# Summary

Nanotechnology is the creation and use of materials, instruments, and systems involving matter that measures between 1 and 100 nanometers, i.e., atoms, molecules, and supramolecular structures. A nanometer (nm) is the unit of measure corresponding to one billionth of a meter ($10^{-9}$ meter).

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. As a result, nanotechnology poses a huge scientific challenge. Researchers must be able to control, manipulate, and characterize matter as well as understand how to exploit its properties in order to build new and useful nanostructures.

Nanotechnology is expected to launch a veritable technological revolution since it will enable humans to control matter at the atomic level. With this report, the Conseil de la science et de la technologie aims to establish the position Québec should take in order to participate fully in the revolution ahead.

An examination of the leading areas of world nanotechnology research leads to the following observations :

- The potential for nanomaterial applications is virtually endless and not a single industrial sector will be unaffected by their development. However, despite the increase in research over the past two years, particularly in the promising area of carbon nanotubes, the field is still very much in its infancy.

- In the area of electronics, and especially computers, conventional lithography will soon hit an impenetrable wall. If computer component miniaturization is to proceed any further, a new paradigm will be required for semi-conductor fabrication by 2015 at the latest. However, nanoelectronics research at private companies, public laboratories, and university centers will lead to the discovery of new technologies likely to replace those that exist today.

- In biotechnology, nanomaterials and nanotechnology have already accelerated the pace of research. Interdisciplinary boundaries are growing increasingly fuzzy, particularly with regard to the line between organic and inorganic matter. Microdevices like MEMS, for example, have linked living cells and/or nanoparticles with inorganic matter such as silicone chips. Once-distinct technologies are converging, notably in electronics and biotechnology.

- Instrumentation, notably the latest generation of microscopes, has proven essential to nanotechnology development. Although a certain level of maturity has been reached, new research is still required to develop instruments adapted to specific experimental conditions.

- Lastly, computer simulations are crucial to nanotechnology. They require extremely powerful computers as well as new simulation software.

The report also sketches a rapid portrait of the research underway in the United States, Europe, and Japan. The main findings are as follows :

- In the United States, public funding for nanotechnology has increased dramatically as the government makes it a top priority. Government funding for nanotechnology research comes from a wide variety of sources, including grant agencies such as the National Science Foundation (NSF) and the National Institute of Health (NIH) of course, but also government departments, notably Defense. Many American universities also receive generous support from the central government, private foundations, their own endowment funds, and sometimes even state governments. These funds are used to build large and very well-equipped research facilities.

- Nanotechnology research involves a phenomenal level of scientific convergence. Virtually all U.S. research centers have assembled teams of physicists, chemists, biologists, mathematicians, and computer scientists. They have also intentionally set up shop near universities to foster maximum interaction between research professors and students.

- In 1997, nanotechnology funding in Japan and in Europe as a whole was on par with levels in the United States. However, the Americans have taken the lead since the U.S. government announced its major increase in funding in 2001. Japan is currently developing a strategy to bridge the gap, which means that overall Japanese investment (as a proportion of GDP) will be greater than the U.S. effort in the years ahead. As for Europe, nanotechnology funding under its 6th framework program will increase moderately by 13%.

- European and Japanese research is highly diverse and often equal or superior in quality to that conducted in the United States. Research centers are outfitted with the latest equipment and provide researchers with extensive staff support (e.g., specialized technicians).

- Neither Europe nor Japan possesses a research center exclusively dedicated to nanotechnology. Most research is conducted in centers that specialize in materials or electronics, given the similarity of requirements in terms of expertise and equipment. Even in the United States, centers specialized exclusively in nanotechnology remain rare.

Whereas the United States, Japan, and most countries in Europe have made nanotechnology research a priority, Canada and Québec lag far behind.

In Canada, only two National Research Council of Canada (NRC) research institutes are currently active in nanotechnology. However, NRC is apparently planning a specialized nanotechnology institute in Alberta. Québec's universities need to pick up the pace in the coming years if they are to avoid falling too far behind. The creation of Nano-Québec, which was announced as part of the project submitted to VRQ, represents a turning point that should result in short-term funding that allows universities to step up their efforts. Nano-Québec will also encourage cooperation and networking among Québec's leading nanotechnology researchers. However, the province remains vulnerable and will require significant investments from both levels of government.

