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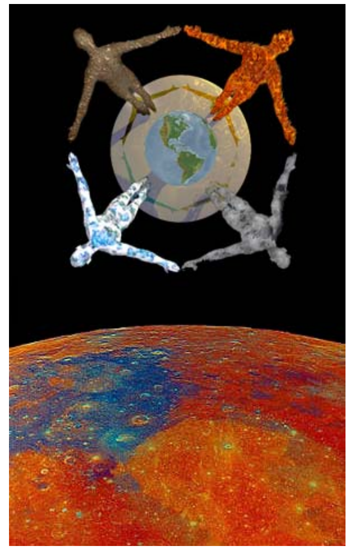
Science & Technology Foresight Directorate
Office of the National Science Advisor
Privy Council Office,
Government of Canada



Toward Understanding
Science and Technology Convergence

(in nano, bio, information and cognitive sciences and their emerging intersectional and innovative technology domains)

September 2005

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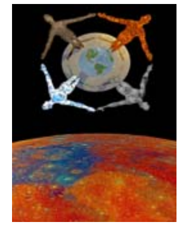

Foreword

This research report is part of a series of several reports that have been produced for the benefit of sponsors, participants and professionals interested in how emerging and prospective developments in global science and technology might impact Canada's future. The Office of Technology Foresight was launched at NRC in 2002 as a resource center for introducing and advancing the practice of science and technology foresight in Canada. In 2004 the federal Foresight center was relocated within the new Office of the National Science Advisor (ONSA) at the Privy Council Office, Government of Canada. The Office operates as a collaboratively structured partnership activity within the Canadian Government and undertakes projects with multiple partners and stakeholders. Partners have included Federal science-based departments and agencies, Provincial ministries and agencies as well as universities and private sector entities. These partnerships are developed around specific themes or projects. They are designed to explore the application of foresight tools to help stimulate longer term thinking and build shared R&D awareness and capacity for engaging broad and horizontal challenges for which the Canadian S&T and policy communities should be better prepared.

It is useful to recall the definition of S&T Foresight that characterizes the scope and focus for ONSA:

> *S&T Foresight involves systematic attempts to look into the longer-term future of science and technology, and their potential impacts on society, with a view to identifying the emerging change factors, and the source areas of scientific research and technological development likely to influence change and yield the greatest economic, environmental and social benefits during the next 10-25 years.*

S&T Foresight is necessarily speculative, creative and analytical because it must rely both on the interpretation of S&T change drivers and on how, if and when these could become significant factors in Canada's prospective social, economic and political realities. Since the future is highly uncertain, foresight is inherently about attempting to understand, dimension and reduce or at least prepare for significant risks. Foresight is best conducted as collaborative research for learning purposes, with the understanding that if a consensus emerges regarding possible application of the insights gained through such a process, one or more of the domains studied might warrant further, more detailed examination. The approach taken by ONSA relies upon consulting a wide range of expertise, with the expectation that through collective experience, imaginative abilities and interactive knowledge of technological development pathways, a coherent view of some of the major developments that can be anticipated within a 10-25 year time horizon can begin to be constructed. Foresight is therefore research that can inform planning, policy and strategic choice amidst uncertainty. Although this work is undertaken under the leadership of the Government of Canada it does not signify endorsement by its Departments and or Agencies, unless so indicated.

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1 INTRODUCTION

This report represents an initial attempt to understand a complex emergent area of new knowledge that has loosely been termed Science and Technology Convergence (S&TC). It summarizes the findings of investigations and analyses carried out in March 2005 on the first phase of the "Understanding Convergence 2005-2025 Foresight Project (UCFP)" proposed by the Science & Technology Foresight Directorate (STFD) to key partners of the Office of the National Science Advisor (ONSA).

This project is designed to take Canada's S&T community collaboratively and intellectually further along the pathways for Understanding S&T Convergence. It is part of a larger effort being designed to create a more coherent foresight capacity in Canada and to quickly assemble networks that can:

- better anticipate global change impacts derived from S&T, and
- share insights and knowledge of new ways of characterizing change and its polarities of threat and opportunity.

