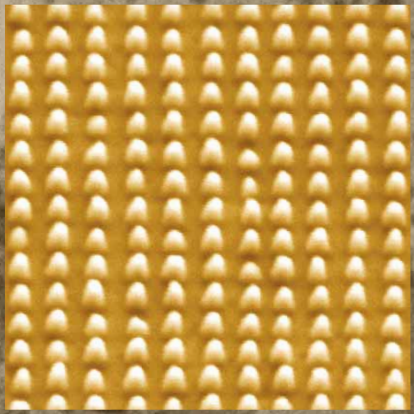
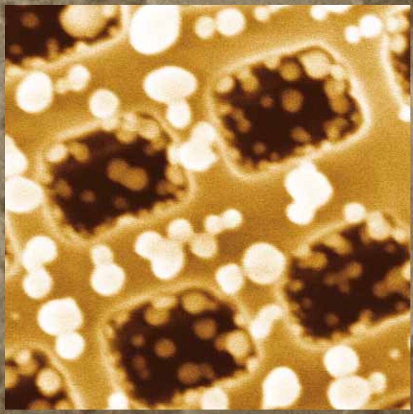
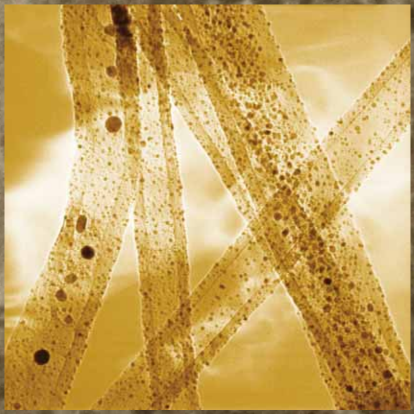
COMMISSION DE L'ÉTHIQUE DE LA SCIENCE ET DE LA TECHNOLOGIE

POSITION STATEMENT

Ethics and Nanotechnology:







A Basis for Action

Québec

COMMISSION DE L'ÉTHIQUE DE LA SCIENCE ET DE LA TECHNOLOGIE

POSITION STATEMENT

ETHICS AND NANOTECHNOLOGY: A BASIS FOR ACTION

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* Statement made at the request of Mr. André Doré, dated March 11th 2006 : "Considering Québec's historically North American character and economic activity, as well as its tradition of 'rational governance', I wish to state that where the development of regulations in the nanotechnology sector is concerned, the top two criteria should be science and market acceptance."

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List of Acronyms

ACST	Advisory Council on Science and Technology (Canada)
ADHD/TDAH	Attention deficit hyperactivity disorder/*trouble déficitaire d'attention avec hyperactivité*
BAPE	Bureau d'audiences publiques sur l'environnement (a government office for public hearings on the environment) (Québec)
CIHR	Canadian Institutes of Health Research
CIRAIG	Interuniversity Research Center for the Life Cycle of Products, Processes, and Services (Québec)
COMEST	World Commission on the Ethics of Scientific Knowledge and Technology
CSST	Commission de la santé et de la sécurité du travail [A government commission on occupational health and safety] (Québec)
DARPA	Defense Advanced Research Projects Agency (United States)
DDT	Dichlorodiphenyltrichlorethane
DNA	Deoxyribonucleic acid
EPA	Environmental Protection Agency (United States)
ESAA	Environmental Services Association of Alberta
FDA	Food and Drug Administration (United States)
FQRNT	Fonds québécois de la recherche sur la nature et les technologies [a Québec funding agency for research on nature and technologies]
FQRSC	Fonds québécois de la recherche sur la société et la culture [a Québec funding agency for research on society and culture]
FRSQ	Fonds de la recherche en santé du Québec [a Québec funding agency for research in health]
GE³LS	Genomics: Ethics, Environment, Economics, Law, and Society
GMO	Genetically modified organism
GNP	Gross national product
HIV	Human immunodeficiency virus
ICAO	International Civil Aviation Organization
ICON	International Council on Nanotechnology
ICT	Information and communications technologies
IRSST	Institut de recherche Robert-Sauvé en santé et en sécurité du travail [a research institute on occupational health and safety] (Québec)
ISO	International Organization for Standardization
IUCN	World Conservation Union
LCA	Life cycle assessment
LED	Light-emitting diode
MRI	Magnetic resonance imaging
NanoIP	NSERC Nano Innovation Platform
NBIC	Nanotechnology, biology, information technology, and cognitive science (in reference to the convergence of nanotechnology, biology, information technology, and the cognitive sciences)

NE^{3}LS	Nanotechnology: Ethics, Environment, Economics, Law, and Society
NIH	National Institutes of Health (United States)
NIST	National Institute of Standards and Technology (United States)
NNI	National Nanotechnology Initiative (United States)
NSERC/CRSNG	Natural Sciences and Engineering Research Council of Canada/Conseil de recherches en sciences naturelle et en génie du Canada
OECD/OCDE	Organization for Economic Cooperation and Development/Organisation de coopération et de développement économiques
OQLF	Office québécois de la langue française [Québec's French language bureau]
PEBBLE	Probe encapsulated by biologically localized embedding
PMACST/CCSTPM	Prime Minister's Advisory Council on Science and Technology/Conseil consultatif des sciences et de la technologie du Premier ministre (Canada)
R&D	Research & development
RFID	Radio frequency identification
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks (United States)
SME	Small and medium-size enterprises
SOLAS	Safety of Life at Sea
SPM	Scanning probe microscopy
STM	Scanning tunnel microscopy
TCPS	Tri-Council Policy Statement
UN	United Nations
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific, and Cultural Organization
WHMIS	Workplace Hazardous Materials Information System (Canada)
WWF	World Wide Fund for Nature

SUMMARY, RECOMMENDATIONS AND COMMENTARIES

Nanotechnology arises from the convergence of basic research in physics, chemistry and biology, and is often considered one of the most promising technologies for the future of humanity. Nanotechnology is innovative in character. It is currently moving from the laboratory to industrial manufacturing and marketing. Significant public and private investments are going into development and promotion, and the anticipated benefits are considerable. For all of these reasons, the Commission has decided to explore nanotechnology from an ethical perspective.

The present position statement consists of three chapters devoted to the scientific, legal and ethical implications of nanotechnology. In its ethical assessment of nanotechnology, the Commission is upholding the protection of health and the environment, as well as respect for many values such as dignity, liberty, the integrity of the person, respect for the person, quality of life, respect for privacy, justice and equity, transparency and democracy.

The Commission has formulated **eight recommendations** to political decision-makers and other interested parties. However, the Commission has sometimes found it impossible to make a specific recommendation on a given subject, even when it judged that subject to be important. In such cases, the Commission has issued a **commentary** instead, in order to highlight the implications of a particular question so that Québec society as a whole may be in a better position to act and make informed decisions about nanotechnology.

A NEW AND EMERGING WORLD: THE UNIVERSE OF NANOTECHNOLOGY

The world of nanoscience and nanotechnology is on the **nanoscale**, that is one billionth of a meter or 10^{-9}. **Nanoscience** is the scientific study, on the atomic and molecular scale, of molecular structures one of whose dimensions measures between one and 100 nanometers*, with a view to understanding their particular physicochemical properties and to defining the means required to manufacture, manipulate and control them. **Nanotechnology** flows from nanoscience and consists of the design and manufacture on the atomic and molecular scale of structures one of whose dimensions measures between one and 100 nanometers, and which have particular physicochemical properties that can be exploited and can also be subject to manipulation and control operations.

Important aspects to consider. In terms of a general reflection on nanotechnology, the Commission has considered important aspects, such as the size of nanometric particles, the means of manipulating materials (top-down and bottom-up), multidisciplinary approaches and the convergence of disciplines with respect to nanotechnology as well as a general fascination with nanotechnology. These aspects provide the foundation of the ethical questions contained in the Commission's present Position Statement.

Research and innovation. Much like electricity and electronics before them, nanoscience and nanotechnology will impact on all spheres of daily life. An enormous range of applications has already been derived from nanotechnology, or may be derived from it in the future. These applications are sometimes puzzling, often fascinating and in some cases worrying. The four main sectors of research and innovation playing a major role in nanotechnology are nanomaterials, nanoelectronics, nanobiotechnology and nanometrology. If nanotechnology fulfills current expectations, it could produce benefits in a multitude of areas from medicine to the environment, and from information technology to agriculture and food. However, it is important to ask questions about the possible or hypothetical impacts of some innovations derived from nanotechnology or from its convergence with other disciplines.

LOOKING AT METHODS FOR MANAGING THE SECTOR

Regarding risk, two factors are worth considering: the probability that an event will occur and the nature and significance of damages resulting from the same event. These two factors are not always present in the case of nanotechnology. They raise the questions of how to deal with scientific uncertainty, which in turn is related to the state of knowledge in this area as well as to ignorance about what could happen once a new technology is adopted.

Risk and nanotechnology. Like any other natural or industrial particle presenting risks of toxicity for living organisms, fabricated nanoparticles (which have been created deliberately) confer risks associated with their manipulation or with their deliberate or accidental release into air, soil and water. These risks need to be taken into consideration in order to protect workers, the public and biodiversity as a whole. A number of laws and regulations currently in force address risks associated with products which have not been derived from nanotechnology. These laws and regulations will eventually need to be adapted to take into account the evolution of nanotechnology.

As the documents consulted by the working committee show, specific risks may be associated with products derived from nanotechnology, whether because of their particular characteristics or because research is not always conclusive:

- The clustering tendency of fabricated nanometric particles and its potential effect on the environment and on living organisms;
- The importance of the specific surface of nanometric matter with regard to its mass, which contributes to modifying or intensifying the properties of the original material;
- The reactivity developed by certain nanometric particles, particularly metallic nanopowders, which may generate risks of explosion, flammability or toxicity;
- The capacity of nanometric matter to cross the protective barriers of human and animal organisms (cutaneous, pulmonary, intestinal, placental, blood-brain barriers).

The current framework. In Canada and in Québec, a number of laws and regulations are in place to control the life cycle of products, from their manufacture to their elimination; these legislative texts also apply to nanomaterials, although the latter are not specifically mentioned. Several international instruments also establish regulations governing the transportation from one country to another of materials considered hazardous and presenting possible health or environmental risks.

Commentary of the Commission

The development of nanotechnology and the marketing of nanometric products or components are well underway and will surely intensify in years to come. Given this, the Commission urges vigilance and attentive monitoring of the evolution of this new technology so that existing regulations may be adapted to the realities of this sector.

Moreover, in order to respond to the needs of business, self-regulation could partially fill the gap left by incomplete regulations in this emerging sector of activity. It is important to note in this respect that the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST – a research institute on occupational health and safety), is currently working with different partners to develop a best practices guide for the Québec nanotechnology industry, including laboratories.

Commentary of the Commission

The Commission encourages Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) as well as its partners to pursue development of this best practices guide so that it may be published as soon as possible. The Commission also calls on the various government ministries interested in nanotechnology development to encourage the research and manufacturing communities in this sector to adhere to the practices recommended in this guide, and to support its promotion and further elaboration. The Commission seeks to avoid any undesirable impacts of nanotechnology on occupational health and on the environment, and considers that such a best practices guide is necessary, given the current state of nanotechnology development.

Responsible approaches to dealing with risk. Given the current state of knowledge and development of nanotechnology, the Commission considered two possible avenues where the need for or lack of need for regulating this sector of activity is concerned – namely invoking the precautionary principle and adopting the “life cycle” approach. In its position statement in 2003 on genetically modified organisms (GMOs), the Commission recommended adopting the approach of precaution, which it considered more flexible. Since that time, the Commission has continued thinking about the ***precautionary principle***, which it sees as a principle of action rather than of abstention, and one able to guide decision-makers in a context of uncertainty. The Commission holds that this principle has the advantage of raising many questions about hypothetical risks in a pluralistic and democratic society, about the best way to understand the gap between the acceptability of individual and collective risk, and between the requirements of health and environmental safety and the legitimate desire for technological development. In the Commission’s view this subject deserves to be debated in society.

From the perspective of sustainable development, the ***“life cycle” approach*** consists in protecting the environment by taking into account the impact of technological innovation, all the way from the acquisition of necessary resources up to the manufacture of, and ultimately, the safe elimination of products, once their service life has come to an end. The idea of sustainable development is understood in the sense defined in Article 2 of the *Sustainable development act* (2006): “development that meets the needs of the present without compromising the ability of future generations to meet their own needs. [It] is based on a long-term approach which takes into account the inextricable nature of the environmental, social and economic dimensions of development activities.” Although the text of the law refers on two occasions to the life cycle, the definition of sustainable development contained in the law does not refer directly to the idea of life cycles, which some researchers consider “essential for the attainment of sustainable development.”

Recommendation No. 1

The Commission recommends:

That the Québec Government, guided by the principle of precaution and from the perspective of sustainable development, be concerned with all phases of the life cycle of a product derived from nanotechnology or containing nanometric components, and that in this respect it should integrate the concept of “life cycle” into all policies where such an approach is appropriate, in order to avoid any damaging impact of technological innovation on health and the environment

Nanotechnology: Ethical Concerns

Fundamental Requirements as Premises

Nanotechnology is an emerging sector of activity, and one that draws on a host of disciplines. For these reasons, steps should be taken to build the foundation of systematic and responsible development.

Commentary of the Commission

The first observation to be made about nanotechnology is that there is a flagrant lack of information about what it is. If there is no common understanding of what nanotechnology is, how can legislators, researchers, businesspeople, workers, or the public make informed decisions? The Commission notes that responsible management of nanotechnology development turns on three premises: establishing a common scientific terminology and nomenclature, establishing procedures and standards, and continuing to perform research and disseminate research results.

Ethical Concerns about Products Derived from Nanotechnology

Health and Safety

Protecting the workers. Two observations caught the attention of the Commission. The first of these is that it is worrisome how little research has been undertaken until now on the possible consequences of nanomaterials on human health and safety. One of the obstacles noted by the IRSST and which may in part explain the lack of knowledge in industrial hygiene is that “tools normally used in industrial hygiene to evaluate the exposure of workers are ill-suited to the applications of nanoparticles in an occupational setting," whereas "the little data available suggests that exposure during the manipulation of powders may be considerable.*

The second observation is that specialists do not agree on the relevance of existing regulations. It will be hard to resolve this question in the absence of precise data on the potential effects of nanotechnology. **While waiting for further research and more complete regulations that are better adapted to the specific characteristics of nanotechnology, the Commission considers that the principle of precaution should guide actions to be undertaken in order to protect occupational health and safety.**

Examples of the actions needed to ensure responsible management of nanotechnology are the best practices guides or works produced by the IRSST on current knowledge about nanoparticles and their possible effects on occupational health and safety. In this regard, **the Commission emphasizes that data gathered by the IRSST should be kept up to date as much as possible and that this information should be transmitted to companies and other research centres active in the nanotechnology sector, so that the latter may take adequate occupational health and safety measures.**

Protecting the public. One of the Commission's major concerns is ensuring that products derived from nanotechnology are harmless. Yet, it is impossible at the present time to know whether the use of products already on the market could prove harmful, since there are few research findings concerning the effects of such products on animal, the environment or human subjects. Moreover, some experts are concerned that health authorities currently lack resources to monitor products on the market. Finally, even if these authorities did have needed resources and personnel, acceptance standards would still have to be decreed, which is not the case presently.

Recommendation No. 2

The Commission recommends:

That the Minister of Economic Development, Innovation and Export Trade, together with the Minister of Health and Social Services, work with the federal government to ensure that health and environmental monitoring agencies establish the mechanisms needed to assess the toxicity of processes and products derived from nanotechnology prior to authorizing their commercialization.

* Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), *Nanoparticles : Actual Knowledge about Occupational health and Safety Risks and Prevention Measures*, Claude Ostiguy and associates, Report R-470, Studies and Research Projects, Gouvernement du Québec, September 2006, p. iii [online] http://www.irsst.qc.ca/en/_publicationirsst_100210.html.

Technological development is evidently an important social value since it contributes to the creation of collective wealth and to the improvement of the quality of life of citizens. Nanotechnology development seems to be in a position to make a contribution in this regard, but such development should never be pursued if it is to the detriment of the health and safety of workers or citizens, which are priority values. **In the Commission's view adequate prevention measures and a good knowledge of the life cycle of products derived from nanotechnology will contribute to protecting human health and safety and will contribute to sustainable development in this sector of activity.**

Health sector applications: the ethics of biomedical research. Given the promising future of nanobiotechnologies, it is important that the principles of research ethics be rigorously applied, in order to protect research subjects participating voluntarily in the advancement of knowledge. Since research ethics boards are in the forefront of protection of human subjects, the members of these boards should be made aware of questions arising in the pursuit of research on nanobiotechnologies and they should be equipped to respond in an adequate manner.

Recommendation No. 3

The Commission recommends:

That the Minister of Health and Social Services ensure that research ethics boards are adequately equipped and supported in their assessment of research protocols relating to the use of materials and processes derived from nanotechnology in the health sector.

Diagnostics and therapeutic applications. The Commission is particularly aware of the issue of nanoparticles interfering with the functions of the human body (or with the environment). For example, given the ability of nanoparticles to cross the blood-brain barrier, their use has obvious potential for the treatment of neurological diseases, but this use is also a cause for concern. The blood-brain barrier is the brain's final defense against the external assaults of various micro-organisms. However, nanotechnology may offer new ways getting past the natural defenses of the brain. Since these technologies have still not been mastered and are invisible to the naked eye, if nanotechnology research and development (R&D) is not subjected to a proper framework, it could have regrettable consequences.

The current state of knowledge hardly enables the Commission to extrapolate the potential economic impact of the introduction of new diagnostic and treatment methods derived from nanotechnology. In all likelihood, some of these new technologies would bring about savings for health services, whereas others would involve prohibitive costs. The Commission calls into question the idea of offering diagnostics without therapeutics to match them. This situation already exists in some cases, and calls to mind the Position Statement previously published by the Commission on genetic databases. This line of questioning underscores the more general problem of resource allocation and governance, and the need for important societal choices to be debated in the public arena.

Commentary of the Commission

The Commission emphasizes the importance of precaution in the creation and development process of medications and therapies with nanotechnology components. Such an approach is an encouragement to continue to research and document the potentially positive and negative effects of nanotechnology applications in the health sector to better assess the outcomes for patients and for the management of the health system in general.

The Environment

Nanotechnology could have many positive impacts on the environment, thereby contributing to sustainable development. The potential benefits of nanotechnology should be encouraged. However, the harm-free character of these technologies remains to be demonstrated and potentially undesirable effects cannot be dismissed out of hand.

As the documents consulted show, the biggest source of concern on the short term, where environmental exposure is involved, is the use of nanoparticles in the remediation of contaminated groundwater and soil. The reason for this concern is the potentially great reactivity of these nanoparticles to plants, animals, micro-organisms and ecosystems. The data gathered so far are not conclusive. Preliminary studies suggest however that certain nanomaterials can damage the organs and tissues of living organisms. In the context of the present Position Statement, **the Commission can only emphasize the importance of increasing the volume of research devoted to the potential environmental consequences of nanotechnology, in order to determine which substances may be hazardous. This proposal calls for a commitment on the part of researchers, industries concerns and government agencies.**

Some answers may be obtained through laboratory studies, but others will have to be obtained through *in situ* analyses; this will be the case regarding the effects of nanotechnology which are unanticipated or unpredicted, or which will occur on the long term. For example, it is possible that some products could have hazardous effects on the environment due to their accumulation in various environmental regulatory systems.

Recommendation No. 4

The Commission recommends:

- **That the Minister of Economic Development, Innovation and Export Trade, together with the Minister of Sustainable Development, Environment and Parks as well as various other interested parties, put in place a system to monitor the potential effects of nanotechnology on the environment, whenever these effects cannot be calculated and taken into account prior to the market release of nanotechnology-derived products**
- **That a procedure be developed to ensure the rapid recall of products in the event of harmful effects on the environment**

Security

Following the terrorist attack of September 11th 2001 in the United States, questions about security and military defense have become increasingly important everywhere in the world. Governments recognize as a priority issue the protection of their territories and populations, on the military level as well as on that of public safety. This situation has served to intensify the process of technological integration which had started at the end of the 1980s. Nanotechnology offers the potential of very diverse applications, in terms of military and public security.

In the military sector: Applications in this sector raise two major ethical concerns: a concern about the ends being pursued, and a concern about the secrecy surrounding laboratory research as well as the outcomes obtained. The question of transparency rises to the forefront, posing an ethical dilemma and raising questions about the degree to which the public can or should trust decision-making authorities in the military sector. A basic observation should be made: whereas developing the means of attacking the enemy and/or defending oneself from this enemy are the *raison d'être* for the existence of various agencies and the allocation of phenomenal resources, it seems that very little effort is being devoted to the avoidance of conflict. **Questions should be raised about the ethical framework of military research and about the ethical issues related to development of new military applications derived from nanotechnology.**

In civil society: In the context of an issues paper on the use of biometric information for security purposes, the Commission expressed concern about the problem of surveillance and raised questions about a possible intrusion of the State and its agencies upon the privacy of citizens and workers. Different technologies can be used for this purpose, but nanotechnology increases and facilitates current capabilities in this regard and opens the door to widespread gathering and use of information on citizens and workers well beyond current capabilities. **The Commission is concerned that in the name of security, standards have been lowered regarding the protection and confidentiality of personal information, and to the protection of privacy and of civil liberties.**

The Convergence of Knowledge and Technology

The convergence of nanotechnology with other disciplines such as biology, information and communications technologies and cognitive sciences poses many ethical and social challenges, particularly where human identity and the relationship of humans with nature is concerned.

Human identity in a context of performance enhancement: Nanotechnology could contribute to enhance certain physiological characteristics of the human being; with the convergence of knowledge and technologies, developments anticipated in this area are potentially unlimited and may include increases in cognitive capability. Some developments will raise many fundamental questions with respect to personal and social representations of human identity: what is considered to be *human*, what is deemed acceptable and what is not. The Commission holds that using nanotechnology to enhance human performances raises ethical concerns particularly about: the subjective boundary between therapy and the optimization of human capabilities; society's mixed messages about the insertion of the disabled population into "active" life; the cult of performance; equity of choice where public health services are concerned; and finally the meaning given to individual autonomy and responsibility in society. The Commission intends to continue this reflection in a future Position Statement on neurosciences.

The human being's relationship with nature. In with the spirit of the *Sustainable development act*, the Commission holds that humans are interdependent with the environment. Society and its decision-makers need to take this interdependence into account when they make decisions that could impact environmental quality, whether in the immediate future or from the perspective of future generations. Nanotechnology could be of considerable benefit in this respect; but some applications may equally prove to contribute to the deterioration of the environment. **It will be important to strike a balance in the use of nanotechnology so that it benefits the greatest number of people while respecting the environment. Striking this balance involves decisions concerning society as a whole, and should therefore be the focus of public debate.**

Ethical Concerns not Limited to Nanotechnology

The development of nanotechnology gives rise to ethical questions about its effect on society and the environment and the use made of these technologies in other domains. However, as the Commission has observed, nanotechnology raises ethical concerns similar to those surrounding other emerging technologies. While these concerns are not entirely new, they should not be underestimated, since they may actually be greatly intensified with nanotechnology.

Concerns Related to Governance

Legitimacy and transparency of the decision-making process. In a democratic setting, legitimacy invariably requires a transparent decision-making process. The Commission has emphasized this point in its Position Statement on genetically modified organisms. Transparency can be seen in the manner in which the public is informed; this is a basic requirement for each citizen's exercise of free choice in a pluralistic and democratic society.

Recommendation No. 5

The Commission recommends:

That the Minister of Economic Development, Innovation and Export Trade, with his colleagues in the ministries and organizations concerned, initiate a process to inform and consult with the public in order to define in all transparency the scientific, economic, and ethical issues associated with the development of nanotechnology.

Oversight and accountability measures. The Commission recognizes that the normative framework of nanotechnology requires a deeper understanding of the potentially harmful consequences that could result from the introduction and dissemination of nanoparticles into the environment or their penetration into living organisms. However, this requirement should in no way limit the steps needed to ensure appropriate governance with respect to the monitoring of an emerging new technology, to reflect on this technology, and to adapt existing normative frameworks where circumstances so dictate. **It is important to emphasize that the network of organizations involved in nanotechnology work together to ensure that their approaches are compatible with the goal of sustainable development. In the Commission's view, it is necessary to bring different interested parties together in order to develop a model of flexible governance, adapted to the reality of nanotechnology and capable of responding to ethical concerns raised by these technologies.**

Recommendation No. 6

The Commission recommends:

That the Minister of Economic Development, Innovation and Export Trade call on granting agencies, together with the various stakeholders concerned, to create a program of multidisciplinary research on the impacts of new technology and on managing the risks associated with nanotechnology that takes into account the ethical and social aspects in play.

Concerns Related to Economic Activity

Ethical choices in the development of Québec economic activity associated with nanotechnology. Since 2004, the Conseil de la science et de la technologie du Québec has been co-ordinating a project entitled Perspective Science-Technologie-Société (STS), with a view toward raising awareness in all sectors of the Québec population about the importance and usefulness of science and technology for understanding and solving socio-economic problems. In addition, this project calls on Québec's scientific community to become more involved in the social and economic goals of science and technology. **In the Commission's view, this kind of initiative should be applied once Québec's nanotechnology development strategy has been drawn up, so that it will be possible to respond to the economic and social needs of Québec and focus on the ethical issues associated with these technologies.**

According to its 2005 report on nanotechnology, the President's Council of Advisors on Science and Technology (a U.S. government council), new technologies can displace obsolete ones, leading to a parallel shift in job opportunities. **Since these new jobs sometimes require different skills, the Council emphasized that such changes pose challenges for workforce training and the educational system. In the Commission's view, this is an important ethical issue, since it is often the most vulnerable workers in society who are adversely affected by transformations in the labor market brought on by the emergence of new technologies.**

Recommendation No. 7

The Commission recommends:

That the Minister of Economic Development, Innovation and Export Trade, upon completion of a Québec nanotechnology development strategy, take into account the ethical and social questions raised by such technologies, particularly with regard to employment and workforce training.

The nano-divide in a context of globalized markets. No one should lightly dismiss the potential of designing and developing nanotechnology innovation in a way that benefits developing countries. Governments, companies, foundations and non-governmental organizations are being and can be called upon to a varied extent, to manage nanotechnology development. These different parties currently have an opportunity to coordinate their efforts with a view toward developing joint approaches, acting in solidarity with the poorest.

COMMENTARY OF THE COMMISSION

In the same vein, the Commission suggests that universities, granting agencies, and developing countries increase or develop their collaborative relationships. The organizations involved should consider taking steps with the specific goal of meeting developing countries' nanotechnology needs, such as creating nanotechnology research partnerships, organizing exchanges of students and professors between universities, and establishing funding programs.

In general, whoever controls R&D also controls the means of production and the supply of products and services. In the establishment of research priorities, the needs of developing countries should be taken into account, and the growth of local industries should be encouraged so that they create sustainable wealth. Partnerships should be encouraged between those holding knowledge and wielding capital, on the one hand, and those offering access to markets, on the other, as long as such partnerships enable each party to benefit and share responsibilities in an equitable manner. This is a matter of respect and solidarity.

COMMENTARY OF THE COMMISSION

Given that human solidarity finds expression mainly in collaborative acts and the sharing of wealth, the Commission encourages support for researcher training and the implementation of R&D infrastructure in emerging and developing countries, with a view to promoting the acquisition of industrial expertise in these countries and to avoiding any deepening of the technological divide.

Intellectual property and patent management. The management of patents and intellectual property may be considered a dynamic source of innovation, but it can also hinder access to knowledge and tools required for R&D. As some authors have suggested, the way of addressing this problem could be to learn from the intellectual property standard applied in computer science to open source software, and to apply this standard to publicly funded research. Another possibility would be to establish *patent pools*.

The Commission also emphasizes the initiative taken by the U.S. National Institutes of Health (NIH) in the biotechnology sector, in announcing the creation of a public-private partnership with various pharmaceutical companies in order to accelerate genetic research on multifactorial diseases. The interest of this initiative resides in the assurance given by the NIH that research findings will be freely accessible.

COMMENTARY OF THE COMMISSION

This type of initiative by NIH raises a number of broader questions: Are public/private research and marketing initiatives equitable for Québec? What are the positive and negative effects of such partnerships? Do the potential benefits offset the negative impacts? Is it possible to reduce or eliminate the negative impacts? Would it be possible to put incentives in place for philanthropic activity? In view of these questions, the Commission feels it is imperative to seriously consider the role of protecting intellectual property in a context of innovation as well as the ethical questions associated with this protection.

Collecting personal information. The convergence of nanotechnology and information technology could make it possible to establish highly specialized typical profiles for marketing purposes, but also for the purposes of exerting police, social or political control on the public or on particular communities. **The Commission emphasizes that gathering information can only be done with the knowledge of consumers and that laws enacted with respect to the protection of personal information require public and private organizations to provide any person asking for access to an information file to be granted this access.** The problem however is that few people are aware of these obligations and moreover, sanctions are rarely applied to companies and public and private organizations which do not respect existing regulations.

Finally, it is important to devote attention to a distinct aspect of the protection of personal information – access to genetic information. With the advent of nanotechnology, DNA chips open the way to analyzing genetic content of cells *in situ* – soon physicians will be able to "read" the genetic code of a patient in a clinical setting and to obtain a large volume of information on the health status of the patient and his/her genetic predisposition to certain illnesses. As the Commission made clear in its position statement on genetic databases, the use of genetic information for non-medical purposes, particularly by insurers, employers or financial institutions, is a practice liable to lead to discrimination when decisions are made concerning particular people such as clients, employers or borrowers. **The Commission reiterates that any use of genetic information by third parties other than health professionals and for other purposes than treatment should be the focus of a wide-ranging debate on such practices and the purposes they serve**.

Concerns Related to Citizenship and Technological Innovation

Consumption is increasingly seen as an issue of power. Citizens are demanding the right to make choices reflecting their values. This exercise of citizenship should be seen as a sign of the health of democracy, as long as citizens are aware of their ability to exercise influence, to recognize the responsibility associated with any decision-making act, and finally, to have access to clear and objective information.

Empowerment of citizens finds expression particularly in the desire to make choices reflecting each person's individual and societal values. Empowerment depends on clear and accessible information, but such information poses a huge challenge in the case of nanotechnologies, given their complexity and the enormous range of potential applications. **The Commission emphasizes the importance of transmitting accurate information to the public and of promoting public participation in decision-making regarding nanotechnology.**

Recommendation No. 8

The Commission recommends:

That the Government of Québec follow the example of the Internet portal on genetically modified organisms in order to create an information portal for the general public devoted to nanotechnology.

Even when information is available and easily accessed, it is important to ensure that citizens are aware of the issue of new technologies and that they understand the ins and outs; the responsibility is theirs to assume although citizens do not always grasp the importance of this responsibility. It is important moreover to note that the interest of young people in science and technology education seems to be on the wane, even though consumption of technological products is continuing to increase. In this context, **the Commission stresses that it is now urgent to address ways of bridging the knowledge gap of the general public through the provision of relatively neutral and objective information.**

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It is with great curiosity and interest that the Commission initiated its deliberation on the ethical issues raised by the development of nanotechnology. On the one hand, because the subject is still little known; on the other, because the possibilities opened up by the development and use of matter on the nanometric scale currently seem virtually unlimited. It is moreover easy to marvel at, and be carried away by, the euphoria and enthusiasm shared by many people involved in nanotechnology.

During the course of its examination of the issues, the Commission grasped the enormity and complexity of the task it had taken on, namely to document the development of nanoscience and nanotechnology in order to identify the ethical issues associated with their emergence. Nanotechnology relates to all fields of activity, involves diverse applications and has a wide range of possible uses. Moreover, thinking about nanotechnology is made more complicated by virtue of the fact that nanometric matter is invisible to the naked eye; the effects, whether positive or negative, are however, quite tangible. Finally, the fact that nanotechnology is an emerging technology also means that it is impossible today to predict all the applications that are to come and what repercussions these applications could have for Québec and the rest of the world.

Serious reflection on the ethical and social issues raised by technology is only beginning and it is important to continue thinking, discussing, expressing views on nanotechnology and the best way to ensure its harmonious development. That is why the Commission sees the need to continue addressing more focused questions about the responsible management of nanotechnology that the State could raise, as it will have to make decision regarding this field in the future.

INTRODUCTION

Nanotechnology*[1] first appeared on the public scene in Québec in 2001 with NanoQuébec, created in the wake of recommendations by Conseil de la science et de la technologie in a position statement entitled *Les nanotechnologies: la maîtrise de l'infiniment petit*[2] *[Nanotechnology: Mastering the Infinitely Small]* published the same year. This infrastructure enabled Québec to join the international movement already underway to ensure nanotechnology development and promotion; today, Québec is considered a leader in Canada.[3] Noting that over 175 university researchers and some forty SMEs in Québec are involved in nanotechnology,[4] and as more and more products derived from nanotechnology become available on the market, Commission de l'éthique de la science et de la technologie decided to explore the ethical issues raised by nanotechnology development and innovation.

With nanotechnology, the Commission has discovered a scientific world that is fascinating, but also highly complex and scattered, particularly due to its highly multidisciplinary nature. It is also an emerging field that provides an opportunity to prepare for any problems technological innovation might bring, in order to offset or minimize certain adverse effects. At the same time, this new field also raises the question of uncertainty and ignorance regarding risk, as research is still limited. Very early in its literature search on the topic and its consultation of experts, the Commission realized it would be impossible to assess the ethical issues of nanotechnology in as much depth as it would have liked. Given the current state of affairs, it believes this position statement is nevertheless an essential first step toward enlightened and responsible development of the field; however, the Commission should continue its work as the field evolves.

While the prefix "nano" has leaked into popular language, mainly through advertising that uses it to describe very small objects not derived from nanotechnology per se (like some digital music players and children's building blocks), the very concept of nanotechnology is still unclear to most people.[5] In

1 Terms followed by an asterisk are defined in the glossary at the end of this position statement.

2 CONSEIL DE LA SCIENCE ET DE LA TECHNOLOGIE, *Les nanotechnologies: la maîtrise de l'infiniment petit*, Gouvernement du Québec, June 2001 [online; French only, with a summary in English] http://www.cst.gouv.qc.ca.

3 MINISTÈRE DU DÉVELOPPEMENT ÉCONOMIQUE, DE L'INNOVATION ET DE L'EXPORTATION (Québec), "Nanotechnologies au Québec" [online] http://www.mdeie.gouv.qc.ca/page/web/portail/science Technologie/nav/technologies_strategiques/42648/65662.html?iddoc=65662

4 *Ibid.*

5 As shown in surveys on the topic. See, among others, Edna F. EINSIEDEL, *In the Public Eye: The Early Landscape of Nanotechnology among Canadian and U.S. Publics*, Report to the Canadian Biotechnology Secretariat and the NSERC Nanotechnology Innovation Platform, University of Calgary, undated [online] http://www.azonano.com/Details.asp?ArticleID=1468; GENOME PRAIRIE (Canada), *First Impressions: Understanding Public Views on Emerging Technologies*, report by the GE³LS team at Genome Prairie at the University of Calgary, undated [online] https://bioportal.gc.ca/CMFiles/CBS_Report_FINAL_ FRENCH249SFP-9222005-5789.pdf; Michael COBB and Jane MACOUBRIE, "Public Perceptions about Nanotechnology: Risks, Benefits, and Trust," *Journal of Nanoparticle Research*, Vol. 6, No. 4, August 2004 [online] http://www.wilsoncenter.org/events/docs/macoubriereport.pdf. Also see a summary of more recent surveys, presented in Chapter 4 (p. 41–56) of Matthew KEARNES, Phil MACNAGHTEN, and James WILSDON, *Governing at the Nanoscale. People, Policies and Emerging Technologies*, London, DEMOS, 2006 [online] http://www.demos.co.uk/catalogue/ governingatthenanoscale/.

short, nanoscience* and nanotechnology deal with matter and its structures at the nanoscale* (for illustrative purposes, note that a single hair varies between 50,000 and 100,000 nanometers in diameter) in order to use the particular properties that matter may acquire at a dimension less than 100 nanometers due to the quantum effects* occurring at that scale. The most commonly sought properties include resistance, lightness, malleability, non-flammability, and conductivity. These properties are obtained by creating nanomaterials* like nanotubes*, fullerenes*, quantum dots*, nanoparticles*, nanopowders*, nanofilms,* and many other forms that matter can take at the nanoscale.

