Towards a Nanotechnology Statistical Framework

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Introduction

This document reports on for the Canadian experience in collecting, validating, storing and accessing information on government expenditure on nanotechnology R&D in Canada and the efforts made to date to measure activities in the private sector on nanotechnology. Specific examples in collecting nanotechnology information are included to illustrate many of the challenges facing those interested in statistical measurement of nanotechnology investments. The Canadian experience is provided as an example for a baseline framework for the development of a common statistical framework for the measurement of nanotechnology investments across the OECD.

In 2005 the Office of the National Science Advisor (ONSA) prepared *An Overview of Canadian Nanotechnology Funding* for an International Science Panel's assessment of Canadian research strengths in nanotechnology. This laid the groundwork for further work with both federal and provincial R&D funding agencies, and federal departments to produce a report on Canadian expenditure on nanotechnology R&D. Statistics Canada began to address the systematic measurement of nanotechnology activities in 2003.

Establishing a systematic and consistent process for investments in nanotechnology research will provide key stakeholders, policy analysts and decision makers with a reliable, validated and comparable information base to help inform strategy and policy decision making on the scientific economic, health, environmental and social impacts of nanotechnology. This situation is comparable to the state of statistical knowledge in biotechnology in Canada and internationally in the mid-1980s.

Strategic Context – Nanotechnology and S&T Policy Implications

Over the past decade and in particular since the launch of the US National Nanotechnology Initiative (NNI) in 2000, nanotechnology has emerged as a high profile, emerging, general purpose technology priority among many OECD and Non-OECD nations. According to Lux Research (2006) emerging nanotechnology was incorporated into more than $30 billion in manufactured goods in 2005, double the previous year, with projections of $2.6 trillion in global manufactured goods by 2014. Lux estimates that some $9.6 billion in R&D was invested in nanotechnology world wide; a 10% increase from 2005 and with private sector investments growing at a rate of between 15 and 18% a year.

As an emerging, potentially disruptive, general purpose technology, based on the convergence of knowledge from a wide range of scientific disciplines, nanotechnology presents new challenges to governments. These challenges can be seen both from the perspective of promoting and encouraging new applications and commercial development for economic and industrial competitiveness as well as addressing concerns with respect to non-intended, health, environmental security as well as social, ethical and legal considerations. The creation of a Working Party to the OECD Chemicals Committee on Manufactured Nanomaterials to investigate and disseminate information on the health and environmental *implications* of manufactured nanomaterials and the proposal to create a Working Group to the OECD Science and Technology Policy Committee on the *application* of nanotechnology is a reflection of the complexity and the importance of these issues.

In addition to the growing body of work within the OECD, other multilateral organizations (UNESCO, International Risk Governance Council, ISO) as well as informal ad hoc groups such as the International Dialogue on Responsible Nanotechnology R&D have focused on issues associated with governance, risk management, and policy coordination.

Nanotechnology in Canada

Total government nanotechnology expenditures in Canada (1998-2004)

The primary funder of nanotechnology R&D in Canada is the federal government through its major research funding agencies, the Natural Sciences and Engineering Research Council (NSERC), Canadian Institutes for Health Research (CIHR), the Canada Foundation for Innovation (CFI), and the government's primary intramural R&D performer, National Research Council (NRC). Since CFI funds up to 40% of infrastructure projects, the provinces have provided substantial infrastructure support for nanotechnology through matching funds. The provinces of Alberta, Ontario and Quebec have also provided significant operating funds for nanotechnology R&D. Table 1 provides the estimated funding levels for the main federal, provincial and non-government funding in nanotechnology both in terms of operating and infrastructure investments between 1998 and 2004.

