "nanomaterials". Numerous foodstuffs already contain nanoscale particles naturally, such as milk which can, schematically, be said to be a suspension of protein nanoparticles in water. Similarly, conventional processes for transforming foods also involve creating nanostructures, such as the processes for producing ricotta or mayonnaise.

Currently, one of the main objectives of using nanotechnologies and nanomaterials in food is to control the composition and the structure of the products (improving the nutritional qualities, changing the flavours, etc.). Thus, nutrients in the form of nanoscale particles added to foodstuffs could be more readily assimilated by our systems. Likewise, changing the structures of foodstuffs would make it possible to use smaller quantities of ingredients that are frequently to be avoided, such as salt or fat, while also preserving the tastiness of the food.

Although such innovation possibilities appear attractive, there has been little publicity on the subject. The press has not reported much about this type of new approach, and practically no food industry firm has communicated on the subject of research conducted in this field.

Admittedly the food industry is traditionally conservative, but this silence is mainly due to the trauma of the introduction of genetically modified (GM) crops into food in the mid-1990s, which, in Europe, resulted in society putting up strong resistance, which, for the moment, has stopped them from booming. The outcry over fears aroused by GM crops and the rejection of them are what the advocates of nanomaterials in food are trying to avoid at all costs. This is why research by companies in this field is mainly taking place in secret, only to be spoken out against by a few consumer organisations.

Naturally, this distrust of innovation has had a strong influence on the development of nanomaterials and their associated applications. All the more so since the studies conducted by the scientific community since the mid-1990s on the dangers of manufactured nanomaterials for humans are concordant and tend to show that, even when, objectively, there are no effects on human health, many nanomaterials have a propensity to diffuse throughout our systems and to build up inside them. Similarly, the data collected on animals and plants indicates that several manufactured nanomaterials have possible ecotoxicological effects. The funding granted, in particular by the authorities, for addressing these crucial issues is still insufficient and numerous gaps in knowledge remain.

Against this backdrop, the companies who are at the cutting edge of manufacture and use of nanomaterials continue to apply the highest possible protection methods as regards safety. This strategy could enable them to make a convincing case of their experience to influence future legislative work leading to specific rules being adopted. In other companies, in particular the more fragile ones, efforts to keep risks under control are very often only cursory.

The State is thus confined to strictly applying the precautionary principle, in a context where dialogue between the various stakeholders has quickly become difficult, and where occurrence of health and environmental effects related to the development of nanomaterials cannot be excluded. New regulations leading to banning manufacture and use of certain nanomaterials have thus come into force, which has also contributed to strongly limiting the deployment of nanomaterials.

Research and production that are targeted

The budgets allocated by the authorities and by industry to research and innovation related to developing manufactured nanomaterials and their applications has fallen drastically over the last ten years in view of the economic and social context.

As a result, the technologies developed and the knowledge acquired have not made it possible to achieve development of the 4th generation of nanomaterials (custom molecules), and innovation remains suspended between the 2nd generation (vectors for delivering medicines, sensors, etc.) and the 3rd generation (supramolecules). Similarly, many applications have not been able to reach the industrial production stage. The increasing shortage of raw materials and energy resources, mainly related to the difficulties encountered in extracting them in countries suffering serious political crises, has also led to considerable curtailment in the development of manufactured nanomaterials and their applications.

The little funding that has been allocated has concerned strategic sectors considered as priorities, such as defence, electronics, transport, energy and the environment. Major international companies have quickly but discreetly positioned themselves in these fields that generally procure good profitability for them. A tendency to subcontract to a few VSEs/SMEs is widespread but always done discreetly. However, these small industrial entities are struggling to survive in a context of exacerbated competition, and due to their financial and decisional room for manoeuvre being limited by the big companies for whom they are working.

THE VERY TINY MAKES THINGS GROW BIG

Researchers at the University of Arkansas at Little Rock have discovered that certain nanomaterials could have a very surprising effect on plants, and thus ultimately and potentially on agriculture in general.

They have shown that, when exposed to carbon nanotubes, seeds for crops such as tomatoes exhibit a higher germination rate, as well as more sustained and amplified growth. This discovery could lead to the development of improved plants for the energy sector, by taking advantage of the increase in biomass when the plants are exposed to nanomaterials.

It would seem that carbon nanotubes, which are long and thin, reinforce water absorption because seeds that are exposed to them contain more moisture.

Although this discovery appears encouraging, the use of carbon nanotubes still raises questions. The effects of such nanomaterials on the environment, and their repercussions on our systems and on the food chain remain poorly understood as yet. Various studies have given alarming results: certain carbon nanotubes would even appear to have the same carcinogenic effects as asbestos on mouse lungs.

This research shows the considerable potential of nanomaterials, and it highlights even more clearly the need for in-depth studies in order to be aware of the risks associated with using such innovations.

Public and also private structures have been set up for developing and extracting value from the results of research associated with these sectors alone. Similarly, in spite of a difficult economic context and an ageing working population, the resources earmarked by universities and engineering schools have been sufficient to propose cutting-edge further and vocational training in nanotechnologies and nanomaterials, but that training has been targeted only on these few, carefully identified strategic fields.

The French chemical industry has adapted to this forced positioning and has become specialised in developing and manufacturing custom-manufactured nanomaterials having high added value and intended exclusively for these rare strategic markets. For its part, the very large scale production of "old" manufactured nanomaterials that are more labour-intensive and less technical has become concentrated in the emerging countries.

Nanomaterials confined to a few strategic sectors

The economic context and above all the societal context have led to a drastic reduction in the development of and in the markets for manufactured nanomaterials in France.

Society's riskophobia and technophobia have constrained the State, but above all Industry to invest only in some areas of certain strategic sectors in which the outlets are, furthermore, not in direct contact with the population.

Thus, using manufactured nanomaterials has been completely abandoned in many fields of activity, such as the food industry (including in packaging), cosmetics, pharmaceuticals, and textiles.

The sectors of defence, electronics, energy, transport, and the environment are the only exceptions.

Since society's environmental awareness has increased considerably in recent years, in particular because of continued climate change, manufactured nanomaterials have found numerous applications in the environment and energy sectors. Nanomaterials have, in particular, contributed to sequestering greenhouse gases. Conversely, the use of manufactured nanomaterials for producing ultra-pure water from seawater, or for treating polluted soil has not been developed because of rejection by the population. In the energy sector, gradual abandonment of nuclear power has made it possible to develop manufactured nanomaterials for alternative energies, and in particular for storing hydrogen, and for new generations of photovoltaic cells. A financial effort has also been made by industry to develop more efficient insulating materials incorporating nanomaterials, in order to limit household energy consumption.

The tense international situation, which has seen lasting international conflict, has contributed considerably to the development of manufactured nanomaterials in the defence sector, in particular for manufacturing robots and drones.

In the field of electronics, the trend for many years now has been for increasing miniaturisation of components. Nanoelectronics have been booming in France since the early 2020s, supported by substantial European public funding. Numerous unprecedented and highly innovative applications have been developed, such as nanosensors making it possible to monitor the presence and the degree of biodegradation of pesticides, and also systems making it possible to prevent automobile collisions, to optimise fuel consumption, etc.