The emerging technologies of the infinitely small suggest possibilities that have spurred phenomenal scientific success, stoked the enthusiasm of researchers, and unleashed the imagination of science fiction writers. Arising from the convergence* of fundamental physics, chemistry, and biology research, nanotechnology is often touted as one of the most promising technologies for the future of humanity. With the evolution and success of research, nanotechnology is less and less confined to university laboratories, and its applications are increasingly appearing in a host of sectors ranging from optics and electronics, information technologies, textile engineering, and the environment to medicine, pharmaceuticals, and national security. The most common nanotechnology-derived products now available on the market include sun creams and a variety of cosmetics, photographic film, paint, household appliances, hard drives, certain textiles, and numerous sporting goods.[6]

As products with nanometric components leave from the laboratory to be manufactured and commercialized, and governments invest in the development and promotion of a technology with potentially unprecedented spinoffs, the Commission felt it wise to explore the topic from an ethical perspective. Undoubtedly, the expected benefits are tremendous and could help solve many of the problems facing developed and developing contemporary societies. What kind of changes are anticipated or expected? How will nanotechnology innovation affect individuals—citizens, consumers, and workers—and society as a whole, not to mention future generations? Should adverse effects on health, the environment, or in other areas be anticipated in order to prevent them or keep them to a minimum? Problems encountered in recent years with asbestos, mercury, lead, DDT, freon, and recently teflon raise the question of the long term effects of new substances like engineered nanomaterials and nanoparticles. Questions also persist about some of the possible aims of nanotechnology, particularly as regards physical or intellectual performance optimization in humans. Moreover, like other technologies that emerged in the second part of the 20th century—particularly biotechnology, genomics, proteomics, and genetics—nanotechnology points to the need to resolve certain problems inherent to scientific and technological progress in democratic and pluralistic societies, including the issues of intellectual property and patent management, as well as the role of citizens in scientific decision making.

The Commission's position statement consists of three chapters that take stock of the scientific, legal, and ethical implications of nanotechnology. In its ethical assessment of nanotechnology, the

[6] Visit the NanoQuébec website for current information on new products on the market or under development: http://www.nanoquebec.ca. Also see the inventory of consumer products derived from nanotechnologies presented by the Woodrow Wilson International Center for Scholars at http://www.nanotechproject.org/index.php?id=44.

Commission was guided by the protection of health and the environment, the importance of economic development in contemporary societies, and respect for the many values that should underpin a responsible approach to nanotechnology, including dignity, liberty, individual integrity and respect, quality of life, respect for privacy, justice and equity, transparency, and democracy.

Chapter 1 defines the basic terms relating to the topic under study—nanometer, nanoscience, and nanotechnology—and briefly lists milestones in the short history of nanotechnology. Next the distinguishing features of this technology are described. In some sense these features serve as premises for the Commission's ethical assessment: the invisibility of nanomatter, its special properties, methods for manipulating it ("top-down" and "bottom-up" approaches), multidisciplinarity and the convergence of disciplines, and popular fascination with nanotechnology development. In the second part of the chapter, the Commission gives a brief overview of four sectors of nanotechnology research and innovation—nanomaterials*, nanoelectronics*, nanobiotechnology*, and nanometrology*—in order to illustrate some of the potential benefits of nanotechnology as well as the type of concerns they raise.

In Chapter 2, the Commission considers mechanisms for monitoring nanotechnology development and the resulting technological innovations. To this end, it first indicates the currently perceived risks in nanotechnology development, as well as the features of nanoscale products that could pose health and environmental risks. It questions the adequacy of current assessment methods for nanotechnology-derived products. After observing the lack of statutes and regulations dealing with nanotechnology (from nanomatter manipulation to elimination) in Québec and the rest of Canada—as in the rest of the world, it should be noted—the Commission mentions Québec and Canadian statutes and regulations that could be updated to cover this new technology; it briefly discusses the international instruments that may apply to nanotechnology in some way and stresses the importance of developing a guide to good practices in order to help the industry manage the risks of new technology responsibly. Lastly, the Commission considers two possible approaches for monitoring nanotechnology: *the precautionary principle*, whereby the risk management process takes into account possible ignorance regarding the harmful effects of technological innovation, and the *"life cycle*" approach*, which encourages consideration of a product's possible impact on the environment, society, and the economy throughout the product life cycle.

Chapter 3 looks at the Commission's ethical assessment of nanotechnology in its current state of development and of scientific knowledge. In the first part of the chapter, the Commission examines nanotechnology use in products. As a premise, it raises the need to establish a solid foundation for responsible nanotechnology management: a common nomenclature, access to standard procedures and samples for characterizing nanomatter, as well as research on nanotechnology safety and the publication of results.

The second part of the chapter addresses ethical concerns tied to health, the environment, and safety. As regards health, the Commission discusses the protection of workers who produce and handle nanomaterials able to cross the body's natural barriers due to their size, as well as the protection of consumers, given that products that are applied to the skin, inhaled, or ingested are available to them on the market. Next, it takes stock of the contribution of nanotechnology to medicine—raising the question of ethics in biomedical research involving nanotechnology—and to the diagnosis and treatment of disease. As regards ethics and the environment, the Commission expresses the need to adopt responsible behaviors. The Commission also considers several ethical questions regarding the use of nanotechnology for military and public safety purposes. To end this part of the chapter, the Commission looks at how nanotechnology might influence the future of human beings and their relationship to nature from the perspective of the convergence of knowledge and technology.

In the third part of the chapter, the Commission briefly considers concerns tied to the responsible management of nanotechnology and *other emerging technologies*. The Commission found it impossible to ignore certain ethical concerns inherent not only to nanotechnology, but also other emerging fields like biotechnology, genomics, and information and communications technologies. As nanotechnology progresses, the questions raised may take on greater importance or a new dimension, justifying further exploration. The Commission looks at governance, economic activity, and citizenship, with particular emphasis on the legitimacy and transparency of the decision-making process, the potential nano-divide* between affluent and less developed countries, intellectual property, and the empowerment* of citizens in the choices they make regarding new technologies.

In its position statement, the Commission formulates eight recommendations to political decision makers and other stakeholders. These recommendations are aimed at putting in place measures to promote responsible nanotechnology development and associated technological innovation in order to ensure every possible benefit for current and future generations. However, the Commission sometimes found it impossible to make a specific recommendation on a given subject, even when it deemed that subject to be important. In such cases, the Commission has issued a commentary instead, in order to highlight a particular aspect of the issue in question so that Québec society as a whole may be in a better position to act and make informed decisions about nanotechnology.

In putting together this position statement, the Commission set up a working committee[7] consisting of Commission members, various university and government stakeholders, and a citizen representative, all of whom had a specific interest in nanotechnology development and related ethical issues. The committee drew inspiration from broader, international assessments of the economic, environmental, ethical, legal, and social issues of nanotechnology (NE^3LS). On an exceptional basis, the Commission worked with Office québécois de la langue française (OQLF) to ensure the quality of the terminology used in its position statement.[8] The committee was active from December 2004 to April 2006. The Commission wishes to express its appreciation to the committee chair and members for their outstanding contribution throughout preparation of the draft statement, to the experts who kindly agreed to provide clarification to the committee as needed,[9] and to the professionals at the secretariat who helped make this position statement possible.

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7 A list of committee members appears at the start of this position statement.

8 The results of this collaboration gave rise to the glossary presented at the end of this position statement, to enhanced and updated nanotechnology content in *Le grand dictionnaire terminologique* on the OQLF website (http://www.oqlf.gouv.qc.ca/ressources/gdt.html), and to the addition of an OQLF terminology glossary on the NanoQuébec website [online] at http://nanoquebec.ca/ nanoquebec_w/site/explorateur.jsp?currentlySelectedSection=259.

9 A list of the people consulted is presented at the end of this position statement.

CHAPTER 1

A NEW AND EMERGING WORLD:
THE UNIVERSE OF NANOTECHNOLOGY

The mysterious world of the infinitely small is on the atomic scale and is measured in nanometers, a dimension invisible to the naked eye and the most powerful microscopes. This world was unreachable until the scanning tunneling microscope was invented. Since then, nanoscience and nanotechnology have taken off and expanded exponentially at the intersection of a number of disciplines, including biology, physics, chemistry, and computer science. Nanomaterials, nanoelectronics, and nanobiotechnology use the special properties of matter to create new products or transform existing ones, and to shape new approaches. While nanotechnology has already produced or promised useful or beneficial applications in many sectors, it is important to determine whether ethical questions should be raised regarding its emergence and potential undesirable effects on individuals and society, so that the proper and timely steps may be taken.*

A WORLD TO DISCOVER[10]

In its 2001 position statement on nanotechnology, Conseil de la science et de la technologie described the appeal of this new field as follows: “Nanotechnology is truly revolutionary. At the nanometric scale, materials and systems may reveal new characteristics that significantly modify their properties as well as the physical, chemical, and biological processes in which they are active. These changes are so fundamental that the properties of matter at the nanometric level cannot be deduced from what we know about solids at more readily observable levels. […] Nanotechnology is expected to launch a veritable technological revolution since it will enable humans to control matter at the atomic level.[11]”

In the same vein, a study released prior to the position statement situated the nascent technological revolution in time: “Nanotechnology is said to be the third technological revolution. The first was the industrial revolution in the late 18th and early 19th century, when humans learned to harness matter at the millimetric scale with inventions like the steam engine. The second technological revolution occurred in the mid-20th century with microelectronics, when humans harnessed matter

10 This chapter is a brief overview of the topic aimed at providing the basic information needed to understand the ethical questions raised in this position statement. Readers are invited to consult the following for a clear and detailed presentation of nanotechnology: Daniel LEBEAU, *Aperçu de la recherche sur les nanotechnologies*, information paper, Conseil de la science et de la technologie, Gouvernement du Québec, June 2001 [online] http://www.cst.gouv.qc.ca. In English, the following report published in Great Britian is also suggested: THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*, London, The Royal Society, July 2004 [online] http://www.royalsoc.ac.uk/document.asp?id=2023.

11 CONSEIL DE LA SCIENCE ET DE LA TECHNOLOGIE, *op. cit.*, English Summary, p. i.

at the micrometric scale (millionth of a meter). The third technological revolution will occur in the 21st century with nanotechnology, which will enable humans to control matter at the atomic scale (billionth of a meter).[12]"

While the history of nanoscience and nanotechnology was first officially recorded in 1959 with Richard Feynman's pioneering speech on atomic engineering, some believe that current interest in nanoscience and nanotechnology must not obscure the fact that the nanoworld is an integral part of nature, and that humans have always known intuitively how to use the particular properties of matter at the nanoscale (see inset). Others, however, believe this type of argument "is based on a philosophical fallacy" that naturalizes science and artificializes nature.[13]

A Bit of History

"The general public should be made aware that the 'nano' dimension is intrinsic to the material world in which humanity has lived for millennia. Particles, atoms, and molecules have existed since the beginning of the universe and are its building blocks. In the 'nano' domain, nature was the first to create molecules like DNA and carotene. The 'nanoworld' is therefore not fundamentally new, and it should be remembered that in both prehistoric times and the Middle Ages, humans were already using their knowledge of complex nanostructured* systems without knowing it […] (paints, dyes, additives, etc.). However, nanotechnology—the controlled manipulation of nanometric objects—appeared only recently, when techniques for observing and working at the nanoscale were commonly used in research laboratories. […] Nanotechnology development exploded when its potential was analyzed and applied, showing that the properties of nanoscale materials and the resulting systems could be fundamentally different from those of macroscopic, non-nanostructured materials* and systems."

Patrick BERNIER[14]

Milestones[15]

1959	Physicist Richard Feynman presents a talk entitled "There's plenty of room at the bottom" on the potential of atomic engineering.
1974	Norio Taniguchi at the Tokyo University of Science uses the term "nanotechnology" for the first time.
1981	Invention of the scanning tunneling microscope by Gerd Binnig and Heinrich Rohrer (Nobel Prize in Physics, 1986) at the IBM research laboratory in Zurich, enabling researchers to see atoms for the first time.
1985	Discovery of fullerenes ("buckyballs") by Robert F. Curl Jr., Harold W. Kroto, and Richard E. Smalley (Nobel Prize in Chemistry, 1996).
1986	Publication of K. Eric Drexler's book *Engines of Creation*, which popularizes nanotechnology.

12 Daniel LEBEAU, *op. cit.*, p. 8 [our translation].

13 Excerpt from a May 2005 personal letter from Céline Lafontaine, a sociologist at Université de Montréal: "Not only does this type of argument found in numerous public documents dealing with the nanoworld cause a degree of confusion regarding the newness of nanotechnology, it is also based on a philosophical fallacy that projects the current state of knowledge on all of human history. Many social science specialists regret that this type of argument is used in public documents, as it draws on a logic that 'naturalizes science and artificializes nature,' as this phenomenon is commonly called" [our translation].

14 Patrick BERNIER, "Nanosciences et nanotechnologies : dimension sociétale et problèmes de santé publique," *Nanosciences et Nanotechnologies : une réflexion prospective*, May 2005, p. 29 [online] http://www.recherche.gouv.fr/mstp/nano_mstp2005.pdf [our translation].

15 See, among others, *Scientific American*, September 2001, p. 36.

1989	Physicist Donald M. Eigler, a researcher at IBM, becomes the first person to manipulate atoms; he arranges 35 xenon atoms to write the letters "IBM."
1991	Sumio Iijima at the NEC research laboratory in Japan discovers carbon nanotubes*.
1993	Warren Robinett and R. Stanley Williams design a virtual reality system that uses a scanning tunneling microscope to manipulate atoms.
1998	Cees Dekker and his research group at Delft University in the Netherlands create the first carbon nanotube–based transistor.
Since 1990	Nanoscience and nanotechnology centers are opened around the world (United States, Japan, European Union, and a number of others).
Since 2000	National nanotechnology initiatives are put in place in many countries (United States, Japan, European Union, France, Germany, China, and a number of others).

Nanoscience and nanotechnology: on a nanometer scale

The world of nanoscience and nanotechnology is on the nanoscale. The prefix "nano" comes from the Greek *nannos*, meaning "dwarf" or "very small." It refers to a billionth (10^{-9}) of a unit of measurement such as the meter. A dimension this small is invisible to the naked eye; for comparison, it is common to indicate that a human hair varies between 50,000 and 100,000 nanometers (nm) in diameter.

Objects are considered part of the nanoworld when one of their dimensions is between 1 and 100 nm. Object size is important because enhancements or changes in the properties of matter—a fundamental aspect of nanotechnology—generally occur between 1 and 100 nm. These include higher reactivity (due to an increase in the specific surface* of the nano object, and therefore in its volume/surface area ratio) as well as optical, magnetic, electrical, mechanical, and biological properties attributable to quantum effects that occur at this scale (like the tunnel effect*) but are not present in the same material at a larger scale.

One final point is essential to properly defining the world of nanotechnology, i.e., human intervention in the manipulation and control of matter at the nanoscale to create nanostructures that can be integrated into larger-scale structures in the development of nanotechnology products.

These three characteristics—size, new properties, and control of matter—are included in the lengthy definition of nanotechnology adopted by the National Science Foundation in the United States and used by the National Nanotechnology Initiative.[16] The Commission reiterates these characteristics in its definition of the terms "nanoscience" and "nanotechnology," as used in this position statement.

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[16] NNI is a multiagency U.S. government program aimed at accelerating the discovery, development, and implementation of science, engineering, and technology at the nanoscale. It defines "nanotechnology" as follows: "*Research and technology development at the atomic, molecular, or macromolecular levels, in the length scale of approximately 1–100 nm range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices, and systems that have novel properties and functions because of their small and/or intermediate size. The novel and differentiating properties and functions are developed at a critical length scale of matter typically under 100 nm. Nanotechnology research and development includes manipulation under control of the nanoscale structures and their integration into larger material components, systems, and architectures. Within these larger scale assemblies, the control and construction of their structures and components remains* [sic] *at the nanometer scale. In some particular cases, the critical length scale for novel properties and phenomena may be under 1 nm (e.g., manipulation of atoms at ~0.1 nm) or be larger than 100 nm (e.g., nanoparticle-reinforced polymers have the unique feature at ~200–300 nm as a function of the local bridges or bonds between the nanoparticles and the polymer).*" See the National Nanotechnology Initiative website [online] http://www.nano.gov.

Nanoscience is the scientific study at the atomic and molecular scale of molecular structures with at least one dimension measuring between 1 and 100 nanometers in order to understand their particular physicochemical properties and identify ways to manufacture, manipulate, and control them. More generally, “nanoscience” can mean research on any structure of matter that comprises at least one nanometric dimension, without necessarily being aimed at the manufacture of objects or materials for a specific purpose.

An offshoot of nanoscience, **nanotechnology** is the design and fabrication of structures at the atomic and molecular scale that have at least one dimension measuring between 1 and 100 nanometers that possess particular exploitable physicochemical properties and that can be manipulated and controlled. The results of certain studies on the behavior of ultrafine particles* with dimensions at this scale (e.g., from diesel engine emissions[17]) that are accidentally released into the air can be used in nanotechnology to better understand the behavior of nanoparticles designed and made in the laboratory.

Therefore, the difference between nanoscience and nanotechnology essentially reflects the conceptual distinction between science and technology. In the documentation consulted, the Commission notes that these two terms are sometimes used interchangeably and recognizes that it is not always easy or essential to distinguish between science and technology in this sector. For this reason, the term “nanotechnology” is often used generically in this statement. The plural form may also be used, probably due to the diverse applications and areas in which nanoscale manipulations occur.

As Conseil de la science et de la technologie noted in its 2001 statement,[18] and as other authors have since indicated,[19] these terms should be defined with caution. The definition should not be so broad as to encompass any technological research or application in a microscopic dimension. Expressions with the prefix “nano” are currently very popular and generally constitute an error in meaning. For example, “nano” building blocks and the “iPod nano” have nothing to do with nanometric technology. While this misuse is largely unimportant in marketing and advertising, this is not so in research. Government investment is gaining significance in nanoscience and nanotechnology research funding; in the world of research the temptation to tack the prefix “nano” onto projects in an effort to attract funding could be detrimental to the development of the sector.

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17 INSTITUT DE RECHERCHE ROBERT-SAUVÉ EN SANTÉ ET EN SÉCURITÉ DU TRAVAIL (IRSST), *Health Effects of Nanoparticles*, Claude OSTIGUY and associates, Report R-469, Studies and Research Projects, Gouvernement du Québec, August 2006, p. 5 [online] http://www.irsst.qc.ca/en/_publicationirsst_100209.html.

18 CONSEIL DE LA SCIENCE ET DE LA TECHNOLOGIE, *op. cit.*

19 Including ACADÉMIE DES SCIENCES ET ACADÉMIE DES TECHNOLOGIES (France), *Nanosciences – Nanotechnologies*, Science and Technology Report No. 18, Paris, April 2004 [online] http://www.academie-sciences.fr/publications/rapports/rapports_html/RST18.htm; OFFICE PARLEMENTAIRE D'ÉVALUATION DES CHOIX SCIENTIFIQUES ET TECHNOLOGIQUES (France), *Nanoscience et progrès médical*, Report by Jean-Louis LORRAIN and Daniel RAOUL, May 6, 2004 [online, French only] http://www.assemblee-nationale.fr/12/rap-off/i1588.asp; THE ROYAL SOCIETY &THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*

Important aspects to consider: a premise for ethical questioning

To better understand the world of nanotechnology, its features will be discussed in further detail: the nanoscale, new properties of matter at this scale, the manipulation of matter, multidisciplinarity and the convergence of disciplines, and worldwide fascination with nanotechnology. In some cases, these features will serve as a basis for the ethical assessment undertaken in the following chapters.

The size of nanometric components

Because devices designed especially to work at the nanoscale are required to explore the nanoworld and manipulate atoms or molecules—like the scanning tunneling microscope (for conducting materials) and the atomic force microscope* (for insulating materials)[20]—the nanoworld and its components remain invisible and undetectable outside research and industrial manufacturing facilities. Operations to monitor the presence of nanometric components in a given product or environment require specific conditions, and current measures to protect against inhalation, ingestion, or absorption through the skin, and to prevent nanoparticle waste from being released into the environment are no longer necessarily appropriate or effective.[21]

The new properties of nanometric matter

With the increase in the volume/surface ratio and the bigger specific surface that results, new properties appear in matter at the nanoscale, e.g., nickel becomes as hard as steel, a formerly soluble substance becomes insoluble, the conductivity of copper diminishes while that of carbon increases, the thermal properties of materials change, certain substances change color, and others become reactive. Discovery and research of these new properties are spurring interest in nanotechnology and the technological innovation it can lead to in many sectors.

However, these new characteristics of matter at the nanoscale are uncharted territory where uncertainty reigns. At less than 50 nm, matter follows the laws of quantum physics* and no longer those of conventional physics. Some of its properties—such as magnetism and conductivity—can change radically. Due to their small size, nanoparticles can become more toxic, since they can be more easily absorbed by living organisms.[22] These new properties inevitably raise the question of the proven or

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[20] MINISTÈRE DÉLÉGUÉ À LA RECHERCHE ET AUX NOUVELLES TECHNOLOGIES (France), *À la découverte du nanomonde*, Paris, 2003, p. 18–19 [online] http://www.nanomicro.recherche.gouv.fr/docs/plaq.nanomonde.pdf.

[21] THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 76.

[22] MERIDIAN INSTITUTE, *Nanotechnology and the Poor: Opportunities and Risks*. *Closing the Gaps Within and Between Sectors of Society*, January 2005, p. 8 [online] http://www.nanoandthepoor.org. See also, among others, SCIENTIFIC COMMITTEE ON EMERGING AND NEWLY IDENTIFIED HEALTH RISKS (SCENIHR), *Opinion on the appropriateness of existing methodologies to assess the potential risks associated with engineered and adventitious products of nanotechnologies*, European Commission, September 2005 [online] http://files.nanobio-raise.org/ Downloads/scenihr.pdf; SWISS RE, *Nanotechnology. Small Matter, Many Unknowns*, Annabelle HETT *et al.*, Swiss Reinsurance Company, Risk perception series, Switzerland, 2004 [online] http://swissre.com; J. Clarence DAVIES, *Managing the Effects of Nanotechnology*, Woodrow Wilson International Center for Scholars, Project on Emerging Nanotechnologies, Washington, D.C., January 27, 2006 [online] http://www.wilsoncenter.org/ events/docs/Effectsnanotechfinal.pdf.

hypothetical risks they may entail, and their identification, evaluation, and management, from nanometric product design to elimination.

Manipulating material

Two approaches are used in the fabrication of nanoscale materials and objects: the top-down approach*—currently more common—and the bottom-up approach*, a progressive technique.

The **top-down approach** consists of gradually reducing the size of an existing material by cutting or sculpting it (by machining or etching) until it has the desired dimensions and characteristics. This can be compared to sculpting a statue from a block of marble using a hammer and chisel.

Microelectronics has used this approach for fifty-odd years, particularly through photolithography*. Appreciated for its reliability and the complexity it is able to achieve, this approach generally requires a significant amount of energy and produces more waste than the bottom-up approach.[23]

The **bottom-up approach** consists of assembling nanometric components from the building blocks of matter, atom by atom or molecule by molecule, until a complete structure able to be integrated into a larger whole is obtained. This approach implies the controlled assembly of small subunits (atoms or molecules) into a functional larger structure. It is also similar to sculpting a statue, but by piling up blocks of marble instead of removing them.

For several billion years, nature has been building the living world using nanometric systems that operate according to the bottom-up approach. Nanotechnology aims to emulate these outstanding examples of self-assembly*.[24] However, self-assembly as it occurs in nature is not the only possible route in a bottom-up approach.[25] Objects can also be built using scanning probe microscopes* that assemble atoms (or molecules) one by one into the desired shape.

Both approaches, bottom-up and top-down, have advantages and disadvantages. In the top-down approach smaller and smaller objects must be created with increasing precision, while in the bottom-up approach the manipulation parameters must be well controlled in order to build units large enough for use in the macroscopic world.

The bottom-up approach, particularly as regards self-assembly, raises popular (and sometimes scientific) fears regarding the possible self-replication* of nanometric components that could result.

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23 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 28.

24 MINISTÈRE DÉLÉGUÉ À LA RECHERCHE ET AUX NOUVELLES TECHNOLOGIES (France), *op. cit.*, p. 3.

25 For more details, see THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 26–28.

Multidisciplinary approaches and the convergence of disciplines

Specialists in a variety of disciplines are already using nanotechnology in their field of research. For example, a biologist may use ferromagnetic nanoparticles made by a chemist to research a new cancer treatment, a physicist may use DNA to filter carbon nanotubes, and a chemist may use scanning probe microscopy* developed by a physicist to observe synthetic molecules. Each contributes to advancing research in his or her own discipline and, consequently, to nanotechnology as a whole. This makes it difficult to name realities in nanotechnology and establish a nomenclature clear and precise enough to enable the implementation of health and environmental protection standards.

The multidisciplinarity and vast potential of nanotechnology result in the convergence of disciplines involved in the development and use of nanotechnology. For example, the development of nanometric sensors* and their use in information and communications technologies could give rise to tightened security and surveillance measures, personalized healthcare, consumer product traceability, and consumption profiles.[26] The possible convergence of nanotechnology and biotechnology, information sciences, and cognitive sciences (*nano-bio-info-cogno/NBIC*[27]) also raises concerns regarding the potential transformation of humans through the harnessing of technology.[28]

A general fascination

In the 1990s, the first nanoscience institutes and centers opened in the United States and Japan. Since 2000, national initiatives have sprung up elsewhere in the world in order to promote the emergence of a local industry and achieve a competitive edge. Substantial investments have been made, as shown in the table below:

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26 *Ibid.*, p. x.

27 See, among others, Mihail C. ROCO and William Sims BAINBRIDGE (dir.), *Converging Technologies for Improving Human Performance. Nanotechnology, Biotechnology, Information Technology, and Cognitive Science*, National Science Foundation, Arlington, Virginia, June 2002 [online] http://www.wtec.org/ConvergingTechnologies/Report/NBIC_report.pdf; Wolfgang BIBEL (dir.), *Converging Technologies and the Natural, Social, and Cultural World*, Special Interest Group Report for the European Commission via an Expert Group on Foresighting the New Technology Wave, July 26, 2004 [online] http://ec.europa.eu/research/conferences/2004/ntw/pdf/sig4_en.pdf.

28 In the wake of the transhumanist philosophical approach that advocates "the moral right of those who wish to use technology to extend their mental and physical (including reproductive) capacities and to improve their control over their own lives […] beyond [their] current biological limitations," see "The Transhumanist Declaration" of the WORLD TRANSHUMANIST ASSOCIATION [online] http://transhumanism.org/index.php/WTA/declaration/.

Estimate of R&D investments by central governments, according to the National Science Foundation (in M$ U.S.)

Region	1997	1998	1999	2000	2001	2002	2003	2004	2005
Europe	126	151	179	200	~225	~400	~650	~950	~1,050
Japan	120	135	157	245	~465	~720	~800	~900	~950
United States	116	190	255	270	465	697	862	989	1,081
Others	70	83	96	110	~380	~550	~800	~900	~1,000
Total	432	559	687	825	~1,535	~2,350	~3,100	~3,700	~4,100

Source: Mihail C. Roco, National Science Foundation[29]

However, this data essentially concerns investments in national strategies implemented in the countries indicated; it excludes investments made by various American states (one billion U.S. dollars for the city of Albany, New York alone), for example, and does not include government investments made in Canada, which does not yet have a national nanotechnology strategy. Note that such a strategy was planned for late 2005[30] and should therefore be implemented soon. For the time being, it is difficult to draw up a quantitative portrait of Canadian investment in nanotechnology. The infrastructure required for nanotechnology development is largely housed in universities[31]; university research is funded through the budgets of national granting agencies (like the Natural Sciences and Engineering Research Council of Canada [NSERC] and the Canadian Institutes of Health Research [CIHR]), and multidisciplinarity makes an overview of nanotechnology funding impossible. As a guide, note that research on the subject in 2004[32] showed that approximately $200 million Canadian was granted annually for nanotechnology through NSERC budgets (team and individual funding).

With 38.6% of the country's nanotechnology enterprises, Québec holds an enviable position in this industry in Canada.[33] With the creation of NanoQuébec in 2001, it became a leader in nanotechnology promotion with a view to increasing Canada's economic development.

Nanoscience and nanotechnology research was marginal in the 1990s, but is now part and parcel of education[34] and research programs at all universities; private enterprises (SMEs often created at universities) are also increasingly present. Research is varied and focuses on the four main sectors considered below: nanomaterials, nanoelectronics, nanobiotechnology, and nanometrology. Most

29 From Mark ROSEMAN, *An Overview of Nanotechnology in Canada. Report 2: A Review and Analysis of Foreign Nanotechnology Strategies*, developed for the Prime Minister's Advisory Council on Science and Technology (PMACST), Canada, October 14, 2005, p. 2 and 3 [available on request] http://acst-ccst.gc.ca/back/home_f.html.

30 See http://www.infoexport.gc.ca/science/india_techsummit_thprof-fr.htm.

31 David J. ROUGHLEY, Victor JONES, and Aaron CRUIKSHANK, *An Overview of Nanotechnology in Canada. Report 3: The Canadian Industrial Capacity to Absorb Nanotechnology*, developed for the Prime Minister's Advisory Council on Science and Technology (PMACST), Canada, October 31, 2005, p. 13 [available on request] http://acst-ccst.gc.ca/back/home_f.html.

32 Peter GRÜTTER and Mark ROSEMAN, *A Study of Canadian Academic Nanoscience Funding: Review and Recommendations*, NSERC/CRSNG NanoIP/PIC, June 2004 [online] http://www.physics.mcgill.ca/NSERCnanoIP/e/Canada_Nano_Funding.pdf.

33 For a detailed discussion of the subject, see David J. ROUGHLEY *et al.*, *op. cit.* Appendixes also provide information on patents, entreprises, and research by Canadian province.

34 Several Québec cégeps also offer technical programs.

research funding in Québec is provided by government. The main funders are governments and their traditional granting agencies, such as the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Institutes of Health Research (CIHR), and Fonds québécois de la recherche sur la nature et les technologies (FQRNT). NSERC has set up a nanoscience and nanotechnology innovation platform (NanoIP[35]) aimed at accelerating and intensifying research, as well as training qualified individuals. This national, multidisciplinary network headquartered at McGill University includes university researchers from the engineering and science sectors, and funds projects with a high financial risk.

Last, it should be noted that nanotechnology development and application projects are not limited to developed countries; China, India, South Africa, and the former Eastern bloc countries also have nanotechnology programs. The increase in nanotechnology research around the world gives hope that the particular needs of less developed countries will also be considered in the development of solutions and that these countries will not be excluded from the expected benefits of research.

This global research effort will inevitably lead to a variety of applications with potential benefits, as well as effects on consumer, researcher and worker health, the environment, work organization, and even the future of humans that must be considered. Will local measures be enough, or will international monitoring and surveillance bodies need to be put in place? What about these concerns on the international scene?

Main areas of research and innovation

Much like electricity or electronics before them, nanoscience and nanotechnology will impact all spheres of daily life. A large range of applications has already been derived from nanotechnology or may be derived from it in the coming years—in the short, medium, and long term. These applications are sometimes puzzling, often fascinating, and in some cases worrying. The four main areas of research and innovation currently playing a major role in nanotechnology are nanomaterials, nanoelectronics, nanobiotechnology (and nanomedicine), and nanometrology.

Nanomaterials

A **nanomaterial** is comprised of particles that have at least one dimension between 1 and 100 nanometers and that impart particular properties. Nanomaterials with a single nanometric dimension (thickness) include film or thin layers and nanostructured surfaces. Nanowires* and nanotubes, which have a diameter less than 100 nm but may be up to several hundred micrometers in length, are two-dimensional nanomaterials. Lastly, nanoparticles, nanopowders, fullerenes, and nanocrystals (or quantum dots) are nanomaterials with entirely nanoscale dimensions.[36]

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35 NanoIP, *NSERC Nano Innovation Platform*, 2005 [online] http://www.physics.mcgill.ca/NSERCnanoIP/e/.

36 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit*., p. 7.

Nanomaterials are produced according to the two main approaches discussed above: the top-down approach and the bottom-up approach. Within these two approaches, a variety of techniques are used to manipulate matter according to the nature of the desired product. In the top-down approach, lithography* techniques are used, e.g., in electronics to produce silicon chips. In optics, precision cutting, etching, and abrasion technologies are used to produce high-precision parts. In the bottom-up approach, a variety of processes may be used: chemical synthesis processes to produce raw materials like the nanoparticles used in cosmetics, paint, and other products; self-assembly or self-organization* processes to produce nanocrystals, nanofilms, and nanotubes, e.g., for screen manufacturing; and positional assembly* processes to experimentally manipulate and position atoms and molecules one by one to create a structure.[37]

In both nanoscience and nanotechnology, "the limits between sectors are confusing and always blurred. This being the case, nanomaterials are the common denominator. They are highly significant, not only as new films and conducting materials in nanoelectronics, but also as sensor materials in nanobiotechnology."[38] In the current state of technology and research development, nanomaterials are primarily integrated into existing products to improve certain features or give them added benefits. Examples include transparent sunscreens, cosmetics that penetrate the skin more deeply, more durable tires, longer-lasting tennis balls that bounce better, corrosion-resistant paints, antiglare glass, antibacterial dressings, wrinkle-resistant fabrics, etc.[39] (also see inset). In the medium or long term, however, nanomaterials will be used for much more ambitious objectives in areas like energy and the environment. Nanomaterials are also an integral part of the development of research and new nanotechnology applications in electronics and health, which will be discussed below.

Possible Uses for Nanomaterials

"The mechanical resistance properties of nanomaterials can be applied to sectors as diverse as building materials, household appliances, and medical devices. Land, water, air, and space transport equipment made with nanomaterials will be lighter, carry a heavier load, use less energy, and therefore be less polluting.

Nanoparticles also have another interesting property due to their small dimensions: an outstanding surface/volume ratio. This will help increase the efficiency of catalysts, particularly those used in oil refining and the fertilizer industry, as well as pollutant absorption (using antipollution filters and catalytic converters in vehicles) and hydrogen storage (to power fuel cells* in electric cars)."

MINISTÈRE DÉLÉGUÉ À LA RECHERCHE
ET AUX NOUVELLES TECHNOLOGIES (France)[40]

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37 *Ibid.*, p. 25–30.

38 AMBASSADE DE FRANCE EN ALLEMAGNE, *Les nanotechnologies en Allemagne*, Domaines des nanomatériaux et de la nanoelectronique, October 2005, p. 9 [online] http://www.bulletins-electroniques.com/rapports/smm05_085.htm [our translation].

39 See, among others, SCIENCE-METRIX, *Canadian Stewardship Practices for Environmental Nanotechnology*, Stéphane BERGERON and Éric ARCHAMBAULT, on behalf of Environment Canada, March 2005, p. 2 [online] http://www.science-metrix.com/pdf/SM_2004_016_EC_Report_Stewardship._Nanotechnology_Environment.pdf and EUROPEAN COMMISSION. COMMUNITY HEALTH AND CONSUMER PROTECTION, *Nanotechnologies: A Preliminary Risk Analysis…*, 2004, p. 138 [online] http://europa.eu.int/comm/health/ph_risk/events_risk_en.htm.

40 *Op. cit.*, p. 28 [our translation].

Nanoelectronics

Nanoelectronics is the study, design, fabrication, and use of electronic circuits or components assembled from nanosize elements in order to take advantage of particular physical properties. Optoelectronics* and information and communications technologies (ICT) are part of the sector. It should be noted that current overlap between innovation at the microscopic and nanometric scales makes it difficult to identify nanotechnology-specific innovation in electronics.

Historically, electronics has always sought to improve the performance of electronic components by continually miniaturizing them. Today, microelectronics is based primarily on the use of silicon and is expected to reach its limits in 2018. According to Moore's law*—that the number of components on a given surface doubles approximately every 18 months[41]—further miniaturization will not be possible, and a shift toward hybrid technologies like conducting polymers* will be required.[42]

To replace the lithographic techniques used to date to manufacture electronic circuits, a variety of nanoscale technologies are being tested, including X-ray lithography*, extreme ultraviolet lithography*, and electron beam projection lithography*.[43] The use of molecular electronics* (see inset) or carbon nanotubes is another option for achieving desired performance levels.

Molecular Electronics

"Molecular electronics research is currently attracting a good deal of attention, as encouraging and highly promising results have been obtained recently. If expectations are met, it will be possible to build computers in a completely different way than current lithographic techniques. A number of researchers are currently working on using chemical and biological molecules as computer components. These molecules would be used as transistors—the building block of any computer.

[…]

"This means that manufacturing methods for future computers will be completely different from current processes. Molecular electronic component manufacturing will be more akin to the processes used by pharmaceutical companies. Chemical components will be placed on a substrate and will assemble themselves. The number of operations will be drastically reduced, as many dozens of steps are currently required to produce a silicon chip. Consequently, not only will these chips have significantly higher processing and memory capacities, but they will also cost far less to manufacture. The first molecular electronics applications will probably emerge in the area of molecular memory.

"It should be noted that molecular electronics has developed faster than expected by researchers themselves in some cases. Of course, it is always extremely risky to make predictions regarding technology, but it seems highly likely that in 2025, certain types of computers will contain molecular components, will deliver thousands of times more processing and storage power, and will be made at a cost equal to or less than that of current computers."