Table 1: Government Operating and Infrastructure Funding for Nanotechnology in Canada

Operating Funds ($M)	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Total**
Natural Sciences and Engineering Research Council - open competitions	4.1	5.8	7.1	8.4	9.9	12.2	18.6	66.1
Natural Sciences and Engineering Research Council - NanoIP						1.0	1.0	2
Canadian Institutes of Health Research		2.2	2.5	2.9	3.3	3.9	6.8	21.6
National Research Council	*	*	*	*	*		14.8	14.8
Natural Resources Canada							1.1	1.1
Defence R&D Canada					1.7	1.8	2.4	5.9
Canada Foundation for Innovation-Infrastructure Operating Fund					1.7	1.9	4.6	8.2
Canada Research Chairs[1]				0.9	2.0	2.8	4.1	9.8
Canadian Institute for Advanced Research	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7
Ontario R&D Challenge Fund		15.7		7.9				23.6
NanoQuebec				3.0	3.0	4.2	2.6	12.8
iCORE				0.5	0.5	1.3	1.3	3.6
Operating Total	**5.1**	**24.7**	**10.6**	**24.6**	**23.1**	**30.1**	**58.3**	**176.5**
Infrastructure Funds ($M)								
Canada Foundation for Innovation	1.9	19.6	46.0	12.6	72.2	11.5	114.2	278
NSERC Research Tools	1.3	1.4	1.3	0.5	0.4	1.6	1.0	7.5
Alberta Science and Research Investment Fund		6.1		40.1	0.2			
Western Economic Diversification						4.5	3.3	7.8
National Research Council[2]				10.0	10.0	10.0	10.0	40
Infrastructure Total	**3.2**	**27.1**	**47.3**	**63.2**	**82.8**	**27.6**	**128.5**	**379.7**
Grand Total	**8.3**	**51.8**	**57.9**	**87.8**	**105.9**	**57.7**	**186.8**	**556.2**

[1] Based on calendar year and start date of Chair

[2] This amount represents cumulative infrastructure investment over the past several years

* indicates data not available

Nanotechnology Funding by Field in Leading Provinces

Figure 1 presents the breakdown of federal operating funds from CIHR and NSERC by field and by province. The majority of federal funding in the leading provinces is going to material development, nanoelectronics/photonics, tools development, and molecular imaging and technology development. Quebec and Ontario have a higher concentration in materials development and nanoelectronics/photonics. Alberta has a noticeably different focus than the other three provinces with more relative emphasis in life sciences and molecular imaging and technology development.

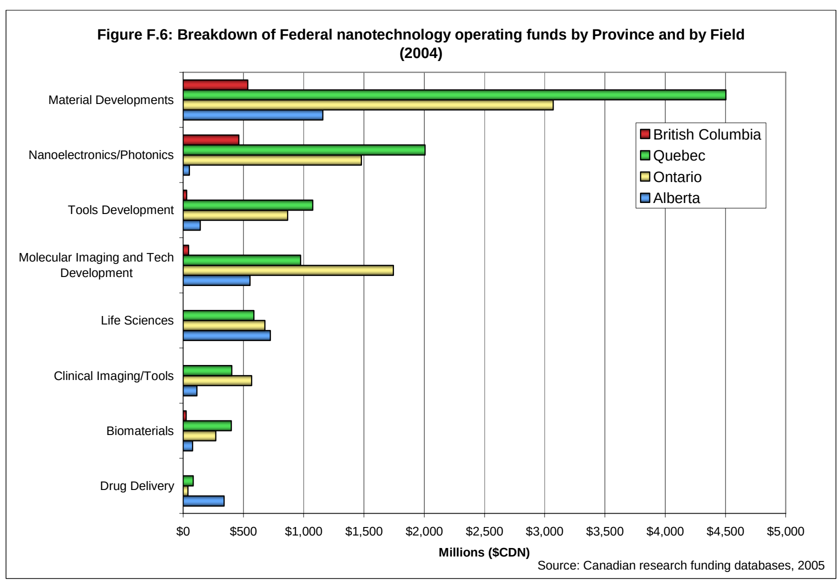

Figure F.6: Breakdown of Federal nanotechnology operating funds by Province and by Field (2004)

Methodological considerations

Definition of nanotechnology

A critical first step in the collection of statistics on expenditures and outcomes on nanotechnology R&D is for stakeholders to agree on a definition of nanotechnology so that government, universities and industry researchers and managers in each sector can consistently report and analyze data using the same language. It should be recognized that there is no internationally accepted formal definition (ISO or OECD) of nanotechnology due to the newness of this field of research, the multidisciplinary aspects of the technology, and its rapidly evolving nature.