Such capacity would enable Canada to increase its leadership potential and be positioned for future innovation benefits through agile knowledge deployment. Once completed, the UCFP will provide the sponsors with a framework to guide investment, education and societal needs assessments around the critical technology platforms, domains and sectors of convergence that are likely to shape the next two decades.

The Phase I report aims to support ONSA and its foresight partners in developing a Framework for Understanding Convergence tailored to Canadian vision, values and perspective. Such a framework will serve as the backbone for the Project future phases whose scope will be jointly defined with STFD current and future partners.

The Phase 1 report presents the following information:

- The origin of the project "Foresight on S&T Convergence, 2005-2025"
- Definitions of convergence and converging technologies
- The rationale for understanding convergence
- The socio-ethical dimensions of convergence and converging technologies
- How other countries or regions are dealing with converging technology foresight
- The situation of technology foresight in Canada
- Some of the tools available for foresight in converging technologies
- Conclusions

2 CONTEXT, DEFINITIONS AND CHARACTERISTICS

As the world becomes more complex and science reveals ever greater degrees of interconnectedness in virtually every domain and between most areas of adaptive knowledge,[1] the scientific and technological boundaries between the most novel areas of new knowledge are becoming blurred. Specifically, as communities are deepening their knowledge about how cognitive and neurological science, information technology, nanotechnology, biotechnology and genomics systems may evolve with new computing and molecular discovery capabilities, they increasingly find that traditional disciplinary approaches do not provide adequate perspectives.

2.1 CONTEXT

In 2002-03, when the Office of Technology Foresight was created at the National Research Council of Canada (NRC), its initial task was to select some topics for analysis. In consulting with the 20 or so partner federal departments and agencies, it was clear that many boundaries were less distinct than they had been in the discussions about interdepartmental collaboration that took place as part of the 1995 federal S&T review. To achieve a consensus about where to direct foresight activities it was necessary to focus on broad systems or domains. Two of these were selected: Biosystemics and Geo-strategics. This approach inadvertently thrust the federal team into discussions about convergence. Initially the discussion focused on sectors, such as energy-environment; however, a more fundamental discussion about the new dynamics and prospects associated with new cross-arching capabilities, more powerful diagnostic tools and new theories of science[2] soon occurred.

During this process, it became clear that some of the foresight perceptions could involve dramatically new frameworks for understanding emerging capabilities. Moreover, the NRC team became cognizant of the US National Science Foundation (NSF) project on Converging Technologies[3] (the NSF Report). These two events shaped a new perspective towards the creation of frameworks to consider technology convergence.

Consequently, in early 2005, the STFD decided to launch a foresight exercise on Science and technology convergence to inform future policy. A number of partners[4] agreed to join forces with ONSA to undertake this first phase.

We also wish to recognize the pioneering work that helped originate this project that was undertaken by the late Raymond Bouchard during 2002-2004. Raymond's work on bio-systemics created a basis for this project and was recognized by the European Commission in its 2004 report on Converging Technologies: Shaping the Future of European Societies EUR document # 21357 ISBN 92-894-8313-X

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[1] The ability of humans to judge any situation appropriately and act accordingly

[2] Such as those being advocated by Stephen Wolfram http://www.wisdomportal.com/Stanford/StephenWolfram.html

[3] The US-NBIC Report: Roco, M. C. and Bainbridge, W. S. Eds: (2002) *Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science*. National Science Foundation and Department of Commerce. http://www.technology.gov/reports/2002/NBIC/Part1.pdf

[4] List of partners: Defence R&D Canada, NSERC, SSHRC, Canadian Biotechnology Secretariat , Ministere DEIE Quebec

2.2 DEFINITIONS

The simplest definition of **convergence** is:

> *"The coming together of two or more disparate disciplines or technologies."*

The definition of Converging Sciences and Technologies (CSTs) depends on context, on the perception of the potential applications of these technologies and on the perception of the socio-ethical issues that may arise from the technologies or their application.