Daniel LEBEAU[44]

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41 See, among others, SWISS RE, *op. cit.*, p. 39.
42 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 17.
43 See Daniel LEBEAU, *op. cit.*, p. 24–40.
44 *Ibid.*, p. 32, 34, 35 [our translation].

Nanobiotechnology and nanomedicine

Like other authors[45] consulted in preparing this position statement, Conseil de la science et de la technologie indicated in its own position statement the difficulty of defining nanotechnology, particularly due to its multidisciplinarity, but also because biotechnology is already working with DNA molecules and viruses at the nanoscale.[46] According to the Council, "one important criterion is the use of nanomaterials or the creation of new instruments or devices that operate at the nanoscale in biotechnology, a field that uses microtechnology and conventional molecular synthetic chemistry methods."[47]

In short, biotechnology uses nanotechnology techniques to develop tools for manipulating living organisms, studying them, or using them or their functional mechanisms to create, at the nanoscale, new materials or devices with particular properties. Nanobiotechnologists develop important biological imaging* applications and identify techniques used to make biochips*, labs-on-a-chip*, and biosensors*. At the intersection of chemistry, biology, and physics, nanobiotechnology applications are of primary interest in the field of health, but also the environment, agriculture, and the food industry.

Nanometrology

Nanoscience and nanotechnology applications cannot develop without proper instrumentation; theoretical and practical progress at the nanoscale is closely tied to advances in this area.[48] Hence the importance of nanometrology, which studies the measurement of nanometric structures and physical phenomena occurring at the nanoscale, and also deals with the measuring devices used to evaluate the quantities in question.

Nanometrology enables scientists to explore the nanoworld and design products using nanotechnology. Apart from measuring length at the nanoscale, nanometrology also deals with force, mass, and the optical, electrical, magnetic, chemical, and other properties of matter at this same scale.[49] It is essential to measuring nanoparticle exposure in the workplace, evaluating the toxicity of nanometric products, and establishing international standards for the sizing and characterization* of matter at the nanoscale.[50]

While standardization plays a key role in risk analysis and quality control, there are currently no standards at the nanoscale. The lack of calibration—a requirement for officially recognized measurements—is not only an obstacle to the scientific and technological replication of results obtained by laboratories or firms, it also prevents regulatory health and safety requirements from being

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[45] Including OFFICE PARLEMENTAIRE D'ÉVALUATION DES CHOIX SCIENTIFIQUES ET TECHNOLOGIQUES (France), *op. cit.*, which indicates that "a reading of various authors shows that there is currently no consensus regarding the definition. Some view this as a stigma characteristic of a nascent or rapidly developing discipline" [our translation], p. 23.

[46] CONSEIL DE LA SCIENCE ET DE LA TECHNOLOGIE, *op. cit.*, p. 17.

[47] *Ibid.* [our translation].

[48] THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 13.

[49] *Ibid.*, p. 13–16.

[50] *Ibid.*, p. 76.

put in place.[51] For example, there are no standardized procedures as yet for measuring nanoparticle size—a significant feature given that penetration depth and route (respiratory tracts, skin, blood, etc.) depend on particle size. This means that, depending on technique, different measurements may be obtained for the same nanomaterial sample and, consequently, the determination (or characterization) of its properties may also differ. Nanometrology is therefore crucial to standardizing measurements and ensuring their replication. In the United States, the National Institute of Standards and Technology (NIST) is working to establish standard procedures and samples.

The instrumentation used in nanometrology draws mainly on scanning probe microscopy (scanning tunneling microscope, atomic force microscope), as well as electronic microscopy (scanning and transmission). Other techniques are based on the use of laser beams, X-rays, or gas absorption. The semiconductor industry uses nanometrology extensively, particularly for product quality control. Nanometrology instrumentation is also essential to work at the nanoscale in chemistry, optics, and biology.

EXPECTATIONS AND CONCERNS WORTH CONSIDERING

Nanotechnology probably holds greater promise and spurs more hope than any other technology that has emerged since the second half of the 20th century, including information and communications technologies and biotechnology. Its newness and the range of technological innovation opportunities it brings raise fears that are largely fueled by literature and film. While these fears are not necessarily founded, this new technology still raises certain questions and ethical concerns regarding the proven or hypothetical risks it may entail, particularly regarding health and the environment, as well as other areas.

Projected benefits

Appendix 1 provides a summary of the possible benefits of nanotechnology in many areas if research delivers the expected results. Specific details on the health, environment, information technology, agriculture, and food sectors—the areas of greatest importance to this ethical assessment it is believed—round out this portrait. Occasionally, the Commission has added examples of work underway in Québec that ties in with the topic in question.

In the health sector

If nanotechnology delivers on its promises, it will impact all areas of medicine by improving diagnosis, ensuring better care, and compensating for acquired or congenital disabilities.[52]

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[51] *Ibid.*, p. 13.

[52] OFFICE PARLEMENTAIRE…, *op. cit.*, p. 17–29.

Improving diagnosis[53]—Advances in diagnosis will be among the most obvious, and the following applications may be available soon: DNA chips* for genetic diagnosis in the lab; labs-on-a-chip for analyzing human tissue or fluid samples in seconds,[54] instead of hours or even days, as is currently required; capsules that circulate in the human body for diagnostic purposes or to install sensors able to transmit information on tissue or organ condition; nanomarkers that use magnetic imaging techniques to detect diseased cells or disturbances in biological function.[55] The development of nanometric vectors using nanoparticles or quantum dots has skyrocketed in recent years, and this technology could help doctors detect the early signs of disease long before onset of the first symptoms, as well as early stage malignant tumors. Microscopic cameras inserted in a capsule are already used to perform endoscopies* of the small intestine; nanotechnology could help considerably reduce the size of the mechanism and enable the insertion of biosensors to measure temperature, arterial pressure, etc.[56] Carbon nanopearls* could also be used to create miniature X-ray tubes that could also be used for endoscopies.[57]

Ensuring better care—Remote drug targeting* and activation* as needed would be a major advance in treating disease, particularly cancer.[58] As indicated by the authors of a previously cited French report, "…a drug is useful only when it is able to hit its target, i.e., be in the right place at the right concentration. […] the ideal drug would not get lost in the twists and turns of the body, becoming diluted and therefore losing some of its potency."[59] The amount of a drug that actually hits the target is currently one to ten parts per hundred thousand, with the rest spreading throughout the body and causing well-known side effects, particularly in chemotherapy. By inserting a drug into a capsule several nanometers in diameter carrying magnetic nanoparticles guided "from outside the body by applying a magnetic field to the treatment area"[60] using magnetic resonance imaging* (MRI), a laser, or X-rays, the desired target could be hit directly and drug release could be activated at the right time (through electronic programming).[61] Because nanoparticles are able to cross the blood-brain barrier*, their use also presents significant interest for the treatment of neurological disorders such as Parkinson's disease, multiple sclerosis, and Alzheimer's disease; in this regard, the ability to deliver drugs to the brain and

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53 *Ibid.* and others, including AMBASSADE DE FRANCE AUX ÉTATS-UNIS, *SCIENCES PHYSIQUES.* Nanoscience, microélectronique, matériau, No. 04, June 2003 [online] http://www.senat.fr/opecst/annexe_ambassade_de_france_USA.pdf and THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 19–23.

54 Like the new self-diagnostic fertility test for men; see the Pria Diagnostics website [online] http://www.priadi.com and information on the Element™ Male Fertility Test.

55 INSTITUTE OF MEDICINE (United States), *Implications of Nanotechnology for Environmental Health Research*, Lynn Goldman and Christine Coussens (dir.), Roundtable on Environmental Health Sciences, Research and Medicine, Board of Health Sciences Policy, Washington, D.C., The National Academies Press, 2005, p. 17 [online] http://www.nap.edu/catalog/11248.html.

56 OFFICE PARLEMENTAIRE…, *op. cit.*, p. 18.

57 See "La nanotechnologie au service des écrans plats", *Club*, the magazine of Université Claude-Bernard – Lyon 1, No. 4, April 2004, p. 8 [online] http://www.univ-lyon1.fr/1126880808734/0/fiche___document/.

58 See, among others, Mauro FERRARI, "Cancer Nanotechnology: Opportunities and Challenges," *Nature Reviews: Cancer*, Vol. 5, March 7, 2005, p. 161–171 [online] http://nano.cancer.gov/news_center/nanotech_news_2005-03-07b.asp.

59 OFFICE PARLEMENTAIRE…, *op. cit.*, p. 21 [our translation].

60 *Ibid.*

61 For more information, particularly on PEBBLE (probe encapsulated by biologically localized embedding) technology, see INSTITUTE OF MEDICINE (United States), *op. cit.*, p. 18–22.

visualize the process is another possible advance that nanotechnology may permit.[62] Still with respect to treatment, it should be noted that dressings already available on the market are coated with silver salt nanoparticles that act as an antibacterial agent on open wounds—a property of silver at the nanoscale.[63] Work is underway in Québec on this technology and on development of a nanoscale release technology (e.g., for drugs that are insoluble in water), as well as nanoparticles that would help release drugs more deeply in the lungs of asthmatics and biodegradable polymers that would be made by bacteria and also used to administer drugs.

Compensating for acquired or congenital disabilities—Nanobiotechnology holds great promise for *in vitro* or *in vivo* genetic correction, as well as organ restoration or replacement due to aging, disease, or accident. Apart from gene therapy* (to fight mucoviscidosis* or immune deficiencies[64]), prosthesis manufacturing also stands to benefit from this technology. Research for the development of prostheses and implants is aimed at improving current approaches, particularly by creating "biocompatible materials with the ability to assemble themselves […] in order to integrate closely with the surrounding tissue without being rejected later."[65] For example, depositing a thin layer of a bonelike nanomaterial on the surface of implants would enhance compatibility and mechanical strength, increasing their service life up to 30 years[66]; current hip and knee implants generally last about ten years, which can mean more than one operation for the same patient over his or her lifetime, and therefore negative repercussions for patients personally, as well as considerable costs for the healthcare system. Nanotechnology could also be used to restore nerve connections and possibly the use of certain senses such as hearing[67] or sight.[68] Various university laboratories in Québec, particularly those with a focus on biomedical engineering* and tissue engineering*,[69] are currently working on biodegradable nanomaterials. The fabrication of neuroprostheses* is also envisioned and would involve establishing a connection between an electronic device and living cells (neurons) in order to restore at least partial motor function.[70]

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62 *NANOTECH NEWS*, "Nanoparticles Provide View of Drug Delivery into the Brain," January 9, 2006 [online] http://nano.cancer.gov/news_center/nanotech_news_2006-01-09b.asp.

63 See, among others, INSTITUTE OF FOOD SCIENCE AND TECHNOLOGY TRUST FUND (United Kingdom), "Nanotechnology," Information Statement, February 2006 [online] http://www.ifst.org/uploadedfiles/cms/store/ATTACHMENTS/Nanotechnology.pdf and THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 20.

64 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 22.

65 OFFICE PARLEMENTAIRE…, *op. cit.*, p. 28 [our translation]; see also presentations on this topic for hearings held by the organization, p. 86 to 111 of the Internet version.

66 *Ibid.*, p. 25.

67 *ISPUB.COM, THE INTERNET JOURNAL OF NANOTECHNOLOGY*, "Nano-Bio-Technology Excellence in Health Care: A Review," RAJESH, GITANJALY, SURBHI, Vol. 1, No. 2, 2005 [online] http://www.ispub.com/ostia/index.php?xmlFilePath=journals/ijnt/vol1n2/nanotech.xml.

68 *PHYSORG.COM*, "Nanotechnology brings brain recovery in sight," MIT, March 14, 2006 [online] http://www.physorg.com/news11755.html.

69 Particularly in tissue engineering to "create hybrid materials that combine nanostructured materials (organic polymers or mineral materials) and living cells to replace defective tissue. The major challenge is to produce biocompatible materials with the ability to assemble themselves […] in order to integrate closely with the surrounding tissue without being rejected later" [our translation]. See OFFICE PARLEMENTAIRE…, *op. cit.*, p. 50.

70 *Ibid.*

In the environment sector

Nanotechnology could be used to develop proactive applications to protect the environment, e.g., by contributing to the development of green energy—like solar power—or more environmentally friendly production methods that would require fewer raw materials, create less waste, or produce more durable goods.[71] Nanomaterials are among the solutions envisioned for energy conservation and the reduction of carbon dioxide emissions (CO_2). They are used to develop fuel cells that, along with hydrogen, are being considered for the production of "clean" energy[72] in the search for a replacement for gas engines; they are a catalyst for converting hydrogen and oxygen into electricity, and are also used to make lighter and more durable hydrogen tanks.[73] In Québec, work is underway on developing more effective, less expensive proton conducting membranes for low-temperature fuel cells, nickel nanoparticles for fuel cells, and tanks that operate on metal hydrides*. A catalytic converter for diesel engine exhaust pipes is also being developed. Designed to convert carbon monoxide and volatile organic compounds in fuel into water and carbon dioxide, it would help reduce polluting emissions.

Nanomaterials can also be used in water treatment and soil restoration. Nanopearls are being tested in Western Canada in order to restore ponds saturated with oil sands that produce large amounts of methane, a greenhouse gas 22 times more potent than carbon dioxide.[74] Thanks to their nanometric properties, membranes used in filtration systems[75] may have the potential to recycle, reuse, and desalinate contaminated water,[76] as well as remove toxic chemicals[77]; certain processes are expected to make this possible at a fraction of the current cost,[78] which some specialists believe will put an end to water shortages in arid regions of the world.[79] New electronic sensors and biosensors, which will be smaller, less expensive, and more selective,[80] could potentially be used to check drinking water quality, and detect and track contaminants (chemical, biological, or bacteriological agents) in the air, soil, or water. These applications will also prove useful in defense and the fight against terrorism (e.g., sarin or

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71 INSTITUTE OF MEDICINE (United States), *op. cit.*, p. 14–16.

72 AMBASSADE DE FRANCE AU DANEMARK, *Les nanotechnologies au Danemark*, November 2005 [online] http://www.bulletins-electroniques.com/rapports/smm05_095.htm.

73 Daniel LEBEAU, *op. cit.*, p. 15 and 16.

74 Maurice SMITH, "Beadwork. Small, reusable beads target residual bitumen in oilsand tailings," *New Technology Magazine*, September 2004.

75 For more information, see ENVIRONMENTAL SERVICES ASSOCIATION OF ALBERTA ([ESAA] Canada), *Nanotechnology in the Environment Industry: Opportunities and Trends*, Final Report and Bibliography for the Nano-Environmental Cross-Sector Initiative, March 4, 2005, p. 40–42 and 61 [online] http://www.esaa.org/abedmesa/doc.nsf/files/F3A8DABC57869C1B8725701400744689/$file/ESAA_Nano-Enviro_Final_Report_04Mar2005.pdf.

76 ENVIRONMENTAL PROTECTION AGENCY ([EPA] (United States), *External Review Draft. Nanotechnology White Paper*, Science Policy Council, Washington, December 2, 2005, p. 20 [online] http://www.epa.gov/osa/pdfs/EPA_nanotechnology_white_paper_external_review_draft_12-02-2005.pdf.

77 Peter A. SINGER, Fabio SALAMANCA-BUENTELLO, and Abdallah S. DAAR, "Harnessing Nanotechnology to Improve Global Equity," *Issues in Science and Technology*, Summer 2005, p. 59 [online] http://www.issues.org/21.4/singer.html.

78 PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY (United States), *The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*, Washington, D.C., May 18, 2005, p. 37 [online] http://www.nano.gov/html/news/PCASTreport.htm.

79 INSTITUTE OF MEDICINE (United States), *op. cit.*, p. 12.

80 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 19.

anthrax detection). A Québec business offers water treatment solutions using membranes with nanosize pores that can filter out chemical and biological contaminants larger than these pores.

In the information technology sector

New miniaturization technology is aimed at increasing the speed of computer components as well as their calculating, processing, and data storage capacities while conserving energy. More discreet (miniature) and more effective control and videosurveillance systems could also ensure tighter security. Sensors could even act as an interface between the human body and the computer in order to improve human performance.[81] A study indicates that “the use of nanostructures in the production of optical and fiber optic components would enable optical communications over very long distances without amplification, as well as the fabrication of highly sensitive liquid or gas sensors.”[82]

Whether science fiction or long-term application, smart dust* is at least a noteworthy curiosity. Consisting of a very large number of extremely miniaturized silicon chips, this dust would be released into the air or incorporated in materials like paint or textiles. Some say that “equipped with sensors, microprocessors, emitters, and power sources, it [smart dust] will form a communication network capable of receiving, processing, and transmitting data. Applications will abound in both defense (detection of chemical and bacteriological substances on a battlefield, detection of enemy movement) and the civilian world (air quality monitoring, food product tracing, medical supervision of patients, detection of material fatigue).”[83] Smart dust could also be used in agriculture.[84]

In the agriculture and food sector

Like biotechnology, nanotechnology should help achieve long-held objectives in agriculture by improving plant production, food processing, and safety and mitigating the environmental impact of food production, storage, and distribution.[85] Nanotechnology development could also help reduce the amount of chemicals used, thanks to the production of monitoring and dosing nanosystems that would accurately measure agricultural production status and the amount of chemicals to release into the

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81 *Ibid.*, p. 19 and 54.

82 AMBASSADE DE FRANCE AU DANEMARK, *op. cit.*, p. 27 [our translation].

83 MINISTÈRE DÉLÉGUÉ À LA RECHERCHE ET AUX NOUVELLES TECHNOLOGIES (France), *op. cit.*, p. 24; also see OFFICE PARLEMENTAIRE…, *op. cit.*, p. 93. [our translation]

84 NATIONAL PLANNING WORKSHOP (United States), *Nanoscale Science and Engineering for Agriculture and Food Systems*, report submitted to the Cooperative State Research, Education, and Extension Service, United States Department of Agriculture, National Planning Workshop, November 18–19, 2002, Washington, D.C., September 2003 [online] http://www.csrees.usda.gov/nea/technology/pdfs/nanoscale_10-30-03.pdf.

85 NATIONAL PLANNING WORKSHOP (United States), *op. cit.*, p. 16; see also SCIENTIFIC COMMITTEE ON EMERGING AND NEWLY IDENTIFIED HEALTH RISKS (SCENIHR), *op. cit.*, p. 5; ETC GROUP – EROSION, TECHNOLOGY AND CONCENTRATION, *Down on the Farm. The Impact of Nanoscale Technologies on Food and Agriculture*, Canada, November 23, 2004 [online] http://www.etcgroup.org/documents/NR_DownonFarm_final.pdf; Mihail C. ROCO and William Sims BAINBRIDGE (ed.), *Converging Technologies for Improving Human Performance...*, *op. cit.*, p. 6 [online] http://www.wtec.org/ConvergingTechnologies/Report/NBIC_report.pdf.

environment.[86] These "smart*" nanometric systems would use biosensors to monitor both plant cultivation and livestock facilities.[87]

In the food industry, research is underway in order to design smart[88] (or reactive) packaging that would indicate that the contents were no longer suitable for consumption or the packaging had been punctured. Nanometric clay sheets added to polymers in the packaging would make it more impermeable to its environment by reducing gas transfer between the product and the ambient air. Nanoparticles coated with a specific vector (like a protein or DNA fragment) and a dye could change color and immediately indicate the presence of bacteria or prions (particles that cause bovine spongiform encephalopathy, or mad cow disease) without waiting hours or days for lab amplification. Currently, to detect the presence of bacteria, lab workers must take a sample, place it in a nutrient medium at a controlled temperature, and wait about 48 hours for enough bacteria to grow that it is observable under the microscope.

From fiction to reality

While the line between science and fiction is clear for educated and informed scientific thinkers, it is not always so clear for the general public, who often substitute real science with literature and film. Stories of aliens invasions and computers that overthrow and dominate humans are among the abundantly depicted popular scenarios. Nanotechnology is no exception, having already inspired novels that emphasize risks that specialists view more as fantasy than reality.[89] Yet a negative perception of nanotechnology can impair citizens' judgment in the choices that must be made regarding nanotechnology development and implementation. For this reason, the Commission has chosen to approach the topic from the dual perspective of self-replication and global ecophagy*, as well as the hype spurred in certain ways by the emergence of nanotechnology.

The self-replication of nanorobots and global ecophagy*

Self-replication is defined as a "process in which a nanomachine* or nanorobot produces copies of itself using materials present in its environment."[90] This scenario is one of the most common fears with respect to nanotechnology, and it is featured in the now famous Michael Crichton novel *Prey*,[91] in

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86 SCIENCE-METRIX, *Canadian Stewardship Practices for Environmental Nanotechnology* , *op. cit.*, p. 7.

87 NATIONAL PLANNING WORKSHOP (United States), *op. cit.*, p. 29.

88 See, among others, "Emballage bioactif pour le secteur alimentaire. Les nanotechnologies pour de meilleurs emballages," *Les Affaires*, March 3, 2006, p. 12; ETC GROUP, *Down on the Farm. op. cit.*, p. 41–43; ECONOMIC AND SOCIAL RESEARCH COUNCIL (United Kingdom), *The Social and Economic Challenges of Nanotechnology*, Swindon, July 2003, p. 20 [online] http://www.shef.ac.uk/physics/people/rjones/PDFs/SECNanotechnology.pdf.

89 Abby FRANK, "Nanotechnology Myths," Earth & Sky Radio Series, April 2005 [online] http://www.earthsky.org/shows/nanotechnology_articles_myths.php.

90 OFFICE QUÉBÉCOIS DE LA LANGUE FRANÇAISE, *Le grand dictionnaire terminologique* [online] http://www.oqlf.gouv.qc.ca/ressources/gdt.html [our translation].

91 Michael CRICHTON, *Prey*, New York, HarperCollins, 2002; in French: *La Proie*, Paris, Éd. Robert Laffont, 2003.

which scientists have lost control over self-replicating nanoparticles, which escape the lab, take possession of humans, and threaten the entire planet.

Yet according to scientists, an event of this nature—which would require a high level of sophistication to create an organism that reproduces and spreads—is virtually impossible, as it violates too many laws of physics in terms of energy flow and thermodynamics.[92]

Fears of global ecophagy and self-replicating nanorobots are closely tied and difficult to separate. Global ecophagy, "according to a catastrophic scenario imagined by certain nanotechnology specialists, [means] the uncontrolled self-replication of nanorobots with the potential to destroy all of earth's ecosystems by transforming everything they find into goo."[93] A commonly used synonym is "the gray goo* problem."

In his 1986 book *Engines of Creation: The Coming Era of Nanotechnology*,[94] scientific visionary Eric Drexler presents a scenario that inspired Crichton's novel and was essentially aimed at warning readers about the potential dangers of this emerging field.[95] In 2000, Sun Microsystems cofounder Bill Joy supported Drexler's vision, as it were, by stating that people have a positive attitude toward innovation, which he presents as a bias toward instant familiarity and unquestioning acceptance.[96] In his opinion, people are so accustomed to living in a world of perpetual scientific discovery that they have a difficult time seeing that 21st century technologies like genetic engineering, nanotechnology, and robotics pose dangers far different from those associated with technologies implemented to date—these new technologies create organisms that can self-replicate accidentally or deliberately.

Crichton's novel[97] on the topic, fears expressed by Prince Charles[98] in Great Britain after reading this book, and catastrophic global ecophagy and gray or green goo* scenarios have spurred media interest and popular fears regarding this aspect of potential nanotechnology development. In December 2003 in letters exchanged with Drexler regarding self-replication and potential ecophagy, fullerene discoverer and Nobel Prize in Chemistry recipient Richard E. Smalley outlined the technical and scientific reasons why such a situation is impossible (according to the principles of chemistry and biology). Since then,

92 See, among others, THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, Appendix D, p. 109: "Mechanical self-replicating nano-robots and 'grey goo'"; Abby FRANK, *op. cit.*; Richard E. SMALLEY "Of Chemistry, Love, and Nanobots," *Scientific American*, September 2001, p. 76–77. For a discussion between Drexler and Smalley regarding "molecular assemblers," see *CHEMICAL AND ENGINEERING NEWS*, "Nanotechnology. Drexler and Smalley make the case for and against 'molecular assemblers,'" Point-Counterpoint, Vol. 81, No. 48, December 1, 2003 [online] http://pubs.acs.org/cen/coverstory/8148/print/8148 counterpoint.html.

93 OFFICE QUÉBÉCOIS DE LA LANGUE FRANÇAISE, *Le grand dictionnaire terminologique*, *op. cit.* [our translation].

94 K. Eric DREXLER, *Engines of Creation*, New York, Anchor Books, 1986.

95 As noted by Christine Peterson, vice president of Foresight Institute, who is quoted in Abby FRANK, *op. cit.*

96 Bill JOY, "Why the future doesn't need us," *Wired*, April 8, 2000, p. 4 of 19 in the Internet version: "*Our Bias toward Instant Familiarity and Unquestioning Acceptance*" [online]http://www.wired.com/wired/archive/8.04/joy.html.

97 *Op. cit.*

98 Essay published on July 11, 2004, in *The Independent on Sunday.*

Drexler[99] and Prince Charles have expressed agreement with Smalley's explanations and, in the current state of knowledge, it is generally recognized that ecophagy scenarios are pure fiction.[100] Therefore, they are no longer perceived as a real threat.

Promises that sometimes prove unrealistic

The promises of biotechnology are similar to those that have marked the progress of genetics—both have given rise to a certain hype regarding the expected benefits. With genetically modified organisms, biotechnology might make it possible to end world hunger, ensure the drinking water supply of the most disadvantaged countries, produce foods with all the required vitamins, develop agricultural production methods that are both environmentally friendly and more effective, etc. Genetics might make it possible to eradicate disease-causing genes, act on them directly in order to fight disease, or match genes with different types of behavior in order to modify it. Nanotechnology gives rise to even more promises due to the potential breadth of innovation in health, energy, the environment, agriculture, and many other sectors, in both developed and developing countries.

Unrealistic promises could undermine nanotechnology instead of helping it gain a foothold in the market. People will only be disappointed if nanotechnology does not deliver the results they expect, and may come to mistrust the management of new technology development. In addition, expectations that are too high could impair the development of other technologies that may be more promising than nanotechnology but are perhaps less fascinating. The advantages should therefore be measured compared to other technical approaches that may sometimes be a better choice for many reasons, such as lower development and implementation costs for comparable benefits. In this regard, **the Commission believes it is unwise to look to nanotechnology alone to solve problems, to the detriment of other approaches being developed or explored**; in the energy sector, for example, the considerable efforts to promote nonrenewable resource conservation should be continued and the search for new energy sources, pursued.

Raising questions, upholding values

As regards nanomaterials, the expected benefits of nanotechnology include solutions to a number of environmental and energy problems—an important factor in favor of their development. Yet concerns must be noted regarding certain materials and applications, particularly with respect to nanoparticles produced in the nanomaterial manufacturing process (engineered nanoparticles*). It is also necessary to determine the possible effects on the environment and on worker and consumer health, as certain products (sun creams and other cosmetics) are already available on the market.

Nanometrology raises few ethical issues, but the limited development of this sector underscores the need to establish a measurement and evaluation system that will ensure standard processes. Standards

99 Chris PHOENIX and Eric DREXLER, "Safe Exponential Manufacturing," *Nanotechnology*, Vol. 15, No. 8, August 2004 [online] http://www.stacks.iop.org/Nano/15/869.

100 See footnote 92.

can help guarantee safe approaches that protect health and the environment, as well as the development of proper regulations.

Nanoelectronics raises concerns primarily with regard to its ties to information and communications technologies and the development of high performance sensors (and, perhaps, smart dust). Ethical questions regarding respect for privacy are not new, but nanotechnology may amplify them, since a significant amount of data on people's health, consumption habits, comings and goings, and more could be recorded without their knowledge. The risk of using nanoelectronics to artificially augment human physical and mental performance (in much the same way as steroids or Ritalin) should also be considered.

Clearly, nanobiotechnology holds out great hope in the area of health. But what about nanotechnology-derived drugs—not to mention cosmetics—and new properties developed at the nanoscale? How will these products—which are not necessarily new, but contain nano ingredients—be controlled? How will nanoproducts able to cross the blood-brain barrier be used? In terms of diagnosis, ethical questions arise regarding the early detection of disability or disease; the same is true of genetics, particularly when medical science offers no therapeutic solution or the health system must shoulder the cost: Who can benefit from scientific progress, and how will this progress be used?

These are but a few examples of the questions raised by nanotechnology innovation in the four main sectors of development. But there are others that the Commission believes worthy of reflection while there is still time, particularly regarding the applications that could result from the triple convergence of biology, nanoelectronics, and nanomaterials with a view to human "enhancement" and the emergence of new eugenic* practices. What does the future hold if such applications become available? What type of society will emerge? What will happen to the most disadvantaged, the most vulnerable, or even those who reject the available changes? All these questions also raise the issue of the instrumentalization and transformation of the human body.

The Commission believes that the ethical questions raised by nanotechnology are not limited to those discussed in this brief overview. **It must develop a broader vision that encompasses other emerging technologies involving the same type of problems, which nanotechnology may only amplify or exacerbate.** For this reason, the Commission is also examining economic development and governance, work organization, research development, and the needs of developing countries.

The Commission believes that certain values might be affected by nanotechnology applications or their unnatural use or misuse, including dignity, liberty, individual integrity and respect, quality of life, protection of health and the environment, respect for privacy, justice and equity, transparency, and democracy. The following pages will explore the ethics of nanotechnology from the perspective of these values and the management of foreseeable health and environmental impacts and will also look at questions that may be raised with regard to governance, social acceptability, and in certain respects, philosophical issues.

But first the Commission will take stock of the normative guides—statutes and regulations—for nanoproduct development and marketing; it will also consider how other normative instruments, such as guides to good practices, might act as a safeguard in an emerging area and how the life cycle approach and precautionary principle might be used to minimize the risks of nanotechnology and the resulting products.

CHAPTER 2

LOOKING AT METHODS FOR MANAGING THE SECTOR

Considering the significance of nanotechnology in terms of technological innovation and the extensive industrial development that may result in the near future, it is legitimate to question how this new field is monitored. After a brief look at the known or hypothetical risks associated with nanotechnology and methods for assessing and managing them, the Commission reviews a number of statutes, regulations, and other monitoring mechanisms aimed at protecting the environment and the health of workers, consumers, and the public in general. The goal of this overview is to determine whether these instruments can deal with the undesirable effects new nanotechnology-derived products may have on health and the environment. In exploring possible decision-making approaches for nanotechnology, the Commission discusses the precautionary principle and the "life cycle" concept.

RISK AND NANOTECHNOLOGY

The concept of risk is highly prevalent in any assessment of the emergence of new technologies[101] when associated ethical issues are in question. Risk can essentially be defined as a "possible, uncertain event that can cause damage and is not solely dependent on a person's desires."[102] Two factors must therefore be considered: the probability that a potentially harmful event will occur and the potential damage such an occurrence would cause.[103]

These two factors, which are not always present in the case of nanotechnology (or other emerging technologies, e.g., biotechnology), raise questions as to how to deal with scientific uncertainty tied to the state of knowledge in the field, as well as ignorance about what might happen after a new technology is implemented. It may seem inappropriate to speak of post-implementation "risk" when this risk is simply a hypothesis regarding the repercussions, effects, or unwanted consequences attributable to nanotechnology throughout the life cycle of the resulting new or transformed products. As regards ethics—and without adopting a catastrophist approach—the hypothesis that an event with possibly harmful consequences might occur cannot be ruled out. It is in this spirit that the Commission uses the expression "known or hypothetical risk" in this position statement. It thus seeks to adopt an "all-encompassing" vision of risk that also considers the hypotheses and fears expressed, knowing that it is giving broader meaning to the word "risk."

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[101] On this subject, see, among others, ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD), *Emerging Risks in the 21st Century: An Agenda for Action*, Paris, 2003.

[102] OFFICE QUÉBÉCOIS DE LA LANGUE FRANÇAISE, *Le grand dictionnaire terminologique*, *op. cit.* [our translation]

[103] ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD), *Emerging Risks in the 21st Century…*, *op. cit.*, p. 30.

Two aspects of nanotechnology should be highlighted in order to demonstrate the importance of better understanding and monitoring the risk it may entail: first, the key role of nanoparticles in the development of new nanotechnology applications—given the relatively well-known industrial hygiene, health, and environmental risks associated with fine and ultrafine (non-nanometric) particles released into the atmosphere—and second, the new properties materials can acquire at the nanoscale (e.g., toxicity, conductivity, reactivity).

Based on this outline of the concept of risk in the area of nanotechnology, the Commission will seek to identify the known or hypothetical risks this technology poses and determine whether current risk assessment and management methods can address the features of nanotechnology-derived products.

The nature of risks to consider

Like any other natural or industrial particles that present toxicity risks for living organisms, engineered nanoparticles (which are created voluntarily) also carry risks associated with their manipulation or their deliberate or accidental release into the air, soil, and water. These risks must be taken into consideration in order to protect workers, the public, and biodiversity as a whole:

- Risks tied to the manufacture, handling, transportation, storage, or elimination of potentially toxic or dangerous products
- Risks that laboratory or industrial workers, or any populations who come into contact with toxic powders or products after their release into the air, water, or soil, will inhale or ingest these products or absorb them through the skin
- Risks that products released into the air, water, or soil will contaminate flora or fauna
- Environmental and health risks tied to the reactivity of certain substances

A number of existing statutes and regulations, briefly presented later in this chapter, already address such risks with respect to products not derived from nanotechnology.

But other risks, that research has not yet demonstrated, may specifically concern nanotechnology-derived products due to their particular characteristics[104]:

- The clustering tendency of engineered nanoparticles and its potential effects on the environment and living organisms
- The ratio of the specific surface of nanomatter compared to its mass, which modifies or intensifies the properties of the original material
- The reactivity of certain nanometric particles, particularly metallic nanopowders, which can lead to explosion, flammability, or toxicity
- The ability of nanomatter to cross the cutaneous, pulmonary, intestinal, placental, and blood-brain barriers that protect human and animal organisms

[104] THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*; SCIENTIFIC COMMITTEE ON EMERGING AND NEWLY IDENTIFIED HEALTH RISKS (SCENHIR), *op. cit.*

Many of the documents consulted indicated that any approach to dealing with the risk posed by nanoparticles must also make a distinction between free particles (including clustered particles) and particles that are part of a non-nanometric object (e.g., a nanometric component of a device used in medicine for endoscopic purposes) and therefore fixed. The latter are currently considered risk free for health and the environment.[105] In contrast, as IRSST observes, "free nanoparticles in the air are cause for concern due to their potentially negative impact on occupational health and safety, their accumulation in the environment, and their enrichment via the food chain. These could have long term risks for the health of populations. Although current knowledge on the toxicity of nanoparticles and the potential level of worker exposure is very limited, preliminary results in most of the important studies reveal significant biological activity and adverse effects. In the short term, it will be almost impossible to acquire adequate knowledge of the risk associated with every type of nanoparticle. This is due not only to the proliferation of new nanoparticles, but also to the modifications made to their surfaces; for these modifications greatly affect the surface properties of nanoparticles and possibly their biological reactivity and toxicity as well."[106]

Assessment and risk management methods: a few observations and questions

While there is still very little environmental and epidemiological data to support a process for assessing and managing the risk associated with nanotechnology-derived products, IRSST believes it has been clearly demonstrated that the degree of toxicity of nanoparticles is tied to their specific surface and resulting new properties, not their mass.[107] Yet studies to date have focused more on mass than the surface area or size of the particles; certain authorities believe this could lead to gross underestimation of the potential risk of nanoparticles.[108] In this regard, one should also consider that the structure of matter and the ratio of its mass to its specific surface can vary according to the nanometric dimension obtained and the matter itself; this means that a 90 nanometer particle of gold may have different properties from a 20 nanometer particle of gold, and that such differences may also be noted in other materials. Of course, this gives rise to an additional problem with regard to product characterization and seems to suggest that a case-by-case approach may be necessary.

These changes in property raise the question of the approval required to market new products. Are nanotechnology-derived or -transformed products considered new products? While products known to present health or environmental risks must be submitted to control agencies like Health Canada or Environment Canada, what about products whose risks are unknown or uncertain? To approve the marketing of a product and guarantee consumers that it is safe for health and the environment, these agencies assess risk according to the nature and purpose of the product, not its manufacturing method or the possible transformation of its components. Can these processes take into account the specific

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105 Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), *op. cit.*, p. 58.

106 Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), *Nanoparticles. Actual Knowledge about Occupational Health and Safety Risks and Prevention Measures*, Claude Ostiguy and associates, Report R-470, Studies and Research Projects, Gouvernement du Québec, September 2006, p. 71 [online] http://www.irsst.qc.ca/en/_publicationirsst_100189.html

107 Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), *Health Effects of Nanoparticles*, *op. cit.*, p. 43.

108 *Ibid.*

features of nanotechnology-derived products (the Commission raised this question before with regard to transgenesis-derived products in a position statement on genetically modified organisms[109])? However, such products are already on the market—the Woodrow Wilson Center database recorded over 200 in winter 2006[110]—and more will be added with advances in research.