The stakes are high. They include ensuring that Québec contributes to the scientific literature, building a critical mass of top-quality researchers in all disciplines affected by nanotechnology, maximizing synergy between researchers and research centers, providing those same researchers with the equipment they need, and lastly, attracting students and training a world-class labor force to enrich the talent pool and achieve necessary critical mass. These challenges are even more daunting because they are closely interrelated. Given the major infrastructure requirements, there is no room for half measures.

Québec, however, already has a number of valuable assets :

1) Some 60 researchers are active in nanotechnology at Québec universities, the equivalent of about 30 full-time specialists.

2) In April 2001, the Board of Directors of Valorisation-Recherche Québec decided to cover the following nanotechnology expenses until 2004 : new equipment operating and maintenance costs, funding for post-graduate fellowships, and the networking of researchers at the Québec and international levels.

3) The five universities involved have agreed to draw up a joint research program under the auspices of a management organization and recruit 54 new professors. This agreement is key to rapid, coordinated development in the sector.

**Recommendations**

The Conseil de la science et de la technologie recommends establishing a critical mass of researchers in a truly integrated, Québec-wide research network, acquiring the necessary physical infrastructures, and securing the support of the federal government, which must contribute to this major endeavor.

The establishment of a minimum critical mass of permanent researchers working in cooperation with associate and guest researchers, postgraduate fellows, and students is crucial to the deployment of the nanotechnology sector. This objective should be met so long as the universities are able to follow through on their commitment.

## Recommendation 1

**That universities and governments take all necessary steps to recruit and encourage the hiring of 54 research professors specialized in nanotechnology as provided for in the plan submitted to VRQ**

Given that nanotechnology is a multidisciplinary field by nature, university research teams must network within their respective institutions, as well as with other universities and government laboratories. Effective networking requires a permanently staffed organization responsible for coordination, planning, and monitoring. Nano-Québec meets this need. It also offers the triple advantage of providing international visibility for future research, maximizing interaction with centers elsewhere in Canada and worldwide, and attracting students, trainees, and guest researchers to the network.-

## Recommendation 2

**That university department heads, deans, and research directors take the steps necessary to stimulate interaction between researchers and students in the nanotechnology field**

With the support of its members, Nano-Québec is the ideal organization for promoting the network among Québec and federal government officials. Nano-Québec will be responsible for structuring Québec research around on a joint program, encouraging networking by researchers at universities and government laboratories, establishing links with leading foreign networks, and promoting nanotechnology research in industry as well as among youth and the general public.

## Recommendation 3

**That universities and the Québec government provide concrete support for the creation of Nano-Québec**

The Council affirms that there is a fundamental and pressing need for a world-class interuniversity nanotechnology institute in Québec. The institute should be based in Montréal, with branches in Québec City and Sherbrooke. To be successful, the institute will require the type of facilities and support available to similar institutes elsewhere. Moreover, the Council suggests that the institute also serve the microtechnology sector. A number of microtechnology techniques, both in the electronics and MEMS field, require the same kind of equipment as nanotechnology

The institute could be run by Nano-Québec.

Construction costs for such an institute should be about $100 million, one third for the building and two thirds for equipment. The institute would be similar in size to major centers in the United States. Consultations held in Québec for the purpose of preparing this report confirm that the figure is realistic.

The Québec government must be the main partner involved in setting up the institute. However, given the scope of the projected investment, a substantial federal government contribution will also be required.

## Recommendation 4

**That the Minister for Research, Science and Technology take responsibility for establishing a major center specialized in nanotechnology and microtechnology within three years**

Universities cannot be the only contributors. All countries investing significantly in nanotechnology have involved public laboratories in their efforts. Canada must be no exception.

The National Research Council of Canada (NRC) has apparently decided to build a nanotechnology institute in Edmonton, Alberta. However, due to the distance involved and the specialization of the Alberta facility, this effort is not sufficient for Québec. NRC labs in Québec must therefore conduct more nanotechnology research.

In addition, the federal government should launch one or more specific programs along the lines of Genome Canada.

## Recommendation 5

**That the Minister for Research, Science and Technology take the necessary steps to secure a substantial federal government contribution for the development of nanotechnology in Québec**