The automobile, aerospace, and boating sectors have worked together to develop a host of unprecedented new applications that incorporate nanomaterials, with the aim of proposing transport means that are increasingly light in weight, while consuming ever less energy, and polluting to an ever smaller extent.

NANOWARFARE FOR ALL

Arms have always been one of the main drivers of technological research, and so, naturally, military leaders have been very interested in the use of nanotechnologies and of nanomaterials. Although most of the innovations developed concern military equipment and engineering, some can be used for designing new weapons, capable of killing and destruction.

The United States Department of Defense has demonstrated the feasibility of a new weapon: powerful and compact bombs that use nanometals such as nanoaluminium to create ultra-high combustion chemical explosives that are much more powerful than conventional bombs.

However, the considerable power of these explosives is itself exceeded by the mini nuclear bombs currently being developed in the United States, Russia, and Germany. These devices, whose manufacture is related to the progress made in nanotechnology, could sweep aside all of the schemes supposed to be limiting the proliferation of weapons of mass destruction in the world. Although its power could reach the equivalent of several hundreds of tons of high explosive, the size and weight (less than a few kilograms) of such a thermonuclear bomb are minute. These devices would contain only a very small amount of fissile matter or even none at all, giving rise to almost no radioactive fallout, which, technically, would mean they would not be weapons of mass destruction. However, their miniaturisation would make them much more likely to be used.

Furthermore, while nanomedicine can deliver medicines to precise organs in the human body, bioterrorists could, using the same techniques, diffuse highly toxic substances to the most vulnerable organs of their enemies.

Nanotechnologies could therefore take potential destructive malevolence into a new dimension, well beyond that of the weapons of mass destruction possessed by nation states, because this horrifying power could fall into the hands of extremist groups.

Scenario 3.
Industry in the driving seat: development in growth sectors only

Unwavering industrial support for sectors deemed to be growth areas

The period from 2015-2030 has been marked by a continuation of the 2007 crisis: periods of low or no growth, in alternation with periods of recession. Although the political will to keep up innovative research and production activities in France was clearly manifested, it was not seen through in practice. Despite stringent budget constraints, some funding and some successive public support plans were granted, without however managing to secure the continuity necessary for developing ambitious and innovative projects. The results did not live up to ambitions or hopes, despite some conclusive progress, and so public contributions became even thinner.

The budgets allotted to research and development by the State in France thus gradually diminished, even in the field of new technologies, which were hitherto spared. The public initiative has clearly marked time. It has been taken over by private initiative, but only in certain sectors deemed to be growth areas.

A few companies of international calibre, who are robust and dynamic, in the sectors of pharmaceuticals, electronics, energy, and transport have invested massively but rationally and in highly targeted manner in research and development for certain manufactured nanomaterials and their associated applications. Those industrial companies have driven the markets to become structured in order to develop, and, in particular, they have used standardisation to achieve that. Standardisation has thus been reinforced and has become a genuine strategic tool enabling companies to make sure that they are competitive. The States have not been the drivers in these dynamics, and all they have managed to do is to go along with industry.

This race for radical innovation has enabled industry rapidly to reach production of the 4th generation of nanomaterials (custom molecules, scalable systems, etc.), and to develop unprecedented applications. However, some scientific and technological obstacles still remain in view of the very precise positioning of the funding granted for innovation.

Many public structures dedicated to developing and extracting value from the results of research were located in France but they were not very effective, and so companies set up private platforms specifically designed for transferring these technologies and discoveries. Most of these platforms were cross-border ones, offering human and material resources that were pooled with a view to supporting the development of the companies. Similarly, specific skills networks led by industrial companies were set up internationally, while the national networks marked time. The complexity of the development pipeline (research, implementation, industrial validation, etc.) required investment in transnational networks.

In order to help them in this perpetual quest for innovation, the big companies cooperated in, and indeed financially supported, the creation of a host of small and medium-sized structures of the start-up type. These entities have generally performed subcontracted assignments for the benefit of the major groups, but they have also developed, in-house, some promising innovations for markets with low or moderate distribution prospects.

In this tense economic context, with a significant increase in the number of unemployed, the French education system, through lack of resources, was no longer capable of delivering initial training that was satisfactory in all fields. However, with sustained help from some industrial companies, initial and vocational training in nanotechnologies and nanomaterials has become an island of excellence in France. University courses focused on certain sectors have been proposed as have many PhD and post-doctoral grants targeted on applications.

DIAMONDS ARE FOREVER

In May, 2014, a team of researchers from the Universities of Bremen, in Germany, and Stanford, in the United States, published the results of their work on the bactericidal properties of nanodiamonds that were only a few nanometres in size – i.e. 200 times smaller than a bacterium.

Their efficacy in killing specimens of the two main classes of bacteria could lead to them being used in practical applications as additives in disinfectants or for surface coatings, constituting an innovative alternative to silver and copper nanoparticles, which are already in widespread use, but to which some bacteria would appear to be developing resistance.

These nanodiamonds, formed in soot during explosion of carbon compounds in a high-pressure environment, were discovered by Soviet scientists in the 1960s, but actually using them in the laboratory only became possible a few years ago.

Although the reason for which these particles destroy bacteria so effectively and quickly still remains a mystery, researchers suppose that this property is due to the acid anhydride groups present on the surfaces of nanodiamonds. Conversely, it would seem that under no circumstances could they be used as antibiotics because they lose their action on coming into contact with body fluids. At the same time, according to the researchers, this is what makes them harmless for human cells.

A manufacturer has already shown interest in incorporating them into cutting fluid in order to avoid formation of bacterial biofilms in its facilities. However, it remains to be demonstrated whether nanoparticles can be efficacious against whole colonies of bacteria.

As for the researchers, they are now planning to explore incorporating these antibacterial nanoparticles into materials used for making surgical implants.

It remains to be seen whether, in terms of cost, these new bactericides can also compete with silver and copper nanoparticles. For, although the price of the raw material is low, it remains costly to transform. Industrial-scale manufacture would doubtless lower the costs significantly.

Impoverishment of the public debate

In a society in which individualism has largely defeated collective initiative, and in a context marked by the State having a role strictly limited to doing its sovereign tasks, the public debate has become considerably poorer. Exchange with civil society on political and economic directions has diminished. The State has lost some of its legitimacy since the occurrence of the crisis in 2007 and the ensuing ongoing recession. The social divide has also widened, with strong opposition between a minority of the working population who are well-off and older, and an increasing proportion of the population who are becoming poorer and less secure. The health and environmental issues are of less concern to that growing proportion of the population who are feeling the full force of the effects of the economic recession. The pressure exerted by society to ensure that any risks for health and for the environment are anticipated is thus only very moderate and only concerns a thin slice of the population.

A BLACK SO DEEP IT BECOMES FLAT

Coating objects with a coat of black that is so deep they take on the appearance of flat holes is potentially important for developing stealth weapons. It would be even more surprising to have everyday items that look like black spots.