An example from the cosmetics industry leads the Commission to question changes in the properties of titanium dioxide (TiO_2), a chemical already used in sun creams that becomes transparent at the nanoscale and penetrates the skin more easily. Use of titanium dioxide in sun creams is nothing new, but the use of nanoparticles is. Can current control agency requirements for new or transformed products address changes of this nature in the preparation of a consumer product already available on the market without nanometric components? Given that the passage of matter to the nanoscale can create changes in terms of both exposure (including the fate, persistence, and bioaccumulation of products in the environment or in living organisms) and the nature or intensity of possible adverse effects,[111] how suitable are current assessment methods for nanotechnology-derived products and their impact on health and the environment?

Lastly, the Commission notes that the effects of nanoparticles on health and the environment have been studied very little in the laboratory to date, particularly on humans, and the few research results obtained are sometimes contradictory and difficult to reproduce. Some believe that current equipment for measuring exposure to free nanoparticles is inadequate, as are assessment methods for determining the environmental fate of nanoparticles.[112] This being the case, the Commission would note the following issues considered crucial to assessing the risks associated with engineered nanoparticles, as proposed following a consultation by leading U.S. organizations[113]:

- Assessment of degree of exposure
- Toxicity
- The ability to extrapolate nanoparticle toxicity using non-nanometric particle and fiber toxicity databases

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[109] COMMISSION DE L'ÉTHIQUE DE LA SCIENCE ET DE LA TECHNOLOGIE, *Pour une gestion éthique des OGM,* [For the Ethical Management of GMOs] Gouvernement du Québec, 2003; see, among others, p. 31 to 42 (in French) For an English summary of this position statement, see www.ethique.gouv.qc.ca/eng/ftp/CESTAvisOGMEnglish.pdf.

[110] WOODROW WILSON CENTER FOR SCHOLARS, "A Nanotechnology Consumer Products Inventory" [online] http://www.nanotechproject.org/index.php?id=44. Due to the collection method used—an Internet search for websites advertising products with nanotechnology-derived components—this list is incomplete, and the number of products in circulation is probably higher.

[111] SCIENTIFIC COMMITTEE ON EMERGING AND NEWLY IDENTIFIED HEALTH RISKS (SCENIHR), *op. cit.*, p. 54.

[112] *Ibid.*, p. 4.

[113] Results of a workshop organized by the National Science Foundation (NSF) and the U.S. Environmental Protection Agency (EPA) cited in Kevin L. DREHER, "Toxicological Highlight. Health and Environmental Impact of Nanotechnology: Toxicological Assessment of Manufactured Nanoparticles," *Toxicological Sciences*, Vol. 77, No. 1, 2004 [online] http://171.66.120.171/cgi/content/full/77/1/3. See also Wolfgang LUTHER (dir.), *Industrial Application of Nanomaterials: Chances and Risks*, Technological Analysis, with the support of the European Commission, August 2004 [online] http://www.vdi.de/vdi/organisation/schnellauswahl/techno/arbeitsgebiete/zukunft/sub/10803/index.php.

- The environmental and biological fate, transportation, persistence, and transformation of nanoparticles
- The recyclability and overall sustainability of nanoparticles

The Commission believes that the emergence of nanotechnology and the marketing of nanotechnology-derived products clearly pave the way for new health and environmental risk assessment methods.

THE CURRENT FRAMEWORK

In Canada and Québec, there are no statutes or regulations directly concerning nanotechnology at any stage of the life cycle of nanoproducts or products containing nanometric components. This is also generally the case elsewhere, primarily because nanotechnology is used more to enhance existing products than to create entirely new products.

But the lack of nanotechnology standards does not mean the sector is not subject to monitoring. A certain number of statutes and regulations must be respected—depending on the applicable jurisdiction (federal or provincial)—from product manufacturing to elimination. As regards health, occupational safety, and the environment, this legislation also applies to nanomaterials, although they are not yet expressly mentioned. However, **as the Commission indicated earlier, existing statutes must be adapted, as they do not necessarily take into account certain features or properties specific to nanotechnology or nanometric products.**

Canadian statutes and regulations

The Commission identified the following statutes and regulations on protecting the environment and health (in general and in terms of industrial hygiene) that must be respected according to the applicable jurisdiction. This list is not exhaustive:

- **The *Canada Labor Code* (R.S., 1985, c. L-2),**[114] Part II of which is dedicated to occupational health and safety
- **The *Canada Occupational Health and Safety Regulations* (SOR/86-304),**[115] particularly parts X (hazardous substances), XI (confined spaces), XII (safety materials, equipment, devices, and clothing), and XIV (materials handling), which are especially pertinent to nanomaterials
- **The *Canadian Environmental Protection Act* (1999, c. 33),**[116] parts 4 (pollution prevention), 5 (controlling toxic substances), 6 (animate products of biotechnology), and 7 (controlling pollution and managing wastes) of which should apply to certain nanotechnology products

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114 See http://laws.justice.gc.ca/en/showtdm/cs/L-2.
115 See http://laws.justice.gc.ca/en/showtdm/cr/SOR-86-304.
116 See http://laws.justice.gc.ca/en/showtdm/cs/C-15.31.

- **The *Hazardous Products Act* (R.S., 1985, c. H-3)[117] and the *Controlled Products Regulations* (SOR/88-66),[118]** which are of interest to nanotechnology particularly as regards the distinction they make between prohibited, limited, and controlled products. The latter category is especially pertinent to nanotechnology, as it includes the following products, materials, or substances: compressed gas, flammable and combustible material, oxidizing material, poisonous and infectious material, corrosive material, and dangerously reactive material (Schedule II), as well as paint, enamel, and other liquid surface coatings (Schedule I, Part II, Paragraph 31) because they may contain nanometric components. Health Canada is responsible for administering the act and regulations, as well as managing the Workplace Hazardous Materials Information System (WHMIS; see inset), to which a number of federal, provincial, and territorial statutes and regulations refer.

  Similarly, it is also important to point out **the *Hazardous Materials Information Review Act* (R.S., 1985, c. 24, 3rd supp.)[119] and associated regulations (SOR/88-456),[120] as well as the *Transportation of Dangerous Goods Act* (1992, c. 34)[121] and associated regulations (SOR/2001-286).[122]**

About WHMIS

"The Workplace Hazardous Materials Information System (WHMIS) is Canada's hazard communication standard. The key elements of the system are cautionary labeling of containers of WHMIS 'controlled products,' the provision of material safety data sheets (MSDSs) and worker education programs.

"WHMIS is implemented through coordinated federal, provincial, and territorial legislation. Supplier labeling and MSDS requirements are set out under the *Hazardous Products Act* and associated *Controlled Products Regulations*. The *Hazardous Products Act* and its regulations are administered by the Government of Canada Department of Health, commonly referred to as Health Canada.

"The *Controlled Products Regulations* establish a national standard for the classification of hazardous workplace materials. In addition to setting out criteria for biohazards and chemical and acute hazards, the regulations specify criteria for chronic health hazards including mutagenicity*, carcinogenicity*, embryo* and reproductive toxicity, respiratory tract and skin sensitization.

"Each of the thirteen provincial, territorial, and federal agencies responsible for occupational safety and health have established employer WHMIS requirements within their respective jurisdiction. These requirements place an onus on employers to ensure that controlled products used, stored, handled, or disposed of in the workplace are properly labeled, MSDSs are made available to workers, and workers receive education and training to ensure the safe storage, handling, and use of controlled products in the workplace.

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117 See http://laws.justice.gc.ca/en/showtdm/cs/H-3.
118 See http://laws.justice.gc.ca/en/showtdm/cr/SOR-88-66.
119 See http://laws.justice.gc.ca/en/showtdm/cs/H-2.71.
120 See http://laws.justice.gc.ca/en/showtdm/cr/SOR-88-456.
121 See http://laws.justice.gc.ca/en/showtdm/cs/T-19.01.
122 See http://laws.justice.gc.ca/en/showtdm/cr/SOR-2001-286.

"WHMIS balances workers' right-to-know with industry's right to protect confidential business information and includes a mechanism for ruling on claims for exemption from disclosure of confidential business information as well as appeals to these rulings."

HEALTH CANADA[123]

- **The *Food and Drugs Act* (R.S., 1985, c. F-27)[124] and associated regulations (C.R.C., c. 870).[125]** This legislation governed by Health Canada concerns food, drugs, cosmetics, and therapeutic instruments. In its current state of development, nanotechnology presents particular interest for health and cosmetics applications but is not as useful for food, as yet, except for packaging. The legislation indicates that "where applicable, these regulations prescribe the standards of composition, strength, potency, purity, quality, or other property of the article of food or drug to which they refer" (A.01.002). For the moment, there is no reference to the use of nanometric products in the composition or coating of new or transformed drugs, the approval process leading up to their marketing,[126] or the approval of other health applications.

Québec statutes and regulations

As a supplement to or apart from Canadian legislation, the following Québec statutes and regulations may be pertinent to nanotechnology and consequently require adaptation:

- **The *Act respecting occupational health and safety* (R.S.Q., c. S-2.1)[127] and its associated regulation (R.R.Q., c. S-2.1, r.19.01).[128]** The purpose of this act is "the elimination, at the source, of dangers to the health, safety, and physical well-being of workers." The provisions most pertinent to nanotechnology are found in Chapter III on the rights and obligations of workers, employers, and suppliers, as well as Chapter VIII on occupational health. But the associated regulation is especially relevant and would require adaptation for nanotechnology. Its purpose is "to establish standards pertaining in particular to the quality of air, temperature, humidity, heat stress, lighting, noise, and other contaminants, sanitary facilities, ventilation, hygiene, sanitation, and cleanliness in establishments, area conditions, storage and handling of dangerous substances, machine and tool safety, certain high risk tasks, individual protective equipment, and the transportation of workers to ensure the quality of the work environment, to safeguard the health of workers, and to ensure their safety and physical well-being."
- **The *Regulation respecting information on controlled products* (R.R.Q., c. S-2.1, r.10.1),[129]** which clarifies Canadian statutes and regulations of the same nature for application in Québec

[123] From the Health Canada website at http://www.hc-sc.gc.ca/ewh-semt/occup-travail/whmis-simdut/application/about-a_propos_e.html.
[124] See http://laws.justice.gc.ca/en/showtdm/cs/F-27/en.
[125] See http://laws.justice.gc.ca/en/showtdm/cr/C.R.C.-c.870.
[126] For more details on the overall process, readers are invited to consult the Commission's position statement on GMOs, *For the Ethical Management of GMOs*, *op. cit.*, p. 27–29 and 35–41 [online] www.ethique.gouv.qc.ca/eng/ftp/CESTAvisOGMEnglish.pdf.
[127] See http://www.iijcan.org/qc/laws/sta/s-2.1/20060412/whole.html.
[128] See http://www.canlii.org/qc/laws/regu/s-2.1r.19.01/20061117/whole.html.
[129] See http://www.iijcan.org/qc/laws/regu/s-2.1r.10.1/20060412/whole.html.

- **The *Environment Quality Act* (R.S.Q., c. Q-2),**[130] which clarifies and elaborates on Canadian statutes on the subject, as needed, and sets out environmental protection requirements for parts of Québec and the province as a whole. Statutes and regulations on industrial waste in Québec are subject to this act. Division VII on residual materials management should be able to address nanotechnology development. Of the act's sixty-odd implementing regulations, the following three are probably the most pertinent.
- **The *Regulation respecting hazardous materials* (R.R.Q., c. Q-2, r.15.2),**[131] which supplements and elaborates on the *Controlled Products Regulations*, particularly Chapter I, which defines oxidizing, corrosive, explosive, gaseous, flammable, leachable*, radioactive, and toxic hazardous materials and their properties, some of which apply to certain nanotechnology products
- **The *Regulation respecting the quality of the atmosphere* (R.R.Q., c. Q-2, r.20),**[132] whose purpose is to "[…] establish ambient air standards and emission standards for particulate matter, vapors, and gases, emissions opacity standards as well as control measures for the prevention, elimination, or reduction of contaminant discharge from stationary sources" (Division II, Section 2)
- **The *Drinking Water Regulation* (R.R.Q., c. Q-2, r.18.1.1),**[133] which specifies that "drinking water must, where it is put at the disposal of a user, comply with the standards of quality of drinking water" described in the schedules regarding the maximum concentrations of inorganic, organic, or radioactive substances that water may contain

It should be noted that with the April 2006 adoption of the new *Sustainable Development Act*,[134] the above-mentioned statutes and regulations also became part of a governance approach based on sustainable development. A number of principles were identified for the purpose of implementing this act; those dealing with prevention, precaution, and polluter pays will play a key role with regard to nanotechnology. Section 11 of the act also provides that the sustainable development strategy the government will later adopt must "implement approaches related [to the principles identified], in particular concerning the life cycle of products and services."

International instruments

Certain international instruments include requirements regarding the transport between countries of dangerous goods that may pose a risk to health or the environment. Such instruments have led national governments to adapt their own instruments for the purpose of international trade. Like the statutes and regulations currently in force in Canada and Québec, these instruments would need to be adapted to take into account nanotechnology products with known or hypothetical risks.

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130 See http://www.iijcan.org/qc/laws/sta/q-2/20060412/whole.html.
131 See http://www.iijcan.org/qc/laws/regu/q-2r.15.2/20060412/whole.html.
132 See http://www.iijcan.org/qc/laws/regu/q-2r.20/20060412/whole.html.
133 See http://www.iijcan.org/qc/laws/regu/q-2r.4.1/20060412/whole.html.
134 See http://www.iijcan.org/qc/laws/sta/d-8.1.1/20060525/whole.html.

- ***UN Recommendations on the Transport of Dangerous Goods. Model Regulations.* 14th evised edition, 2005.**[135] The organization's recommendations are intended for governments and international organizations that must deal with regulations on the transport of dangerous goods.
- ***Technical Instructions for the Safe Transport of Dangerous Goods by Air.* International Civil Aviation Organization (ICAO).**[136] This text sets out the guidelines behind the instructions and includes a list of goods deemed dangerous and the requirements for their transport with a view to harmonizing international approaches.
- ***2006 Regulation for the Transport of Dangerous Goods.* 47th edition.**[137] Subject to ICAO requirements, this regulation also contains its own requirements.
- ***International Maritime Dangerous Goods (IMDG) Code.***[138] The Code supplements the *International Convention for the Safety of Life at Sea (SOLAS), 1974*[139] by setting out requirements for the sea transport of dangerous goods.

COMMENTARY OF THE COMMISSION

The development of nanotechnology and the marketing of nanometric products or components are well underway and will surely intensify in years to come. Given this, the Commission urges vigilance and attentive monitoring of the evolution of this new technology so that existing regulations may be adapted to the realities of this sector.

Supporting industry

Statutes and regulations are certainly an important part of the necessary monitoring of technology innovation, but legislation almost always lags behind technology development and is not a panacea. In order to meet the needs of business, other mechanisms should therefore be used to ensure some form of self-regulation in an emerging sector and fill the gap that may be left by the lack of regulations; best practices guides are a part of this.

Such a guide is currently being prepared for the Québec nanotechnology industry (including laboratories), with publication expected by late 2006. Developed under the responsibility of Institut de recherche Robert-Sauvé (IRSST)[140] with the collaboration of Commission de la santé et de la sécurité du travail (CSST – a government commission on occupational health and safety) and NanoQuébec, the guide will help inform nanotechnology professionals about the work environment in this sector and the

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135 See http://www.unece.org/trans/danger/publi/unrec/rev14/14files_e.html.

136 This document is not available online; the organization's website contains only proposed amendments to certain parts of the text. See http://www.icao.int/icaonet/dcs/9284/9284_add1_en.pdf.

137 This document is not available online. However, see the product description at https://www.iataonline.com/Store/Products/Product+Detail.htm?cs_id=9066%2D47&cs_ catalog=Publications.

138 Revised every two years. The latest amendments came into force in January 2004. The document is not available online. However, see the product description available at http://www.imo.org/home.asp.

139 See http://www.imo.org/Conventions/contents.asp?topic_id=257&doc_id=647#description.

140 The Institute has published two reports (R-469 and R-470, cited above) on occupational health and safety risks and prevention measures.

best approaches to ensuring the health and safety of everyone involved (including students and researchers) while promoting environmental protection.

COMMENTARY OF THE COMMISSION

The Commission encourages Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) as well as its partners to pursue development of this best practices guide so that it may be published as soon as possible. The Commission also calls on the various government ministries interested in nanotechnology development to encourage the research and manufacturing communities in this sector to adhere to the practices recommended in this guide, and to support its promotion and further elaboration. The Commission seeks to avoid any undesirable impacts of nanotechnology on occupational health and on the environment, and considers that such a best practices guide is necessary, given the current state of nanotechnology development.

RESPONSIBLE APPROACHES TO DEALING WITH RISK

Rarely is a society able to consider the importance of monitoring the development of a new technology in the early stages of its emergence. While it certainly did not have the opportunity with genomics, transgenesis, and information and communications technologies, nanotechnology could be different. It needs to ask if this technology should be monitored and to what extent. Some hold that legislation on nanotechnology is not necessary,[141] others believe it is,[142] and still others believe that imposing a moratorium on nanotechnology is the only possible solution.[143] In the current state of affairs, the Commission considered two approaches to nanotechnology monitoring: the precautionary principle and the "life cycle" approach.

The precautionary principle

Considering the uncertainty and ignorance regarding the possible repercussions of nanotechnology on health and the environment, many writings on nanotechnology refer to the precautionary principle, generally to point out the lack of true consensus on its definition and the difficulty of implementing it without undermining scientific progress. There is no common position either regarding the role this principle should play in the risk analysis process.[144]

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141 This is the opinion of THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, whose authors nevertheless recommend vigilant monitoring of the technology's evolution.

142 Among other possibilities, J. Clarence DAVIES of the WOODROW WILSON INTERNATIONAL CENTER FOR SCHOLARS, *op. cit.*, proposes a set of measures, including a law on managing the risks associated with nanotechnology.

143 E.g., as suggested by Canada's ETC GROUP (ACTION GROUP ON EROSION, TECHNOLOGY AND CONCENTRATION). See "No Small Matter II: The Case for a Global Moratorium. Size Matters!" *Occasional Paper Series*, Vol. 7, No. 1, April 2003 [online] http://www.etcgroup.org/upload/publication/165/01/ occ.paper_nanosafety.pdf.

144 ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD), *Uncertainty and Precaution: Implications for Trade and Environment*, Joint Working Party on Trade and Environment, September 5, 2002, p. 14 [online] http://www.olis.oecd.org/olis/2000doc.nsf/4f7adc214b91a685c12569fa005d0ee7/98a7c482bccb43afc1256c2b003fe2ce/$FILE/JT00130913.PDF.

In its 2003 position statement on GMOs,[145] the Commission recommended adopting a precautionary "approach," which it considered more flexible than a formal principle like the precautionary principle; this decision was also motivated by the confusion regarding the exact meaning of this principle and the resulting difficulty of using it in a manner befitting its inherent spirit. In this position statement, however, the Commission felt the need to revisit the issue and consider the precautionary principle with regard to nanotechnology, among other things based on a seminar it hosted on this topic in November 2005. It has dual objective: to determine whether the precautionary principle rather than a precautionary "approach" is justified for nanotechnology and to fight—albeit modestly—the increasing use of this principle to justify the lack of a decision. Note that UNESCO considers that "*principle* is employed as the philosophical basis of the precaution and *approach* as its practical application."[146]

UNESCO suggests the following definition of the precautionary principle: "When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm."[147] Like most other definitions of the concept, this one is based on the text adopted at the June 1992 Earth Summit held in Rio: "Principle 15: In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."[148] Over the years, this definition has spread to areas other than the environment, particularly public health, in certain cases with additional wording with an economic flavor stating that preventive steps shall be taken "at an economically acceptable cost."[149]

A few clarifications

Regardless of the definitions or terminology used, there is considerable confusion surrounding the principle with respect to the notion of risk (occurrence and consequences), as well as the distinctions to be made regarding the state of knowledge and among the notions of prudence, prevention, and precaution in decision making. This confusion also arises from prejudices that the precautionary principle is paralyzing and requires the demonstrated absence of all risk. For this reason, the Commission felt it necessary to provide an overview of the issue in the following paragraphs.[150]

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145 COMMISSION DE L'ÉTHIQUE DE LA SCIENCE ET DE LA TECHNOLOGIE, *Pour une gestion éthique des OGM* [For the Ethical Management of GMOs], *op. cit.*, p. 54–56. An English summary is available at http://www.ethique.gouv.qc.ca (English).

146 WORLD COMMISSION ON THE ETHICS OF SCIENTIFIC KNOWLEDGE AND TECHNOLOGY (COMEST), *The Precautionary Principle*, Paris, UNESCO, 2005, p. 23 [online] http://unesdoc.unesco.org/images/0013/001395/139578e.pdf.

147 *Ibid.*, p. 14.

148 UNITED NATIONS, *Rio Declaration on Environment and Development.* See text online at http://www.unep.org/Documents.multilingual/Default.asp?DocumentID=78&ArticleID=1163.

149 Olivier GODARD, "Principe de précaution," *Nouvelle encyclopédie de bioéthique. Médecine. Environnement. Biotechnologie*, Gilbert Hottois and Jean-Noël Missa (dir.), Brussels, Éditions DeBoeck Université, 2001, p. 650 [our translation].

150 Apart from the documents cited in this section, the reader is also invited to consult the following: INSTITUT FÜR ÖKOLOGISCHE WIRTSCHAFTSFORSCHU (IÖW), *Nanotechnology and Regulation within the Framework of the Precautionary Principle*, Final Report, Rüdiger HAUM *et al*., Berlin, February 2004.

Danger, risk, known risk, hypothetical risk. Danger is "exposure to possible evil, injury, or harm," (*Webster's*) while risk is "the possibility of suffering harm or loss; a factor, course, or element involving uncertain danger" (*Webster's*). According to these definitions, it is possible to say that danger exists absolutely, in and of itself, while the possible occurrence of danger is what creates a risk. A known risk is one whose existence has been demonstrated; and, depending on the circumstances, its probability of occurrence can be calculated—from low to extremely high; never zero[151]—or not (e.g., in cases of scientific uncertainty like avian flu). Hypothetical (or potential) risk is not demonstrated and may be impossible to demonstrate; its probability of occurrence cannot be calculated, but it is still plausible based on common sense or past experience (it does not arise from a foolish fear). In a certain sense, it is an affirmation that there is a risk that a risk exists—and that the feared event may never occur (optimistic attitude) or, at the other extreme, that it will almost certainly occur (catastrophist attitude). It should be pointed out that not all hypotheses have the same value, and just because a hypothetical risk exists does not mean it must be avoided at all costs.[152]

Unreasonable, harmful, irreversible risk, or morally unacceptable danger. At the two extremes, the known or hypothetical consequences of a risk may be benign or deadly, with a whole range of possibilities between the two, from least to most harmful. According to UNESCO, "*morally unacceptable harm* refers to harm to humans or the environment that is

– Threatening to human life or health, or
– Serious and effectively irreversible, or
– Inequitable to present or future generations, or
– Imposed without adequate consideration of the human rights of those affected"[153]

Of all the notions that define the precautionary principle, "unreasonable risk" is undoubtedly the most difficult to pin down, the most subjective, and the least tied to scientific expertise and mathematical quantification. How many lives must be sacrificed, how many workers must suffer from an occupational disease that reduces their life expectancy, how many animal or plant species must become extinct, what level of air, water, and soil pollution must be reached for a risk to be deemed unreasonable? Is irreversibility a criterion that can help answer all these questions and many other similar ones? Such concerns lead to the issues of risk perception and societal acceptability, which, according to the OECD, call for "a consensual approach to the use of precaution in risk management, informed use of cost-benefit and decision analysis tools, and a participative-deliberative approach to decision making"[154]—an ethics-based approach, in some sense, since a moral judgment must be made regarding the acceptability of the risk according to socially shared values.

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151 Philippe KOURILSKY and Geneviève VINEY, *Le principe de précaution*, report to the prime minister, Paris, October 15, 1999, p. 5 of the PDF version [online] http://www.ladocfrancaise.gouv.fr.

152 Mark HUNYADI, "Qu'est-ce que le principe de précaution? Nouvelles réflexions sur les usages du PP," speaking notes, seminar on the precautionary principle, Commission de l'éthique de la science et de la technologie, November 4, 2005, p. 8.

153 WORLD COMMISSION ON THE ETHICS OF SCIENTIFIC KNOWLEDGE AND TECHNOLOGY (COMEST), *The Precautionary Principle*, *op. cit.*, p. 14.

154 ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD), *Emerging Risks in the 21st Century...*, *op. cit.*, p. 85.

State of knowledge: certainty, uncertainty, ignorance. Any decision to determine whether a risk exists and assess its probability of occurrence is rooted in the state of knowledge, i.e., information available about "the potential consequences of a product, process, or activity in order to take the necessary measures to prevent or minimize any damages linked thereto."[155] At a certain level of scientific advancement or technology development, research results are a significant source of accumulated knowledge on the subject and the possible positive or negative consequences of associated applications. But these results can also include incomplete, questionable, even contradictory information on certain research subjects, creating uncertainty in the determination of risk. Moreover, some research may never have been done or may be impossible for a number of reasons (limits in instrumentation, research and experimentation methods, the body of appropriate research, the use of human subjects, etc.), creating a zone of temporary or permanent ignorance in certain areas that makes it impossible to determine whether a risk exists in using the knowledge available at a given moment in the evolution of a technology.

Prudence, prevention, and precaution. These very similar concepts are difficult to distinguish semantically, contributing to confusion and misunderstanding of the precautionary principle, i.e., knowing when prudence, prevention, or precaution are required and for which risks or hypothetical risks. For this reason and due to the numerous and sometimes conflicting points of view on the matter, the Commission will use the distinction established by Mark Hunyadi, in the belief that it might foster responsible decision making: *act with prudence* for risks whose repercussions and probabilities of occurrence are known, *take a preventive approach* in situations of uncertainty, i.e., when the risks are known but their probability of occurrence is not (avian flu is an example of such a situation), and *use precaution* when there are only hypotheses and no information on the existence of a risk or its probability of occurrence,[156] as with certain fears regarding an emerging technology like nanotechnology.

Prejudices regarding zero risk and paralysis. Fears of the worst-case scenario and hopes of eliminating or preventing any danger that could harm health and the environment in the short, medium, or long term could prompt decisions aimed at taking no risks and rejecting any activities that could result in any risk whatsoever. Clearly, such a position can be unjustifiable and lead to aberrations: No technological progress would have been possible over the centuries, and life itself would be impossible if no risk were allowed. On the other hand, would this position have helped prevent problems like bovine spongiform encephalopathy (mad cow disease), or those caused by asbestos, DDT, teflon, and many others?[157] Instead of seeking to avoid all risk, the question is probably how to determine which risks are acceptable. What adverse effects might a risk have? What is their scope and

[155] ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD), *Uncertainty and Precaution…*, *op. cit.*, p. 15.

[156] Mark HUNYADI, *op. cit.*, p. 8.

[157] These and other similar cases were studied under the auspices of the European Environment Agency and the results published in INSTITUT FRANÇAIS DE L'ENVIRONNEMENT, *Signaux précoces et leçons tardives : le principe de précaution – 1896–2000*, Orléans, 2004 [online] http://www.developpement.durable.sciences-po.fr/publications/Bibliographies/signaux_precoces.pdf.

magnitude? What is the probability?[158] Yet it is difficult to answer these questions with respect to hypothetical risks, since they involve ignorance and sometimes irrational fears. Does this mean that fear and the lack of an answer should lead to abstention? Is imposing moratoriums the only possible option? What avenues are possible to ensure that the precautionary principle leads to action?

Action steps

As noted by Olivier Godard, "the original contribution of the precautionary principle is that it sets out a requirement for early responsibility (in scientific time) for hypothetical, unproven risks that could have serious and irreversible consequences; such risks theoretically fall outside the prevention principle, which concerns risks that have been proven by scientific knowledge or experience."[159]

This discussion of the precautionary principle and the desire to make it a principle for action, rather than abstention, raise many questions, including the following: How can hypothetical risks be managed in a pluralistic and democratic society? How can society take into account the differing degrees of acceptability between individual and collective risk, and between health and environmental safety requirements on the one hand and the legitimate desire for technological development on the other? In the Commission's view, this subject deserves to be debated in society. In the meantime, however, both to guide and spur this debate, as well as enable a responsible development and implementation of nanotechnology, the Commission offers a few observations and possible solutions.

Observations to consider. The following observations are provided as a guide in order to promote the adoption of realistic and responsible measures for decision making regarding the known and hypothetical risks of nanotechnology:

- Due to the radically new challenges certain emerging new technologies may pose (including nanotechnology and biotechnology) and the transformation of regulatory methods in contemporary society, as well as the diversity of stakeholders in the context of globalization, "novel risk situations might be met with excessive inertia or inappropriate institutional responses […]."[160]
- Risks must increasingly be considered as potential due to their newness in emerging technologies; risk management should therefore be based more on the evolution of technology rather than historical records of past risks,[161] while keeping in mind that relatively minor incidents could have disastrous effects after many years[162] (asbestos is a noteworthy example).

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158 On this subject, see, among others, ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD), *Uncertainty and Precaution…*, *op. cit.*, p. 18.

159 Olivier GODARD, "Le principe de précaution et la proportionnalité face à l'incertitude scientifique," *Rapport public 2005 : jurisprudence et avis de 2004. Responsabilité et socialisation du risque*, Conseil d'État, Paris, La Documentation française, 2005, p. 385 [our translation].

160 ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD), *Emerging Risks in the 21st Century...*, *op. cit.*, p. 48.

161 *Ibid.*, p. 49.

162 ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD), *Uncertainty and Precaution…*, *op. cit.*, p. 6.

- Considering that zero risk does not exist, decision makers are not expected to ensure a totally risk-free environment; however, they must keep in mind potential scientific uncertainty and ignorance with respect to hypothetical risks and take responsible measures, including precaution.[163]
- Considering the societal aspects of risk is essential, and acceptability is a key notion in the risk assessment and management process[164]; in view of this, the precautionary principle "imposes a clear need to improve communication and reflection on various levels and types of uncertainty in scientific assessment."[165]
- The precautionary principle is not a substitute for scientific risk assessment, and it is not an alibi for circumventing agreements on free trade.[166]

To round out these observations indicated in the sources consulted, **the Commission feels it should mention the importance of considering, from an ethical perspective, the potential consequences of refusing to accept a measure of risk, particularly as regards the meaningful benefits to the public of technological advances and their commercialization.**

Examples of precautionary measures. The measures to be considered are "interventions undertaken before harm occurs that seek to avoid or diminish the harm. Actions should be chosen that are proportional to the seriousness of the potential harm, with consideration of their positive and negative consequences, and with an assessment of the moral implications of both action and inaction. The choice of action should be the result of a participatory process."[167] These measures can differ, may be applied simultaneously or successively, as the case may be, and are therefore not mutually exclusive. In the spirit of this position statement, which limits use of the precautionary principle to situations of ignorance or considerable uncertainty, the Commission points out the following measures aimed primarily at managing such situations:

- Promote research as essential to countering ignorance and considerable uncertainty; while research is multidisciplinary, due to the very nature of nanotechnology it must also be interdisciplinary in order to bring together different areas of knowledge, including the social and human sciences
- Use citizen participation and consultation mechanisms to determine the social acceptability of hypothetical or known risks with a high degree of uncertainty
- Develop methods for controlling and monitoring research results and incidents—even minor—in order to promote the early detection of potentially dangerous or harmful situations
- Enact legislation to impose the necessary prohibitions and restrictions, including moratoriums on certain practices

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163 *Ibid.*, p. 29 and 30.

164 Organization for Economic Cooperation and Development (OECD), *Emerging Risks in the 21st Century...*, *op. cit.*, p. 89.

165 World Commission on the Ethics of Scientific Knowledge and Technology (COMEST), *The Precautionary Principle*, *op. cit.*, p. 35.

166 Organization for Economic Cooperation and Development (OECD), *Emerging Risks in the 21st Century...*, *op. cit.*, p. 17.

167 World Commission on the Ethics of Scientific Knowledge and Technology (COMEST), *The Precautionary Principle*, *op. cit.*, p. 14.

The following chapters discuss certain ethical issues relating to nanotechnology and indicate any ignorance or considerable uncertainty regarding the possible effects on health and the environment, particularly with respect to nanoparticles, the Commission will issue recommendations to the various stakeholders based on the observations and action steps indicated above.

The "life cycle" approach from the perspective of sustainable development

In 1997, the ISO 14040 (from the 14000 series[168]) international standard on life cycle assessment for environmental management was adopted. The following year, Environment Canada published a guide entitled *Environmental Life Cycle Management: A Guide for Better Business Decisions*, including the following definition: "[The life cycle concept takes] a 'cradle to grave' approach to thinking about products, processes, and services. It recognizes that all product life cycle stages (extracting and processing raw materials, manufacturing, transportation and distribution, use/reuse, recycling, and waste management) have environmental and economic impacts."[169]

There is clearly international interest in considering the issue of life cycle with respect to nanotechnology. Examples of this include the European Union's sixth framework program,[170] the joint report by the Royal Society and the Royal Academy of Engineering in Great Britain,[171] a draft white paper by the U.S. Environmental Protection Agency (EPA),[172] and a briefing by the California Council on Science and Technology.[173] In this briefing, however, interest in product life cycle is primarily tied to the industrial production of nanometric components, particularly as regards worker and environmental protection, since nanocomposites* may accumulate in the environment over time.[174]

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168 Readers should note that "the main purpose of the ISO 14000 series standards is to promote more effective and efficient environmental management in organizations and the provision of useful and usable tools (cost-effective, systems-based, flexible, based on the best organizational practices available) for gathering, interpreting, and communicating environmentally relevant information, the end result of which should be the improvement of environmental performance." See http://www.intracen.org/tdc/Export%20Quality%20Bulletins/eq53eng.pdf, p. 2–3.

169 See http://www.ec.gc.ca/ecocycle/en/whatislcm.cfm for an overview of the guide.

170 EUROPEAN UNION, "Sixth Framework Program: Nanotechnologies and nanosciences" [online] http://europa.eu/scadplus/leg/en/lvb/i23015.htm.

171 *Op. cit.*

172 ENVIRONMENTAL PROTECTION AGENCY ([EPA] United States), *op. cit.*

173 CALIFORNIA COUNCIL OF SCIENCE AND TECHNOLOGY, *Nanoscience and Nanotechnology. Opportunities and Challenges in California*, A Briefing for the Joint Committee on Preparing CA for the 21st Century, California, January 2004 [online] http://www.larta.org/lavox/articlelinks/2004/040223_nanoreport.pdf.

174 "*It is the transition to large-scale commercial manufacturing of these materials that is the primary concern, not the small amounts of material produced in the research process. The exposure of workers to nanoparticulates will require investigation, and potential regulation as with chemicals found to be hazardous but useful. With large production quantities, it will also be important to study the full life cycle of these materials, including the associated process of producing them, their use, and eventual disposal. Nanocomposites, for example, may be more difficult and more energy-intensive to recycle than single-phase material, and may accumulate in the environment over time. Since environmental impacts may be slow to develop and ascertain, one of the challenges will be to determine what needs to be monitored over the course of time as an important and relevant effect.*" *Ibid*., p. 108.

Such concern is increasingly obvious with respect to sustainable development, as can be seen in the new *Sustainable Development Act*.[175] Whether with regard to life cycle thinking[176] or the life cycle approach[177] or, more concretely, life cycle management[178] or life cycle assessment[179] (LCA) (see inset), the basic goal is to protect the environment by taking into account the impact of "cradle-to-grave"[180] technological innovation, i.e., from the time the resources required to manufacture a product are obtained to final disposal of the product at the end of its useful life.

Life Cycle

"The concept of 'life cycle thinking' is […] a management philosophy that enables the associated tools to cover the entire life cycle, thus ensuring that local environmental improvements do not result simply from the displacement of pollution loads in time or space. The concrete expression of this thinking in businesses requires a set of tools whose use, as part of life cycle management, confers a certain management discipline. […] Therefore, with a view to sustainability, life cycle thinking promotes a systemic approach to resolving pollution problems at the source and using resources efficiently. […]"

Gisèle BELEM[181]

"The 'life cycle approach,' as opposed to a fragmentary approach, includes all existing consumption and production strategies. It gives rise to the 'life cycle management' of products and services, i.e., a set of highly effective tools that enable a business or government to operate within a framework of sustainable development. These tools include the life cycle assessment (LCA) of products and services, whose methodology is governed by the ISO 14040 and following standards, and which enables assessment of the environmental impacts of a product, service, or regulation in consideration of all stages of this product or service, from raw material extraction to disposal at the end of its useful life. The LCA must be supplemented by an analysis of social and economic impacts in order to guide sustainable development. With this analysis, the LCA becomes a powerful decision-making tool for identifying the best possible compromise among the environmental, social, and economic aspects involved in choosing a product, service, policy, or regulation."