For the purposes of this report the starting definition of nanotechnology is that of the US National Nanotechnology Initiative:

> ***Nanotechnology*** *is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where* **unique phenomena enable novel applications**. *Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.*

Annex A contains a summary of the various definitions of nanotechnology used by the federal funding agencies compared with that of the US National Nanotechnology Initiative (NNI). All definitions contain two essential statements: the length scale of 1 to 100 nanometres and the use of unique phenomena at that scale.

Annex A also shows that the definition used by an agency can be affected by the agency's mandate. The principal example is that of the Canadian Institutes of Health Research (CIHR) as the overlap of nanotechnology with biotechnology is complex, as many biological structures and processes occur at the nanometre length scale. As a comparison, when the US National Institutes of Health (NIH) reviews its projects for inclusion in NNI reporting, only those R&D projects that use nanotechnology tools and concepts to study biology; that propose to engineer biological molecules toward functions very different from those they have in nature; or that manipulate biological systems by methods more precise than can be done by using molecular biological, synthetic chemical, or biochemical approaches that have been used for years in the biology research community, are classified as nanotechnology projects. CIHR has adapted a similarly stringent set of criteria for inclusion of nanomedicine projects (see Annex B for a sample list of eligible nanomedicine projects).

In a similar manner to biotechnology, it is expected that the OECD and ISO will produce a list based definition of nanotechnology. Annex B contains examples of such lists produced by Roseman (2005) for the Prime Minister's Advisory Council on Science and Technology (PMACST) and the CIHR for a nanomedicine Request For Applications.

The inaugural meeting of the International Organization for Standardization (ISO) Technical Committee 229, Nanotechnologies, was held in November, 2005 where it was decided that ISO/TC 229 will approach the development of International Standards for nanotechnology within three working groups: terminology and nomenclature; metrology and characterization; and health, safety and the environment, convened by Canada, Japan, and the United States, respectively. The TC229 Working Groups are expected to report on their findings in November 2006 in Seoul Korea.

R&D expenditures

<u>Operating</u>

Operating expenditures have been one of the more difficult categories of expenditure to consistently collect. For example, some Canadian agencies only fund the direct cost of research and do not fund, in general, faculty salaries or institutional overheads. The challenges in the international comparisons is highlighted by this, for example it is difficult to compare Canadian funding data with US funding data where universities receive funding for both direct costs and overheads. This could be compounded when even more OECD member countries begin comparisons. Grütter and Roseman (2004) made the following observations:

> *Finally, it is important to note when comparing Canadian and US academic operation funding levels that the cost structure of Canadian universities is extremely competitive by international standards. For example, typically, $15,000 CDN is paid from a research grant to support a graduate student at a Canadian institution. By contrast, in the US between $40,000-80,000 US is required, with $25,000 US going towards the graduate student fellowship while the remainder is directed towards university overhead and tuition support for the student.*

It is important that basic components of operational expenditure be identified for universities and government agencies so that analysis and direct comparisons can be made within and between OECD countries.

Equipment expenditure is directly comparable however it is important that only equipment which is exclusively or mostly committed to nanotechnology R&D be included in future data collections.

<u>NE3LS: Nanotechnology Ethical, Environmental, Economic, Legal and Social aspects</u>

The need to undertake research into NE3LS issues has been strongly advocated to the Government of Canada's by the International Science Panel that reviewed Canada's nanotechnology research. This type of research is different to traditional scientific and engineering research and needs to be explicitly identified either through the analysis of the funding databases of the federal and provincial governments or by Statistics Canada surveys.