*This reality has just become more likely with the novel material called "*Vantablack*" that British researchers have developed. It absorbs 99.965% of light, breaking the previous world record held by NASA with its material* Superblack*. Its capacity to absorb light wipes out any three-dimensional appearance of the objects it covers – it is so dark that the eye cannot understand what it is looking at.*

Vantablack *(which owes the first part of its name to an acronym for "Vertically Aligned NanoTube Arrays") operates somewhat similarly to an anechoic chamber having walls covered with foam wedges, because it is made up of a forest of carbon nanotubes that absorb any residual light that their neighbours might have reflected. The light is thus lost in the forest and is transformed into heat.*

The main use of light-absorbing materials is in optical instruments, especially in ultrasensitive telescopes where any light reflected by the components generates noise interfering with the resolution of the image. The coats of black paint conventionally used do not absorb all of the light, and light pollution always remains a problem for such instruments.

In addition, this new material retains its good cohesion, so that it avoids any crumbling that, in the past, made similar projects unviable when dust fallout caused background noise that was too high. In addition, its thermal stability and structural strength make it a suitable candidate for building orbital telescopes.

Its manufacturer, Surrey NanoSystems, confirms that military applications are also being studied, but secrecy issues prevent that company from communicating on this subject.

The price has not been indicated either, but it is very high. It is thus unlikely that Vantablack *will, in the near future, be found on everyday objects, amusing as that would be.*

Conversely, pressure groups representing the interests of industrial firms and of financial groups remain highly mobilised and organised, and their influence with the weakened public authorities is growing considerably. The political weight of the groups defending the economic interests is thus by far outstripping that of the few non-governmental organisations, citizens' associations and trade unions still active in France and in Europe.

It thus falls almost exclusively to companies to communicate about the new products they develop and bring to market, such as manufactured nanomaterials and their applications, without any genuine dissemination of knowledge being sought, or any exchange being organised, the worse they need to fear by way of negative publicity being possible scepticism from the population.

Health and environment risks not assessed

The health and environmental risks of manufactured nanomaterials have been mobilising scientists since the mid-1990s. However, as of 2015, the continued economic recession led Europe and its Member States to limit considerably their involvement in funding of studies and research projects on the subject.

Industry thus stepped in to replace the States, but only partially, by funding certain areas of academic research and by developing private research relating in particular to making nanomaterials and their applications safe by design.

However, that funding for studies on the risks of manufactured nanomaterials for human health and for the environment, has been insufficient, and the knowledge gap between technological progress and nanosafety research has widened unceasingly. The health and environmental risks still remain difficult to assess.

Through lack of scientific progress making it possible to establish the exact nature of the risks of particular exposure to each nanomaterial, the law has only changed marginally on the subject. Deregulation of the labour market has increased considerably and individual contracts between the company and its workers have become the rule. In this context, the companies that are the most prosperous in manufacturing and using nanomaterials, and that are generally the largest, apply stringent and thorough protection methods as regards safety, with the aim, in particular, of retaining qualified labour. This strategy could enable them to make a convincing case of their experience to influence future legislative work leading to specific rules being adopted. In other companies, in particular the smallest ones, efforts to keep risks under control are very often very incomplete.

A majority of sectors of activity have decided not to develop the use nanomaterials

The food, textile, and packaging industries have had to cope with a lifeless internal market, and very strong competition from Eastern European and Asian countries which offer the advantage of having cheaper but increasingly well qualified labour. The development and manufacturing costs are thus prohibitive in France and cannot be passed on to the sales price in view of the low purchasing power of a large majority of the population. Therefore, the use of manufactured nanomaterials in food, textiles, and packaging remains of merely anecdotal interest.

In an ageing society where the cult of youth reigns supreme, demand for cosmetics and care products is growing. However, in the cosmetics sector, research and development investment into use of manufactured nanomaterials has been highly targeted because the market has been considerably limited by the economic recession. A few top-of-the-range products incorporating nanomaterials have been developed and are being marketed in small quantities for demanding customers who are generally well-off and are therefore but a few.

Finally, with the international situation becoming more peaceful, with only a few very localised conflicts of limited intensity remaining, and with ever-shrinking public budgets, the use of manufactured nanomaterials in the defence sector has been reined in considerably.

A few rare dynamic growth sectors

In the pharmaceuticals and healthcare sector, nanomedicine is in an increasingly predominant and unavoidable position because of its positive long-term effects on health and of its reasonable costs. The budgets allocated by companies to innovation in France have grown unceasingly. Research is thus very dynamic and fruitful, and the transition to the industrial stage is taking place easily. The French industry has become highly competitive internationally, and nanomedicine has become one of France's areas of excellence. The external markets also offer numerous prospects even though the French market is showing a marked downturn due to decreased solvency.

In the field of electronics, the trend for many years now has been for increasing miniaturisation of components. Nanoelectronics very rapidly imposed itself in France as a key sector of activity, supported by major financial efforts for innovation granted by major industrial groups in Europe, and by means of ready access to strategic metals in the world. A multitude of original applications have thus been developed and brought to market, such as nanosensors guaranteeing development of strains of plant that withstand unfavourable climate conditions, or equipment for screening and early diagnosis of rare

A NANO-NETWORK FOR DIABETICS

Nanomedicine is booming. And what better subject for research than a disease affecting the lives of over 356 million people across the world, including 3 million in France, and of which the number of sufferers is constantly increasing: diabetes.

Diabetics, both type 1 and type 2 sufferers, have to fight continuously to cope with the failure of their body to produce insulin, or with its incapacity to make effective use of the insulin it produces. Their first daily constraint is to check their blood glucose level regularly, on pain of suffering complications such as cardiovascular diseases and irreversible damage to the retina, kidneys, and nervous system.

A team from North Carolina State University is attempting to develop systems that could make it possible to mitigate pancreas failure directly. Professor Zhen Gu and his team are using nanotechnologies with the aim of creating an artificial substitute for beta cells in the islets of Langerhans in the pancreas that normally release insulin for countering high blood glucose levels.

They have developed an injectable network of nanoscale sensors. Nanoparticles are coated with films whose electric charge (positive or negative) enables the nanoparticles to fit into the mesh of a network once they have been injected under the skin.

When the blood glucose level is high, the network would degrade in order to release insulin. The core of this "nano-network" is formed by nanoparticles of Dextran loaded with insulin and with enzymes specific to glucose. High levels of glucose activate these enzymes to convert the glucose into gluconic acid, decomposing the Dextran and releasing the insulin to control the blood glucose level.

The team has announced that one of these networks has already maintained normal blood glucose levels for about ten days in a mouse with type 1 diabetes, and work is apparently in progress to make it biocompatible for humans and to optimise it so that its response speed corresponds to the cells of the pancreas. Professor Zhen Gu's team is also experimenting with the use of ultrasound to trigger, from a distance, release of insulin by the same implanted network.

These innovations could not only free diabetics of the obligation to be continually checking their blood glucose levels, but above all could make the process more accurate while also reducing the need for regular injections with insulin.

diseases, etc. France is one of the world leaders in nanoelectronics.

The building and civil engineering sector has, since the 2000s, been investing in implementing new innovative applications incorporating nanomaterials, and this has secured their deployment in most buildings and on most roads, e.g. for the purposes of improving strength of materials, safety, and impacts on the environment and energy.

In the energy sector, the steady rise in the prices of gas and electricity, and of raw materials, has led the industry to increase research funding considerably with a view to developing renewable energies, in particular by using nanomaterials and nanotechnologies.