CIRAIG[182]

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175 GOUVERNEMENT DU QUÉBEC, *Sustainable Development Act* (R.S.Q., c. D-8.1.1) [online] http://www.iijcan.org/qc/laws/sta/d-8.1.1/20060525/whole.html.

176 Gisèle BELEM, "L'analyse du cycle de vie comme outil de développement durable," under the direction of Jean-Pierre Revéret and Corinne Gendron, *Les cahiers de la Chaire*, research collection, Chair of Social Responsibility and Sustainable Development, No. 08-2005 [online] http://www.crsdd.uqam.ca/pdf/pdfCahiersRecherche/08-2005.pdf.

177 INTERUNIVERSITY RESEARCH CENTER FOR THE LIFE CYCLE OF PRODUCTS, PROCESSES, AND SERVICES (CIRAIG), *Mémoire*, as part of consultation on the draft Québec Sustainable Development Plan and the draft Sustainable Development Act, February 2005 [online] http://www.polymtl.ca/ciraig/Memoire_CIRAIG_DD.pdf.

178 *Ibid.*

179 *Ibid.* and Gisèle BELEM, *op. cit.*

180 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 32.

181 Gisèle BELEM, *op. cit.*, p. 7 and 11 [our translation].

182 INTERUNIVERSITY RESEARCH CENTER FOR THE LIFE CYCLE OF PRODUCTS, PROCESSES, AND SERVICES (CIRAIG), *op. cit.*, p. 3 [our translation].

> "The poor cousin of the LCA [life cycle assessment] is the social dimension and with it the condition of democracy, which is generally accepted as essential to decision making. Yet the inclusion of social criteria in LCA methodology is problematic—primarily according to stakeholders—due to objectivity, given the scientific nature of the tool."
>
> Gisèle BELEM[183]

The concept of sustainable development refers to the meaning given in Québec's Sustainable Development Act: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs. [It] is based on a long term approach which takes into account the inextricable nature of the environmental, social, and economic dimensions of development activities."[184] As indicated in a consultation paper released prior to adoption of the act,[185] "this definition draws on the following:

- The idea of intergenerational equity from the initial definition in the Brundtland Report
- The idea of improved living conditions from the enhanced definition issued in 1991 by IUCN, UNEP, and WWF
- The international consensus that the environment, society, and the economy should be the three fundamental dimensions of sustainable development"[186]

Although the act mentions life cycle twice—with regard to the internalization of costs (Section 6, Paragraph *p*) and the preparation of a government sustainable development strategy (Section 11, Paragraph 2)—there is no indication that life cycle is "essential for the attainment of sustainable development," as some believe.[187]

Recommendation No. 1

The Commission recommends

That the Québec Government, guided by the principle of precaution and from the perspective of sustainable development, be concerned with all phases of the life cycle of a product derived from nanotechnology or containing nanometric components, and that in this respect it should integrate the concept of "life cycle" into all policies where such an approach is appropriate, in order to avoid any damaging impact of technological innovation on health and the environment

183 Gisèle BELEM, *op. cit.*, p. 44 [our translation].
184 Section 2 of the *Sustainable Development Act*, GOUVERNEMENT DU QUÉBEC, *op. cit.*
185 GOUVERNEMENT DU QUÉBEC, *Plan de développement durable du Québec,* consultation paper, November 2004, p. 19 [online] http://www.mddep.gouv.qc.ca/developpement/2004-2007/plan-consultation.pdf.
186 *Ibid.* [our translation].
187 INTERUNIVERSITY RESEARCH CENTER FOR THE LIFE CYCLE OF PRODUCTS, PROCESSES, AND SERVICES (CIRAIG), *op. cit.*, p. 7 [our translation].

CHAPTER 3

NANOTECHNOLOGY:

ETHICAL CONCERNS

In its examination of the ethical issues of nanotechnology, the Commission first notes that the responsible management of nanotechnology development turns on three fundamental premises: establishing a nomenclature specific to nanoscience and nanotechnology, developing nanometrology to establish international standards, and continuing to conduct research and disseminate research findings. After explaining these premises, the Commission first raises a number of ethical concerns related to nanotechnology-derived products, specifically those associated with health, the environment, and safety. It then explores the broader ethical questions raised by the development of nanotechnology as well as other emerging technologies, such as biotechnology and genomics. The issues raised include governance, economic activity, and citizenship. It is important to be aware of all of these concerns right from the outset and to intervene as early as possible so these emerging technologies can realize their potential to the benefit—and not the detriment—of society and the public.

FUNDAMENTAL REQUIREMENTS AS PREMISES

Since Feynman's now famous speech on the world of the infinitely small,[188] the field of nanoscience and nanotechnology has emerged across a broad range of disciplines, including physics, chemistry, biology, information and communication science, cognitive science, and other well-established disciplines. The newness of the field and the contributions to its emergence by numerous disciplines have created a need for action to ensure its systematic, responsible development. This includes developing a common terminology and nomenclature, establishing procedures and standards, and continuing research efforts to clear up current uncertainties as to nanotechnology's impact on health and the environment.

The need to establish a common scientific terminology and nomenclature

The cross-fertilization of knowledge from various disciplines and the emergence of new discoveries underscore the need to standardize the scientific terminology (i.e., coming to consensus on definitions for the terms used) and scientific nomenclature (i.e., agreeing on the rules for naming a group of similar objects) specific to the field of nanotechnology. This is a complex issue, because the scientific nomenclature is based on the *size* and *chemical composition* of nanoparticles, but does not take into account specificities of the nanoscale material in terms of its *physical structure*—like that of carbon

[188] Richard P. FEYNMAN, "There Is Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics," *Engineering and Science*, vol. 23, No. 5, 1960 [online] http://clsdemo.caltech.edu/archive/00000047/02/1960Bottom.pdf.

nanotubes or fullerenes—or its specific *surface effects*. Moreover, the U.S. Institute of Medicine mentions in a 2005 report that it still remains to be determined whether or not these particles are actually new substances.[189]

The terminological vagueness and lack of a common scientific nomenclature among the various players in the field—evident in research work and the published scientific literature—demonstrates the creativity and speed with which knowledge is generated. Although not necessarily an obstacle to fundamental research, the lack of a standardized scientific vocabulary could eventually hinder development in the field. It is important to have an internationally recognized terminology and nomenclature agreed upon by the various stakeholders in the field in order to transfer knowledge through training, facilitate communications between scientists with different training and cultural backgrounds or with the general public, facilitate new consumer product development and commercialization, and set guidelines for the sector.[190] Such standardization would present numerous advantages: It would make it easier to index articles published in the various specialized magazines likely to cover nanoscience and nanotechnology, it would make it easier to popularize the terminology for the media and laypeople while promoting a dialog with the public, and it would also help clarify regulations that could apply to nanotechnology activities. This would help all those concerned to readily understand what the law is referring to,[191] particularly in the event of legal disputes.

In 2005, the International Organization for Standardization (ISO) created three committees dedicated to developing standards for "terminology and nomenclature; metrology and instrumentation, including specifications for reference materials; test methodologies; modeling and simulation; and science-based health, safety, and environmental practices."[192] Moreover, Canada chairs the terminology and nomenclature committee. The results of these efforts will most certainly contribute informed decision making with regard to nanotechnology research, monitoring, use, production, and consumption.

Also of note is Québec's prime role in contributing to the development and dissemination of French terminology for use in the scientific and commercial development of nanotechnology, where English predominates. Cooperation between NanoQuébec and Office québécois de la langue française (OQLF) during preparation of this position statement led to the posting of the OQLF nanotechnology vocabulary on the NanoQuébec website in addition to its inclusion in *Le grand dictionnaire terminologique*. OQLF is also working in partnership with various European countries to develop a multilingual nanotechnology vocabulary.

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189 INSTITUTE OF MEDICINE (United States), *op. cit.*, p. xii.

190 See, among others, EUROPEAN COMMISSION. COMMUNITY HEALTH AND CONSUMER PROTECTION, *Nanotechnologies: A Preliminary Risk Analysis…*, *op. cit.*, p. 24-25 [online] http://europa.eu.int/comm/health/ph_risk/events_risk_en.htm; Jean-Pierre DUPUY and François ROURE, *Les nanotechnologies : éthique et prospective industrielle*, Tome 1, Conseil général des mines and Conseil général des technologies de l'information, section « Innovation et Entreprise », November 15, 2004, p. 5 [online] http://www.cgm.org/themes/deveco/develop/nanofinal.pdf; MERIDIAN INSTITUTE and NATIONAL SCIENCE FOUNDATION, *International Dialogue on Responsible Research and Development of Nanotechnology*, Virginie, June 17–18, 2004, p. 8 and 11 [online] http://www.nanoandthepoor.org/Final_Report_ Responsible_ Nanotech_RD_040812.pdf.

191 INSTITUTE OF MEDICINE (United States), *op. cit.*, p. 42-43 ; SWISS RE, *op. cit.*, p. 85.

192 INTERNATIONAL STANDARD ORGANISATION – ISO, "ISO launches work on nanotechnology standards," press release, November 28, 2005 [online] http://www.iso.org/iso/en/commcentre/pressreleases/archives/2005/Ref980.html.

The importance of establishing procedures and standards

In order to determine the levels of acceptable risk, the potential dangers to human health and the environment need to be identified and quantified. Currently, "science has no methodologies needed to assess the toxicity of all of these new products on short deadlines and at reasonable costs."[193] In addition, the tests used do not indicate which physical property of a given nanotechnology component is responsible for the toxicity of the material examined.[194] It will be difficult to determine whether a product with a new nanoscale component needs to be retested if the original product has already been certified.[195]

This underscores the importance of establishing procedures and standards to…

- Make it possible to replicate and nanotechnology test hypotheses and research findings
- Facilitate risk assessments and quality control
- Make it possible to develop suitable health and safety requirements

However, as the U.S. Environmental Protection Agency points out, these procedures and standards cannot be developed as long as there are no adequate nomenclature agreements[196] and nanometrology instruments likely to provide consistent, uniform measurements.

The pursuit of research and the dissemination of results

While uncertainties remain regarding the safety of nanoparticles, there are also very few guidelines on issues such as how to steer clear of products containing nanoparticles.[197] One of the major problems raised in the literature is the shortage of data on synthetic nanoparticles. Nanotechnology experts advise against relying solely on existing data, which mainly concerns natural* or incidental* nanoparticles.[198] As mentioned in the IRSST report on the health effects of nanoparticles, "the toxicological data specific to nanoparticles remains insufficient due to the small number of studies, the short exposure period, the different composition of the nanoparticles tested (diameter, length and agglomeration), […] etc."[199] Nevertheless, it is interesting to note that in the summer of 2005 the International Council on Nanotechnology (ICON) created a databank of articles dealing with the health and environmental impact of nanomaterials.[200] This directory of scientific publications is

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193 Institut de recherche Robert-Sauvé en santé et en sécurité du travail – IRSST, *Health Effects of Nanoparticles*, *op. cit.*, p. ii.
194 The Royal Society & The Royal Academy of Engineering (United Kingdom), *op. cit.*, p. 48.
195 Environmental Protection Agency – EPA (United States), *op. cit.*, p. 26.
196 *Ibid.*
197 Science-Metrix, *Canadian Stewardship Practices for Environmental Nanotechnology*, *op. cit.*, p. 2.
198 Institute of Medicine (United States), *op. cit.*, p. 2.
199 Institut de recherche Robert-Sauvé en santé et en sécurité du travail – IRSST, *Health Effects of Nanoparticles*, *op. cit.*, p. ii.
200 Accessible at the following address: http://icon.rice.edu/research.cfm.

primarily designed to help researchers and government agencies make informed decisions about the safety of nanomaterials.[201]

Most of the concerns reported in the consultations held at the behest of the Royal Society in Great Britain dealt with the possible effects manufactured nanoparticles and nanotubes could have on the health and safety of humans, wildlife, plants, and ecosystems. In particular, the fact that nanoparticles are of the same order of magnitude as cellular components and large proteins has led to the hypothesis that they could bypass living organisms' natural defenses and damage their cells.[202] The same has been observed on this side of the Atlantic. Witnesses speaking about the safety and environmental impact of nanotechnology at the U.S. Committee on Science and Technology on November 17, 2005, called for more extensive research in this regard: "[…] if nanotechnology is to fulfill its enormous economic potential, then more must be invested right now in understanding what problems the technology might cause. This is the time to act—when there is a consensus among government, industry and environmentalists."[203] The environmental and health impacts thus remain to be documented, but also the economic and social impacts.

It would therefore appear important to ramp up research efforts to quickly produce a standardized characterization of nanotechnology-derived products, some of which are already on the market. The need must also be stressed to make research results more accessible not only to the scientific community, but also to decision makers and the general public, as will be discussed later in the chapter.

Commentary of the Commission

The first observation to be made about nanotechnology is that there is a flagrant lack of information about what it is. If there is no common understanding of what nanotechnology is, how can legislators, researchers, businesspeople, workers, or the public make informed decisions? The Commission notes that responsible management of nanotechnology development turns on three premises: establishing a common scientific terminology and nomenclature, establishing procedures and standards, and continuing to perform research and disseminate research results.

ETHICAL CONCERNS ABOUT PRODUCTS DERIVED FROM NANOTECHNOLOGY

The diversity of products derived from nanotechnology raises ethical questions that need to be considered at face value. The Commission is first concerned about the impact nanotechnology research and innovation could have on human health and the environment. It also questions the potential uses

[201] INTERNATIONAL COUNCIL ON NANOTECHNOLOGY, "Nano Coalition Unveils Environmental, Health and Safety Database," press release, Houston, August 19, 2005 [online] http://www.nanotech-now.com/news.cgi?story_id=11111.

[202] THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 35. The report puts this issue into perspective by noting that human beings have always been exposed to various types of nanoparticles from natural sources such as photochemicals or forest fires, and that exposure to millions of inhaled pollutant nanoparticles has been common since fires were first used.

[203] COMMITTEE ON SCIENCE (United States), "More research on environmental, safety impacts of nanotechnology is critical to success of the industry, witnesses say," press release, Washington, November 17, 2005 [online] http://gop.science.house.gov/press/109/109-165.htm.

for nanotechnology in the area of national defense and public security, and feels that serious ethical issues are at stake. Lastly, the Commission addresses the issue of nanotechnology's potential to transform human beings and nature in order to note related concerns regarding human identity and humankind's relationship with nature.

Human health

The main ethical issues the Commission has examined with regard to human health concern the health and safety of workers and consumers and nanotechnology's medical applications, particularly biomedical research, diagnostic tools, and therapeutic applications.

Health and safety

Like natural and residual nanoparticles, synthetic nanoparticles may have undesirable effects on health. The people most likely to be affected are those who produce, handle, use, or dispose of nanoparticles. With the increasing amount of nanotechnology research and industrial manufacturing of nanotechnology-derived products, the Commission is concerned about the health and safety of workers in the industry. But it is also concerned about the possible health and safety impact for those in the general public who will consume or use products derived from nanotechnology.

Protecting the workers

The properties of nanotechnology raise specific concerns about the health and safety of the workers who will be in close contact with them throughout their development. These people include all personnel who handle nanoscale substances: researchers, students, lab employees, and all workers involved in assembling, transporting, repairing, using, recycling, and disposing of products derived from nanotechnology—in short, anyone whose work puts them into contact with nanoscale components at any stage in the life cycle of the product containing them.

As mentioned in the first chapter of this position statement, it is mostly the characteristics (size, potential toxicity, mobility, surface property) of the nanomaterials themselves that raise questions about the health and safety impact of producing and handling these materials. Human dignity and responsibility are the main values underpinning these concerns. Protecting human dignity implies that the workers are not considered simply as a means of production, but first and foremost as human beings, and that in this sense they have the right to integrity and respect. The notion of responsibility implies that the government and employers provide workers with a safe work environment, but also that the workers follow the safety regulations and mechanisms in force and help improve them.

Two observations have drawn the Commission's attention. First, it is worrisome how little research has thus far been conducted on the possible impact of nanomaterials on human health and safety.[204] Very

[204] Christopher J. PRESTON, "The Promise and Threat of Nanotechnology. Can Environmental Ethics Guide US?", *HYLE – International Journal for Philosophy of Chemistry*, Special issue on nanotech challenges, part II, vol. 1, No. 1, section 4.1 [online] http://www.hyle.org/journal/issues/11-1/preston.htm.

little is known about the topic. A lot of research needs to be done in ecotoxicology in order to assess the toxicity of these new particles and to understand the surface properties that may lead to toxicity.[205] One of the obstacles noted by IRSST and that in part explains the lack of knowledge in industrial hygiene is that "at present, the tools normally used in industrial hygiene to evaluate the exposure of workers are ill suited to the applications of nanoparticles in an occupational setting,"[206] whereas "the little data available suggests that exposure during the manipulation of powders may be considerable."[207]

The second observation is that specialists do not agree on existing regulations. Some say that no mechanisms are currently in place to regulate these new objects that blend the classic and quantum properties of materials—they claim that current instruments concern themselves only with the materials' original state.[208] Others feel that regulations cover a good portion of nanotechnology production, specifically in terms of industrial hygiene, but that modifications must be made to clearly mention that the regulations in force also apply to nanotechnology.[209] It will be difficult to settle this issue until more specific data on nanotechnology's potential impact becomes available.

Until more advanced research is done and more comprehensive regulations tailored to the specificities of nanotechnology are introduced, the Commission feels that the precautionary principle must underpin all actions taken to protect worker health and safety. Worker protection is the responsibility of

- Employers, who must identify, control, and eliminate dangers; outfit their facilities with safe equipment, tools, and working methods; and ensure that workers follow the safety measures in place
- Workers, who must take the necessary measures to protect their health, their safety, and that of their coworkers, and help identify and eliminate risks in the workplace
- The government, and more specifically, Commission de la santé et de la sécurité au travail (CSST), which must make sure existing norms and regulations are upheld.[210]

Actions to take

The risk of unexpected and undesirable consequences depends on the degree of toxicity of the nanotechnology and the level of exposure to nanoparticles, which shows the importance of setting special health and work safety standards. In the United States, the President's Council of Advisors on Science and Technology feels that researchers must be aware of the potential hazards when working

205 The Royal Society & The Royal Academy of Engineering (United Kingdom), *op. cit.*, p. 42.
206 Institut de recherche Robert-Sauvé en santé et en sécurité du travail – IRSST, *Nanoparticles. Actual Knowledge… op. cit.*, p. iii.
207 *Ibid.*
208 Christopher J. Preston, *op. cit.*
209 J. Clarence Davies, *op. cit.*, p. 17.
210 For more information on the rights and responsibilities of employers and workers, consult the CSST website, particularly the section on prevention [online] http://www.csst.qc.ca/portail/en/prevention/prevention.htm

with new materials whose properties are not yet fully understood.[211] As for IRSST, it recommends the implementation of strict prevention measures to hinder the development of occupational diseases.[212] Publishing best practices guides or works such as those produced by IRSST on the state of knowledge about nanoparticles and their possible effects on workers are some of the actions that could be taken to ensure the responsible management of nanotechnology. To this effect, **the Commission stresses the importance of making sure the data compiled by IRSST remains as up-to-date as possible and that this information is sent to businesses and research centers active in the field of nanotechnology so they can take the appropriate measures to protect workers.** As such, it supports the following statement by IRSST: “The development of Québec expertise in nanotoxicology should be encouraged and focus primarily on the study of products developed and imported in Québec. The aim should be to advise and support the various stakeholders in occupational health and safety, businesses and people concerned with research and development of nanotechnology-based products.”[213]

Moreover, the Government of Canada has commissioned a number of studies on governance and the potential effects of nanotechnology.[214] An interdepartmental committee—including representatives from Health Canada, Environment Canada, the Canadian Food Inspection Agency, Fisheries and Oceans Canada, the Office of the National Science Advisor, and National Research Council Canada—held a workshop on March 29 and 30, 2006, to examine the potential effects of nanotechnology on health and the environment. The committee, which continues to meet, plans to release a federal action plan in fall 2006. One of the objectives of the plan is to increase understanding of the properties of nanotechnology, its effects, and the level of exposure to nanoparticles. It also explores the actions that could be undertaken—or even completed—within the same year. Some of these actions should lead to better control of so-called occupational activities.[215]

In the United States, the National Institute for Occupational Safety and Health is taking multidisciplinary efforts to find ways to help workers more effectively apply existing workplace health and safety principles while taking into account the particularities associated with exposure to

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211 PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY (Unided States), *op. cit.*, p. 35.

212 INSTITUT DE RECHERCHE ROBERT-SAUVÉ EN SANTÉ ET EN SÉCURITÉ DU TRAVAIL – IRSST, *Health Effects of Nanoparticles*, *op. cit.*, p. ii.

213 *Ibid.*

214 SCIENCE-METRIX, *Canadian Stewardship Practices for Environmental Nanotechnology*, *op. cit.*; *Canadian Biotechnology Initiatives Addressing Developing Countries Issues*, Final Report, David CAMPBELL and Grégoire CÔTÉ, National Research Council Canada, Research Program Support Office, March 2005 [online] http://www.science-metrix.com/pdf/SM_2005_001_NRC_Biotechnology_Developing_Countries.pdf; Lorraine SHEREMETA, “Nanotechnology and the Ethical Conduct of Research Involving Human Subjects,” *Health Law Review*, vol. 12, No. 3, 2004 [online] http://www.law.ualberta.ca/centres/hli/pdfs/hlr/v12_3/12-3-11%20 Sheremeta.pdf; Mark ROSEMAN, *op. cit.*; Lorraine SHEREMETA, “Nanoscience and Nanotechnology: The Ethical, Environmental, Economic, Legal and Social Issues (Ne³LS) – An Overview of NE³LS Research in Canada,” paper prepared for the Office of the National Science Advisor, September 13, 2005; OFFICE OF THE NATIONAL SCIENCE ADVISER (Canada), *Assessment of Canadian Research Strengths in Nanotechnology*, Report of the International Scientific Review Panel, November 2005 [online, available on request] http://acst-ccst.gc.ca/back/ home_f.html.

215 The information contained in this paragraph was validated by Mr. Hans Yu of Health Canada in his presentation at Nanoforum 2006.

nanomaterials.[216] Some companies are very active in developing guidelines to keep the undesirable effects of nanotechnology to a minimum. For example, in 2005, the Virginia firm Luna Innovations implemented a management program called NanoSAFE aimed at the following five objectives:[217]

- Regularly monitor worker health in order to quickly detect potential harmful effects of occupational activities
- Implement mechanisms to check workplace safety (specifically by installing sensors that can measure the presence and rate of nanoparticles, but also basic safety measures like wearing long gloves or sleeves that sufficiently cover wrists to avoid all exposure to the skin)
- Carry out toxicological studies
- Conduct studies on the possible environmental impact
- Assure strategic management of the workplace and products, notably in order to prevent nanoparticle emissions into the environment.

Protecting the public

The Commission stresses that protecting the public is a fundamental value to uphold when marketing any kind of nanotechnology-derived consumer product. It also believes that companies are responsible for the products they release, for ensuring said products are in no way harmful, and for keeping the decision-making process transparent.

As the promoters themselves have observed, public acceptance of new nanotechnology-derived products is a prerequisite for sector growth. This observation stems from hard-earned experience in other emerging high tech fields (genetically modified organisms are a prime example of this).[218] Products and services derived from nanotechnology will only be accepted if the public has faith in them and in the companies developing them. Two factors will play a role in determining the public's level of trust: conviction that the safety of the products and services on the market has clearly been demonstrated—in other words, confidence that the public is sufficiently protected against the possible harmful effects—and the transparency of authorities (government, industrial, or others) involved in the monitoring process. This latter factor will be discussed further on.

Confidence in the safety of nanotechnology-derived products is a major concern for the Commission. As mentioned above, there is an increasing number of these products, and some are already available on the market as consumer products: certain cosmetics (foundations, lipsticks, sun creams, anti-wrinkle creams, etc.), various health products (vitamin supplements, diet products), cleaning and maintenance

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216 NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH – NIOSH (United States), *Position Statement on Nanotechnology: Advancing Research on Occupational Health Implications and Applications* (undated) [online] http://www.cdc.gov/niosh/topics/nanotech/position.html.

217 Josh CABLE, "A Best Practices Approach to Minimizing EHS Risk in Nanotechnology Manufacturing," *Occupational Hazards*, October 6, 2005 [online] http://www.occupationalhazards.com/safety_zones/42/article.php?id=14129.

218 John BALDUS *et al.*, "Getting Nanotechnology Right the First Time," *Issues in Science and Technology*, vol. XXI, No. 4, Summer 2005, p. 67 [online] http://www.issues.org/21.4/balbus.html.

products (aerosol or non-aerosol), and a smattering of food products (milk shake powders, oils, etc.).[219] At present, it is impossible to know if these products may be harmful to use, due to the paucity of research findings on their effects on animals, the environment, and humans. Furthermore, experts are concerned about the inadequate means of health authorities to control products released on the market.[220] Even if these authorities had the necessary means and personnel, acceptance standards would still need to be set out, and this has yet to occur. To this effect, the Royal Society has suggested that the industry publicly disclose the methods used to test the safety of nanotechnology-derived products, particularly those that contain free particles. As pointed out in Chapter 1, these are the particles that could pose the most problems for individual health or the environment.[221]

For example, a first-ever recall of a product possibly containing nanoparticles[222]—a bathroom cleaning product called *Magic Nano*—occurred in late March 2006 in Germany after 77 people reported major respiratory problems that persisted for some 18 hours.[223] A few weeks after this recall, the German Federal Institute for Risk Assessment reported that the product in question contained no ultrafine particles and that the term "nano" had only been used to draw attention to the extremely thin film the product left on sprayed surfaces.[224] Nevertheless, the situation remains troubling. As with the risks associated with using new products (nanotechnology-derived or otherwise), the possibility of health and environmental problems cannot be dismissed. Ethically speaking, such risks must be reduced as much as possible—if not totally eliminated—notably by testing product safety before putting a product on the market.

Another topic of concern is the long term impact of using such products or applications, particularly in the cosmetics sector. This sector is not governed in the same way as the health sector—research is conducted on a small scale and findings are rarely available. Could the nanoparticles used in all sorts of creams cause long term health problems? Could they create harmful reactions in the body? It is still too soon to have answers to such questions, yet cosmetic products made up of nanoparticles are already available on the market.

As with genetically modified organisms,[225] the Commission once again stresses how important it is for health agencies and the private sector to conduct the toxicological studies needed to market products that use nanotechnology and to monitor the effects that nanotechnology could have on human health on a longer term basis. Such studies should be a priority for products already on the market.

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219 See list of the numerous products on the market compiled by the WOODROW WILSON CENTER FOR SCHOLARS, *op. cit.*, at http://www.nanotechproject.org/index.php?id=44.

220 J. Clarence DAVIES, *op cit.*, p. 10.

221 THE ROYAL SOCIETY (United Kingdom), "Industry should disclose safety testing methods," press release, May 4, 2006 [online] http://www.royalsoc.ac.uk/news.asp?year=&id=4639.

222 Because it is important to keep in mind that certain products claiming to be "nano" do not necessarily have anything to do with nanotechnology and the name may simply be part of the marketing scheme.

223 Rick WEISS, "Nanotech Product Recalled in Germany," *Washington Post*, April 6, 2006, p. A02 [online] http://www.washingtonpost.com/wp-dyn/content/article/2006/04/05/AR2006040502149.html.

224 FEDERAL INSTITUTE FOR RISK ASSESSMENT (Germany), "Nanoparticles were not the cause of health problems triggered by sealing sprays!" press release, May 26, 2006 [online] http://www.bfr.bund.de/cms5w/sixcms/detail.php/7842.

225 See Chapter 4 of the position statement *Pour une gestion éthique des OGM* (French only) [online] http://www.ethique.gouv.qc.ca/fr/ftp/CESTAvisOGMfinal.pdf.

Recommendation No. 2

The Commission recommends

That the Minister of Economic Development, Innovation and Export Trade, together with the Minister of Health and Social Services, work with the federal government to ensure that health and environmental monitoring agencies establish the mechanisms needed to assess the toxicity of processes and products derived from nanotechnology prior to authorizing their commercialization.

Technological development as a means of enrichment and improvement of quality of life is certainly an important value in society, and the development of nanotechnology seems able to contribute to this. But under no circumstances can it be done to the detriment of the health and safety of workers or the public, because the protection of life is clearly the highest priority. **The Commission is of the opinion that appropriate prevention measures and a good understanding of the life cycle of nanotechnology-derived products will help protect human health and safety and will contribute to the responsible development of this sector.**

Health sector applications

The properties of nanotechnology have led scientists to examine promising new diagnostic and therapeutic approaches. In studying the issue, the Commission first looked at the ethics of biomedical research, which lead it to then study the ethics of medical diagnoses and therapeutic applications linked to the use of nanotechnology. Nanotechnology could also someday play a significant role in optimizing human performance, a notion generally associated with the field of medicine. However, since this touches on symbolic conceptions of what it means to be a human being, the Commission has decided to tackle the subject separately below.

Ethics of biomedical research

For many years, biomedical research has evolved within a defined ethical framework. In Québec, the following institutional instruments have guided university research: the *Tri-Council Policy Statement* (TCPS)[226] issued by federal granting agencies and upheld by Québec granting agencies; the *Plan d'action ministériel en éthique de la recherche et en intégrité scientifique*,[227] which regulates research conducted at facilities in the health and social services network; articles 20, 21, 22, 24, and 25 of the *Civil Code*,[228] which

[226] CANADIAN INSTITUTES OF HEALTH RESEARCH, NATURAL SCIENCES AND ENGINEERING RESEARCH COUNCIL OF CANADA, *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans*, August 1998, amended in 2000, 2002, and 2005 [online] http://www.pre.ethics.gc.ca/english/pdf/TCPS%20October%202005_E.pdf.

[227] MINISTÈRE DE LA SANTÉ ET DES SERVICES SOCIAUX (Québec), *Plan d'action ministériel en éthique de la recherche et en intégrité scientifique*, 1998 [online] http://ethique.msss.gouv.qc.ca/site/download.php?id=1081608,5,1. This document is currently being revised.

[228] GOUVERNEMENT DU QUÉBEC, *Civil Code of Québec* (R.S.Q., c. C-1991) [online] http://www.iijcan.org/qc/laws/ sta/ccq/20061117/whole.html.

address human experimentation; the *Food and Drugs Act;*[229] and *Food and Drug Regulations,*[230] which govern drug testing; and Health Canada's *Good Clinical Practice: Consolidated Guideline.*[231] Furthermore, Fonds de la recherche en santé du Québec (FRSQ), which funds public health research in Québec, has developed an ethics guide.[232] Public nanotechnology research involving human experimentation is also subject to all of these regulations. However, private biomedical research is subject only to *Good Clinical Practices* and under certain circumstances Article 21 of the *Civil Code.*

Because nanotechnology is viewed as an enabling technology*, the ethical concerns raised by research on the health applications of nanotechnology should be the same as with other emerging biomedical technologies. These notably include such matters as the confidentiality of personal information, respect for persons, respect for free and informed consent, the purpose of the research, the scientific and social value of the research, etc. These concerns are abundantly documented, and the Commission has addressed them in its position statement on the ethical issues of genetic databanks.[233]

The ethical constraints of biomedical research observed by the Commission in 2003 have evolved. Some are disappearing, at least in part. This is the case with regard to the setup and funding of hospital research ethics committees. However, a number of issues have not yet been resolved, such as the difficulty of diligently following research protocols, assessing multicenter protocols at a time of increasing competition between the various centers, and the impossibility of assessing the relevance or social scope of certain research. The Commission assumes that the same issues will apply to nanotechnology development in the health sector.

Given the promising future of nanobiotechnology, it is important to rigorously enforce the principles of research ethics in order to protect research subjects who participate voluntarily in the advancement of knowledge. With research ethics boards as the frontline protectors of human subjects, board members must be made aware of the issues inherent to nanobiotechnology research and equipped to react appropriately.

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[229] L.R., 1985, ch. F-27 [online] http://laws.justice.gc.ca/en/F-27/.

[230] C.R.C., ch. 870 [online] http://laws.justice.gc.ca/en/showdoc/cr/C.R.C.-c.870///en?page=1.

[231] HEALTH CANADA, *Guidance for Industry. Good Clinical Practice: Consolidated Guideline*, Health Products and Food Branch, 1997 [online] http://www.hc-sc.gc.ca/dhp-mps/alt_formats/hpfb-dgpsa/pdf/prodpharma/e6_e.pdf.

[232] FONDS DE LA RECHERCHE EN SANTÉ DU QUÉBEC – FRSQ, *Ethics, Scientific Integrity and Best Practices*, 2nd edition, August 2003 [online] http://www.frsq.gouv.qc.ca/fr/ethique/ethique.shtml.

[233] COMMISSION DE L'ÉTHIQUE DE LA SCIENCE ET DE LA TECHNOLOGIE, *Les enjeux éthiques des banques d'information génétique : pour un encadrement démocratique et responsable* [The Ethical Issues of Genetic Databases: Towards Democratic and Responsible Regulation], Gouvernement du Québec, 2003 [online] http://www.ethique.gouv.qc.ca/fr/ftp/AvisBanquesGen.pdf. In particular, see Chapter 2 on the environment of genetic databanks and Chapter 3 on issue governance. An English summary is available at http://www.ethique.gouv.qc.ca (English).

Recommendation No. 3

The Commission recommends

That the Minister of Health and Social Services ensure that research ethics boards are adequately equipped and supported in their assessment of research protocols relating to the use of materials and processes derived from nanotechnology in the health sector.

It is difficult to predict in which directions nanotechnology will develop. Nonetheless, its objectives and its proven or hypothetical consequences must be discussed now, and all concerned must work to find the best way to protect research subjects without hindering research and development.

Diagnostics and therapeutic applications

As seen in Chapter 1, the development of nanotechnology has raised numerous hopes in the area of medical diagnosis and treatment, and the expected benefits are considerable. Although the ethical concerns raised by these new technologies are not limited to nanotechnology's contribution to the health sector alone, the Commission considers it important to point them out so they can be taken into consideration in future decisions on the topic.

In the field of diagnostics, nanotechnology-derived innovations like labs-on-a-chip or magnetic resonance imagery techniques could allow medical professionals to more quickly diagnose patients and implement the appropriate treatments. The main therapeutic applications derived from nanotechnology currently include drug targeting and activation, which would make it possible to maximize a drug's therapeutic potential while reducing its harmful effects on the surrounding healthy tissues, and could even be used to restore or replace organs or functions, including hearing, sight, or motor skills.

The issue of nanoparticle interference with the functions of the human body (or with the environment) has also attracted the Commission's attention. When a structure is smaller than 100 nanometers, it interacts with the organism's proteins, which could have unexpected and as yet little understood effects.[234] Other issues have been raised about what happens once the human body eliminates nanodrugs: What is the potential impact on plant and wildlife? This issue was raised in the wake of recent studies that found oral contraceptives in treated water that could affect the reproductive systems of certain fish, even making them hermaphrodites[235] or going so far as to cause males to change sexes.[236] Such cases need to be researched in further detail, which points to the need to forge ties between various disciplines—environment and health, in this case.

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234 INSTITUTE OF MEDICINE (United States), *op. cit.*, p. 20.

235 William COCKE, "Male Fish Producing Eggs in Potomac River," *National Geographic News*, November 3, 2004 [online] http://news.nationalgeographic.com/news/2004/11/1103_041103 _potomac_fish.html.

236 Melanie Y. GROSS-SOROKIN, Stephen D. ROAST and Geoffrey C. BRIGHTY, "Assessment of Feminization of Male Fish in English Rivers by the Environment Agency of England and Wales," *Environmental Health Perspective*, vol. 114, No. S-1, April 2006 [online] http://www.ehponline.org/members/2005/ 8068/8068.pdf.

In addition, given nanoparticles' ability to cross the blood-brain barrier, they have obvious potential for use in treating neurological diseases like Parkinson's, multiple sclerosis, or Alzheimer's. But this is also a cause for concern. The blood-brain barrier is the brain's last defense against the external assaults of certain micro-organisms. The fact that new ways have been found to bypass the brain's natural defenses using technologies not yet fully mastered and that are invisible to the naked eye could have harmful consequences without proper guidelines for nanotechnology R&D. The use of nanotechnology in neurology for therapeutic purposes—and perhaps to improve brain function—is intimately tied to the field of neuroscience. The Commission plans to prepare a position statement on this topic in 2007 that will address the ethical issues raised by the variety of possible uses for nanotechnology and the concerns these have created.

Information is sorely lacking for the Commission to infer the potential economic impact of the introduction of new nanotechnology-derived diagnostic and treatment methods. In all likelihood, some of these new technologies will bring about savings for health services, whereas others will incur prohibitive costs. The issue is the much broader concern of resource allocation and governance, where society will have important decisions to make.