<u>Classification of categories of nanotechnology</u>

Classifications reflect differences amongst government departments, for example the CIHR has the following categories:

- **Molecular Imaging and Technology Development** (basic application of quantum-dots, atomic force microscopy, optical imaging tools, microfluidics, lab-on-a-chip, etc)
- **Clinical Imaging/Tools** (nano-contrast agents, clinical application of quantum dots, femtosecond laser surgery, etc.)
- **Biomaterials** (nanostructured surfaces and coatings, nanoparticle safety, etc.)
- **Drug Delivery** (nanoparticulate delivery, novel gene delivery vectors, nano-immunoliposomes)

In comparison NSERC has the following categories:

- Nanomaterial Development
- Nano-electronics/Photonics
- Tools Development
- Life Sciences

The process of coming to an international definition of nanotechnology is progressing; however, the definition of commonly accepted categories or fields of nanotechnology is by necessity lagging behind. It will be important to collect this information in a consistent manner as nanotechnology is a very broad area of research and it will greatly assist policy development to identify trends within nanotechnology R&D and its uptake by industry.

Statistics Canada

Statistics Canada has used the NRC's definition of nanotechnology in its initial steps towards collecting information on nanotechnology (Annex A).

Statistics Canada used the Emerging Technology Surveys for reference years 2003 and 2005 to begin to identify and inventory firms engaged in nanotechnology activity. The questionnaire is mailed to all firms in industry codes were nanotechnology has been observed, or where there is a possibility of nanotechnology activities. In 2003 89 firms were identified, while the 2005 results showed 118 firms self identifying as being involved in nanotechnology.

The Biotechnology Use and Development Survey – 2005 contains a dedicated nanotechnology section that asks basic question of firms that have been identified as being active in nanotechnology. Results are expected in fall 2006. This process was successfully utilized in 2003 for Bioproducts, contributing to a full survey the following year for Bioproducts. The Survey of Innovation reported that 5% of ICT firms provided services to nanotechnology firms.

Questions on nanotechnology are included in the Advanced Technology in Canadian Manufacturing Survey – 2006 with results expected in 2007. Inquiries on nanotechnology R&D expenditures are included in the 2006 survey Research and Development in Canadian Industry using a combination of tax and survey data. These surveys are intended to provide concrete information on nanotechnologies as well as test concepts and definitions, with the intent to implement dedicated nanotechnology surveys in the future. These surveys will provide useful information not just on R&D expenditures, but will also provide information on the where to find nanotechnology activity in the Canadian economy. This will aid in accurate coverage for potential future dedicated nanotechnology surveys. Currently all nanotechnology surveying activities at Statistics Canada are done on an ad hoc unfunded basis. Inclusion of nanotechnology in the Federal S&T survey and other existing surveys is being explored.

The biotechnology statistics program at Statistics Canada serves as a workable model, completing the first national surveys on biotechnology and participating in the development of international definitions and model surveys on biotechnology at the OECD. All these potential steps would benefit from the early and active participation of stakeholders, creation of definitions and concepts that are rigorous enough for international comparisons, but flexible enough to capture and reflect the evolving and multi-sector nature of nanotechnology.

Approaching Measurement of Nanotechnology: Using Lessons Learned

Even a brief search for a definition of nanotechnology uncovers many competing definitions of making one of the first challenges defining exactly what nanotechnology is. The challenge of defining what exactly is nanotechnology is complicated by the fact that the boundaries surrounding nanotechnology are not clear, nanotechnology cuts across many different sectors of the economy. For example where does nanotechnology end and information technologies and biotechnologies begin? Beyond the interest in the economic impact of nanotechnology are related activities such as regulation, education and training, and government expenditures and activities.

In order to address the numerous questions and issues, the guidelines outlined in the Science, Innovation, and Electronic Information Division's (SIEID) *Activities and Impacts: A framework for a statistical information system*[1] can be used in conjunction with the lessons learned in recent Statistics Canada surveys (for example the *Biotechnology Use & Development* surveys). The framework addresses a series of who, what and where questions[2], which take the form of:

- *What is nanotechnology*? Nanotechnology is a catch all term of activities and techniques that cuts across sectors and this can be extended further to addressing the question: What is a nanotechnology firm?

- *Who are the actors in nanotechnology*? The usual suspects of academia, business and government will be named but the specifics of these will need to be identified along with their respective roles and contributions.