Finally, the aerospace and boating sectors have been deploying effective efforts, including cross-cutting ones, for several years now. This synergy has made it possible to enrich French know-how and to develop a range of innovations that, for the most part, incorporate nanomaterials and nanotechnologies: reduction in emissions, increase in energy efficiency, etc.

The French chemical industry has organised itself to meet the needs of these growth sectors as well as possible, and has become specialised in developing and manufacturing custom-manufactured nanomaterials. For its part, the very large scale production of the less advanced manufactured nanomaterials, that is more labour-intensive and less technical, has become concentrated in the emerging countries.

Scenario 4.
Sustained regional will: development based on local skills

A dynamic Europe of regions

The 2020s have seen significant economic growth return to developed countries, in particular to Europe and France. This recovery is due to a large extent to the emergence, after many very difficult years, of a Europe that is strong both politically and economically. This Europe sees itself above all as a Europe of regions, rather than a Europe of nations. A clear drop in unemployment and a rise in consumption have come with this return to growth, in particular in the most dynamic regions. The European and French industrial fabric as a whole has been stimulated, and production has been boosted. The wealth and the living standards of European society have increased very significantly while political crises continue in Africa, Asia, and the Middle East.

In this favourable economic, political, and social context, the wealthiest regions, some of which are cross-border ones, have invested massively in innovation and new technologies, and in particular in the field of manufactured nanomaterials, while applying for European funding, and while making use of a dynamic local industrial fabric.

Depending on the specificity of the local industrial fabric, which very often matches the academic research already located there, the funding is targeted on precise sectors of activity. The European public funding granted for developing manufactured nanomaterials and their applications has been supplemented by a sustained financial effort by industry.

In order to encourage this dynamic process, Europe and industry have been acting in coordinated manner through standardisation structures like CEN (the European Committee for Standardization). These entities, which have enjoyed increasingly recognised legitimacy, have gradually gathered together all of the expertise necessary for preparing technical, general, and sector-based standards.

Research focuses that depend on local skills

However, the boom in manufactured nanomaterials and in associated applications remains slowed down or indeed obstructed in France, and also in other European countries, by the absence of clear and assertive national political will on this subject, and by a resulting lack of coordination.

Since each region, even if it is a cross-border region, focuses on highly targeted sectors and applications, pooling of acquired knowledge, expertise and know-how is sometimes laborious. Exchange and collaboration has been developing, with some difficulties, while research work has remained rather compartmented and economies of scale are often very limited.

Thus, despite numerous and conclusive discoveries, which have not been hindered by major constraints related to availability of energy and of raw materials, the scientific and technical progress has not enabled researchers systematically to achieve development of the 4^{th} generation of nanomaterials (custom molecules, scalable systems, etc), and innovation has remained, depending on the disciplines, sometimes blocked between the 2^{nd} generation (vectors for delivering medicines, sensors, etc.) and the 3^{rd} generation (supramolecules).

Certain processes and applications have also been struggling to go beyond the laboratory stage to the pilot or industrial production stage, even though numerous public and also private structures have been put in place that are located within precisely identified territories and that are dedicated exclusively to developing and extracting value from the results of research associated with particular target sectors. Clusters of competitiveness, as well as business nurseries, incubators, and technopoles focused on the development of manufactured nanomaterials and of their applications have thus been set up throughout France. The skills networks specifically dedicated to nanomaterials, such as C'Nano, that were set up in France in 2004 have disappeared in favour of networks focused on given sectors of activity and located locally.

Given the multiplicity of the sectors of application in question, numerous small or medium-sized enterprises have, through support from Europe and the regions, been able to invest in the field. They coexist with large international companies already fully involved in developing and producing nanomaterials and associated applications. These smaller entities generally perform subcontracted assignments for the benefit of the major groups, but they also develop, in-house, a few promising innovations for markets with low or moderate distribution prospects.

Economic recovery has brought increasing initial and further training needs, both for ensuring that the ageing indigenous population remains employable, and also for training a large immigrant workforce. Helped by the private sector, which is always looking for qualified labour, and by the regions, a vast range of initial and further training in nanotechnologies and nanomaterials, focused mainly on very precise sectors, is proposed by the universities and engineering schools. The regions are also awarding an increasing number of PhD and post-doctoral grants.

Serious health and environment risks that have been poorly anticipated

The health and environment risks of manufactured nanomaterials have been issues for civil society and for the authorities since the mid-1990s.

However, the budgets allocated both by Europe and by the regions relate essentially to the development of new nanomaterials and associated applications, to the detriment of research relating to their potential risks. A major gap therefore remains between the technological progress associated with nanomaterials, and what we know of their possible impacts on health. This is despite the fact that the tools available not only for assessing the dangers of nanomaterials for human health and for the environment, but also for characterising exposure of the population, of animals, and of plants show only low predictivity.

In spite of this poor knowledge of the risks and in the absence of political decision at national level, the development, production, and marketing of manufactured nanomaterials is intensifying with the possibility that certain nanomaterials whose potential hazards might have been underestimated or ignored give rise to serious effects on health and the environment in the coming years.

In this context of uncertainty, the companies that are most flourishing in manufacturing and using nanomaterials are implementing the highest possible protection methods as regards safety, without however knowing whether they are sufficient. In other companies, in particular the smallest ones, efforts to keep risks under control are very often highly deficient.

Civil society shows unabashed indifference

The new-found prosperity and the shared fruits of it have placated the population, in particular in the more privileged regions. And yet, society has undergone profound changes related to the development of numerous new technologies, including manufactured nanomaterials, but it has integrated them without any significant difficulty. All the more so since this progress was rapidly identified as bringing a significant improvement to quality of life.

The debates about which directions to take have abated to a large extent, with citizens putting their full trust in decisions made by Europe. Civil society has thus, over the years, become passive or even indifferent about both economic and political choices, while proclaiming the right to be indifferent and being unabashed about it, with western societies appearing as havens of peace in a chaotic world bogged down in various ongoing conflicts.

In this context, the pressure exerted by society to ensure that any risks for health and for the environment are anticipated is thus very moderate and only concerns a minority fraction of the population. Some dialogue is however being proposed at regional level between the various stakeholders, but the dissemination of knowledge and information about the emergence of new technologies such as nanomaterials remains limited, through lack of public interest.

WHITER THAN THE SUN

Titanium dioxide has, for many years now, been used as a pigment, the famous "titanium white", in particular because of its remarkable light refraction properties. It is present in many everyday products, from the white lines on tennis courts to toothpaste and processed cheese (the additive E171).

It is also used, in nanoscale form, in sun creams as an absorber of ultraviolet rays. It enables a cream to be obtained that is highly protective while also remaining transparent due to the size of the titanium dioxide particles.

But it is other properties that make nanoscale titanium dioxide the star in increasingly numerous and promising applications.

Nanoscale titanium dioxide has photocatalytic activity, i.e. under the under the effect of light, it enables decomposition of certain organic and inorganic matter to be accelerated.

Nanoscale titanium dioxide is thus being incorporated into a multitude of materials that then acquire self-cleaning, depolluting, and disinfectant properties.

Buildings and roads can thus contribute to depolluting the air, packaging can protect its contents chemically, and it is even possible to imagine a sofa whose impregnated fabric cleans itself in the sun.