There are concerns about economic access to the full benefit of nanomedicine in a public health system. Who will have access to these new technologies? What diseases will be given priority and who will benefit? These questions, about access to care and the type of medical coverage the community wants and is able to provide, deserve to be debated in the public arena. This would have the merit of enhancing public awareness about the ethical and social issues raised by the development of new technologies and the convergence of certain scientific disciplines—nanotechnology, biology, information science, and cognitive science (*NBIC*)[237]—with health care.

Likewise, the Commission questions the idea of offering diagnostics (through nanotechnology or otherwise) without the appropriate therapeutics to match—for example a test to diagnose a given disease for which no preventative or curative treatment yet exists. This situation already exists and calls to mind the position statement previously published by the Commission on genetic databases, and specifically on the right to know or not to know.[238] In its position statement, the Commission also expressed its concerns about seeing a sort of personal eugenics emerge in the practice of procreation. For example, in the event of a positive prenatal diagnosis of a genetic disease that *may or may not occur* (susceptibility test) for which no treatments currently exist, the only medical choices available to the future parents are to monitor the health of the unborn child or voluntarily interrupt the pregnancy. Nanotechnology could therefore play a role in amplifying a dilemma parents already face and that has yet to be debated by society.

[237] Lorraine SHEREMETA, "Synthesis Paper. Nanotechnology: the NE^{3}LS Issues," Prepared for Health Canada, July 18, 2005, p. 6.

[238] COMMISSION DE L'ÉTHIQUE DE LA SCIENCE ET DE LA TECHNOLOGIE, *Les enjeux éthiques des banques d'information génétique*…[The Ethical Issues of Genetic Databases…], *op. cit.*, p. 48.

COMMENTARY OF THE COMMISSION

The Commission emphasizes the importance of precaution in the creation and development process of medications and therapies with nanotechnology components. Such an approach is an encouragement to continue to research and document the potentially positive and negative effects of nanotechnology applications in the health sector to better assess the outcomes for patients and for the management of the health system in general.

The environment

The Commission's approach to environmental ethical issues raised by nanotechnology is from a perspective of sustainable development, including the life cycle approach and the precautionary principle, which in its view are essential management considerations. The responsibility of individuals and the community as a whole with regard to the environment, future generations, and quality of life are some of the values that guided the Commission in its discussions.

The documentation consulted indicates that nanotechnology may have numerous positive impacts on the environment that could contribute to sustainable development. Certain potential applications will seek to restore non-viable habitats and ecosystems (proaction), while others will protect the environment from the potentially harmful effects of human activity (protection, prevention). These potential benefits of nanotechnology must be encouraged. However, its safety remains to be proven, and potentially undesirable effects cannot be dismissed out of hand.

In the short run, the biggest source of potential environmental exposure is the use of nanoparticles in sanitizing contaminated groundwater and soil; concerns have been raised about the impact the high reactivity of nanoparticles might have on plants, animals, micro-organisms, and ecosystems.[239] This is a crucial issue because "past experience with human and environmental health suggests that scale is a relevant factor in determining whether a material will cause harm to a biological system. Inhalation, absorption, diffusion, and transmission across natural barriers have all proven to be vectors for disease and biological harm that depend upon scale. The introduction into the human and natural environment of large numbers of nanoparticles before their biological and dispersion effects are well known does seem to be a cause for concern."[240] Data compiled thus far does not give a reliable overview of the situation. Preliminary studies suggest, however, that certain nanomaterials can damage the organs and tissues of living organisms. Particularly, concerns have been raised about the toxicity of fullerenes (C_{60}).[241] A report by the French parliamentary bureau in charge of assessing scientific and technological choices also mentioned that, although a major factor, "size is only one aspect of the problem for toxicologists. For example, the biological effects of carbon depend on whether it is in the form of

239 Edna F. EINSIEDEL and Linda GOLDENBERG, "Dwarfing the Social? Nanotechnology Lessons from the Biotechnology Front," *Bulletin of Science, Technology & Society*, vol. 24, No. 1, February 2004, p. 29 [online] http://bst.sagepub.com/cgi/reprint/24/1/28.

240 Christopher J. PRESTON, *op. cit.*, section 4.1.

241 Tanya SHEETZ *et al.*, "Nanotechnology: Awareness and Societal Concerns," *Technology in Society*, August 27, 2005, p. 334.

fullerene, nanotubes, or graphite. Furthermore, the results also depend on the manufacturing process and possible impurities."[242]

The Royal Society feels that it is possible that in cases of sanitization, any negative impacts on ecosystems will be outweighed by the benefits of the cleanup of contaminated land and waters, but this needs to be validated by appropriate research.[243] The U.S. National Nanotechnology Advisory Panel notes that "many technologies and products have associated risks that are successfully managed in order to gain their benefits—for example, gasoline, electricity, and X-rays."[244] The same could apply to a number of nanotechnology-derived products and processes.

In this position statement, **the Commission can only emphasize the importance of increasing the amount of research on the potential environmental consequences of nanotechnology in order to determine which substances may be hazardous. This proposal calls for a commitment on the part of researchers, industry, and government agencies.** To do otherwise would be irresponsible and could even jeopardize the development of products derived from nanotechnology and their acceptance by the public. Specialists even suggest that "if the danger becomes known after the product is widely used, the consequences can go beyond human suffering and environmental harm to include lengthy regulatory battles, costly cleanup efforts, expensive litigation quagmires, and painful public-relations debacle."[245] Clearly, regardless of the perspective taken—ethical, social, or economic—such a situation must be avoided.

Lab tests may provide some answers, but others will have to come from *in situ* analyses; this will be the case for the unanticipated effects of nanotechnology or that could only occur over the long term. It is possible that some products could have hazardous effects on the environment through their accumulation in various environmental regulatory systems. Climate change is a good example of the long term effect human activities can have on the environment, one that provides important lessons.

Recommendation No. 4

The Commission recommends

- **That the Minister of Economic Development, Innovation and Export Trade, together with the Minister of Sustainable Development, Environment and Parks as well as various other interested parties, put in place a system to monitor the potential effects of nanotechnology on the environment, whenever these effects cannot be calculated and taken into account prior to the market release of nanotechnology-derived products**
- **That a procedure be developed to ensure the rapid recall of products in the event of harmful effects on the environment**

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242 Jean-Louis PAUTRAT, "Comment définir les nanosciences?" in OFFICE PARLEMENTAIRE…, *op. cit.*, p. 83. [Our translation]

243 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 46–47.

244 PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY (United States), *op. cit.*, p. 35.

245 John BALDUS *et al.*, *op. cit.*, p. 65.

Implementing such a procedure has proven to be a pressing matter, because there is very little data on how to dispose of products manufactured with nanoparticles, because very little is known about their safety, and because of the number of such products already on the market.[246]

The costs associated with introducing nanotechnology must also be examined, and cost-effectiveness studies will be needed. The Commission illustrates this point using an example showing that although implementing a new road lighting system using LED (light-emitting diode) technology would require major front-end investments, its large scale use could reduce city lighting costs by 50% by 2025.[247] Dilemmas like this fully bring to bear the importance in ethical decision making of ideas like life cycle, preserving the environment, and considering the needs of future generations.

Many issues remain unresolved and must be debated. How can the economic development of Québec society be ensured while the quality of the environment is preserved? How can the needs of future generations be predicted? And since human activity in industrialized countries has worldwide repercussions, how can development that fosters equity for all be ensured? The wisdom of political and institutional decision makers will be measured by their answers to these questions.

Security

Since the terrorist attack on the United States on September 11, 2001, issues of security and military defense have come increasingly to the fore in Canada and the rest of the world. For the government, securing national borders and protecting the lives of citizens have become major challenges both from a military and public security standpoint and have intensified the wave of technological integration that took shape in the late 1980s. In both sectors, nanotechnology presents a wide variety of potential security applications. However, like any other nanotechnology-based development, ethical concerns must be addressed to make sure the objectives and security applications being developed do not have undesirable—or even harmful—repercussions on society.

In the military sector

The Commission has taken a very preliminary look at this issue. There is not enough information available in Québec and across Canada on military R&D objectives and research funding to address the issue in more depth. To spark reflection on the ethical issues of the situation, the Commission has therefore drawn largely on information about the situation in the U.S. in the following overview of the possible uses and challenges of nanotechnology.

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246 SCIENCE-METRIX, *Canadian Stewardship Practices for Environmental Nanotechnology*, *op. cit.*, p. 2.

247 ENVIRONMENTAL SERVICES ASSOCIATION OF ALBERTA (Canada) – ESAA, *op. cit.*, p. 21; example provided by Terry McIntyre of Environment Canada.

A few examples of "nanomilitary" applications[248]

Nanomilitary research efforts capitalize on the combination and convergence of nanomaterial properties, nanoelectronic performances, and nanobiotechnology's potential to meet ambitious goals, including

- ***Protecting soldiers and ensuring their survival***, specifically by designing high tech combat suits. Research is aimed at combining the potential benefits of nanotechnology to manufacture a light and comfortable suit with the following characteristics: changes color like a chameleon to blend into the surrounding environment, protects against projectiles and chemical and biological agents, becomes rigid when needed to act as a compress or splint in the event of injury, is equipped with sensors to monitor the soldier's vital signs and inject medications as needed, and is equipped with a remote instant communications system and an exoskeleton to aid in transporting heavy loads. The soldiers themselves could possibly be equipped with retinal implants to access electronic information, cochlear implants to receive messages or improve their hearing, or neural or muscular implants to improve mental and physical performance.[249] In the short run, the first step would be to reduce the load soldiers carry from 60 kg to 20 kg.
- ***Increasingly relying on remote robotization and communications***[250] to replace military personnel or to help them in dangerous or complex tasks, specifically on the battlefield. It may be helpful to remember that a robot is not necessarily shaped like a human, and that the term refers to all devices, systems, or units capable of carrying out certain functions of varying degrees of sophistication, whether via remote control or autonomously via electronic programming (like the Spirit and Opportunity robots used on Mars). Depending on the situation, robots may be used to attack or defend (tanks and other similar war machines); transport munitions or heavy loads; collect information; clear mines or set bombs; detect chemical, biological, or nuclear weapons; conduct air surveillance (drones*) and electronic surveillance (as with the smart dust mentioned in Chapter 1);

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248 The content of this section is based on information posted on the sites of U.S. military organizations, notably including DARPA (Defense Advanced Research Projects Agency) http://www.darpa.mil/body/off_programs.html, DMEA (Defense MicroElectronics Activity) http://www.dmea.osd.mil/home.html, and ISN (Institute for Soldier Nanotechnology) http://web.mit.edu/ISN/. The following texts were also consulted: Jürgen ALTMANN and Mark Avrum GUBRUD, "Military, Arms Control, and Security Aspects of Nanotechnology;" D. Baird, A. Nordmann and J. Schummer (dir.), *Discovering the Nanoscale*, Amsterdam, IOS Press, 2004 [online] http://cms.ifs.tu-darmstadt.de/fileadmin/phil/nano/toc.html; Jürgen ALTMANN, "Military Uses of Nanotechnology: Perspectives and Concerns," *Security Dialogue*, Vol. 35, No. 1, 2004; Alexander Huw ARNALL (for Greenpeace), *op. cit.*; ETC GROUP – EROSION, TECHNOLOGY AND CONCENTRATION, *From Genome to Atoms. The Big Down, Atomtech: Technologies Converging at the Nano-Scale*,Winnipeg, January 2000 [online] http://www.etcgroup.org/documents/TheBigDown.pdf; Joachim SCHUMMER, "Identifying Ethical Issues Amidst the Nano Hype," 2005 (for UNESCO); NATIONAL SCIENCE FOUNDATION (United States), *Societal Implications of Nanoscience and Nanotechnology*, Arlington, Virginia, March 2001 [online] http://www.wtec.org/loyola/nano/societalimpact/nanosi.pdf; CALIFORNIA COUNCIL OF SCIENCE AND TECHNOLOGY, *op. cit.*; THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*; Lorraine SHEREMETA, "Nanoscience and Nanotechnology…," *op. cit.*; Tim WEINER, "A New Model Army Soldier Rolls Closer to the Battlefield," *The New York Times*, February 16, 2005 [online] http://www.nytimes.com/2005/02/16/ technology/16robots.html.

249 See, among others, the Institute for Soldier Nanotechnologies website at http://web.mit.edu/isn.

250 For more information on the topic, see U.S. Future Combat Systems (FCS): http://www.globalsecurity.org/military/systems/ground/fcs.htm.

etc. The convergence of nanotechnology and information technology—particularly in the field of artificial intelligence—plays a fundamental role in robot development.

- ***Developing virtual reality and artificial intelligence***, specifically for the purposes of training the armed forces, controlling robotic forces, and using combat management and strategic planning systems to aid in decision making or to enable decisions to be made without human intervention.
- ***Improving human performance***, whether physical or mental, to make soldiers better able to do their job. This could include creating a cerebral human/machine interface using a chip implanted in the brain; improving vision and communication through retinal implants; modifying the biomedical makeup of the human body to compensate for lack of sleep; connecting electrodes to sensory organs and nerves, motor nerves or muscles, or the appropriate region of the cerebral cortex (for example, to accelerate pilot reaction time); etc.

An overview of ethical concerns

From the outset, it is important to stress that military applications (whether or not they are associated with nanotechnology is relatively unimportant) raise two major ethical concerns: their purpose (their stated purpose may be defense, but could they not be used for the purposes of aggression or repression?) and the secrecy of the lab work and findings. Very few researchers publish on the topic of military research or give details of how new technology is used by the military. The most important issue is therefore that of transparency, which poses an ethical problem and raises questions about the degree of trust the public can and must have in military decision-makers (governments and military officers). A basic observation must also be made: Whereas in all the research and projects currently under way, developing the means to attack enemies or defend against them (an often ambiguous distinction) is the very *raison d'être* of the agencies involved, and colossal sums are devoted to the purpose, it would appear at first glance that very little effort is being made to address ways of avoiding conflict. This too is an ethical concern.

That said, it is generally acknowledged that military research can be "dual" research,[251] in that it entails a type of reciprocity between the harmful effects it can have (e.g., development of attack or defense devices and lethal devices of all sorts) and the benefits that may result from it, both in terms of military or civil protection and the technological spinoffs for society (e.g., for health or the environment). Since this type of research draws largely on the fundamental—and relatively accessible—knowledge developed in university research laboratories, some worry that certain individuals or groups could misuse it.[252]

As Altmann stresses, certain military applications pose few or no problems (e.g., development of systems to protect soldier health), others build on research already under way in civil society (e.g., improving computers), and some could also help protect civilians or foster disarmament (such as sensors to detect biological agents).[253]

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[251] Michel CALLON *et al.*, *Démocratie locale et maîtrise sociale des nanotechnologies. Les publics grenoblois peuvent-ils participer aux choix scientifiques et techniques?,* Grenoble, September 22, 2005, p. 11.
[252] See THE ROYAL SOCIETY & THE ROYAL SOCIETY OF ENGINEERING (United Kingdom), *op. cit.*, No. 28, p. 56.
[253] Jürgen ALTMANN, *op. cit.*, p. 69.

However, other avenues of research in nanotechnology raise ethical concerns, particularly given that too many unknowns remain to ethically frame the research. For example:

- Research on improving human performance (e.g., neurological and organic implants)
- Animal robotization research (e.g., mammals and insects equipped with electrodes used for surveillance, detection, or even attacks in military zones)[254]
- Artificial intelligence research
- Research on molecular assemblers
- Research on decision-making robot development (surveillance and attack machines)
- Research on surveillance and data transmission system miniaturization
- Nuclear, biological, and chemical weapons research
- And so on

This very brief overview demonstrates that **questions need answering with regard to the ethical framework of military research and the ethical issues related to developing new nanotechnology-derived military applications.** Based on what ethical basis and values are decisions made in the military sector? What mechanisms protect civil society, health, and the environment? When artificial intelligence systems are developed, particularly to automate instruments of war, what control mechanisms are used to protect human life (friend or foe)? How are civilians and military personnel told apart? What is the ethical basis of research to improve the human performance of soldiers, and how is their human dignity taken into account? To what extent can the development of atomic, biological, and chemical weapon defense mechanisms be used to also develop arms for the purposes of attacking an enemy? Moreover, how are enemies to be defined in a time when conflicts are changing in nature and increasingly "asymmetrical"[255], and can sometimes render military technology obsolete? And finally, what are the chances that the government will use military applications against its own citizens in certain situations where military intervention may be required?

In civil society

The convergence of nanotechnology and information and communication technology in the development of increasingly smaller and more effective control and surveillance instruments is a major source of ethical concern. Nanotechnology development in electronics and information and communication technology, on the one hand, and the resulting state-of-the-art and potentially inexpensive miniaturized (virtually invisible) applications on the other hand are called upon to play a major role in the surveillance and tracking not only of products, but also of civilians for the purposes of security. Cybersurveillance, video surveillance, audio surveillance, biometric controls, illicit substance detection, and many other technologies—developed by the army to spy on enemies, but that could have civilian uses in the fight against terrorism (e.g., to target certain dissident groups or communities)—raise serious ethical questions.

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[254] *Ibid.*, p. 68.

[255] On this subject, see Michael O'HANLON, *Technological Change and the Future of Warfare*, Washington, Brookings Institution Press, 2000 [online] http://brookings.nap.edu/books/0815764391/ html/index.html.

In its examination of the security uses of biometric data,[256] the Commission has addressed the issue of surveillance and raised questions about possible intrusion by the government and its agencies upon citizen and worker privacy. Various technologies can clearly be used for this purpose, but nanotechnology, and specifically nanoelectronics, increases and facilitates current capabilities in this regard and opens the door to the widespread collection and use of information on citizens and workers that goes well beyond current capabilities. **The Commission is concerned that "in the name of security, it now can seem routine to lower standards with regard to the protection and confidentiality of personal information and the protection of privacy and civil liberties."**[257] This leads to question of whether it must truly be this way and whether a balance can be struck between security and individual and civil liberties.

Ethical concerns in civil security matters, but also the new control and surveillance potential that nanotechnology holds out will be addressed more comprehensively in an upcoming position statement by the Commission.[258] The position statement will elaborate on the issues raised here and offer possible ways to protect citizens while respecting the fundamental values of a democratic and pluralistic society.

The convergence of knowledge and technology

Convergence is one of the topics that involves the greatest uncertainty because it raises questions about what *could happen* in the field of nanotechnology without people actually knowing what *will happen*. The Commission feels it is important to address the issue of convergence because it presents numerous ethical and social challenges, particularly where human identity and humankind's relationship with nature is concerned. Many thinkers query the impact certain techniques and man-made technologies could have on ways of life and on what it means to be a human being,[259] and nanotechnology, being a product of convergence, will not be exempt from such questioning.[260] In its ethical exploration, the Commission specifically stresses the following values: dignity, personal integrity, responsibility, freedom, solidarity, quality of life, justice, and fairness.

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[256] COMMISSION DE L'ÉTHIQUE DE LA SCIENCE ET DE LA TECHNOLOGIE, *L'utilisation des données biométriques à des fins de sécurité : questionnement sur les enjeux éthiques*, study paper, Gouvernement du Québec, 2005, p. 31–34 [online] http://www.ethique.gouv.qc.ca/fr/ftp/Biometrie-reflexion.pdf. In French only.

[257] *Ibid*., p. 34 [our translation].

[258] The Commission is currently working on a position statement on the ethical concerns raised by the use of biometric data in security, as well as the issues of videosurveillance and cybersurveillance (the position statement will be published in 2007). In the meantime, its study paper on the subject (in French only) is available for consultation, *op. cit.*

[259] See the writings of Hannah Arendt, Francis Fukuyama, Dominique Lecourt, Jeremy Rifkin, and Mihail Roco on the topic.

[260] In Québec, philosopher Jean-Pierre BÉLAND led a collective entituled *L'Homme biotech : humain ou posthumain?* published by Presses de l'Université Laval in 2006. Sociologist Céline Lafontaine is also directing a research program entitled "Les nanotechnologies : de l'imaginaire scientifique aux transformations culturelles" [online] http://www.socio.umontreal.ca/personnel/documents/projetcrsh.pdf. Other university research projects are expected in the coming months.

Human identity in a context of performance enhancement

The literature consulted signals that nanotechnology could help optimize certain physiological characteristics of human beings. Potential developments are virtually limitless and can extend to cognitive capacities.[261] Even though the extreme visions of nanotechnology's potential applications conveyed by such schools of thought as transhumanist philosophy—such as the possibility of considerably prolonging life or separating human consciousness from the body to place it in a computer—seem exaggerated in the eyes of a good number of scientists, these visions nonetheless provide a backdrop for discussions on the impact of nanotechnology for intellectuals examining these issues.[262]

Certain developments—even if mostly involving physical interventions intended to offer therapeutic benefits—raise a number of fundamental questions with regard to the personal and social aspects of human identity: what we understand and consider to be *human*, what is deemed normal (or *acceptable*), and what is not. Furthermore, the boundary between therapy (healing, treating, restoring to normal) and the optimization of human performance (improving, boosting beyond the norm) can be tenuous and hard to define. What is the difference between an intervention meant to enhance performance and a therapeutic intervention designed to correct an acquired or innate disability? How is a disability defined?

The Royal Society report notes that disability rights groups are against the kind of human optimization nanotechnology could one day permit. They feel that this could lead to a situation where those whose abilities are not improved would be stigmatized.[263] The Royal Society maintains that the real ethical issue for those with disabilities is *resource allocation and access to technology*. The groups consulted also stressed that persons with disabilities would rather resources be used to combat discrimination, for example, than to develop specific therapies. It was also noted that medical technology is pointless unless those in need of it have access to it or the means to take advantage of it.[264]

The idea of improving physical or cognitive performance is a controversial one. Those consulted in the abovementioned British consultation asserted that any improvement to a person's health using gene therapy was a form of eugenism; that genetic improvements to basic abilities, such as intelligence or height, could only be acceptable if administered fairly among the various segments of the population. However, others believe that if it is acceptable to increase individual abilities for education and physical training, other types of improvements, like cosmetic surgery or cognitive drugs, should also be acceptable.[265] Viewed from this perspective, this dilemma pits the self-determination of those who

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[261] Note that science did not wait for nanotechnology to develop before seeking to improve human physical or mental performance, as demonstrated by the substances used to improve strength and resistance in elite sports or concentration in intellectual work.

[262] THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kindgom), *op. cit.*, p. 55.

[263] THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 54.

[264] *Ibid.*

[265] *Ibid.* A similar debate exists between those concerned about drug use by athletes (their arguments are usually based on the principle that it is an unfair practice or that it may be harmful to the athletes' health) and those who think that if it is acceptable to improve one's abilities through exercise, the same should go for medication.

would like to benefit from physical and cognitive improvements[266] against the rights of those who could feel stigmatized. Such a shift from therapy to performance enhancement could put major pressure on the healthcare system, particularly the Québec drug insurance plan.

The Commission cautions against using drugs prescribed for a specific therapeutic purpose to improve cognitive functions, even on an ad hoc basis. It is already known that drugs prescribed to treat narcolepsy or attention deficit disorder can also boost powers of concentration. The temptation is strong to take this type of drug in order to be more alert in a time of intensive work or when taking a test.[267] The safety and efficacy of the molecules are tested for specific therapeutic purposes and medical conditions, not to boost "normal" human abilities. In addition, these molecules generally have side effects deemed acceptable only because the patients taking them have no other choice.[268] The pharmaceutical potential of nanotechnology could magnify this phenomenon.

The Commission holds that using nanotechnology to enhance human performance raises ethical concerns, particularly with regard to the subjective boundary between therapy and performance enhancement, society's mixed messages about the insertion of the disabled population into "active" life, the cult of performance, equity of choice in public healthcare services, and how individual autonomy and responsibility are viewed in society.

Provided nanotechnology makes good on its promise, certain of its applications will inevitably call into question the very meaning of the human experience, because they will have the potential to modify the self-perception and cultural identity of all human beings. Given this, how is being human or living as a human being to be defined? What sets human beings apart from other living organisms? What makes human beings unique? To what extent can human beings transform themselves yet still remain human? To what extent are people responsible for and masters of their own actions? How far are human beings prepared to go in the pursuit of perfection? How much freedom is society willing to give individuals in this pursuit? Is the immortality coveted by groups like the transhumanists morally acceptable? Nanotechnology applications in neuroscience add even more weight to these questions, particularly with the development of technologies to manipulate the brain through drugs or to create human-machine interfaces.

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266 Also see Patrick LIN and Fritz ALLHOFF, "Nanoethics and Human Enhancement: A Critical Evaluation of Recent Arguments," *Nanotechnology Perceptions*, Vol. 2, No. 1, March 27, 2006 [online] http://nanoethics.org/paper032706.html; Éric de RUS, "Humanisme et transhumanisme : l'Homme en question," *L'Observatoire de la génétique*, No. 26, February–March 2006 [online] http://www.ircm.qc.ca/bioethique/obsgenetique/cadrages/cadr2006/c_no26_06/ci_no26_06_02.html; Arthur CAPLAN, "Is it wrong to try to improve human nature?" in Paul Miller and James Wilsdon (dir.), *Better Humans? The Politics of Human Enhancement and Life Extension*, DEMOS, Collection 21, 2006 [online] http://www.demos.co.uk/catalogue/betterhumanscollection/.

267 Kate DOUGLAS *et al.*, "11 Steps to a Better Brain," *NewScientist.com*, May 25, 2005 [online] http://www.newscientist.com/channel/being-human/mg18625011.900; Andrea NURKO and Megan ROARTY, "Students turn to study drugs to improve grades, concentration," *GW Hatchet*, April 19, 2004 [online] http://www.gwhatchet.com/media/storage/paper332/news/2004/04/19/Style/Students.Turn.To.Study.Drugs.To.Improve.Grades.Concentration-64366.shtml?norewrite200606011448&sourcedomain=www.gwhatchet.com.

268 *Medical News Today*, "FDA panel suggests adding black box warning to ADHD medications about risk of sudden death, heart problems," February 16, 2006 [online] http://www.medicalnewstoday.com/medicalnews.php?newsid=37631.

The debate on these emerging practices has only just begun, and the Commission will address these issues in more detail in its upcoming work on neuroscience.[269] In the meantime, it urges an open dialog on these questions so clear positions can be taken on the values that should guide technological development and on what it means to be human and a member of a society defined in time and space.

Humankind's relationship with nature

As with self-perception and the way each person defines him or herself as human beings, the increasing development and use of nanotechnology-derived products could help change the way people look at the environment, both individually and collectively. In a technologized world where the artificial and natural meet and intermingle, certain philosophical guideposts have proven vital. Jean-Pierre Dupuy stresses that "the problem is no longer knowing to what extent we can 'transgress nature'," but that the very notion of transgression is losing its meaning. Humankind will no longer encounter anything but a world made in the likeness of its own artificial creations."[270]

Humanity's relationship with nature has changed a lot over the centuries. After being dominated by nature and the elements for a large part of its history, humankind has managed to better grasp the world around it and objectify—as well as partially control—its environment through developments in science and philosophy.

With science comes not only knowledge that influences the ability of each person to act, but also an understanding of the effects of their actions on the environment. The notion of responsibility is important in this regard, and it is essential to remember that the power to affect the elements comes with a responsibility for the consequences.

Increasingly, philosophers and environmentalists are working on a way to determine the values, attitudes, and behaviors humans demonstrate toward animals, natural objects, and even the biosphere. Such reflections are part of the relatively recent discipline of environmental ethics. As Luc Bégin observes, for some specialists environmental ethics is an extension of sorts of traditional ethics, while others see it as an entirely new school of thought with a very unique approach.[271]

The value a society attributes to the environment (i.e., flora, fauna, ecosystems, etc.) will dictate, in part, the actions taken to preserve it (e.g., decontaminating sites so that plants and animals can flourish there once more) or to minimize the direct or indirect effects of a lifestyle that may prove harmful to the environment (e.g., by limiting the use of vehicles or by making them more energy efficient).

There are three conceptual models in environmental ethics. The first is utilitarian, i.e., nature's value derives only from its usefulness to humankind. This is a highly anthropocentric school where

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269 *Op. cit.*

270 Jean-Pierre DUPUY, "Le problème théologico-scientifique et la responsabilité de la science," Les effets sur le rapport à la nature (effets ontologiques), 2004 [online] http://formes-symboliques.org/article.php3?id_article=66. [Our translation]

271 Luc BÉGIN, "Éthique environnementale," in Gilbert Hottois and Jean-Noël Missa (dir.), *Nouvelle encyclopédie de bioéthique. Médecine. Environnement. Biotechnologie*, Brussels, Éditions DeBoeck Université, 2001, p. 399.

humankind is the yardstick by which all else is measured. A second model, the one endorsed by the Government of Québec with the adoption of its *Sustainable Development Act* and the definition contained therein,[272] is a moderate anthropocentrism that recognizes the interdependence of humankind and nature. The third conceptual model is biocentric in that all life is considered to have the same value, whether it be human, animal, or plant. According to this model, nature has its own purpose and its own rights; humankind cannot under any circumstances seek to modify or manipulate it for its own benefit.

It is in the spirit of the *Sustainable Development Act* that the Commission holds that humans and the environment are interdependent. Society and its decision makers need to take this interdependence into account when they make decisions that could impact environmental quality, whether in the immediate future or for future generations. Increasingly, and particularly in the wake of the adoption of the Kyoto protocol, efforts have been made in this regard on a local and global scale. However, people's daily lives and behaviors—as decision makers or ordinary citizens—stand as a reminder of the disconnect that sometimes exists between what they say and what they do.

Given the current state of development of nanotechnology and the potential it holds for the preservation or restoration of the environment, the technology could prove a boon for improving the quality of the environment, although, as stressed above, some applications may also contribute to the environment's deterioration. **It will therefore be important to strike a balance in the use of nanotechnology so that it benefits the greatest number of people while respecting the environment. Striking this balance entails decisions that concern society as a whole, and should therefore be the focus of public debate**, which is a theme of governance addressed in the next section.

ETHICAL CONCERNS NOT LIMITED TO NANOTECHNOLOGY

As mentioned above, the development of nanotechnology raises ethical questions about its possible impacts on health and the environment, its applications in the field of security, and its influence on how people perceive human identity and their relationship with nature. But the Commission has observed that nanotechnology also raises other ethical concerns not limited to nanotechnology. While not totally new, these concerns cannot be overlooked. They have to do with nanotechnology management in terms of governance and economic development, and the role individuals can play in this regard. The Commission feels it is important to consider the rapid development of nanotechnology in this position statement and to offer possible solutions that are flexible enough to develop alongside the technology to ensure that nanotechnology is managed ethically and responsibly.

Concerns related to governance

Governments are responsible for protecting the environment, human health, and the wellbeing of society as a whole. This responsibility manifests itself through governance, i.e., "the manner in which one oversees, guides, and coordinates the activities of a country, region, social group, or private or

[272] See Chapter 2 of this position statement.

public organization."[273] According to Einsiedel and Goldenberg of the University of Calgary, the notion of governance encompasses issues of legitimacy, accountability, and management of the inherent societal tensions between maintaining public trust in the way decisions are made and the role played by the various stakeholders (like businesses, government bureaucracies, and even market forces).[274] It concerns all political, social, and economic stakeholders in one way or another.

In the short to medium term, the Commission feels that society must ask a certain number of questions regarding the development of nanotechnology[275] or other emerging technologies. For example, who controls and benefits from their use?[276] What are the risks and who bears them?[277] Who guides the government grant strategies for new technology R&D? Do political decision makers have a duty to make sure nanotechnology-derived products are safe for human health and the environment? Do the existing regulations implemented before the emergence of these technologies still meet society's needs in this regard?[278] All these are questions of societal governance and readily bring to mind the GMO saga, which saw the public boycott genetically modified products when presented with a *fait accompli*. This difficult experience taught valuable lessons. Nanotechnology promoters want to avoid a similar situation at all costs by informing the public and fostering dialog to ensure the social acceptability of these new technologies.[279] However, an important point is often overlooked in comparing nanotechnology to GMOs: Much research still needs to be done in the field of nanotechnology before the various nanotechnology applications under development flood the market. This is in fact why those concerned agree that it is critical to seize this opportunity to collectively debate the social choices that must be made with regard to nanotechnology.

In the following paragraphs, the Commission questions some of the mechanisms likely to contribute to the ethical governance of technological development, more specifically that of nanotechnology. To this end, the Commission draws on values such as legitimacy, transparency, democracy, and responsibility.

Legitimacy and transparency of the decision-making process

First, it is important to remember that various federal departments document the potential repercussions of nanotechnological development in their respective fields of jurisdiction, and that Industry Canada implemented a federal interdepartmental public service network on nanotechnology in 2002. The national science advisor to the prime minister has also stressed the need for a national

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273 OFFICE QUÉBÉCOIS DE LA LANGUE FRANÇAISE, *Le grand dictionnaire terminologique*, *op. cit.* [online] http://www.oqlf.gouv.qc.ca/ressources/gdt.html. [Our translation]

274 Edna F. EINSIEDEL and Linda GOLDENBERG, *op. cit.*, p. 31.

275 In this regard, see Appendix 3, which lists questions to ask regarding nannotechnology research, development, and commercialization in Canada. These questions are taken from Lorraine SHEREMETA and Abdallah S. DAAR, "The Case for Publicly Funded Research on the Ethical, Environmental, Economic, Legal and Social Issues Raised by Nanoscience and Nanotechnology (NE^{3}LS)," *Health Law Review*, Vol. 12, No. 3, 2004.

276 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. x.

277 Edna F. EINSIEDEL and Linda GOLDENBERG, *op. cit.*, p. 30.

278 INSTITUTE OF MEDICINE (United States), *op. cit.*, p. 8.

279 See, among others, Ronald SANDLER and W.D. KAY, "The GMO-Nanotech (Dis)Analogy?" *Bulletin of Science, Technology and Society*, Vol. 26, No. 1, February 2006, p. 57–62; Mark ROSEMAN, *op. cit.*, p. 14.

nanotechnology strategy since taking the office in 2004.[280] The industry minister also commissioned the Advisory Council on Science and Technology (ACST) to draw up a report on Canada's nanotechnology perspectives as a first step in a national strategy that was to be tabled in April 2005. The elections delayed the report's publication, but four supporting studies where published on the ACST website.[281]

In Québec, NanoQuébec is recognized as the leader in nanotechnology development and promotion. The organization sits on numerous committees that address the specific aspects of governance, not only with regard to government research policies, the standardization process, and ISO standards related to nanotechnology, but also the ethical issues raised by such technology. It has also led to the creation of a working committee cochaired by the granting agencies Fonds québécois de la recherche sur la nature et les technologies (FQRNT, for research on nature and technologies) and Fonds québécois de la recherche sur la société et la culture (FQRSC, for research on society and culture). The objective of the committee is "to develop a strategy and action plan to develop and organize research expertise, advanced training, and knowledge dissemination on the socioeconomic, ethical, and environmental issues needed for the safe and responsible development of nanotechnology."[282]

One important role the Québec and federal governments play is to set out (or, if necessary, to delegate this responsibility to others) the thrusts of economic development, government research, business support, and oversight needs for nanotechnology. Increasingly, the decision-making process is tending toward greater transparency, and governments are doing such things as asking for public opinion on the societal choices to be made (with organizations like Bureau d'audiences publiques sur l'environnement [BAPE] or various forums) or surveying the level of public acceptance for specific measures. On the national scale, the national science advisor recently convened a panel of international experts as part of a July 2005 initiative to assess the strengths of Canadian nanotechnology research. The resulting report particularly stresses the need to have the public take part in discussions on nanotechnology development and research choices.[283]

What amount of flexibility can elected officials and their agents legitimately be expected to have? Ad hoc citizen and public interest groups are asking to play an increasingly active role in the decision-making process. What role should they play[284] in a field where the issues are complex and the public is often relatively uninformed of scientific progress? An analysis in this regard by Michael D. Mehta

280 Arthur J. CARTY, *Keynote Address—Nanoforum Canada*, Canada Nanoscience and Nanotechnology Forum, Edmonton, June 17, 2004 [online] http://strategis.ic.gc.ca/epic/site/onsa-bcns.nsf/en/00012e.html.

281 See http://acst-ccst.gc.ca.

282 http://nanoquebec.ca/nanoquebec_w/site/explorateur.jsp?currentlySelectedSection=415&removed%20Section=-1&showMoreOptions=false&ascending=false&showCancel=true&type=-1&intention=%20&home=false&chosenSections=-1. [Our translation] This committee should have concluded its work by the time the Commission's position statement is released.

283 OFFICE OF THE NATIONAL SCIENCE ADVISOR (Canada), *Assessment of Canadian Research Strengths in Nanotechnology… op. cit.*, p. 12–13.

284 On this topic, see Chapter 4 of the Commission position statement on genetic databanks, *Les enjeux éthiques des banques d'information génétique*, *op. cit.*, p. 59–69.

indicates that in the biotechnology sector “the use of substantial equivalence[285] and reliance upon an artificial distinction between product and process has fostered a regulatory approach that excludes the public from participating in a meaningful way. If future regulators of nanotechnology adopt this approach, the public is likely to be excluded systematically under the guise of science-based assessment.”[286]

In a democratic context, legitimacy can only derive from the transparency of the decision-making process. This is a topic that the Commission stressed heavily in its position statement on genetically modified organisms, and that led it to issue a recommendation in this regard.[287] Transparency can also be demonstrated in the ways the public is informed. The repeated requests to have labels on genetically modified food products indicate the public’s expectations of greater transparency on the part of regulators and producers.[288] Likewise labeling appears to be an expression of the freedom of choice granted each citizen in a democratic and pluralist society.

