Commission de l'éthique de la science et de la technologie
Québec

POSITION STATEMENT

ETHICS AND NANOTECHNOLOGY: A BASIS FOR ACTION

Summary, Recommendations and Commentaries

NOVEMBER 2006

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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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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 nanotechnologies.

A NEW AND EMERGING WORLD: THE UNIVERSE OF NANOTECHNOLOGIES

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 applications. Much like electricity and electronics before them, nanoscience and nanotechnologies 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 nanotechnologies fulfill current expectations, they 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 nanotechnologies or from their convergence with other disciplines.

LOOKING AT METHODS FOR MANAGING THE SECTOR

In terms of 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 nanotechnologies. 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 nanotechnologies. 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 nanotechnologies and the marketing of nanometric products or components are well underway and will surely intensify in years to come. In this context, the Commission urges vigilance and attentive monitoring of the evolution of these new technologies 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 the 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 the development of nanotechnologies to encourage the research and industrial communities in this sector of activity to adhere to the practices recommended in this guide, and to support the promotion and further elaboration of the guide. The Commission seeks to avoid any undesirable impacts of nanotechnologies on occupational health and on the environment, and judges 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 nanotechnologies, 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 Gouvernement du Québec, guided by the principle of precaution and from the perspective of sustainable development, should be concerned with all phases of the life cycle of a product derived from nanotechnologies 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.

NANOTECHNOLOGIES: ETHICAL CONCERNS

Fundamental Requirements at the Outset

Nanotechnologies are 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

A first observation to be made about nanotechnologies is that there is a flagrant lack of information about what they are. If there is no common understanding of what nanotechnologies are how can informed decisions be taken by legislators, researchers, business people, workers or citizens? The Commission notes that responsible management of nanotechnology development relies on three premises: establishing common scientific terminology and nomenclature, establishing procedures and standards, and pursuing research and disseminating research findings.

Ethical Concerns Related to Nanotechnology-Derived Products

Health and Safety

Occupational safety. 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."[1]

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 nanotechnologies. **While waiting for further research and more complete regulations that are better adapted to the specific characteristics of nanotechnologies, 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 nanotechnologies 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 nanotechnologies 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.

[1] 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 et al., Report R-470, studies and research projects, Gouvernement du Québec, September 2006, p. iii [online] http://www.irsst.qc.ca/en/_publicationirsst_100210.html.

Recommendation No. 2

The Commission recommends:

That the Ministre du Développement économique, de l'Innovation et de l'Exportation, together with the Ministre de la Santé et des Services sociaux, intercede with the federal government so that health and environmental monitoring agencies establish the mechanisms needed to assess the toxicity of processes and products derived from nanotechnologies prior to authorizing their commercialization.

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 nanotechnologies will contribute to protecting human health and safety and will contribute to sustainable development in this sector of activity.**

Applications in the health sector: 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 Ministre de la Santé et des Services sociaux ensures that research ethics boards are adequately equipped and supported in their assessment of research protocols relating to the use in the health sector of materials and processes derived from nanotechnologies.

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, nanotechnologies 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 nanotechnologies. 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 exercising precaution in the process of creating and developing medications and therapies with nanotechnology components. This precautionary approach encourages the pursuit of research and the documenting of potentially positive and negative effects of nanotechnology applications in the health sector, in order to make a better assessment of outcomes for patients and for the management of the health system in general.

The Environment

Nanotechnologies could have many positive impacts on the environment, thereby contributing to sustainable development. The potential benefits of nanotechnologies 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 nanotechnologies, 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 nanotechnologies 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 Ministre du Développement économique, de l'Innovation et de l'Exportation, together with the Ministre du Développement durable, de l'Environnement et des Parcs as well as various other interested parties, put in place a monitoring system with respect to the potential effects of nanotechnologies on the environment, whenever these effects cannot be calculated and taken into consideration prior to the commercialization of products derived from nanotechnologies;**

- **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. Nanotechnologies offer 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 nanotechnologies.**

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 nanotechnologies increase and facilitate current capabilities in this regard and open 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 of Disciplines

The convergence of nanotechnologies 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 human enhancement. Nanotechnologies 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 nanotechnologies 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. Nanotechnologies 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 nanotechnologies so that they benefit 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 Restricted to Nanotechnologies

The development of nanotechnologies gives rise to ethical questions about their effect on society and the environment and the use made of these technologies in other domains. However, as the Commission has observed, nanotechnologies raise 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 Ministre du Développement économique, de l'Innovation et de l'Exportation, together with other ministries and interested parties, launch a process of information and consultation with the public, in order to define in all transparency the scientific, economic and ethical issues associated with the development of nanotechnologies.

Methods for managing and accountability practices. The Commission recognizes that the normative framework of nanotechnologies 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 nanotechnologies 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 nanotechnologies and capable of responding to ethical concerns raised by these technologies.**

Recommendation No. 6

The Commission recommends:

That the Ministre du Développement économique, de l'Innovation et de l'Exportation call on the granting agencies, together with different interested parties, to create a program of multidisciplinary research on the impacts of new technologies and on the management of risk associated with nanotechnologies, that will take into account ethical and social aspects.

Concerns Related to Economic Activity

Ethical choices in the development of Québec economic activity associated with nanotechnologies. 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 nanotechnologies, 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 Ministre du Développement économique, de l'Innovation et de l'Exportation, once Québec's nanotechnology development strategy has been drawn up, take into account the ethical and social questions raised by these technologies, particularly where the employment and workforce training are concerned.

The nanotechnological 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, such as creating nanotechnology research partnerships, organizing exchanges of students and professors between universities, and establishing funding programs with the specific goal of responding to the needs of developing countries with respect to nanotechnologies.

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 the support of training for researchers and the establishment 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 taken by the NIH raises a number of broader questions: Are research and marketing initiatives based on public-private partnership equitable for Québec? What are the positive and negative effects of such partnerships? Do the potential benefits offset the negative effects? Is it possible to reduce or eliminate the negative effects? Would it be possible to establish incentives for philanthropic activity? In view of these questions, the Commission deems it imperative that serious thought be devoted to the role of protecting intellectual property in a context of innovation and to ethical questions associated with this protection.

Collecting personal information. The convergence of nanotechnologies 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 nanotechnologies, 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 nanotechnologies.**

Recommendation No. 8

The Commission recommends:

That the Gouvernement du Québec follow the example of the Internet portal devoted to 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 nanotechnologies. 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 nanotechnologies in order to identify the ethical issues associated with their emergence. Nanotechnologies relate to all fields of activity, involve diverse applications and have a wide range of possible uses. Moreover, thinking about nanotechnologies 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 nanotechnologies are emerging technologies 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 nanotechnologies and the best way to ensure their harmonious development. That is why the Commission sees the need to continue addressing more focused questions about the responsible management of nanotechnologies that the State could raise, as it will have to make decision regarding this field in the future.

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[2]

[2] 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 NANOTECHNOLOGIES[3]

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.

[3] 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/MultimediaFiles/Live/FullReport/5886.pdf.

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.
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 RESEARCH, DEVELOPMENT AND COMMERCIALIZATION IN CANADA[4]

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?

IV. Equity and Global Governance Issues

- What will the impact of nanotechnology be on the developing world and on disadvantaged communities in Canada?

[4] 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^3LS) », *Health Law Review*, vol. 12, no. 3, 2004,p.75-76.

- 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?

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[5] When the present position statement was adopted.