In addition, a surface provided with a coating based on nanoscale titanium dioxide and exposed to ultraviolet radiation offers no retention of rainwater, which can thus run off more easily, this property being known as "superhydrophilic", reinforcing the self-cleaning effect, and, for example, leading to the antifogging and antifouling glass that has been marketed since the early 2000s.

Other uses are also being studied, such as the use of nanoscale titanium dioxide, for photovoltaic energy production, and even for electronic data storage.

However, fears exist on the subject of risks both for humans and for the environment that are associated with this promising nanomaterial. Its ecotoxicity remains poorly known, and diffusion of nanoparticles could have harmful effects on ecosystems.

In the meantime, titanium dioxide is one of the nanomaterials that is the most produced and the most used in the world, and it would appear that this boom is tending to become bigger.

THE GRAPHENE REVOLUTION

A material that is going to revolutionise the world: graphene.

This material, which is a sheet of pure carbon, is so thin (the thickness of a single carbon molecule) that one gram would suffice to cover an area the size of a football pitch. It has properties that make it 200 times stronger than steel. Flexible and transparent, it conducts electricity and heat better than any other material.

These peerless properties make it a material of choice for building a totally innovative technological world, with flexible equipment, electronic clothing, or computers that interface directly with the cells of the body.

While people had been theorising for decades about its existence, graphene was only isolated for the first time in 2004 by researchers from the University of Manchester, who were later rewarded by the Nobel Prize for Physics in 2010. And since then, this incomparable material has been attracting ever-increasing attention.

It would appear to have innumerable applications. It enables electronic equipment to be produced that is thinner and faster than silicon-based equipment, with the added advantage of making it transparent and flexible. Graphene-based batteries charge fast and they last.

Graphene is not corroded on coming into contact with liquids, graphene-based electronic items are immersible, to the extent that, thanks to their smallness, they could be incorporated into biological systems, in other words they could be implanted in the body at cell level.

In April 2014, Samsung, in Korea, announced it had developed transistors made of graphene on a silicon film, while IBM, Nokia, and SkanDisk researchers have used the material to create sensors, transistors, and backup memory.

It remains to solve the issue of the cost of this electronic "Grail". While, only a few years ago, it was being said that it would cost 600 billion euros to produce one square metre of graphene, and in 2009 only two companies were capable of producing it, numerous projects have been launched since that have made it possible to cut its manufacturing cost very considerably.

Graphene, if it were very cheap, would have the potential to change our world, much like plastics and semiconductors did in the last century.

Nevertheless, the pressure groups representing the interests of industrial companies and of financial groups remain highly mobilised and highly organised. They are increasing their influence with Europe very considerably on regulatory issues. This sustained pressure, coupled with an increasingly deficient French State, has resulted in very little change in European and French regulations.

Clusters of excellence in the regions

Many European regions, most of which are cross-border regions, have invested in specific sectors considered to be strategic or growth areas, mainly based on the local economic fabric and on the public research bodies already located there.

Clusters of excellence have thus been set up throughout Europe in the fields of electronics, food, pharmaceuticals, cosmetics, textiles, energy, packaging, and plastics. The use of manufactured nanomaterials and nanotechnologies has contributed to a large extent to the image of technological success of these sectors, and thus to the wealth of the associated regions.

Only a few sectors, such as defence, remain in the hands of the States. This field has also experienced major development because of the persistent conflicts in Africa, Asia, and the Middle East. Manufactured nanomaterials have also contributed greatly to the manufacture of new robots and drones.

Against this backdrop, the French and European chemical industry has remained very competitive and has developed numerous custom innovations designed for each one of these sectors.

The impacts of the scenarios on occupational health and safety in France in small enterprises, and the consequences on prevention needs

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Consequences for occupational health and safety of Scenario 1

In the context of a major technological leap forward like the one described in Scenario 1, there is an accelerated development in the number of new nanomaterials, coupled with an increase in the capacity to assess their toxic properties (and those of chemicals in general). The risk assessment methods benefit both from this technical and technological progress and from the corresponding financial dynamics. In other words, tools and money are available not only for innovation and production, but also for risk prevention. Although the toxicology of certain new products is not always fully known, it is usually possible, by using elaborate structure-activity relationship models, to categorise new products correctly and to put in place a suitable level of occupational (and environmental) risk prevention. This dynamism is supported effectively by various specialist bodies in France: social security's occupational risk prevention network, occupational health services of companies, the labour inspectorate, and inter-company structures dedicated specifically to risk prevention issues in the smallest entities. It is also helped by a context of particularly active negotiations between social partners that has led to numerous industry-wide agreements being signed.

The many SMEs/VSEs [1]who are active in the sector of nanotechnologies (be it for developing, manufacturing, or using nanomaterials) benefit from this progress and from this favourable climate. Their command of the processes has improved by taking advantage of all of the technological progress. This also applies to phases such as maintenance or cleaning and for operations related to waste (treatment, and depollution of facilities or of sites), because knowledge of the hazards, technical progress, and less restrictive economic and time constraints enable prevention measures to be implemented satisfactorily during such phases and operations. The collective and personal protective equipment necessary for performing these specialist operations has undergone major developments during the period considered in the exercise, in particular in terms of specificity (the right equipment for the right hazard), of effectiveness, and comfort. A corollary to this facilitated use of

[1] Small and medium-sized enterprises / Very small enterprises

protective equipment is that the residual constraints that such equipment continues to put on the user are taken into account to a larger extent both in companies and in the regulations, through provisions for adjusting methods and work pace.

This favourable outlook should, however, be toned down due to the specific context of the highly dynamic development of nanomaterials. The continued appearance of new products and the short "industrial life" of some of them compels companies to adapt their facilities continuously: the risk thus lies in a gap opening up, even transiently, between such adaptation and the real health and safety needs. Here the concept of the end of a technological cycle takes on its full significance: production can have started a major change corresponding to a new cycle, without the occupational risk prevention means having incorporated the necessary changes.

The context is also favourable to there being a profusion of initiatives that can lead to the company not having sufficient command of the development in certain cases: a one-product start-up who might struggle to find the means for subsequent development of the product, use of facilities that are not properly suited to producing a new product whose future is still uncertain. The safety culture of the company might find it hard to cope with these rapid changes. And, in the same way, the in-house health and safety structures might not be able to keep up with the pace of change of the company. The mobility of staff who change structures, encouraged by the dynamism of the activity, can be an obstacle to proper monitoring and traceability of their exposures.

By means of the progress made in toxicology, and in particular of the use of structure-activity relationship models, the level of prevention can be adapted to the risk: nanomaterials are considered to be either chemicals or hazardous chemicals. However, in conjunction with the above-mentioned dynamism of the activity, circumstances in which these good practices fall short do exist: for example, development or production of new nanomaterials in semi-wholesale facilities whose emissions are insufficiently collected, or use of such products in basic formulations of the manufacturing industry (for manufacturing resins or pre-compounds, for example) in pre-mashing phases during which respiratory exposure is potentially very high. In the same way, the exponential development of production and use of nanomaterials has led to them now being present in a very large number of buildings or of consumer goods. Towards the end of the period, concerns start to be raised about the capacity to identify the most dangerous ones during equipment recycling operations or during maintenance and cleaning operations on building fixtures and fittings, in particular in the smallest entities.