Recommendation No. 5

The Commission recommends

That the Minister of Economic Development, Innovation and Export Trade, with his colleagues in the ministries and organizations concerned, initiate a process to inform and consult with the public in order to define in all transparency the scientific, economic, and ethical issues associated with the development of nanotechnology.

Even though not enough is yet known to be able to determine an ideal public consultation and participation model before the decision-making step, various formula have nonetheless been adopted in other societies (like citizen conferences or other public debate activities) that could be adapted to the current needs of Québec society in this regard. The Commission encourages the pursuit of research and experimentation in this area.

[285] In its position statement on GMOs, the Commission summarized the notion of substantial equivalence as follows: “In as much as a product is considered equivalent in substance to an already existing product, it fits into the same approval process as any other product” [our translation]. Organizations that back this approach are currrently working on evaluating new products, namely Health Canada and the Canadian Food Inspection Agency. See the Commission position statement, p. 33 and 34.

[286] Michael D. MEHTA, “From Biotechnology to Nanotechnology: What Can We Learn from Earlier Technologies?” *Bulletin of Science, Technology & Society*, Vol. 24, No. 1, February 2004, p. 36 [online] http://www.nanoandsociety.com/ourlibrary/documents/mehta-feb2004a.pdf.

[287] The Commission recommends “that the Government of Québec intervene with the Government of Canada a) to ensure that the assessment of transgenic products for environmental and human and animal health risks is conducted in open consultation with a Commission made up of independent experts from the natural and social sciences and, where appropriate, members of the public; and b) to ensure that the expert Commission, in the interests of transparency, makes its work public and readily available.” Commission de l’éthique de la science et de la technologie, *Pour une gestion éthique des OGM* [For the Ethical Management of GMOs], *op. cit.* ., p. 64; English Summary p. 15.

[288] Edna F. EINSIEDEL and Linda GOLDENBERG, *op. cit.*, p. 31.

Oversight and accountability measures

Nanotechnology oversight measures are another aspect of governance that make it possible to manage the conflicts inherent to the divergent interests present within society or between nations. As seen in Chapter 2, such oversight may take a variety of forms: legislation, regulation, code of conduct, guide to best practices, standards, guidelines, declarations, etc. It dictates the prerequisites for conducting work in nanotechnology; it confers both rights and responsibilities on those involved in nanotechnology development and innovation.

In Canada like elsewhere around the world, no government agency has full authority over nanotechnology. Each has its own field of jurisdiction on the subject, and the tendency is to adapt existing laws rather than to create new ones.[289] Regulating or managing emerging technologies is particularly complex, especially when there is very little data on their possible effects on human health and the environment. However, “social reference points” such as the precautionary principle[290] and the life cycle approach[291] addressed above can underpin governance.

The Commission recognizes that nanotechnology oversight requires a deeper understanding of the potentially harmful consequences that could result from the introduction and dissemination of into the environment of nanoparticles or their penetration into living organisms. However, such a constraint should in no way limit the actions taken to monitor and examine emerging technologies and update existing regulatory measures as needed. **It is also important that all those involved in nanotechnology work together to adopt behaviors in line with the goal of sustainable development. In the Commission’s view, it is necessary to bring all interested parties together in order to develop a model of flexible governance, adapted to the reality of nanotechnology and capable of responding to ethical concerns raised by these technologies.**

One last point deserves stressing with regard to oversight measures: It is imperative to ensure that the rules are upheld. Quality control measures, toxicological data verification, inspections to verify the innocuity of production areas, and respect for the health and safety of workers and the public are examples of actions that must be taken systematically. Faced with major budgetary constraints, how will government agencies responsible for protecting human health and the environment be able to do their jobs as new and still little-known categories of products arrive on the market? What protective measures are taken will doubtless depend on the costs involved,[292] as well as the political will and the cooperation of all those concerned. To what extent can current risk management methods account for the many facets of emerging technologies and address the uncertainty associated with them in terms of risk?

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289 J. Clarence DAVIES, *op. cit.*

290 Michael D. MEHTA, *op. cit.*, p. 37.

291 INTERNATIONAL RISK GOVERNANCE COUNCIL, *Survey on Nanotechnology Governance, Volume A. The Role of Government*, IRGC Working Group on Nanotechnology, December 2005, p. 18 [online] http://www.innovationsgesellschaft.ch/images/fremde_publikationen/IGRC_Nano_Governance.pdf.

292 MERIDIAN INSTITUTE and NATIONAL SCIENCE FOUNDATION, *op. cit.*, p. 12.

Recommendation No. 6

The Commission recommends

That the Minister of Economic Development, Innovation and Export Trade call on granting agencies, together with the various stakeholders concerned, to create a program of multidisciplinary research on the impacts of new technology and on managing the risks associated with nanotechnology that takes into account the ethical and social aspects in play.

Concerns related to economic activity associated with nanotechnology

The economy is an important area of activity in all societies. The development of knowledge, availability of highly skilled workers on the market, and existence of vibrant companies and an open market are all prerequisites to maintaining and improving the public's standard of living. In this day of globalization, it is also important to be concerned about the needs of less fortunate societies and to strive towards a fair distribution of wealth—as well as risks. The Commission also wishes to provoke discussion of the possibility companies will build consumer profiles by drawing on the increased data storage capacities available to them. The values that guided the Commission's reflection in this section were responsibility, solidarity, freedom, quality of life, social justice, fairness, and privacy.

Ethical choices in the development of Québec economic activity associated with nanotechnology

Although there is no consensus on the specific impact nanotechnology will have on the economy, specialists nevertheless estimate that the worldwide economic spinoffs could be in the order of $2.6 trillion USD in 2014.[293] The Royal Society report notes that the short term effects will be limited, but since nanotechnology will enable or improve a number of applications, the long term impact could be significant, by spurring growth in the gross national product (GNP), enhancing efficiency, and reducing waste in industrial processing.[294]

It is important not to underestimate the importance of these assertions, specifically with regard to Québec's economic activities. Nanotechnology could have a positive and significant impact on traditional industries—such as agrifood, textiles, or even pulp and paper—by enabling the development of value-added products and services. Ultimately, increased collective wealth would make it possible to invest in education or health—two areas where money is always sorely lacking.

Since 2004, Conseil de la science et de la technologie du Québec has been coordinating a project called Perspective Science-Technologie-Société (STS) with a view to raising awareness in all sectors of Québec society about the importance and usefulness of science and technology for understanding and

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[293] LUX RESEARCH, "Revenue from Nanotechnology-Enabled Products to Equal IT and Telecom by 2014, Exceed Biotech by 10 Times," press release, October 25, 2004 [online] http://www.luxresearchinc.com/press/RELEASE_SizingReport.pdf.

[294] THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 52.

solving social and economic problems.[295] A secondary goal of this project is to encourage Québec's scientific community to get more involved in the social and economic goals of science and technology.[296] **In the Commission's view, this kind of initiative should be implemented once a nanotechnology development strategy has been drawn up for Québec, so that it will be possible to meet Québec's economic and social needs while paying specific heed to the ethical issues associated with these technologies.**

In a 2005 report on nanotechnology, the U.S. President's Council of Advisors on Science and Technology observed that new technologies could displace obsolete ones, leading to a parallel shift in job opportunities.[297] **Since these new jobs sometimes require different skills, the Council pointed out that such changes could pose huge challenges for workforce training and the educational system.[298] In the Commission's view, this is an important ethical issue, since it is often the most vulnerable workers in society who are adversely affected by transformations in the labor market brought on by the emergence of new technologies.**

Likewise, the Commission worries about the fate that awaits Québec SMEs involved in the development of nanotechnology-derived products once the startup financial assistance they generally receive from the government dries up.[299] Developing an economy based on advanced know-how requires that high tech sectors and highly skilled jobs be preserved. If these businesses disappear or move abroad, the Commission feels that government funds that could have been used for other purposes will have been wasted and society will lose important expertise.

Recommendation No. 7

The Commission recommends

That the Minister of Economic Development, Innovation and Export Trade, upon completion of a Québec nanotechnology development strategy, take into account the ethical and social questions raised by such technologies, particularly with regard to employment and workforce training.

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295 See http://www.cst.gouv.qc.ca/LE-PROJET-PERSPECTIVES-Science.

296 *Ibid.*

297 PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY (United States), *op. cit.*, p. 35. The Royal Society fully agrees with this, and notes that, generally, the introduction of new technologies creates winners and losers; for example, when jobs are lost in a given sector to the benefit of another: THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 52.

298 *Ibid.*

299 On this topic, see Sylvain D'AUTEUIL-ROBILLARD, "Les orphelins du développement économique," *PME*, Vol. 21, No. 10, December–January 2005, p. 40–42.

The nano-divide in a context of globalized markets

Numerous authors[300] stress the possibility that nanotechnology will widen the gap between rich and poor countries by forming a nano-divide in terms of the knowledge acquisition and the use of these new technologies. With economic progress increasingly reliant on the exploitation of scientific knowledge, the cost of acquiring these new skills and procedures may very well accentuate this divide.[301]

Guiding nanotechnology R&D

In its reflection on the ethical concerns raised by nanotechnology-related economic activity, the Commission asks the following question: Does a privileged society have a moral obligation to develop and share advanced technologies that could benefit poorer nations? Some observers, like Mohamed H.A. Hassan, president of the African Academy of Sciences and head of the Academy of Sciences for the Developing World, see a number of potential uses nanotechnology could have for poorer countries, including the creation of more efficient filtration systems to produce clean water or the provision of cheap and clean energy.[302] Peter Singer and his colleagues point out that nanotechnology could significantly help attain five of the eight United Nations *Millennium Development Goals* aimed at promoting worldwide human, social, and economic development. These goals include eradicating extreme hunger and poverty, ensuring environmental sustainable development, reducing mortality of children under five, improving maternal health, and combating HIV/AIDS, malaria, and other diseases.[303]

What nanotechnology-derived products will be given priority and who will they benefit? Like Singer and his colleagues, Hassan believes that it is possible that "the majority of resources and expertise (in the North and South) may be applied to products and services that hold the most promising market potential in the North where the richest consumes live."[304] In the short run, it is therefore highly likely that the development of nanotechnology will benefit those who already possess the wealth and

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300 See, among others, THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*; SOUTH CENTRE, *The Potential Impacts of Nano-Scale Technologies on Commodity Markets: The Implications for Commodity Dependent Developing Countries. Trade-Related Agenda, Development and Economy (T.R.A.D.E.)*, Research Papers No. 4, Prepared by ETC, November 2005, p. 18 [online] http://www.southcentre.org/publications/researchpapers/ResearchPapers4.pdf.; Anisa MNYUSIWALLA, Abdallah S. DAAR, and Peter A. SINGER, "'Mind the Gap': Science and Ethics in Nanotechnology," *Nanotechnology*, 14: R19-R13, 2003 [online] http://www.utoronto.ca/jcb/home/documents/nanotechnology.pdf; NANOFORUM.ORG, *4th Nanoforum Report: Benefits, Risks, Ethical, Legal and Social Aspects of Nanotechnology*, June 2004 [online] http://www.nanoforum.org/nf06~modul~showmore~folder~99999~scid~341~.html?action=longview_publication&.

301 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 52.

302 Mohamed H.A. HASSAN, "Small Things and Big Changes in the Developing World," *Science*, Policy forum, Nanotechnology, Vol. 309, July 1, 2005 [online] http://www.sciencemag.org/cgi/content/full/309/5731/65.

303 Peter A. SINGER, Fabio SALAMANCA-BUENTELLO, and Abdallah S. DAAR, *op. cit.*, p. 58; See also UNITED NATIONS, *Investing in Development: A Practical Plan to Achieve the Millennium Development Goals*, Millenneum Development Goal Project, Report to the UN Secretary General, New York, 2005 [online] http://www.unmillenniumproject.org/reports/fullreport.htm.

304 Mohamed H.A. HASSAN, *op. cit.*, p. 66; Peter A. SINGER, Fabio SALAMANCA-BUENTELLO, and Abdallah S. DAAR, *op. cit.*, p. 57.

power—to the detriment of the rest of the world. However, the possibility of conceiving and developing nanotechnological innovations that benefit developing countries should not be dismissed out of hand. Governments, businesses, foundations, and nongovernment organizations are or could be called on in various capacities to help manage nanotechnology development. For these various stakeholders, this is an opportunity to pool efforts to maximize reflection and act together in solidarity with those who are less fortunate.

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In the same vein, the Commission suggests that universities, granting agencies, and developing countries increase or develop their collaborative relationships. The organizations involved should consider taking steps with the specific goal of meeting developing countries' nanotechnology needs, such as creating nanotechnology research partnerships, organizing exchanges of students and professors between universities, and establishing funding programs.

Possessing nanotechnology expertise

In general, whoever controls R&D also controls the means of production and the supply of products and services. In establishing research priorities, the needs of developing countries should be taken into account, and the growth of local industries should be encouraged so that they create sustainable wealth. Partnerships should be encouraged between those who wield the knowledge and capital, on the one hand, and those who provide market access, on the other, as long as such partnerships entail an equal and fair division of the benefits and responsibilities. This is a matter of respect and solidarity.[305]

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Given that human solidarity finds expression mainly in collaborative acts and the sharing of wealth, the Commission encourages support for researcher training and the implementation of R&D infrastructure in emerging and developing countries, with a view to promoting the acquisition of industrial expertise in these countries and to avoiding any deepening of the technological divide.

Intellectual property and patent management

Management of patents and intellectual property may be viewed as a great source of innovation, but it can also hinder access to the knowledge and tools required for R&D. While recognizing that this issue is not exclusive to the field of nanotechnology and that it falls under federal jurisdiction, the Commission finds it useful to touch on it in this position statement, because current practices may have an impact on fundamental research and technological innovation in this field.

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305 A number of forums have already begun considering new types of partnerships. For example, participants at a workshop organized in June 2004 on the *international dialog on responsible nanotechnology R&D* suggested that ongoing international dialog and cooperation would help developing countries take part in nanotechnology R&D. MERIDIAN INSTITUTE and NATIONAL SCIENCE FOUNDATION, *op. cit.*, p. 8; See also p. 19 on the possible contribution of the private sector.

Although holding patents is considered an economic advantage, experience in scientific fields other than nanotechnology has demonstrated that patents that are too broad or that do not strictly meet the criteria of novelty and non-obviousness can work against the public good.[306] To that effect, the following problems are generally raised about holding patents: difficulty obtaining the required licenses due to the large number of patent holders in a given field of research or for an application in particular, the refusal of patent holders to grant licenses to a third party—which can be legal in some countries like the United States—and the exorbitant licensing fees that certain patent holders demand in exchange for using their technology.[307] In such conditions, acquiring knowledge is a major challenge and can even be a source of iniquity.

However, part of the problem surrounding intellectual property and patent management is people's misunderstanding of how the system works. Brazilian chemist Galembeck maintains that a large portion of scientists from non G7 countries (now G8) do not read patents or think to file patents for their discoveries. This situation has two harmful consequences. First, a number of scientific efforts are conducted in vain, because the research objectives may have already been met by other teams who already hold the related patents. Second, scientists who work in emerging countries are contributing more and more to scientific publication, but without protecting the results of their work. "This new information will be finally transformed into products and processes that will be imported into the country, bringing in modernity but also unemployment and pressures on the economy."[308]

Some questions are also raised about public versus private control of intellectual property. In a sector like nanotechnology where new technology also furthers basic knowledge in physics, chemistry, and other fields, shouldn't efforts be made to prevent the fact that research has been both publicly and privately funded from imposing limits on knowledge development as a result of the intellectual protection system currently in force? Einsiedel and Goldenberg hold that knowing who owns knowledge engendered by initiatives involving both public universities and private corporations remains a very problematic issue. Research by Baber [holder of the Canada Research Chair in Science, Technology, and Social Change] demonstrates that funding conditions for university researchers in Japan and Singapore have reduced their resistance to directly translating into monetary value any knowledge derived from research. A large portion of what is referred to as nanotechnology concerns the acquisition of new knowledge in basic science and quantum processes, which poses a serious challenge in terms of existing approaches to ownership rights.[309]

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306 See, among others, THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 53 and Edna F. EINSIEDEL and Linda GOLDENBERG, *op. cit.*, p. 30.

307 David B. RESNIK, "A Biotechnology Patent Pool: An Idea Whose Time Has Come?" *The Journal of Philosophy, Science & Law*, vol. 3, January 2003 [online] http://www6.miami.edu/ethics/jpsl/archives/papers/biotechPatent.html.

308 Fernando GALEMBECK, "Ethical issues of nanotechnology" speech given at the 3rd session of COMEST, December 1–4, 2003, Rio de Janeiro, UNESCO, p. 129 of *Proceedings* [online] http://unesdoc.unesco.org/images/0013/001343/134391e.pdf.

309 Edna F.EINSIEDEL and Linda GOLDENBERG, *op. cit.*, p. 30.

Solutions in sight

Managing intellectual property and patents is not a simple issue, and the emergence in recent years of companies whose main goal is to purchase patents with a view to reselling them to the highest bidder complicates things;[310] when a select few control a high concentration of patents, this can ultimately limit access to technology.[311] As Einsiedel and Goldenberg note, some maintain, given the biotech patenting model, that the current trend could obstruct rather than encourage innovation, and one way to tackle the problem would be to take inspiration from the intellectual property protection methods used in IT for open source software with regard to government-funded research.[312] Although this model has gained a wide following in the public domain, one wonders whether its adoption by larger numbers of users has not been hindered by the fact that open source code, unlike patents, accords little monetary value to innovation (generally only to technical support).

Another possibility would be the establishment of patent pools.[313] Patent pools have existed for over a century.[314] They are generally viewed as conducive to competition, but they could also have the opposite effect in certain circumstances.[315]

It is also interesting to note the recent initiative by the U.S. National Institutes of Health (NIH) in the field of biotechnology. They announced a public/private partnership with various pharmaceutical firms to accelerate genetic research on multifactorial diseases. NIH promised that the research findings would not become the property of the private companies investing in the project, but would remain available to all.[316]

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310 Lisa K. ABE, *Nanotechnology Law: The Legal Issues*, report presented as part of NanoForum 2005, McGill University.

311 ETC GROUP, *From Genome to Atoms: The Big Down…, op. cit.*

312 Edna F. EINSIEDEL and Linda GOLDENBERG, *op. cit.*, p. 30. For more information on the subject, also see Francis ANDRÉ, *Libre accès aux savoirs/Open Access to Knowledge*, Paris, Futuribles, 2005, p. 47–49.

313 A patent pool generally allows "participating patent holders to use the patents being pooled, establishes a license type for these patents for the benefit of licensees who are not members of the pool, and distributes royalties among its members, in accordance with the agreement." See the *Standards and Patents* section on the World Intellectual Property Organizaton website [online] http://www.wipo.int/patent/law/en/developments/standards.html.

314 The U.S. Patent and Trademark Office has record of one of the first patent pools in 1856 regarding sewing machine patents. Recent initiatives in electronics and communications concern products manufactured in accordance with DVD-ROM and DVD-Video formats. For more information, see UNITED STATES PATENT AND TRADEMARK OFFICE, *Patent Pools: A Solution to the Problem of Access in Biotechnology Patents?* Jeanne CLARK *et al.*, December 5, 2000 [online] http://www.uspto.gov/web/offices/pac/dapp/opla/patentpool.pdf.

315 For more information, see the section on the procompetitiveness and anticompetitiveness of patent pools, UNITED STATES PATENT AND TRADEMARK OFFICE, *op. cit.*, p. 6–7.

316 Lauran NEERGAARD, "Federal Project Probes Environment, Genes," *Washingtonpost.com*, February 8, 2006 [online] http://www.washingtonpost.com/wp-dyn/content/article/2006/02/08/AR20060208 00793.html.

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This type of initiative by NIH raises a number of broader questions: Are public/private research and marketing initiatives equitable for Québec? What are the positive and negative effects of such partnerships? Do the potential benefits offset the negative impacts? Is it possible to reduce or eliminate the negative impacts? Would it be possible to put incentives in place for philanthropic activity? In view of these questions, the Commission feels it is imperative to seriously consider the role of protecting intellectual property in a context of innovation as well as the ethical questions associated with this protection.

Collecting personal information

The convergence of nanotechnology and information technology will make it possible to connect increasingly powerful, effective, and complex networks for monitoring and surveillance purposes. Certain nanoscale devices may be easily incorporated into a variety of electronic products, and such developments could be put to a multitude of uses: ensuring a higher level of safety and security, providing personalized health care, or offering businesses a wide range of benefits (e.g., for performing various types of tracking on equipment and products). However, it is also possible to conceive of such developments as restricting the privacy of individuals or groups through their ability to conduct invisible surveillance, collect and distribute personal information without express consent, or concentrate information in the hands of those with the resources to develop and control such networks.[317] These possibilities must be carefully examined, taking into account the prevailing social and political context in the United States since the attacks on September 11, 2001.

Personalized marketing holds obvious appeal for businesses, which could gain a better understanding of their clientele's consumer habits and conduct campaigns specifically targeting certain individuals or groups. This practice is already in effect,[318] and the increasingly powerful data storage and processing capabilities that nanotechnology will make possible could magnify this phenomenon.

The convergence of nanotechnology and information technology could heighten consumer concerns about the use of radio frequency identification (or RFID) to replace barcodes—a technique that is currently being tested in certain supermarkets and stores.[319] This raises the following main concerns: the possibility of linking personal information (credit card) to a specific product in order to establish an individual's consumer profile, addressing personalized marketing to this person, and even tracking the movements of an individual carrying a product equipped with an RFID label. Other possible impacts include an increase in the amount of personal data collected and greater use of surveillance, as well as the possibility of tracking highly specialized profile types for the purposes of police, social, or political control.[320] These issues have been of interest to the Office of the Privacy Commissioner of Canada for

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317 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 53; Fernando GALEMBECK, *op. cit.*, p. 128 of *Proceedings.*

318 Notably at *Amazon.com*, which regularly sends its clients personalized offers based on their previous purchases.

319 In Québec, this technology is currently being tested in certain SAQ, Metro supermarket, and Staples stores. See PRESSE CANADIENNE, "Bureau en gros fera l'essai du RFID avec Bell," *Direction informatique express*, Le bulletin des actualités technologiques, November 1, 2005 [onligne] http://www.directioninformatique.com/di/client/fr/DirectionInformatique/Nouvelles.asp?id=37276

320 THE ROYAL SOCIETY & THE ROYAL ACADEMY OF ENGINEERING (United Kingdom), *op. cit.*, p. 53–54.

a number of years,[321] and it recently raised the issue once again of safeguarding the personal data collected by governments.[322]

The Commission insists that gathering and using personal information from commercial transactions or market studies must not be done without the knowledge of consumers, who have the right not only to be aware of these practices, but also to refuse to allow their personal information to be filed away and used for marketing or any other purposes they do not approve of.[323] **Laws already exist in Québec and Canada as a whole that protect personal information[324] and that require public and private organizations to allow anyone who so requests to have access to their information file.** The problem is that few people are aware of these obligations, and public and private companies and organizations that do not respect existing regulations are rarely penalized. For the sake of transparency and given the financial value of consumer profiles, businesses that engage in this practice should inform their customers and obtain the consent of those concerned.

One final aspect of the protection of personal information that deserves to be addressed is access to genetic information. With the advent of nanotechnology, silicon DNA chips will make it possible to analyze the genetic content of cells *in situ.* Soon physicians will be able to "read" a patient's genetic code directly in a clinical setting and obtain a large amount of information on the patient's health status and genetic predisposition to certain illnesses. Such information will also be available to the police and even customs agents for identification purposes—and not diagnostic ones—in well-defined legal contexts. As the Commission made clear in its 2003 position statement on genetic databases, the use of genetic information for non-medical purposes, particularly by insurers, employers, or financial institutions, is a practice liable to promote discrimination when decisions are made concerning specific people (e.g., customers, employees, or borrowers).[325] **The Commission still feels that any use of genetic information by third parties other than health professionals and for purposes other**

321 OFFICE OF THE PRIVACY COMMISSIONER OF CANADA, *Annual Report to Parliament*, Report on the *Personal Information Protection and Electronic Documents Act*, 2005 [online] http://www.privcom.gc.ca/information/pub/pa_reform_060605_e.asp.

322 OFFICE OF THE PRIVACY COMMISSIONER OF CANADA, "Privacy Commissioner tables report calling for urgent reform of Canada's Privacy Act," press release, Ottawa, June 5, 2006 [online] http://www.privcom.gc.ca/media/nr-c/2006/nr-c_060605_e.asp.

323 Only information needed for the purpose of the file may be compiled.

324 Canada-wide: GOVERNMENT OF CANADA, *Canadian Charter of Rights and Freedoms* (Appendix B of *The Constitution Act, 1982*, ch. 11 [UK]), *Privacy Act* (R.S., 85, ch. P-21), *Personal Information Protection and Electronic Documents Act* (C-6); Québec: GOUVERNEMENT DU QUÉBEC, *The Québec Charter of Human Rights and Freedoms* (R.S.Q., c. C-12), *Act to establish a legal framework for information technology* (R.S.Q., c. C-1.1), *Act respecting access to documents held by public bodies and the protection of personal information* (R.S.Q., c. A-2.1), and *Act respecting the protection of personal information in the private sector* (R.S.Q., c. P-39.1).

325 COMMISSION DE L'ÉTHIQUE DE LA SCIENCE ET DE LA TECHNOLOGIE, *Les enjeux éthiques des banques d'information génétique*…[The Ethical Issues of Genetic Databases…], *op. cit.*, p. 51–52. The Commission had also made the following recommendation, which is more appropriate than ever given the enhanced possibilities offered by nanotechnology for the collection of genetic information: "That the Government of Québec declare a five-year moratorium for employers, insurers, and financial institutions in the use of information obtained through genetic testing and that, during this period, the organizations involved be asked to draft and adopt a self-regulation policy regarding the use of genetic information in their evaluations. If the policies proposed at the end of this period do not agree with Québec's social values, the government should create legislation to set guidelines and restrict the use of genetic information in areas other than health."; p 12 of the English Summary.

than treatment should be the subject of a social debate on such practices and the purposes they serve.

Concerns related to citizenship and technological innovation

Technological innovation goes through an assimilation process that determines its utility or value and leads to its acceptance or rejection by society. This process normally allows citizens to become familiar with new techniques or products before incorporating them into their lifestyle. The subjectivity with which technological innovation is assimilated may seem disconcerting. Consumption is increasingly seen as a power issue where citizens demand the right to make choices reflecting their values. This exercise in citizenship should be seen as a sign of healthy democracy, as long as citizens are aware of their ability to influence, recognize the responsibility that comes with any decisions they make, and have access to clear and objective information.

Citizen empowerment is the "process by which individuals or social groups gain control over the factors that allow them to be informed, improve their potential, and adapt in order to evolve and improve their living conditions and environment."[326] It finds expression particularly in the desire to make choices reflecting each person's individual and societal values. In a highly fragmented society where little trust is placed in politicians, citizens have the feeling that they can decide for themselves and have an influence when it comes to their life and consumer choices—choices that must be made again and again.

When looking at how the markets and public will react to products derived from nanotechnology innovations, the fate of genetically modified foods is once again the example cited. Sociologist Michael D. Mehta notes on the topic of GMOs that "Canadian regulators prohibit labeling that would give consumers an opportunity to distinguish between foods approved on the basis of manufacturing process rather than the actual nature of the food. Many consumers see both process and product as important to decisions they make on a wide range of items. The lesson for future technologies like nanotechnology is that labeling is likely to be a regulatory and public relations nightmare. It is likely that debates over mandatory and voluntary labeling and process versus product will emerge when consumers are exposed to more products derived from nanotechnology."[327]

In the event that this hypothesis proves true, those involved in developing nanotechnology (researchers, promoters, investors, governments, and interest groups) would have every reason to work together on ways to facilitate the integration process for nanotechnological innovations. Does this mean products derived from nanotechnology should be labeled? For now, the Commission believes that it would be pointless to move forward with the labeling of products derived from nanotechnology or that contain nanoscale components until these products are better characterized and their effects better understood, and until the public has been better informed about them.

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[326] OFFICE QUÉBÉCOIS DE LA LANGUE FRANÇAISE, *Le grand dictionnaire terminologique*, *op. cit.*[Our translation]
[327] Michael D. MEHTA, *op. cit.*, p. 37.

Although ensuring the availability of clear information is a prerequisite for citizen empowerment, it is also a major challenge. How does one connect with the public? How does one make sure the information conveyed is accurate and free of value judgments, and that it answers society's questions? For nanotechnology, this is a very daunting endeavor, due to the complexity of the technology and the variety of possible applications. Nevertheless, the groups concerned must take special care not to repeat what happened with genetically modified organisms, which some would deem the epitome of poorly managed public policy.[328] **The Commission stresses the importance of transmitting accurate information to the public and of promoting public participation in decision making regarding nanotechnology.** By drawing on solid technical data on the potential impact of nanoparticles on health and the environment, and by fostering an open dialog with all stakeholders on the potential social and ethical outcomes, nanotechnology can avoid following in the footsteps of GMOs.[329]

As Einsiedel and Goldenberg observe, public awareness and education initiatives are important mechanisms, but they are destined to fail if their only goal is to garner public acceptance. What matters to the public more than the subtleties of science and technology is the purpose of an application: how and under what circumstances it will be used, and how the resulting risks and benefits will be managed.[330] An examination of the relationship between citizens and innovation would give a better understanding of the assimilation process for products derived from new technologies.

By creating an Internet portal with information on genetically modified organisms[331], the Government of Québec has taken a commendable step in informing the public in the most objective manner possible, specifically by working with partners like Office de la protection du consommateur; the ministries that deal with matters of health, environment, and agriculture; and Commission de l'éthique de la science et de la technologie. Similar efforts would also be worth taking for nanotechnology, particularly if they were implemented relatively early in the nanotechnological innovation process in order to evolve and develop with the technology over the years.

Recommendation No. 8

The Commission recommends

That the Government of Québec follow the example of the Internet portal on genetically modified organisms in order to create an information portal for the general public devoted to nanotechnology.

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328 Kristen KULINOWSKI, "Nanotechnology: From "Wow" to "Yuck"?" *Bulletin of Science, Technology & Society*, vol. 4, No. 1, February 2004, p. 19 [online] http://bst.sagepub.com/cgi/content/short/24/1/13.

329 *Ibid.*

330 Edna F. EINSIEDEL and Linda GOLDENBERG, *op. cit.*, p. 31. See also Claire MARRIS, coauthor of the PABE report [Public Perceptions of Agricultural Biotechnologies in Europe]: "Public Views on GMOs: Deconstructing the Myths," EMBO Reports, Vol. 2, No. 7, July 2001 [online] http://www.emboreports.org. The main points of this article are given in the Commission position statement on GMOs on page 82, and may also apply to nanotechnology.

331 See http://www.ogm.gouv.qc.ca/ [in French only].

Even though the information is available and easily accessible, it is important to make sure the public is aware of and fully understands the issue of new technologies; this is the public's responsibility, but it does not always grasp the importance of it. Given that young people's interest in science and technology is waning, even as consumption of high tech products continues to rise; that nanotechnology will make it possible to create brand new products whose impacts are not necessarily yet fully understood; and that the convergence of sciences is boosting data processing capabilities and increasing the potential for privacy infringements, **it is now urgent to address ways to bridge the knowledge gap by providing the public with relatively neutral and objective information.**

CONCLUSION

It is with great curiosity and interest that the Commission initiated its deliberation on the ethical issues raised by the development of nanotechnology, on the one hand, because the subject is still little known; on the other, because the possibilities represented by the development and use of nanoscale materials seem virtually unlimited. It is easy to marvel at—and even be carried away by—the euphoria and enthusiasm shared by many people involved in nanotechnology.

While examining these issues, the Commission realized the enormity and complexity of the task it had taken on, namely to document the development of nanoscience and nanotechnology in order to identify the ethical issues associated with their emergence. Nanotechnology affects all fields of activity, with a variety of applications and an extremely wide range of possible uses. Moreover, examining nanotechnology is made more complicated by the fact that nanoscale matter is invisible to the naked eye; however, the effects—whether positive or negative—are quite tangible. Furthermore, the fact that nanotechnology is still an emerging technology also means that it is impossible today to predict all the applications that are to come and what repercussions these applications could have for Québec and the rest of the world. By way of illustration, consider the emergence of the Internet, which has revolutionized communications and had a profound affect on the way people live. Who could have predicted this technology would have such a deep cultural impact when it was developed over thirty years ago by a computer science professor with grants from the U.S. Department of Defense? The same goes for the subject at hand.

Nanotechnology is emerging from a convergence of the sciences, a relatively recent phenomenon in and of itself. The types of knowledge needed to comprehend the challenges that will arise are thus quite varied: chemistry, biology, physics, and computer science for the purely scientific impacts, but also philosophy, sociology, and law to understand the impacts of its development on modern societies. One of the pitfalls nanotechnology may encounter and that could influence its possible impacts on society is the degree of individual specialization in very advanced fields that it demands, which could in some way obscure the big picture of the actual developments these new technologies could bring about, as well as the questions that should be raised.[332] Indepth understanding of science, in addition to more comprehensive general knowledge, are needed to fully grasp the development of the convergence technologies that nanotechnology is a part of.

The Commission feels that nanotechnology's potential impact cannot be minimized and that caution must therefore be used in implementing the measures needed to ensure responsible management thereof. In support of this assertion, the Commission has given examples of applications in the health, environment, and security sectors that boast laudable goals, but that could also have potentially harmful indirect consequences. It has further provided several examples that show how the peaceful use for nanotechnology could be diverted from its original altruistic or protective purposes and instead be used to aggressive ends of potential danger to humankind. The potential for modifying human behavior, monitoring people without their knowledge, or releasing harmful substances into the environment

[332] Willem H. VANDERBURG, "Some Reflections on Teaching Biotechnology, Nanotechnology, and Information Technology," Editorial, *Bulletin of Science, Technology & Society*, Vol. 24, No. 1, February 2004, p. 7.

must spur those involved in promoting nanotechnology and producing nanotechnology-derived products to act responsibly and transparently.

Nevertheless, one must not believe that nanotechnology can only lead to doom and ruin. Undue apprehension could result in the untimely demise of budding technologies with extremely positive potential—if used properly. Improving human health through early disease detection and targeted therapy, restoring habitats damaged by human actions, and making more effective use of available resources are just a few examples of the possible positive contributions nanotechnology could make. However, those involved in nanotechnology must be willing to discuss the objectives being pursued and the actions to take for these benefits to be enjoyed, because it is often society as a whole that must deal with the consequences.

The Commission comes out of this exercise knowing one thing for certain—that serious reflection on the ethical and social issues raised by technology is only beginning and it is important to continue thinking, discussing, and expressing views on nanotechnology and the best way to ensure their harmonious development. This is why the Commission is willing to continue examining more specific questions the government may have about responsible nanotechnology management as it develops policies and guidelines and makes future decisions in this regard.

GLOSSARY*

Atomic force microscope – Scanning probe microscope able to image a sample at the atomic and molecular scale by scanning its surface with a probe placed within a few nanometers of it that senses the repulsive or attractive forces of electrons in order to measure dimensional variations in structure or manipulate particles of matter

Atomic force microscopy (AFM) – Scanning probe microscopy* in which a sample is imaged at the atomic and molecular scale by scanning its surface with a probe placed within a few nanometers of it that senses the repulsive or attractive forces of electrons in order to measure dimensional variations in structure or manipulate particles of matter. Syn.: scanning force microscopy (SFM)

Biochip – Tiny glass, silicon, or plastic disk on which organic molecules are deposited that is used to execute one or more tasks, generally involving the analysis or detection of other molecules. Syn.: biological chip

Biological imaging – Set of techniques tied to the study of living organisms that enable the visualization of molecules, cells, and biological processes using radiation produced by electromagnetic or sound waves. Syn.: bioimaging

Biomedical engineering – Set of people and intellectual or technical activities (using mechanics, electronics, etc.) that contribute to the development, construction, and maintenance of devices used for medical diagnosis, therapeutics, or artificial organs and systems

Biosensor – Sensor that transforms a biological phenomenon into an electric signal that can be analyzed and used for the detection or direct dosage of a biological species

Blood-brain barrier – Set of physiological mechanisms that prevent certain substances in the blood from freely passing into the cerebrospinal fluid and the cells of the central nervous system. Syn.: blood-cerebral barrier, BBB

Bottom-up approach – Method for manufacturing nanometric components that consists of assembling them from the building blocks of matter, atom by atom or molecule by molecule, until a complete structure able to be integrated into a larger whole is obtained. Syn.: bottom-up, bottom up approach

Buckminsterfullerene – Fullerene consisting of 60 carbon atoms grouped together in a stable structure comprising 12 pentagons and 20 hexagons, with a spherical shape reminiscent of a soccer ball. Syn.: bucky ball, buckyball, C_{60} fullerene, C_{60} molecule, fullerene-60

Cancerogenicity – Property of a substance that can cause cancer. Syn.: carcinogenicity

* Unless otherwise indicated, glossary definitions are taken from *Le grand dictionnaire terminologique*, compiled by Office québécois de la langue française (OQLF). Go to http://www.oqlf.gouv.qc.ca or http://www.granddictionnaire.com for more details [in French] on these and other nanotechnology-related terms. In collaboration with OQLF, NanoQuébec also features a nanotechnology glossary on its website at http://www.nanoquebec.ca. Certain non-nanotechnology terms are included in the glossary as an aid to reader comprehension of this position statement. Translation is ours.