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[1] For detailed information the reader is referred to the divisional framework document Science and Technology Activities and Impacts: A framework for a Statistical information System Statistics Canada, Ottawa , Catalogue no. 88-522-XIE (1998)

[2] See Rose for a comprehensive discussion of the development of biotechnology statistical program. Rose's work serves as the model for this section.

- *Where is nanotechnology*? This not only refers to physical location but to the sector location, where in the economy is nanotechnology. Nanotechnology cuts across sectors and activities.

- *Why use nanotechnology? What are the results of using nanotechnology?* Issues such as reasons for adopting nanotechnologies and the benefits that resulted from adopting and using nanotechnology can be addressed.

- *How many resources have been committed to nanotechnology*? The expenditures both monetary and human can be explored.

- *How connected*? Questions can be asked on how firms link together using as an example, strategic alliances.

Based on experience, development of a statistical program on nanotechnology benefits from the meaningful engagement of stakeholders, the use of this framework, and integrating the methodologies and techniques developed and refined in other innovation surveys. An example of lessons learned is the use of a list-based definition. Rather than a statement defining nanotechnology, nanotechnology could be transformed into a list of measurable products and processes, which as an added benefit addresses in part the cross-sector nature of nanotechnology.

Discussion

Database methodologies

Database methodologies are an important and useful tool for understanding the evolution of nanotechnology R&D in Canada. First and foremost funding databases for Research Granting Agencies such as those within NSERC, CIHR, CFI are quite extensive with detailed information such as compete titles, keywords and in some cases abstracts as well as the names of research leaders, teams and institutions. As such they can provide consistent, comparable data over time. Data capture, analysis, and quality control, however, pose a number of challenges. First and foremost existing databases are not specifically designed with the intention of capturing nanotechnology spending and given the multidisciplinary nature of the field, key words, and terminology can differ from discipline to discipline. NSERC database searches by keyword in 2005 required review by a subject area expert to ensure consistency and resulted in culling close to 50% of the initial hits. Nevertheless the final data produced through this process is considered to be truly reflective of the level and nature of activity for federal government support for academic research in Canada. The 2006 database review will expand the scope of coverage to government funded programs dealing directly with industry such as Technology Partnerships Canada (TPC), Industrial Research Assistance Program and Sustainable Development Technologies Canada and regional Granting Agencies such as Canada Economic Development for the Québec Regions. These databases while more restrictive in their coverage of specific research details because of private sector confidentiality, will provide greater insight into the linkage between government-sponsored funding programs and industrial application in nanotechnologies. Similarly, the 2006 review will have more detailed coverage of provincial government funding for nanotechnology research.

Survey Data

Survey data can provide insight into the activities and environment of firms involved in nanotechnology activity. Questionnaire can probe the intricacies of topics such as raising capital, human resources and barriers faced by firms, providing information to policy makers. However surveys do face challenges, not least which is the very nature of nanotechnology. The nanotechnology sector is a rare population with potential respondents found in numerous sectors of the economy, raising the challenge of accurately and completely developing a survey frame. Nanotechnology is a blanket term that describes both products and processes. Nanotechnology can be a product, and nanotechnology can be a process used to create a product posing a challenge to accurate measurement. Surveys in a sense compete with each other, and respondent burden becomes an issue for most surveys since they rely on the participation of the firms involved in the sector, and that requires time and resources of the respondent, who often times are providing sensitive information. Questions are subject to interpretation by respondents, who also self-identify for participation in surveys of this nature. These and other challenges must be addressed in the development of the survey and data interpreted and analyzed in this context.

Government surveys can be used to gain information on nanotechnology. They can question both the government's internal research and development activities and government's funding of external nanotechnology use, complementing data base searches and analysis. Surveys could include federal and provincial governments.

Case Studies

These can provide the detailed insight into nanotechnology sector. For example, in-depth analysis of firms can lead to a better understanding of the firms' activities and environment than can surveys. Investigators can pursue lines of questioning impossible for a questionnaire to explore with accuracy. The face to face nature of the case study leads to discussion that reveals new topics and interviewers can then explore those topics. Case studies tend to topical and current and usually involve a willing respondent who is eager to talk about their organization.