As defined in the NSF Report, the term Converging Technologies (CST) refers to:

> *"..the synergistic combination of four major "NBIC" (nano-bio-info-cogno) provinces of sciences and technology, each of which is currently progressing at a rapid rate: (a) nanocience and nanotechnology; (b) biotechnology and biomedicine, including genetic engineering; (c) information technology, including advanced computing and communications; and, (D) cognitive sciences, including cognitive neuroscience."*

The European Union High Level Expert Group (the EU-HLEG Report)[5] defines converging technologies likewise but uses a unique and more comprehensive approach that focuses on the need to set agendas or common goals for these technologies and their applications:

> *"…enabling technologies and knowledge systems that enable each other in the pursuit of a common goal."*

Accordingly, they have introduced the term CTEKs or **Converging Technologies for a European Knowledge Society**. Furthermore, the Third Special Interest Working Group of the EU-HLEG distinguishes between NBIC[6] convergence in scientific terms, with integration of basic science at the nanoscale and where the capabilities become generic, and NBIC convergence in terms of using combinations of two or more NBIC technologies to develop new capabilities. This they call **Convergent Transformational Technologies** (CTTs).[7]

Other regions are using definitions that are derived from those developed in the USA and the European Union.[8] These two regions are presented here as two key benchmarks for Canada's own foresight activity on technology convergence.

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[5] The EU-HLEG Report: Nordmann, A**.** Rapporteur**: (**2004) *Converging Technologies – Shaping the Future of European Societies* http://europa.eu.int/comm/research/conferences/2004/ntw/index_en.html

[6] See Appendix 2 for a brief overview of the NBIC technologies

[7] Ringland G. Ed.: (2004) *New Technology Wave: Transformational effect of NBIC Technologies on the Economy*. Report of the 3rd Special Interest Working Group, http://europa.eu.int/comm/research/conferences/2004/ntw/index_en.html

[8] Although this report presents the EU's views as expressed in the EU-HLEG Report, there is much diversity in the approach of individual EU countries to the issues of CST.

2.3 KEY CHARACTERISTICS OF S&T CONVERGENCE

In order to explore further the breadth, potential and risks of S&T Convergence on Canada's future, the team[9] assembled by the STFD uses the following key characteristics, drawn from the US-NBIC Report and the EU-HLEG Report, to define CST:

Material unity at the nanoscale: an understanding about how atoms combine to form complex molecules and, in turn, aggregate to form organic and inorganic structures. Natural processes can be harnessed to engineer new materials, bio-products, machines, etc., from the nano- to the macro- scale. Complex microsystems, such as neurons, and macrosystems, such as human metabolism, can thus be controlled.

Embeddedness: CSTs are capable of forming an invisible technical infrastructure around us, analogous to the visible infrastructure provided by buildings and cities. The better this invisible infrastructure works, the less one will notice a dependence on them or even their presence.

Unlimited reach: Nanotechnology's dream to control everything molecular follows upon information technology's increasing ability to transform everything into information.

Engineering the Mind and the Body: Some proponents[10] of CSTs advocate "engineering *of* the mind and *of* the body." For example, electronic implants and physical modifications could enhance our current human capacities. The STFD proposes, as did the European HLEG[11] on Convergence, that CST research should focus on "engineering for the mind and for the body."

Specificity: CSTs are viewed as having the ability to provide unique solutions for specific problems.

Unknown potential: CSTs and their applications are still at a very early stage. Their full potential and impact are not envisaged for another 10-20 years, perhaps more. While the capabilities may be there earlier, it often takes extended periods for applications to be adopted. For example, the Internet was expected to become the universal tool that it became in the 1990, 15-20 years sooner. However, it is possible that many CST applications will become as universally adopted as the computer.

3 RATIONALE FOR UNDERSTANDING CONVERGING SCIENCES AND TECHNOLOGIES AND THEIR POTENTIAL APPLICATIONS

Each of the characteristics of CST applications described in Section 3.3 presents opportunities to solve societal problems, to benefit individuals and to generate wealth. Each of these also poses threats to culture and tradition, to human integrity and autonomy, and perhaps to political and economic stability.

[9] Jack Smith (ONSA), Danielle Tanguay (Trema Gestion Conseil Inc), Nicole Bégin Heick (Nicole Bégin-Heick & Associates Inc.), Steffen Christensen (ONSA), Hassan Masum (ONSA), Afaq Ahmad (DRDC)
[10] The US-NBIC Report, op.cit.
[11] The EU-HLEG Report, op.cit.