Carbon nanopearl – Spherical carbon compound with a structure consisting of amorphous and crystalline nanosize elements and a diameter between one and several hundred nanometers that strings together with other similar spheres to form a three-dimensional foam that produces an electric field able to create a stable source of electrons. Syn.: nanopearl, carbon nanobead, nanobead

Carbon nanotube – Carbon sheet wound around itself that is generally closed at both ends by a half molecule of fullerene, forming a tube several nanometers in diameter and 10 to 100 micrometers in length. Syn.: bucky tube, buckytube

Carcinogenicity – See cancerogenicity

Characterization – Analytical process aimed at describing the properties specific to a material or the distinctive features of a phenomenon

Convergence – Process by which once separate scientific disciplines gradually merge and combine, creating synergy, which at the same time unifies a number of technologies arising from their different applications

Disruptive technology – Set of new processes and techniques whose implementation has significant repercussions on the use of older technologies

DNA chip – Tiny glass, silicon, or plastic disk on which known DNA nucleic sequences that are characteristic of certain genes are deposited and that pair with complementary nucleic sequences in a mixture of molecules in order to detect the presence of the same genes in cells under analysis. Syn.: DNA biochip, DNA microarray, DNA array, microarray

Drone – Small, pilotless plane used for a variety of missions that is generally operated remotely using radiowaves and is semi-autonomous or autonomous when it is programmed to execute various tasks or when it has the electronic equipment required for self-guidance

Drug activation – Operation that allows the active ingredient contained in drugs to be released at the desired time and begin acting on an organ, tissue, or cell. Syn.: activation

Drug targeting – The association of drugs with molecular structures able to send the active ingredient they contain to the exact location where it will act in an organ, tissue or cell. Syn.: targeting

Electron beam projection lithography – Lithographic technique in which a beam of electrons, generally directed by a system of electromagnetic lenses, is projected through a stencil mask toward a sensitive resin in which the pattern of a micrometric or nanometric structure is to be reproduced. Syn.: electron projection lithography (EPL), projection electron lithography

Embryotoxicity – Characteristic of a drug or chemical substance that adversely affects embryo development

Empowerment – Process by which an individual or social group gains control over the means required to raise its awareness, boost its potential, and transform itself with a view to developing and improving its living conditions and environment

Enabling technology – Set of new processes and techniques that help improve existing technologies

Endoscopy – Method used to investigate, for diagnostic or therapeutic purposes, the internal surface of a hollow organ, natural cavity, or duct of the body via natural pathways using an endoscope

Engineered nanoparticle – Nanoparticle created voluntarily in a lab or enterprise (carbon nanotubes, fullerenes, nanocrystals, etc.) (CEST, according to OQLF)

Eugenics – Science that studies and seeks to implement the conditions most conducive to improving the human gene pool, particularly in order to eliminate hereditary diseases

Extreme ultraviolet lithography – Lithographic technique that uses electromagnetic rays with a wavelength between 10 and 14 nanometers to reproduce the pattern of a nanometric structure in a sensitive resin toward which they are directed through a mask using a system of mirrors. Syn.: extreme UV lithography, EUV lithography, soft X-ray lithography

Fluorescent nanocrystal – Nanosize crystal made up of one or more semiconducting materials that, when excited by ultraviolet radiation, emits light waves whose length—corresponding to a color in the spectrum—is determined by its size. Syn.: fluorescent semiconductor nanocrystal, luminescent nanocrystal, luminescent semiconductor nanocrystal, fluorescent quantum dot, luminescent quantum dot

Fuel cell – Energy converter in which hydrogen obtained from a fuel is combined with oxygen from the air in an electrochemical process in order to produce electricity

Fullerene – Cage-like molecule comprised of carbon atoms grouped together in a structure consisting of pentagons and hexagons

Gene therapy – The introduction of a functional gene into the cells of an organism for preventive, curative, or diagnostic purposes

Global ecophagy – According to a catastrophic scenario imagined by certain nanotechnology specialists, the uncontrolled self-replication of nanorobots with the potential to destroy all of earth's ecosystems by transforming everything they find into goo. Syn.: ecophagy, gray goo problem, grey goo problem

Gray goo – Blob of material imagined by certain nanotechnology specialists that would result from the uncontrolled self-replication of nanorobots that take over, transform, and destroy the resources of ecosystems. Syn.: grey goo

Green goo – Proliferation of harmful, self-replicating organisms or series of biological disturbances that some nanobiotechnology specialists believe could lead accidentally or through malicious intent to hybrid nanorobots made from living organisms and nonorganic materials

Incidental nanoparticle – Nanoparticle created involuntarily through a human-induced process generally associated with pollution, such as chimney fires, gasoline engine combustion, metal working, or biodegradable products (CEST, according to OQLF)

Lab-on-a-chip – Miniature biological or chemical analysis system consisting of a minuscule glass, plastic, or silicon disk engraved with a number of channels that mechanically route sample fluids to various tanks for molecular analysis. Syn.: LOC, lab-on-chip, laboratory-on-a-chip, laboratory-on-chip, microfluidic chip, micro-total analysis system, micro-TAS, µTAS

Leachable – Said of a material from which one or more soluble components can be extracted using a solvent

Life cycle – Period consisting of all phases in the life of a product, from design and production to decline, including withdrawal from the market, elimination, and environmental release. Syn.: product life cycle, PLC

Lithography – Set of techniques for reproducing the pattern of a structure that is to be manufactured in a resin deposited on the surface of a material

Magnetic force microscopy – Scanning probe microscopy* in which a sample with a magnetized surface is scanned with a probe covered in a magnetic material placed within a few nanometers of it in order to obtain an image based on variations in the magnetic field created among the elements present, which correspond to variations in structure

Magnetic resonance imaging (MRI) – Medical imaging method that uses magnetic resonance to obtain tomographic images of the distribution of atomic elements like hydrogen. Syn.: magnetic resonance tomography, zeugmatography

Metal hydride – Chemical compound resulting from the combination of hydrogen gas with a metal like aluminum or lithium. Syn.: interstitial hydride

Micrometer (μm) – International system (SI) unit for measuring length that corresponds to one millionth of a meter, i.e., 10^{-6} meter

Molecular electronics – Field of electronics that involves the study, design, manufacture, and use of electronic circuits or components assembled from chemical or biological molecules in order to take advantage of their small size and conductive properties. Syn.: moletronics, molectronics

Molecular nanotechnology – The controlled mechanical fabrication of molecular structures through a bottom-up approach that consists of assembling them, step by step and molecule by molecule, using specialized devices capable of causing nanoscale chemical reactions and physical phenomena. Syn.: molecular manufacturing, nanomanufacturing, molecular engineering

Moore's law – Observation that the number of transistors a silicon chip can hold doubles every 18 months, proportionately increasing the processing capacity of the microprocessor it supports

Mucoviscidosis – Autosomal recessive hereditary disease characterized by the hypersecretion of a highly viscous mucus that clogs the ducts of affected organs, possibly predisposing subjects to fatal respiratory infections. Syn.: cystic fibrosis (in Québec)

Multi-walled carbon nanotube – Nanotube consisting of a number of carbon atom sheets wound around themselves to form concentric cylinders. Syn.: multi-wall carbon nanotube, multi-walled nanotube, multi-wall nanotube

Mutagenicity – The ability of a biological, physical, or chemical agent to cause mutations in the genetic material of cells

Nanobiology – Offshoot of both biology and nanoscience that studies the behavior of elements that are part of living organisms at the nanoscale, and that uses these organisms or imitates their functions to create new materials or devices with particular properties. Syn.: nanobioscience, bionanoscience

Nanobiotechnology – Field that applies nanotechnology to develop tools for manipulating or studying living organisms, or that uses these organisms or simply emulates their functions to create new nanoscale materials or devices with particular properties

Nanocomposite material – Material with two or more distinct phases*, at least one of which involves elements with a dimension between 1 and 100 nanometers. Syn.: nanocomposite, NC

Nano-divide – Division expected to occur in the near future between groups of individuals, societies, countries, or geographic groups in the acquisition of knowledge and the use of new techniques in areas tied to nanoscience and nanotechnology development

Nanoelectronics – Field arising mainly from nanotechnology and electronics research that involves the study, design, fabrication, and use of circuits or electronic components assembled from nanosize elements at the atomic and molecular level for their particular physical properties

Nanofabrication – Fabrication of structures containing at least one nanosize element with dimensions between 1 and 100 nanometers

Nanofilm – Film less than 100 nanometers thick used mainly, because of its size, to impart particular properties to the material on which it is deposited or in which it is integrated. Syn.: nanoscale film, ultrathin film, nanolayer

Nanolithography – Set of techniques for reproducing the pattern of a molecular structure on the surface of a material at the nanoscale. Syn.: nanoscale lithography

Nanomachine – Assemblage of molecules in which certain nanosize elements are set in motion when they receive an external signal

Nanomaterial – Material comprised of particles with at least one dimension between 1 and 100 nanometers that impart particular properties at the nanoscale

Nanomaterials – Field of nanotechnology that involves the study and fabrication of materials comprised of particles with at least one dimension between 1 and 100 nanometers that impart particular properties at the nanoscale

Nanometer (nm) – International system (SI) unit for measuring length that corresponds to 10^{-9} meter, i.e., one billionth of a meter

Nanometrology – Field of metrology that studies the measurement of nanometric structures and physical phenomena occurring at the nanoscale, and also deals with the measuring devices used to evaluate quantities

Nano-object – Assemblage of atoms or molecules with at least one dimension less than 100 nanometers that forms a unit with well-defined properties that can be used for a specific purpose. Syn.: nanometric object

Nanoparticle – Particle of matter formed of atoms and molecules with one or more dimensions measuring between 1 and 100 nanometers and particular physicochemical properties. Syn.: nanometric particle, nanosize particle, nanosized particle, nanoscale particle

Nanopowder – Powder generally consisting of metal, alloy, ceramic, or composite nanoparticles with a diameter less than 100 nanometers. Syn.: nanometric powder, nanosize powder, nanosized power, nanoscale powder

Nanorobot – Nanomachine created to accurately perform a specific task or a series of repetitive tasks. Syn.: nanobot, nanoscale robot

Nanoscale – Measurement scale between 1 and 100 nanometers that is used to calculate the dimensions of extremely small structures found at the molecular level. Syn.: nanometer scale, nanometric scale, nanoscopic scale

Nanoscience – The scientific study at the atomic and molecular scale of molecular structures with at least one dimension measuring between 1 and 100 nanometers, in order to understand their particular physicochemical properties and identify ways to manufacture, manipulate, and control them

Nanostructured – Object whose structure includes at least one nanoscale dimension between 1 and 100 nanometers

Nanostructured material – Material whose structure includes at least one nanoscale dimension between 1 and 100 nanometers. Syn.: nanostructure material

Nanotechnology – Multidisciplinary field that deals with the design and fabrication of molecular structures at the atomic and molecular scale that have at least one dimension measuring between 1 and 100 nanometers, possess particular exploitable physicochemical properties, and can be manipulated and controlled

Nanotube – Hollow, closed cylindrical molecular structure only a few nanometers in diameter

Nanowire – Wire, generally made of metal or ceramic, with a diameter or width not exceeding several dozen nanometers. Syn.: nanometric wire

Natural nanoparticle – Nanoparticle created by a natural process (volcanic ash, forest fires, etc.) (CEST, according to OQLF)

Neuroprosthesis – Device designed to restore a nerve connection generally tied to a motor function by enabling the electronic devices it contains to exchange signals with a neural network

Optoelectronics – Branch of electronics that deals with the conversion of electrical signals into optical signals and vice versa. Syn.: optronics

Phase – Part of a physicochemical system that is homogenous in composition and physical state, and separated from other parts by an interface

Photolithography – Technique for reproducing the pattern of a micrometric structure in a resin deposited on the surface of a material using a light beam as a printing tool. Syn.: optical lithography, photo-lithography

Polymer – Substance consisting of a large number of small, identical or different lightweight molecular structures that bind together in a chain or network to create molecules with a higher molecular weight

Positional assembly – Technique for assembling molecular structures in which atoms and molecules are gradually positioned where required to form the desired whole, according to a process determined in advance. Syn.: positional synthesis

Quantum dot – Semiconducting nanometric structure that results when electron movement is confined in the three dimensions of space. Syn.: QD, Qdot, Q-dot, quantum box, nanocrystal, nanodot, artificial atom

Quantum effect – Particular phenomenon that occurs or unique property acquired by a structure of matter in the gradual shift from the macroscopic scale to the atomic and molecular scale, where the laws of quantum physics prevail

Quantum physics – Branch of modern physics that seeks to explain a number of phenomena tied to matter function through the existence and behavior of quanta—fundamental energy particles detectable only at the microscopic scale. Syn.: quantum mechanics, quantum theory

Quantum well – Two-dimensional nanometric structure that results when electron movement is confined in a single dimension of space

Scanning probe microscope – Microscope able to investigate a physical unit at the atomic and molecular scale by scanning the surface of a sample with a probe placed within a few nanometers of it in order to create a digital image of the data using a computer. Syn.: local probe microscope

Scanning probe microscopy (SPM) – Technique for investigating a physical unit at the atomic and molecular scale that consists of scanning the surface of a sample with a probe placed within a few nanometers of it in order to create a digital image of the data using a computer. Syn.: near-field microscopy, local probe microscopy

Scanning tunnel microscopy (STM) – Scanning probe microscopy* in which a sample is imaged at the atomic and molecular scale by scanning its surface with a probe placed within a few nanometers of it that, through a tunnel effect, creates a beam of electrons that is used to measure dimensional variations in structure or manipulate particles of matter. Syn.: scanning tunneling microscopy, scanning tunnelling microscopy, scanning tunneling electron microscopy, scanning tunnelling electron microscopy

Scanning tunneling microscope – Scanning probe microscope able to image a sample at the atomic and molecular scale by scanning its surface with a probe placed within a few nanometers of it that, through a tunnel effect, creates a beam of electrons that is used to measure dimensional variations in structure or manipulate particles of matter. Syn.: scanning tunnelling microscope

Self-assembly – Assembly technique in which atoms and molecules placed under particular conditions spontaneously join together to form a structure, without outside intervention

Self-organization – Process by which the atoms and molecules in a structure organize themselves differently when placed under certain conditions, with no outside intervention, spontaneously creating a new arrangement with unique properties

Self-replication – Process by which a nanomachine or nanorobot produces copies of itself using materials present in its environment. Syn.: self-reproduction

Sensor – Part of a measuring device used to record size-related data

Single-walled carbon nanotube – Nanotube consisting of a single carbon atom sheet wound around itself. Syn.: single-wall carbon nanotube, single-walled nanotube, single-wall nanotube

Smart – Said of any apparatus, machine, system, device, or object that has the electronic or computer resources required to independently process the data it collects or is sent, and to use the information to control its actions

Smart dust – Set of chips with interlinked microsize or nanosize components that form a wireless network in which they can exchange the data they collect, process, and transmit, as applicable, to a central unit when they are released into the air like particles of dust or spread in materials

Solar paint – Flexible material consisting of nanosize solar cells that can be spread like paint on a surface and that converts solar energy into electric energy. Syn.: photovoltaic paint

Specific surface – Total dimension of the surface of a body in relation to its mass or volume. Syn.: specific surface area, mass surface

Tissue engineering – Set of techniques that draw on the principles and methods of engineering and the life sciences in order to understand the relationship between the structures and functions of normal and pathological tissues in mammals, and to develop biological substitutes for restoring, maintaining, or improving tissue function. Syn.: organogenesis

Top-down approach – Method for manufacturing nanometric components that consists of gradually reducing the size of an existing material by cutting or sculpting it until it has the desired dimensions and characteristics. Syn.: top-down, top down approach

Tunnel effect – Quantum phenomenon that occurs when a particle of matter like an electron crosses an energy zone opposite to it even though it lacks the energy to break the barrier according to the laws of conventional physics. Syn.: tunneling effect, tunnelling effect, tunneling, tunnelling, quantum tunneling, quantum tunnelling

Ultrafine particle – Particle in suspension in the air with an aerodynamic diameter measuring between 1 and 100 nanometers. Abbr.: UFP

X-ray lithography – Lithographic technique that uses X-rays with a wavelength between 0.5 and 5 nanometers to reproduce the pattern of a nanometric structure in a sensitive resin toward which they are directed through a mask. Syn.: XRL, X-lithography

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Recommended Sites for Current Information on Nanotechnology Research & Development*

QUÉBEC

NanoQuébec

NanoQuébec seeks to strengthen nanotechnology innovation in order to increase sustainable economic development in Québec and Canada.
http://www.nanoquebec.ca/nanoquebec_w/site/explorateur.jsp?currentlySelectedSection=72

Nanotechnologies in Québec and Worldwide

Section on the website of Ministère du Développement économique, de l'Innovation et de l'Exportation du Québec.
http://www.mdeie.gouv.qc.ca/page/web/portail/en/scienceTechnologie/nav/technologies_strategiques/42648.html?iddoc=42648

Institut de recherche Robert-Sauvé en santé et en sécurité au travail (IRSST)

Scientific research organization that aims to contribute to the prevention of industrial accidents and occupational diseases, as well as the rehabilitation of affected workers.
http://www.irsst.qc.ca/en/home.html

CANADA

National Institute for Nanotechnology

Integrated, multidisciplinary institution that brings together researchers working at the nanoscale—the world of individual atoms and molecules—in physics, chemistry, engineering, biology, informatics, pharmacy, and medicine. Established in 2001, the Institute is operated as a partnership between the National Research Council and the University of Alberta. (website under development)
http://nint-innt.nrc-cnrc.gc.ca/home/index_e.html

NSERC Nano Innovation Platform (NanoIP)

The objective of the NSERC NanoIP, a multidisciplinary national network of university researchers in many fields of science and technology, is to accelerate and intensify research and the education of highly qualified nanoscience and nanotechnology personnel in Canada.
http://www.physics.mcgill.ca/NSERCnanoIP/e/#welcome

NanoForum Canada

Website of the annual Canada Nanoscience & Nanotechnology Forum.
http://www.uofaweb.ualberta.ca/nanoforum/

ETC Group: Action Group on Erosion, Technology, and Concentration

Interest group that supports socially responsible development of technologies and addresses international governance and corporate power issues.
http://www.etcgroup.org/en/issues/nanotechnology.html

* Commission de l'éthique de la science et de la technologie does not claim this is an exhaustive list, nor can it vouch for the quality of the information available on these sites. Furthermore, it wishes to indicate that readers interested in staying up-to-date on nanotechnology news can subscribe to an e-newsletter on a number of sites.

UNITED STATES

National Nanotechnology Initiative
U.S. government R&D program that coordinates multiagency efforts in nanoscale science, engineering, and technology.
http://www.nano.gov/

Nanotechnology at NIOSH (National Institute for Occupational Safety and Health)
Section on nanotechnology on the website of the U.S. Institute for Occupational Safety and Health.
http://www.cdc.gov/niosh/topics/nanotech/

Center for Biological and Environmental Nanotechnology (CBEN)
Although most CBEN research activities at Rice University are focused on bioengineering, environmental engineering, and basic research, the Center also addresses the health, environmental, and societal impacts of nanotechnology and offers educational materials.
http://www.ruf.rice.edu/%7Ecben/

Nano Science and Technology Studies, Societal and Ethical Implications
A multidisciplinary group of researchers at the University of South Carolina who pursue scholarly research and education about the societal, epistemological, and ethical dimensions of nanotechnology.
http://nsts.nano.sc.edu/

Nanotechnology Consumer Product Inventory
An inventory created by the Woodrow Wilson International Center for Scholars that provides up-to-date information on nanotechnology-derived consumer products currently on the market.
http://www.nanotechproject.org/index.php?id=44

Institute for Soldier Nanotechnologies
Interdepartmental research center at the Massachusetts Institute of Technology (MIT) aimed at using nanotechnology to dramatically improve the survival of soldiers.
http://web.mit.edu/isn/

Center on Nanotechnology and Society
Research center at the Illinois Institute of Technology created to catalyze interdisciplinary research, education, and dialog on the ethical, legal, policy, business, and societal implications of nanotechnology—with a special focus on the human condition.
http://www.nano-and-society.org/

Nanotechnology Industries
Site aimed at providing nanotechnology information and resources in order to promote research, communication, and innovation.
http://nanoindustries.com/links/

Foresight Nanotech Institute
Nonprofit organization aimed at informing and preparing the public for the introduction of nanotechnology and its expected impacts.
http://www.foresight.org/

EUROPE AND INTERNATIONAL

Nanotechnology Homepage of the European Commission
Overview of nanotechnology-related activities at the European Commission.
http://www.cordis.lu/nanotechnology/

Portail NanoSciences NanoTechnologies
Portal presenting descriptions of nanotechnology-related activities and projects currently underway in France, as well as the means that have been put in place to support them.
http://www.nanomicro.recherche.gouv.fr/

Nanotechnology and Nanoscience
Site created in the wake of publication in Great Britain of the joint report on nanotechnology by the Royal Society and the Royal Academy of Engineering; includes a discussion forum.
http://www.nanotec.org.uk/

International Risk Governance Council (IRGC)
Independent Swiss foundation aimed at helping improve the anticipation and governance of global, systemic risks; a section of the website is devoted to nanotechnology.
http://www.irgc.org/irgc/projects/nanotechnology/

Nanoforum.org: European Nanotechnology Gateway
Network aimed at providing information on European nanotechnology efforts and support to the European nanotechnology community.
http://www.nanoforum.org/

Center for Responsible Nanotechnology (CRN)
CRN's mission includes raising awareness of the benefits, dangers, and responsible use of nanotechnology.
http://www.crnano.org/

Nano Ethics
Independent organization that studies the ethical and societal implications of nanotechnology.
http://www.nanoethics.org/

Meridian Institute
Organization aimed at helping decision makers solve some of society's most contentious public policy issues, including those related to nanotechnology.
http://www.merid.org/projects.php#Nanotechnology

International Council on Nanotechnology
Database of scientific documentation on the environmental and health risks of nanotechnology.
http://icon.rice.edu/research.cfm

Journal of Nanobiotechnology
Online journal that publishes scientific articles in the medical, biological, and nanoscale sciences.
http://www.jnanobiotechnology.com/home

Nanotechnology News

AzoNano
http://www.azonano.com/

International Small Technology Network
http://www.nanotechnology.com

Nano Science and Technology Institute
http://www.nsti.org/news

Nanotechnology Now
http://www.nanotech-now.com/

Nanotechweb.org
http://www.nanotechweb.org/

Nanotechwire.com
http://www.nanotechwire.com

NanoTsunami
http://www.voyle.net/

Observatoire des Micro et Nanotechnologies
http://www.omnt.fr/

Smalltimes
http://www.smalltimes.com

APPENDIX 1

A few examples of nanotechnology applications

Automotive and aeronautics industries: nanoparticle-reinforced materials for lighter bodies, nanoparticle-reinforced tires that wear better and are recyclable, external painting and windows that do not need cleaning, cheap non-flammable plastics, self-repairing, wrinkle-free and stain-resistant textiles and coatings, catalysts.

Electronics and communications industries: all-media recording using nanolayers and dots, flat panel displays, wireless technology, sensors, new devices and processes across the entire range of communication and information technologies, factors of thousands to millions improvements in both data storage capacity and processing speeds – and at lower cost and improved power efficiency.

Chemicals and material industries: catalysts that increase the energy efficiency of chemical plants and improve the combustion efficiency (thus lowering pollution emission) of motor vehicles, super-hard and tough drill bits and cutting tools, "smart" magnetic fluids for vacuum seals and lubricants, filters for molecule separation.

Pharmaceutical, biotechnology and healthcare industries: new nanostructured drugs, drug delivery systems targeted to specific sites in the human body, biocompatible replacements for human body parts and fluids, self-diagnostic tests for home use, sensors for labs-on-a-chip, material for bone and tissue regeneration, cosmetic products.

Manufacturing : precision engineering based on new generations of microscopes measuring techniques, new processes and tools to manipulate matter at the atomic level, nanopowders that are sintered into bulk materials with special properties that may include sensors to detect incipient failures and actuators to repair problems, self-assembling of structures from molecules, bio-inspired materials and biostructures.

Energy technologies: new types of batteries, artificial photosynthesis for clean energy, safe storage of hydrogen for use as a clean fuel, energy savings from using lighter materials and smaller circuits, nanostructured coverings, fuel cells, solar cells, catalysts.

Space exploration: lightweight space vehicles, economic energy generation and management, ultra-small and capable robotic systems.

Environment : selective membranes that can filter contaminants or even salt from water, nanostructured traps for removing pollutants from industrial effluents, characterization of the effects of nanostructures on the environment, significant reductions in materials and energy use, reduced sources of pollution, increased possibilities for recycling.

National security: detectors and detoxifiers of chemical and biological agents, dramatically more capable electronic circuits, hard nanostructured materials and coatings, light and self-repairing textiles, blood replacement, miniaturized surveillance systems, new types of weapons.

National Science and Technology Council*

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* NATIONAL SCIENCE AND TECHNOLOGY COUNCIL (United States), *Nanotechnology Research Directions: IWGN Workshop Report*, September 1999 [online] http://www.wtec.org/loyola/nano/IWGN.Research.Directions/IWGN_rd.pdf. The Commission reproduces this document here with a few minor modifications.

APPENDIX 2

Summary of applications areas for nanotechnology*

INFORMATION TECHNOLOGY SECTOR

Material / technique	Applications	Time-scale (to market launch)
Pre-2015		
Quantum well* structures	Telecommunications / optics industry. Potentially very important applications in laser development for the data communications sector.	Quantum well lasers already used in CD players. Not yet optimized for the communications markets (4-6 years).
Quantum dot structures	Use of fiber optic communications in building computers.	Quantum dots still in research stage (7-8 years).
Photonic crystal technologies	Optical communication sector, i.e. fiber optics. Photonic integrated circuits can be nearly a thousand times denser than electronic circuits. Their tighter confinement and novel dispersion properties also open up opportunities for very low power devices.	Still in basic R&D, but very strong commercial interest emerging.
Carbon nanotubes in nanoelectronics	Memory and storage: commercial prototypes RAM, display technologies and *E-paper*.	Consumer flat screens available. Commercial prototypes of RAM. Commercialization of E-paper in near future.
Spintronics: the use of electron spin for significantly enhanced electronics	Ultra-high capacity disk drives and computer memories.	Read head has been demonstrated.
Polymers	Display technologies (screens).	Commercialization underway.
Post-2015		
Molecular electronics (including DNA computing)	Circuits based on single molecule and single electron transistors.	Single-electron transistor demonstrated. Still immature but huge potential.
Quantum information processing	Use of quantum physics to process data using quantum computers.	Still in pure research phase.

PHARMACEUTICAL AND MEDICAL SECTOR

Material / technique	Property	Applications	Time-scale (to market launch)
Diagnostics			
Nanosized markers	Minute quantities of a substance can be detected, down to individual molecules.	Detection of cancer cells.	Long term.
Lab-on-a-chip	Miniaturization and speeding up of the analytical process.	The creation of miniature, portable diagnostic laboratories for uses in the food, pharmaceutical and chemical industries; in disease prevention and control; and in environmental monitoring.	On the market, but the cost is high.
Quantum dots	Quantum dots can be tracked very precisely when molecules are 'bar coded' by their unique light spectrum.	Diagnosis.	In early stage of development. Commercial interest.

* Taken in part from: Alexander Huw ARNALL, *Future Technologies, Today's Choices. Nanotechnology, Artificial Intelligence and Robotics; A Technical, Political and Institutional Map of Emerging Technologies,* A report for the Greenpeace Environmental Trust, London, July 2003 [online] http://www.greenpeace.org.uk/Multimedia Files/Live/FullReport/5886.pdf.

Material / technique	Property	Applications	Time-scale (to market launch)
Drug delivery			
Nanoparticles (50-100 nm)	Able to penetrate tumor pores.	Cancer treatment.	Long term.
Nanosizing in the range of 100-200 nm	Low solubility.	More effective treatment with existing drugs.	Long term.
Polymers	These molecules can be engineered to a high degree of accuracy.	Nanobiological drug carrying devices.	Long term.
Ligands on a nanoparticle surface	These molecules can be engineered to a high degree of accuracy.	Ligands can recognize damaged tissues and target drugs to a precise location.	Long term.
Nanocapsules	Evading body's immune system while directing a therapeutic agent to the desired site.	AIDS and cancer treatment.	Early clinical trials using Buckyballs in AIDS treatment.
Increased particle adhesion	Degree of localized drug retention increased.	Slow drug release.	Long term.
Nanoporous materials	Evading body's immune system while directing a therapeutic agent to the desired site.	Drug-delivering implants could be developed.	Pre-clinical trials for treatment of diabetes.
Pharmacy-on-a-chip	Monitor conditions and regulate and maintain hormonal balance.	Diabetes treatment.	More distant than lab-on-a-chip technologies.
Nanoporous membranes	Sorting biomolecules.	Gene analysis and sequencing.	Commercialization underway.
Tissue regeneration, growth and repair			
Prosthetics	Miniaturization, weight reduction, increased strength, increased biocompatibility.	Retinal, auditory, spinal and cranial implants.	Most immediate will be external tissue grafts; dental and bone replacements; internal tissue implants to follow.
Cellular manipulation	Manipulation and coercion of cellular systems.	Persuasion of lost tissue to grow, growth of body parts.	6-7 years.

ENERGY PROCESSING SECTOR

Material / technique	Applications	Time-scale (to market launch)
Power generation		
Polymer materials	Solar cells.	5 years.
Combinations of organic and inorganic molecules	Solar cells. Photocatalytic water treatment. Manufacturing process could be very low cost.	Commercialization underway, but limited. Low energy consumption applications to enter the market first.
Quantum wells	Quantum well solar cells. The absorption of a large part of the solar spectrum would increase the efficiency of solar cells.	Pure research.
Nanorods	These structures can be engineered to respond to different wavelengths of solar spectrum. Low cost solar cells.	Long term.
Fuel conversion / storage		
Nanostructured catalysts	Fuel conversion.	Current – 5 years.
Nanotubes	Fuel storage: hydrogen, methane for fuel cells.	2-5 years.
Nanoparticles	Improving battery capacity.	Long term.
Nanostructured metallic hydrides	Storing hydrogen for fuel cells.	1-5 years

APPENDIX 3

Proposed taxonomy of the major issues likely to face nanotechnology in research, development and commercialization in Canada*

I. Public Perception and Public Engagement

- What is the nature and source of public perception about nanotechnology in Canada and abroad?
- What is the nature and impact of popular representations of nanotechnology?
- What should the role of scientists be in the broad public debate about nanotechnology?
- What communication and public engagement strategies are needed to foster an authentic debate about the risks and benefits of nanotechnology?

II. Regulatory Issues

- What are the effects of nanoparticles and nanomaterials on the environment and on humans?
- What ought the role of the "precautionary principle" be in the regulation of nanomaterials and nanotechnology?
- Given their unique properties, can nanomaterials be appropriately regulated under existing regulatory regimes?
- If legislative and/or regulatory and policy reform is deemed necessary in the context of nanotechnology, unprecedented cooperation between various levels of government and various agencies within those levels of government will be needed. How can government best ensure that the regulatory framework encompassing nanotechnology will be logical, efficient, transparent and readily adaptable to technological change?

III. Economic and Commercialization Issues

A. General Commercialization Issues

- What will the economic impact of nanotechnology be? How will the economic effects of nanotechnology commercialization impact the various economic sectors?
- If nanotechnology is a disruptive technology*, what methods can we use to evaluate its impact on the economy?
- In what ways, if any, will the commercialization of nanotechnology differ from the commercialization of other technologies? Will there be unique opportunities for conflicts of interest to arise?

B. Intellectual Property Issues

- What are the intellectual property issues that will arise in the area of nanotechnology? Will the issues be different from those encountered with other emerging technologies?
- Will the accrual and exploitation of intellectual property as part of the commercial process create unique challenges to the commercialization of nanotechnology?

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* Lorraine SHEREMETA and Abdallah S. DAAR, « The Case for Publicily Funded Research on the Ethical, Environmental, Economic, Legal and Social Issues Raised by Nanoscience and Nanotechnology (NE^{3}LS) », *Health Law Review*, vol. 12, No. 3, 2004, p. 75-76.

IV. Equity and Global Governance Issues

- What will the impact of nanotechnology be on the developing world and on disadvantaged communities in Canada?
- How can we ensure that the fruits of nanotechnology are shared equitably by people in developing countries and by marginalized communities in Canada- and avoid the creation of a "nanodivide"?
- Is there a role for benefit-sharing in the context of nanotech commercialization?

V. Philosophical and Ethical Issues

- What are the larger philosophical issues that need to be addressed in relation to nanotechnology?
- What will the impact of nanotechnology be on the perception and definition of normalcy, health and disease?
- How, and in what areas, will nanoscience and nanotechnology challenge the traditionally conceived concepts of privacy and confidentiality?

VI. Application-Specific Issues

- What are the anticipated military uses of nanotechnology? How should they be regulated?
- What are the potential applications of nanotechnology in medicine? How will they challenge the existing ethical, legal and social frameworks?

The Consultation and Information Activities of the Commission

Experts who made presentations to the working committee

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André Van Neste, Vice President, Technology, and cofounder of Nanox (Sainte-Foy, Québec)

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The Commission thanks all these people for their contribution to developing and enhancing the content of its position statement.

Participation at various events

- NanoQuébec Forum, May 26, 2005, Montréal: *Using Nanotechnology to Meet the Needs of Industry and Society*
  Presentation by CEST president in the panel on responsible development of the industry: “Éthique, nanoscience, nanotechnologies”

- NanoForum 2005, June 15, 2005, McGill University (Montréal)

- ACFAS annual conference, NanoQuébec symposium, May 16, 2006, McGill University (Montréal): *Les nanotechnologies : formation et éthique*
  Presentation by working committee chair: “Bilan des travaux de la CEST sur les enjeux éthiques des nanotechnologies”

- Fourth Annual Nanomedicine Meeting, June 19–20, 2006, University of Alberta (Edmonton)

- NanoForum Canada: 3rd Canada Nanoscience & Nanotechnology Forum, June 20–22, 2006, University of Alberta (Edmonton)
  Presentation by the working committee secretary: “Responsible Development of Nanotechnology: A Perspective from Québec’s Commission de l’éthique de la science et de la technologie”

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* When the present position statement was adopted.

Nanotechnology arises from the convergence of basic research in physics, chemistry and biology, and is often considered one of the most promising technologies for the future of humanity. Nanotechnology is innovative in character. It is currently moving from the laboratory to industrial manufacturing and marketing. Significant public and private investments are going into development and promotion, and the anticipated benefits are considerable. For all of these reasons, the Commission has decided to explore nanotechnology from an ethical perspective.

Ethics and Nanotechnology: A Basis for Action is the fourth position statement issued by Commission de l'éthique de la science et de la technologie. It consists of three chapters devoted to the scientific, legal and ethical implications of nanotechnology. In its ethical assessment of nanotechnology, the Commission is upholding the protection of health and the environment, as well as respect for many values such as dignity, liberty, the integrity of the person, respect for the person, quality of life, respect for privacy, justice and equity, transparency and democracy.

This position statement is available at **http://www.ethique.gouv.qc.ca**.

Images 1 and 2 on the cover page are illustrations of nanostructured surfaces obtained by using nanolithographic printing techniques. This technology makes it possible to manufacture inexpensive miniature devices that could notably be used to produce biological sensors or transistors. Source: Bo CUI, Industrial Materials Institute (NRC, Boucherville). The third image is an illustration of carbon nanotubes 50 nm in diameter. The small dots on the surface of the nanotubes are nanostructured platimum catalysts on the nm scale. These nanomaterials could be used to produce pollution-free fuel cells. Source: Jean-Pol DODELET and Marco BLOUIN, INRS Énergie, matériaux et télécommunications (Varennes).

The mission of CEST consists, on one hand, of informing, raising awareness, gathering opinions, fostering reflection, and organizing debates on the ethical issues raised by developments in science and technology and, on the other hand, of proposing general guidelines for stakeholders to refer to in their decision making.

Québec