No single method or data source is sufficient to measure or monitor nanotechnology and its changes over time. Data collected in each method are subject to time and value constraints. Most funding apparatus such as grants and research projects are carried out over multiple years and allocation of funds to particular years may prove challenging.

By its very nature, multi-sectoral, evolving, destructive, nanotechnology is a moving target, making measurement a challenging task. However a variety of methods, including database analysis, survey data, and case studies can be utilized to provide an integrated picture of nanotechnology. This variety of methods does not imply haphazard approach to measurement, rather demands a systematic approach that examines and considers all perspectives in nanotechnology, government funding, research in higher education, industrial research and development, adoption by industry and its eventual entry into the consumer marketplace. It is here that the need for a common understanding and language is most needed. The different methodologies need, in the end, to be measuring the same things. Use of only one technique would only provide one perspective, leaving stakeholders with an incomplete view and subsequent understanding of nanotechnology. Good decisions require good information; information that is timely, accurate, reliable, and complete and a comprehensive statistical program is a significant component of any strategic approach to the development and nurturing of the Canadian nanotechnology sector.

Summary

Despite the challenges facing systematic measurement of nanotechnology, precedent can be found in the approaches in which the challenges can be addressed. Methods and techniques have been developed and refined that addresses the who, what, where, why and what results, how much, and how connected questions raised in SIEID's divisional framework. Canada is a leader in development of national biotechnology statistics and is a leader in developing international definitions. The list-based definition of biotechnology tentatively adopted by the OECD is based on the Canadian list-based definition successfully used in surveys.

Measurement of nanotechnology is in its infancy, and much work and many challenges remain. Important first areas to focus on include the following.

Definition of nanotechnology: As evidenced by the numerous definitions mentioned in this document, steps need to be taken to establish a definition of nanotechnology that recognizes the complex and changing nature of the phenomena and facilitates international comparisons.

Classification of categories of nanotechnology: Coincidental to the defining nanotechnology, the issue of classification requires clear and rigorous attention, in order to fully measure and then understand the emerging sector.

Data collection by analysis of funding databases: A method of collecting nanotechnology R&D expenditure data is through searching funding databases as it enables the most consistent application of the

nanotechnology definition. That representatives from the federal funding organizations for industrial nanotechnology R&D be consulted on the methodology for addressing database searches
Data collection by surveys: Surveys can collect public and private sector data from performers of nanotechnology and this work could include introducing nanotechnology to the annual federal survey of science expenditures and personnel (FSEP); include a nanotechnology section in the provincial surveys and finally, in consultation with stakeholders, develop a program of survey(s) and associated analysis on the development and adoption of nanotechnologies and related issues in Canadian industry.
Human Resources: Classifying and counting the specialized work force in nanotechnology will be a challenge and will require extensive work to reach international comparability.

Nanotechnology poses many challenges to those that are attempting to systematically classify and measure this emerging and evolving set of activities, but challenges that that can be managed. The first steps have been taken but much work faces the international community in the development comprehensive internationally comparable statistics.

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Annex A: Summary of single definitions of nanotechnology

NNI	NSERC	CIHR	NRC	PMACST
Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where **unique phenomena enable novel applications**. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale.	**Nanoscience** involves the manipulation, study, or exploitation of systems and structures, where at least one dimension is on the order of the nanometer length scale. This results in **a qualitatively different behavior** than that of the corresponding bulk material, arising due to either surface effects or quantum mechanics.	**Nanomedicine** is defined as the design, synthesis, or application of materials, devices, or technologies in the nanometer-scale for the basic understanding, diagnosis, and/or treatment of disease. Key to this definition is that phenomena and materials at the nanometer scale are known to have properties that are **uniquely attributable to that scale length**.	**Nanotechnology** is the application of science and engineering at the atomic scale. It facilitates the construction of new materials and devices by manipulating individual atoms and molecules, the building blocks of nature. Nanotechnology enables the atom-by-atom design and fabrication of tiny structures that are very small, typically 1-100 nanometres, and which have **new properties** and powerful application in medicine and biotechnology, in energy and the environment, and in computing and telecommunications	**Nanotechnology** is a suite of technologies which enable the direct manipulation, study or exploitation of systems or structures where at least one dimension is on the nanometre length scale (typically less than 100 nm). The ability to control matter within this regime allows us to **exploit phenomena which predominate at these length scales**, leading to the production of novel materials and devices which exhibit **qualitatively different properties and functions** than that of the corresponding bulk material. The expression or controlled exploitation of novel properties and/or functions arising from the nanometre scale structure distinguishes nanotechnology from incremental advances in microtechnology, as well as from biology or macromolecular chemistry.