In terms of immediate health risks, it is, however, accident risks that predominate: whether it be in terms of physical or mechanical risks related to failure (or insufficient command) of the facilities, or in terms of respiratory or skin exposure of workers. Conversely, the dynamism of the economic activity and the rapid changes in production would suggest that such malfunctioning would be temporary: the social dynamics and the regulatory framework mean that a defaulting company ceases rapidly to trade, even if it then re-starts on other bases with new equipment.

In addition, ageing of the working population is an important contextual feature. The technological leap forward that has taken place in the industrial world has made it possible to automate certain tasks (in particular by using physical assistance robots) so as to reduce physical arduousness and so as to put distance between the workers and the potential sources of exposure. And yet this ageing population, faced with an acceleration in industrial development and with the appearance of new production techniques, is encountering problems: the dynamism of the activities related to nanomaterials might make it difficult for this population to adapt. Although the economic situation for companies is generally comfortable, the economic and industrial upheavals are exerting non-negligible pressure on the working world at all levels.

Venus Beauty

In 2024, in his Warsaw clinic, Dr Zabik, a cosmetic surgery specialist, develops Nanozabine, a substance made up of various nanoparticles and that, once injected under the skin and activated by radiation, almost entirely halts the visible effects of ageing on the skin by blocking any further change in the tissues. Once it has begun, treating the skin with Nanozabine must be reiterated every month, otherwise there is a risk that the skin will age prematurely and be covered with blemishes.

Although the scientific community and the press are highly critical regarding the incalculable risks and the constraining nature of the method, this preservation "miracle" is very popular with wealthy clients seeking eternal plastic youth.

After having been administered only in Dr Zabik's clinic, Nanozabine now enjoys a limited marketing authorisation for Poland, from where it is imported by the back door by several establishments who offer their services in administering it in France.

This applies to the Élysée Jouvence medical beauty institute, where Isabelle, a cosmetic care nurse, works. On the instructions of the doctor trained by Dr Zabik, she, among other things, injects Nanozabine under the skin of the patients, and then places them under ionising radiation to activate and consolidate the injected Nanozabine.

Although the safety measures specific to the medical field are complied with at Élysée Jouvence, one day, while Isabelle is about to inject Nanozabine under the skin of a patient, the syringe slips out of her hand. It then sticks itself into her forearm: a fraction of the dose is injected intramuscularly on the inside of her arm.

Isabelle immediately follows the protocol to be applied for this type of accident, and, in the absence of any precedent, the doctor in charge deems that the risks run by Isabelle are low since Nanozabine is injected into patients. Isabelle therefore goes straight back to work, administering several Nanozabine treatments to patients in the hours and days that follow.

During these treatments, the activation of the substance by ionising radiation also exposes Isabelle to the radiation, which is sufficient to trigger the reaction of the Nanozabine that she accidentally injected into her arm muscles. The motricity of the muscles starts to decrease, strongly adversely affecting the dexterity she needs to do her job.

Consequences for occupational health and safety of Scenario 2

In this scenario, development of nanomaterials is, like the political and economic contexts, difficult, except in a few sectors of activity. When they started to be developed, nanomaterials received only very meagre support from the authorities (who had only very meagre budgets) and the market took over only insofar as rapid return on investment could be foreseen. In the other sectors, no investment was made because, following in the wake of serious health crises, nanomaterials were received with the utmost distrust from society, as were innovations in general. In particular, this has led to the companies that use them retreating into themselves to a marked degree, and wanting to protect themselves from the eyes and questions of the public. We thus remain in a niche market logic with no prospects for generalised development in the short and medium terms. In this unfavourable economic context, the fact that certain producers and users of nanomaterials (or of materials containing them) are positioned on economically strategic sectors nevertheless ensures they enjoy good profitability. However, in view of the attitude of society, those enterprises are showing the same level of discretion or indeed of secrecy.

The public systems for occupational risk prevention are therefore not welcome in a context of opacity: their resources and their capacities for intervention are, in any case, very limited. And yet, societal pressure means that, in particular through unmitigated application of the precautionary principle, the few interventions from the State can have serious impacts on companies who work in cutting-edge technology fields, in particular those who produce or use nanomaterials. Generally, the companies are working in a context where the legal risks are high.

This limited general development is mirrored in the toxicological studies devoted to nanosciences: with very little funding, a small number of research laboratories work on the toxicological effects and struggle to assert their existence amidst a substantial amount of scientific popularisation literature more focused on the approximative and on the sensational than on scientific rigour. Knowledge of the hazards is therefore very deficient.

The few producer and user sectors have taken this situation on board. The high-visibility large companies in the growth sectors (energy, transport, etc.) limit as far as possible the use of nanomaterials at their own facilities. The tendency to subcontract to small industrial structures of the VSE and SME type is very widespread and strongly imbued with discretion, even though the number of VSEs/SMEs manufacturing or handling nanomaterials remains relatively limited in view of the narrowness of the market. Due to the unfavourable economic situation, those enterprises are themselves subjected to exacerbated competition, and therefore have little decisional and financial room for manoeuvre in dealings with the big companies for whom they are working (even though some of those big firms can be generating significant margins, as mentioned above). To remain competitive, production equipment and facilities are continuously adapted, as well as is possible, depending on the companies and on the manufacturing, to suit the nanomaterials produced or used: investments are low, and some equipment and facilities are old. As a result of this forced flexibility, the issue of process safety is a pressing problem in all of the phases of the processes in those small enterprises.

This also applies for maintenance or cleaning operations, for which personal protective equipment (PPE) is the essential (or indeed only) resource for risk prevention, without any in-depth studies having been able to be conducted on how effective such equipment is. The waste treatment and depollution sector is in the same situation: uncertainty about knowledge of the hazards, difficulties involved in adapting to situations for which the basic risk assessment data is deficient, and the exposure knowledge is fragmentary, risks related to defective process safety, etc. The context has not led to specialist know-how emerging, and the companies handling the maintenance or cleaning operations indiscriminately apply pretty much the methods developed previously for preventing risks encountered with conventional chemicals. The same applies to operations on equipment coming to the end of its life or to recycling operations that take place in a context of opacity and of deficient knowledge of the risks.

In this context, the enterprises concerned at all levels of the production chain are subjected to different types of risks, mainly related to the possible malfunctions in the processes and to organisational defects (high time constraints):

- fire and explosion;
- multi-exposure to all types of hazardous chemicals, including certain nanomaterials: these aspects are particularly significant in this scenario, in view of the lack of stabilised information on the toxicity of nanomaterials; it is naturally mostly medium-term and long-term toxicity that is involved;
- mechanical risks; and
- risks related to handling and to postures, in particular in a context of high constraints related to production requirements (forced and random adaptability of industrial structures not designed for such versatility).

Some of these risks are further reinforced in a context of high unemployment and of an ageing working population, subjected to high demands at the work station. The resources devoted to training are also limited.

In view of the pervading riskophobia, of the nanomaterials being rejected by society, and of the culture of secrecy generally adopted by industry (both the big firms and the subcontractors working for them), workers can be faced with ethical conflict situations. The confrontation between their professional practice and the dominant opinion might lead to paradoxical instructions, through being officially required to comply with strict procedures (highly recommended due to societal pressure), without having the means to apply them. Psychosocial risks thrive in an atmosphere favourable to them. Risk perception by workers is all too often expressed through euphemism or denial.