The ability to understand CSTs and define their potential applications carries with it an enhanced capacity to take pre-emptive actions such as:

Ensure the existence of an appropriately educated workforce: The exploitation and application of converging technologies will require adaptations in the way people work and in the skills needed for success. This in turn asks for an education system that promotes innovative thinking together with a solid grounding in mathematics. Understanding the potential and the impacts of CSTs is a first step in ensuring that educational programs, including life-long learning, are appropriately designed.

Define goals: The NSF Report sets educational and transformational goals, and recommends a national R&D priority area on CSTs focused on enhancing human performance. The EU-HLEG Report proposes a European approach to CSTs by focusing them on the European Knowledge Society. To remain competitive, Canada and its regions need to define the specific goals that they have for the exploitation of this technological revolution.

Explore a country/region's competitive advantages and find appropriate niches (defining strategic areas of application): Canada has neither the might of the USA, nor the budgets of the EU. This means that Canada must select its priorities strategically, by understanding the power of CSTs and how they could be exploited to Canada's advantage.

Exploit CSTs potential through enlightened innovation policies: Innovation is essential to success in the knowledge economy. It is therefore important that to set forward looking innovation policies in Canada and its provinces and territories, all levels of government understand the potential impacts that the convergence of technology will have on companies and the workforce. There are many questions about the future of the converging technologies. There is a need to try to anticipate what inventions will be practical enough to become innovations and when. It is important to understand, among other things, how fields will interact to produce innovations; how commercialization will occur and what are the risks to CST innovation. Foresight exercises can provide a framework to answer these questions. However, given the breadth of converging technologies, it is important to define and select key applications of CSTs to narrow the field and plot future directions.

Establish appropriate legal and regulatory frameworks to deal with ethical, economic, health & environment related issues by anticipation rather than reaction: Products of the CSTs could upset existing normative frameworks. This would have consequences for the legal system, which is built on a set of norms that are understood as the correct (or at least the majority) way of interpreting the world in which we live.[12] Their development could require shifts in regulatory paradigms and/or frameworks. For example, before a drug is put to market, it must undergo a rigorous process of evaluation. Drug trials that are a necessary part of the evaluation process are regulated. Should "agricultural trials" for genetically modified organisms (GMO) be subject to a similar regulatory process?

[12] http://mauritsmusings.typepad.com/technology_dynamics/

"… These [NBIC] emerging fields are accelerating rapidly, have the potential for enormous impact, and are almost entirely ungoverned nationally and internationally."[13]

Gain an understanding of and mitigate risks: Both positive and negative impacts of CSTs are foreseeable. What these impacts might be will depend on the selected applications. The social, legal, and ethical impacts are likely to be significant.[14] Indeed, the four S&T areas pose similar risks: self-replicating technologies are a danger in nanotechnology (e.g. the "grey goo" scenario[15] or variants), biotechnology (e.g. pandemics and bioterrorism), and information technology (e.g. computer viruses, worms, and "malware").

Distinguish between science fact and science fiction: The level of maturity of various technologies varies. It is important to be able to assess what is practical in the short and medium term from visions that may only be realized in the much longer term.

Deal with rapid change through collaborations: CSTs and their applications will have impacts at all levels of society. A cadre of experts must be developed who understand the issues and can come together to offer timely solutions. The exploitation of CSTs also has the characteristic of being highly distributed and amenable to "open source" mechanisms both of which require a high degree of cohesion

Ensure an accountability framework appropriate to a distributed nature and "open innovation" paradigm: The distributed nature of CST innovation could lead to "distributed responsibility," that is, a potential lack or accountability.

Ensure the appropriate use of CSTs for furthering the aims of civil society: The converging technologies offer great promise for innovations and, at the same time, pose risks many of them unforeseen. The organizations of civil society could be brought in to act as a social conscience and to ensure that the exploitations of the selected technologies are based on the values held by Canadians. For example, the "technology divide" could cause an even greater chasm between the rich and the poor. Civil society in many nations is coming to awareness of the problems that need to be overcome, and in some instances, even to some degree of agreement on the world to be built for this generation and its descendants.

Engage private sector collaboration: The realization of the promise held by CSTs depends on harmonization of objectives between the research community, the government and the private sector. To achieve such an outcome, all players need to understand the stakes.