Annex B: Summary of list based nanotechnology definitions

PMACST *NANOSCIENCE*	CIHR *NANOMEDICINE*
Nanophotonics*: development and use of photonic band gap materials, all-optical information processing, quantum optics, etc.* ***Nanoelectronics:*** *development and use of spintronics, molecular electronics, molecular switches, single electron devices, etc.* ***Quantum Computing:*** *theoretical and experimental research into all aspects of quantum information processing* ***Self Assembly:*** *theoretical and experimental research and use of the techniques whereby molecules spontaneously form into covalently bonded, well-defined, stable structures* ***Nanobiotechnology:*** *the design, synthesis, or application of materials, devices, or technologies in the nanometre-scale for the basic understanding, diagnosis, and/or treatment of disease (e.g. drug delivery, diagnostics, etc.).* ***Nanomedicine:*** *the specialized biomedical measurement or intervention needed – at a molecular scale – needed to treat disease or restore function.* ***Nanomaterials:*** *development and use of nanocomposites, nanopowders, nanoparticles, nanocoatings, etc.* ***Instrumentation Development:*** *construction of novel types of microscopes, manipulation techniques, fabrication facilities, sensors, theoretical modeling packages, plus contributions to the understanding of such processes*	*Novel approaches to functional molecular-scale imaging, including devices, compounds, integrated techniques and correlated approaches;* *Novel drug delivery approaches, devices, materials;* *Novel approaches to the synthesis, design, implementation, and characterization of biomolecular arrays (small molecule, peptide, protein, biomolecule, antibody) for high-throughput, multiplex screening;* *Integration of nanostructured materials, devices, sensors with microfluidic systems for identifying, measuring, and mapping biomolecular interactions;* *Development and application of novel physical, chemical, or electronic probes, tools, and techniques to the determination of single molecule (peptide, protein, biomolecular complex) structure-function relationships;* *Novel approaches for the rapid in situ determination of single molecule structure, dynamics and reactivity;* *Characterization of the genetic, molecular and signaling pathways associated with physiological integrity, disease, injury, loss of function, and cell or tissue senescence;* *Definition of important gene-environment interactions in determining health and new potential therapeutic targets for diseases and conditions;* *Novel approaches to understanding the development of the structural and functional hierarchy present in complex biomolecular systems;* *Ethical, legal, cultural, and social consequences of nanomedicine, as well as the potential economic costs of such treatments*

Annex C: Summary of database search terms

NSERC	CIHR	CRC	CFI
	aptamer		
AFM	AFM		
Atomic Force Microscop*	atomic force microscop*		
	biochip		
	biomedical imag*		
	cellular imag*		
	dendrimer		
	femtosecond		
	lab-on-a-chip		
	liposom*		
	medical imag*		
	MEMS		
	microfluidic*		
Microscop*			
Mol* elec*			
Molecular beam epitaxy	molecular beam epitaxy		
	molecular comput*		
	molecular manufactur*		
	molecular elec*		
	molecular imag*		
Molecular switch	molecular switch		
Nano*	nano*	*nano*	*nano*
		*nano*tech*	
	NEMS		
	optical imag*		
	optical tweezer		
Photonic	photonic*		
Quantum	quantum		
Scan* prob*	scanning prob*		
Scanning Tunneling Microscop*	scanning tunnel*		
Self assem*	self assem*		
	self-assem*		
Single electron	single electron*		
	sub-micro*		
	submicro*		
STM	STM		
	ultrafast		
	ultrafine		