Effective monitoring of the workers is made difficult for several reasons: the dedicated structures lack intervention means, and there is a lack of transparency on the working conditions in the VSEs/SMEs, who are themselves often deprived of information from the big companies they work for. The exposed workers being dispersed in small enterprises does not facilitate knowledge of the risks through job studies or epidemiological studies. But, in view of the questions being asked by society on the issue of nanomaterials, monitoring is maintained. Ultimately, it often seems more symbolic than genuinely effective.

Nano start-up

In 2026, Nanozorg is a small start-up that produces additives for special, high added value resins. This production uses an ultra-confidential process whereby metal nanoparticles are combined at very high temperature and under high pressure in a controlled atmosphere containing xenon.

Due to the high toxicity of the materials used by Nanozorg, the occupational physician has blood tests done on all of the staff in order to detect any presence of these nanoparticles in the systems of the people involved in the production process.

Unfortunately, the results of these analyses show an abnormally high concentration in one of the engineers of the team, Karim, even though he has not been in direct contact with actual manufacture of the additives.

To keep the manufacturing processes secret from competitors, Karim builds the special ovens in which the additives are prepared. This activity, which generates a large quantity of extremely fine dust, is performed with minimum precautions in the workshop adjacent to the one in which, with a great many precautions, Nanozorg produces its additives.

Building the oven requires parts made of a special composite material treated thermally to withstand the very high temperature and pressure conditions. Unbeknown to the Nanozorg team, these plates of resin contain the nano-additives that they manufacture.

The Nanozorg additives are delivered to the company Plastiplak who incorporate them into the resins it produces. These resins are then purchased by the firm Moule-Insar who use them to manufacture moulded plastics parts for industrial use. The plastic parts marketed by Moule-Insar are based on a range of products produced by the company Thermarefortex who subjects the parts to thermal and physical treatments in order to enable them to withstand high pressures and heat.

It is precisely the parts supplied by Thermarefortex that Karim uses to build the Nanozorg production ovens. The manufacturing secrets jealously guarded by each of the companies involved, and the ever smaller proportion of initial ingredients used at each stage of production have led to the toxic nanoparticles used disappearing from the Thermarefortex product datasheets.

This is how Karim, who had never set foot in the high-security production workshop of the company, found himself with a high concentration of these nanomaterials in his blood after being exposed to the ultrafine dust coming from machining the plastic parts for the ovens.

Consequences for occupational health and safety of Scenario 3

Although the development of nanomaterials has not involved all sectors of industry, it has had major impacts on certain activities, in which the technological progress could be considered revolutionary. In France, in particular, pharmaceuticals & healthcare, energy generation, and electronics have seen their activities revolutionised and made much more dynamic. The progress made has been all the more remarkable since the overall economic situation has remained difficult. In a context of considerable weakening of the State (reduced to doing no more than its sovereign tasks), it is these sectors of activity who have made the entire technical and financial effort: research development, industrialisation, and worker training. However, knowledge of nanomaterials remains fragmentary, with toxicological research having stood still. It is not a priority for industry, the State does not have the means to support it, and civil society is not putting any pressure on them to have it done.

Deregulation of the labour market is almost complete, and individual contracts between the company and its workers have become the rule. Risk prevention is left entirely to industry. It is therefore mainly guided by a rationale of preserving the "production tool", and the essentially insurance-based response is expressed mainly in terms of compensation and not in terms of primary prevention. Similarly, recognition of an occupational disease is left to the civil courts, and requires evidence.

For all that, occupational risk prevention has not disappeared. But, depending on the choices made by the company, it is often developed to a much greater extent in the largest companies that want to preserve and retain qualified labour - which has become rare in a context of general ageing of the working population - and for whom they bear the cost of their training to become qualified. The regulatory arsenal for dealing with occupational risk prevention matters, that had already been cut back compared with what existed at the beginning of the period in question, has been further lightened for small enterprises.

Through this contrasting picture of the occupational risk prevention situation in the various companies, we can clearly see that there is a major disparity in the monitoring available for workers: it is high-performance in certain cases, or no more than ineffective individual monitoring at the worker's initiative, conducted by structures who are more or less specialised, or indeed by the worker's own doctor in certain cases.

Research spin-off in the form of start-ups has developed considerably. The rationale behind it is an outsourcing logic whereby large companies can be more flexible and reactive by subcontracting work to SMEs and VSEs. In view of the differential between wage and social protection levels, work having low added value and/or higher risks is often entrusted to small enterprises. However, some of them do play significant parts in innovation and new product development. They can even have developed specific skills that give them a preferential position (relative to the average subcontractor) in relations between the large companies and their subcontractors. The social relations in such enterprises with special skills can then be of the type described above for the larger structures.

Occupational risks in SMEs and VSEs are logically related to this dependence and to this obligation to be reactive. And yet, the overall picture is a very contrasting one. The high level of requirements in a sector like pharmaceuticals, and the dangerousness of some of the products (including intermediate ones) that are manufactured (in particular in nanoscale form) means that stringent rules have to be complied with, in particular for operations that are not directly related to production, such as facilities maintenance or waste treatment. Thus, decontamination of equipment is of crucial importance between production of any two batches, and protection of the finished product requires very high performance decontamination of the facilities, and therefore effective protective clothing to be worn by the operator, who should, under no circumstances, be able to pollute the products. Conversely, in other cases, the absolute need to preserve the product (e.g. by means of pressure relief devices) can give rise to particular difficulties in protecting workers. Generally, the high cost of the finished products, resulting from the rarity of certain ingredients (precious metals, and genetically engineered molecules), and from a succession of numerous reactions and purification operations, is also a good reason for making sure that good general safety standards are achieved during production and maintenance operations. The picture is a similar one for most of the enterprises in the nanoelectronics sector. Conversely, other industrial sectors, engaged in producing lower added value products, are not subjected to the same constraints.

This applies, in particular, to the building and civil engineering sector, which is a case in point. Since the early 2010s, these industries have been incorporating nanomaterials into various structural and surfacing materials (concretes, asphalts, glasses, plastics, etc.). These nanomaterials can be incorporated either at permanent facilities (of the off-site ready-mix concrete plant type) or just before the materials are used on the building sites, and so the possible uses in small enterprises therefore vary, as do the prevention means. The issue of risk prevention also arises during subsequent work on the materials containing the nanomaterials: asphalt milling, sanding, demolition, deconstruction, etc., naturally with the question arising of how to identify them.

It is therefore impossible to provide a general picture of occupational risks for small enterprises, because those risks are so dependent on the situation of each enterprise. SMEs and VSEs can have to cope with process accidents, with the ensuing risks of fire, explosion, and acute poisoning. Depending on the degree of development of the manufacturing process, the type of accident and the levels of risk are very variable: low for highly automated processes, and much higher for facilities that are more flexible and that involve a higher proportion of human intervention. The same applies to the risk of musculoskeletal disorders, and more broadly to physical risks, which depend to a large extent on the type of work organisation that the enterprises should (or have the leeway to) put in place.