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[13] Spence, R., Davy, B., Dufour, P., Lafond, R., Leppan, W. & Woo, J.: *IDRC, Biotechnology, and Emerging Technologies: A Basic Primer*. http://web.idrc.ca/uploads/user-S/1084840901101_Foreword.doc

[14] See for example: Institute on Biotechnology & the Human Future http://www.thehumanfuture.org/topics/geneticdiscrimination/index.html

[15] The "Grey Goo scenario" refers to the potential danger of self-replicating nanotechnology run out of control

Enable SMEs to position themselves as globally competitive receptors and partners of the research community: Given that most of Canadian companies are SMEs, the more they understand the issues around CSTs, the better prepared they will be to take advantage of the promises held by these technologies. SMEs by their very nature are more nimble than large corporations and, therefore, should be well positioned to play leading roles in future developments. A particular attention should be devoted to ensure SMEs the access to appropriate resources required to create an optimal interface between research, development and commercialization of CSTs.

4 IMPORTANCE FOR ONSA PARTNERS OF UNDERSTANDING CONVERGING TECHNOLOGIES

4.1 FOR GRANTING AGENCIES

Understanding convergence means that a granting agency will have an enhanced capability to influence thinking about convergence within the research community and appropriately define and/or structure its activities and policies.

Fostering foresight within the research community: Granting agencies need to devise means to engage their communities in forward thinking about the directions of research, their impact on Canada and the world and the interconnectivity required among disciplines to realize the benefits of CSTs and analyse and mitigate the potential risks posed by them.

Creating multidisciplinary intellectual spaces & clusters in and out of academe: The creation of knowledge clusters across disciplines, across sectors nationally and internationally is essential to exploit maximum benefits from Canadian research.

> *"It is increasingly important for Canadians to participate in, learn from and shape **national and international networks in and outside academe**. These are the foundation for innovative and cutting-edge research of global importance and impact. Without such participation, we risk severely limiting Canada's ability to exercise leadership on the international research stage. More importantly, perhaps, Canadian scholarship risks losing its vitality and its ability to contribute to the well-being of Canadians."*[16]

Funding policies: Understanding what future developments are likely to be and which avenues/domains would be appropriate for Canada to pursue could help shape the definition of strategic areas of research and the boundaries in the purview of each agency. Agencies might consider creating specific categories in funding programs for risks, ethics, legal and societal aspects of CSTs. Indeed the UK Royal Society and the Academy of Engineering (the UK-RS&RAE Report) recommended:

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[16] The Social Sciences and Humanities Research Council: (2005) *From Granting Council to Knowledge Council: Renewing the Social Sciences and Humanities in Canada*
http://www.sshrc.ca/web/whatsnew/initiatives/transformation/reports/Volume3_final_e.pdf

"… that the research councils and the Arts and Humanities Research Board (AHRB) fund an interdisciplinary research programme to investigate the social and ethical issues expected to arise from the development of some nanotechnologies."[17]

Likewise developing such an understanding might lead to changes in the allocation of funding from a model that is largely discipline based to one that is more domain or outcomes based. In turn, this would help define innovative joint industry / university / public laboratory programs in various combinations.
A granting agency might also wish to ensure specific developments in CSTs by launching a program of S&T procurement on strategic CST niches for Canada (e.g. through requests for proposals in specific areas or applications).

Evaluation processes: Converging technologies and their application are likely to profoundly alter the evaluation processes of granting agencies. For the most part, these are discipline based and, in general, agencies have found it difficult to appropriately evaluate interdisciplinary proposals. Since convergence of technologies spells interdisciplinarity, it will be important to strike committees capable of evaluating such research proposals. Given the multiple technical, social and ethical issues that arise, it might be appropriate in many cases to carry out cross-agency evaluations and to include private and public sector experts in the evaluation process. Agencies might consider enlarging the peer review systems with a check on risks and with an ethical, societal and legal review.

Ethics and risk mitigation policies: New technologies bring with them a range of new ethical issues and risks that will need to be anticipated and addressed. A profound knowledge of the potential of CSTs and the applications that are envisaged for them will be necessary to ensure that appropriate policies are developed without generating bureaucratic nightmares. Agencies might consider creating specific institutional arrangements for deliberation and research on risks, societal, legal and ethical issues in relation to their funding programs.