Conversely, given society's indifference to the development of nanomaterials (considered as ordinary as any other product produced by manufacturing industries), psychosocial risks should be at a low level. Nevertheless, the high technical level of certain production processes (in particular in pharmaceuticals and nanoelectronics, as already mentioned) can lead to extremely stringent levels of protection for workers: isolation from the outside world, absence of contacts with colleagues, highly demanding levels of quality required for the work in view of the economic stakes, restricted movements, etc. Independently of the relationship society has with nanomaterials, these conditions under which tasks are performed can themselves adversely affect well-being at work, in particular since they can be accompanied by problems related to heat (wearing personal protective equipment), to constraining postures, etc.

Agricultural fibrosis

In 2027, José is 38 years old. He is a farm worker in Picardy. After working for years for the same cereal farm, he was hospitalised after suffering a seizure in a field. For many months prior to that, he had been suffering from a chronic dry cough that had even driven his partner to sleep in a separate room, because she found José's coughing and wheezing disturbed her too much. José also felt extremely weak, had lost a lot of weight, and found he had great difficulty breathing, but he put all that down to his anxiety about his daily difficulties.

In the hospital, while the X-ray of his lungs did not show any anomaly, the CT scan gave clear indications that were then confirmed by a biopsy: José was suffering from pulmonary fibrosis, the causes of which initially appeared mysterious because none of the conventional origins of this disease were identified.

But José had been spreading fertilisers on his employer's maize fields for years. Those fertilisers contained, in particular, recycled sewage sludge.

The residual sludge from wastewater treatment offers a good feed of nutrients for crops. Using it on fields is common practice throughout the world. From 2014 to 2027, the proportion of sewage sludge spread on farmland and forestland grew from 60% to 85% in the United States, and from 34% to 72% in Europe.

However, the artificial nanomaterials used in numerous fields often find their way into urban wastewater, in particular silver and titanium dioxide nanoparticles. That is where these particles build up, and, since the sewage treatment plants do not have any equipment for filtering them out, they are to be found in the residual sludge.

Furthermore, increasing numbers of technological innovations for treating wastewater and for depollution use nanomaterials, which further increases the concentration of nanomaterials in the residual sludge. While they are being spread on farmland, these artificial nanoparticles are released into the atmosphere, with all of the ensuing possible toxicological consequences for public health.

Although the case of José is only an anticipated possibility, in 2014, already, cases of pulmonary fibrosis were reported in the United States that had occurred after spreading sewage sludge containing artificial nanomaterials, which is concordant with the results of studies showing pulmonary pathologies in laboratory rats exposed to nanomaterials.

Consequences for occupational health and safety of Scenario 4

With the Europe of Nations having been deemed to be a failure, political organisation giving the regions pride of place has been preferred, since that is considered to be a better way of taking up the industrial and economic challenges and of satisfying the desires and needs of the citizens. This version of federalism is based, in particular on the asserted capacity of the regions (often cross-border regions) to develop fields of excellence based on the specificities and the strengths of their academic and industrial fabrics. Although geographically contrasting and while allowing substantial disparities to remain, the results have materialised, and the overall economic situation has improved throughout the period in question.

The same regional specialisation model has also been applied to nanomaterials, with the result being a corresponding specialisation in the user manufacturing industries. This has given a dense mesh of small and medium-sized enterprises operating in networked manner, and very well backed up by structures of the chamber of commerce type deployed, in particular, through clusters of competitiveness. Naturally, these regional structures also address occupational safety and health issues and, as regards governance, apply the rules decided at European level, based on co-management between employer associations and trade unions. The medical monitoring of workers meets very general requirements defined at European level, but it is specified in more detail and steered by the regional bodies. This co-management is taking place in a context in which societal debates, in particular on nanomaterials, appear to have been pretty much put to sleep, in particular due to the pervading prosperity.

Although the economic results have been good, the technological results are more mixed: some developments have fallen short of the level that was hoped for. Over-specialisation of each region and insufficient pooling of knowledge at European level have been blamed. Obstacles slowing down the development of new types of nanomaterials have also been identified, such as insufficient assessment of their toxicity, delays in industrialisation of the new products, and slowness of change in the existing processes. All this has been accompanied by a more major role being given to standardisation, resulting from a drive to seek compromise. Furthermore, although in view of the specialisation of each region, trade with other regions and further afield is considerable, from the point of view of human resources, local considerations predominate: worker training is very much focused on local needs, and companies play a predominant part, in particular through their relations with the local university. Training constitutes a major issue insofar as the disparities between the regions and the labour shortage in some of them have led to considerable intra- and extra-European immigration.

As regards occupational risks, although accident and disease rates remain constant, they mask what is, in reality, a contrasting picture: a gradually decreasing rate that has levelled off at a very low level for the vast majority of activities, while being marred randomly by a few accidents, some of which are very serious. The studies and investigations commissioned following such accidents generally put the blame on insufficient assessment of the risks related to new innovation parameters being improperly introduced into processes that are generally considered as being safe.

These statistics on accident and disease rates mainly concern accident risks. The studies devoted to occupational diseases are, for the most part, mainly descriptive (reporting cases): the minimum standardisation required at European level is insufficient to enable the available data to be collated relevantly (and above all effectively) beyond the regional level. Since the level of toxicological knowledge remains generally low and since toxicology is not considered to be a priority when distributing budgets for the clusters of competitiveness, no risk assessment dynamic has been generated, in particular for assessing occupational risks. A few health alerts have been triggered at regional level, without it having been possible to take the investigations very far (the uncertainty remains), or for their results to have aroused any reaction at regional level, or for the issue to have been addressed at European level: at the level of each region, the relevant staffing levels remain low. In particular, these alerts have been triggered in sectors like the finishing/fixtures & fittings trades of the building industry, during maintenance or renovation work, or in activities such as recycling of consumer goods. However, in view of the relative newness of the nanomaterials that are in most widespread use, little is yet known about the consequences of exposure to them, in particular since few chronic toxicity studies have been conducted. However, conducting epidemiological studies in a context of an ageing working population, whose total length of exposure to nanomaterials is increasing, could provide data in the coming years.

Thus, although, as indicated above, companies generally have good command of the processes, in particular thanks to the experience they have acquired over time, their command of specific operations such as, in particular, maintenance and cleaning/decontaminating the facilities is often less good. In the clusters of competitiveness who have invested in these issues, in particular because the volume of activity on the local market justified specialist companies being set up who fitted into the local industrial fabric well, the consequences for occupational health and safety are analogous to those described for scenario 1; the risks are mainly accidental against an overall backdrop of operations that are performed well.

Conversely, when the critical mass is not reached locally, non-specialist local companies can intervene in a wide variety of processes, both in the field of nanomaterials and in other industrial sectors. Here, we find the characteristics of scenario 2, marked by a high accident and disease rate, even though the economic conditions under which the work is done are much more favourable.

However, at the same time, since these production support activities are very widespread, some large companies have developed such activities at European level, which offers feedback and relative standardisation of the techniques that are used. But, since preference has been given to the regions, those companies are constrained to have a strong local presence through setting up subsidiaries. The consequences for occupational safety and health are then those described in scenario 3. The local subsidiaries can benefit from the analysis capacity acquired through the knowledge pooled by the parent company, but the prevention measures adopted can sometimes lack specificity or relevance.

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