Expansion of learning and diversification of skills through research: Future CST researchers will need to be much more multi- and interdisciplinary than most training programs currently allow for or encourage. It might be necessary to modify existing programs or to implement new ones to meet future needs. Our societies are open and driven by education. It is important to teach youth the meaning of S&T as well as how we value the systems by which we evaluate and decide on risks, society and moral issues associated with S&T. The challenge is to motivate students to develop their civic engagement by stimulating them to be critical and enlightened and above all, to think as autonomous citizens.

Communication of impacts and risks: Just as they have a duty to set up a framework to ensure ethics in research, the funding agencies need to ensure that they have programs to communicate the impacts and risks of the research they fund. Had more attention been paid to communications in the case of GMOs, their acceptance would be higher than it is now. That is not to say that the risks should be ignored, but they should have been anticipated and proper measures taken to

[17] The UK-RS&RAE Report: The Royal Society & the Royal Academy of Engineering, London: (2004) *Nanoscience and nanotechnologies: opportunities and uncertainties* www.royalsoc.ac.uk/policy

mitigate them. Such communication should not be unidirectional, but engage civil society and government. In the words of the Special Interest Group #2 of the EU (The SIG2 Report)[18]:

> *"In general, the institutions of science and technology cherish an instrumental view on the … methodologies to communicate with civil society and government. This vision implies a unidirectional communication. From us (S&T) to them; and in most cases the general idea is that society should properly be informed about new developments. The premise is that when people are properly informed prejudices are relinquished, realistic (S&T) perspectives are shared, (moral) concerns in society can be brought 'under control' and managed, and policy crises can be prevented; and by these efforts, trust will be re-enforced."*

They add that in most of the European countries this approach has not contributed to the handling of morally contested developments. What is required is a strategy that fosters collaboration with society in the construction of ideas and languages to bridge the value gaps and design risk assessment procedures. Agencies might, therefore, wish to implement training programs on communication and public discourse for scientists.

Given the multidisciplinary nature of CSTs and their applications, there is an urgent need ***to foster interagency collaboration in setting processes and policies around CSTs***

4.2 FOR THE CANADIAN BIOTECHNOLOGY SECRETARIAT

The Canadian Biotechnology Secretariat is charged with the implementation of the Canadian Biotechnology Strategy (CBS), which among other things has the mission:

> *"To enhance the quality of life of Canadians in terms of health, safety, the environment and social and economic development by positioning Canada as a responsible world leader in biotechnology. The guiding principles of the CBS centre on reflecting Canadian values; engaging Canadians in open, ongoing, transparent dialogue; promoting sustainable development, competitiveness, public health, scientific excellence and an innovative economy; and ensuring responsible action and cooperation domestically and internationally."*[19]

Therefore, for the CBS to realize its goals, it needs to acquire a profound understanding of CSTs and particularly of the relationship between and the convergence of biotechnology, nanotechnology, information, and cognitive technologies.
Furthermore it must understand how biotechnology and other CSTs impact on:

- the environment
- human and animal health
- social contexts

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[18] The SIG2 Report: Staman, J. (Rapporteur): (2004) *New Technology Wave: SIG II-report on the ethical, legal and societal aspects of the converging technologies (NBIC).* Report of the 2nd Special Interest Working Group http://europa.eu.int/comm/research/conferences/2004/ntw/index_en.html

[19] The 1998 Canadian Biotechnology Strategy: An Ongoing Renewal Process http://www.biostrategy.gc.ca/CMFiles/1998strategyE49RAI-8312004-5365.pdf

- ethics, law and regulatory policies

It must also understand the human implications of the convergence of technologies to protect human dignity.

4.3 FOR DEFENCE RESEARCH AND DEVELOPMENT CANADA

Defence R&D Canada (DRDC) is an agency of the Canadian Department of National Defence responding to the scientific and technological needs of the Canadian Forces. Its mission is to ensure that the Canadian Forces remains scientifically and operationally relevant. DRDC has a broad scientific program and actively collaborates with industry, international allies, academia, other government departments and the national security community.[20]
For DRDC, understanding CST will:

- provide S&T leadership to:
  - increase the knowledge base of the defence community regarding CSTs
  - maintain capabilities and relevance of Canadian Forces in the future
  - understand changing practices
  - understand potential threats and risks posed by CST applications
- help define and structure funding policies, evaluation of projects and allocation of funding
- enable the development of appropriate ethics and other policies

The NBIC technologies have great potential for the defence and security domain. Many of Canada's allies have recognized this. As a result, they are committing substantial resources for the exploration of opportunities as well threats that can result from NBIC convergence. Appendix 8 lays out some possible scenarios that could result from the convergence of robotics, open source and NBIC domains in the near future. Other areas such as health and environment also have potential CST applications which will directly or indirectly impact the defence and security. Clearly inter-departmental effort in this area needs continued support.

5 FUNDAMENTAL ISSUES

Many of the highest-impact new technologies are turning out to have unexpected common features; this is the case for "NBIC" - nanotechnology, biotechnology, information technology, and cognitive science. Nanotechnology and biotechnology are using many of the same information technology tools, such as advanced modeling, visualization, adaptive heuristics, and manipulation of matter at a fine scale. Moreover there is an increasing realization that biotechnology, specifically genomics, is actually merely information technology in a different medium: a gene fills the same role in biology as a segment of programming code in a computer program. Conversely, the burgeoning field of evolutionary computation uses real evolution to solve problems of interest to engineers, as well as biologists. Synthetic biology is implementing, in the present, the first stages of the "assembler,"[21] a self-replicating system that can be programmed to produce mass quantities of desired atomically precise materials. The ethical

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[20] http://www.drdc-rddc.gc.ca/about/us_e.asp
[21] Drexler, K.E.: (1990) *Engines of Creation: The Coming Era of Nanotechnology* Anchor Books,.

issues that come with advanced biotechnology and nanotechnology are overlapping and often intertwined. The legal decisions being made in information technology presage those now emerging in biotechnology and soon to happen in nanotechnology.

US and EU opinion leaders have adopted a different approach to the ethical implications of CSTs. Stressing the importance of economic and scientific opportunities, US opinion leaders mention the ethical implications of CSTs as something of which to be aware without the clearly expressed concern that some of the concepts presented might be highly controversial (e.g. brain to brain communication, genetic modifications of human beings, humanity of a single, distributed and interconnected "brain"). It is as if for them technology development will precede ethical debates.

"…widespread consensus about ethical, legal and moral issues will be built in the process"[22]

By contrast, EU opinion leaders[23] are gearing to ensure the consideration of ethical concerns from the beginning through the EuroSpecs process and well in advance of the development of CSTs. They aim at promoting in the EU, engineering ***for*** the mind and improvements of the cognitive environment instead of the type of approach that considers engineering ***of*** mind and body. They propose to pursue CSTs as tools for the development of local solutions that foster natural and cultural diversity instead of the type of approaches to CSTs that promote an increasingly homogeneous technical culture. They aim at balancing CST-based solutions against low-technology or no-technology policy alternatives. They also promote sustainable development, environmental awareness and precautionary approaches. Finally they opt for a foresight process that will promote citizens' empowerment and aid consumers in understanding, using and controlling CSTs and to help them maintain a sense of ownership.

Several ethical and social issues are currently of concern to civil society. It is anticipated that new issues will arise, as convergence increases and the use of the technologies expands.

> *In general new scientific and technological developments, as well as existing complex technological practices, enforce re-thinking, refining and an articulation of risks and values over and over again. Environmental ethics and risk assessment procedures successfully encouraged the redefinition of our values and norms concerning the environment, and the way restraints are put on technological systems in the marketplace.*[24]

Canada has yet to define its own approach in addressing the risks and ethical concerns related to the research, development and deployment of CSTs and the underlying sciences. The SIG-2 Report suggests the following topics for dialogue in setting a framework, which could serve as a model:

> *"1. Human and constitutional rights; human autonomy, dignity, privacy, integrity, etc*
> *2. Public moral, comprehensive views and societal identity*

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[22] The US-NBIC Report: op. cit.
[23] The EU-HLEG Report: op. cit.
[24] The SIG-2 Report: op.cit.

3. Economical and institutional S&T pressure on society, for instance on public goods (sic) (the commons)
4. Fostering the European identity in S&T policy
5. Identifying and handling risks and their perceptions"

Among fundamental issues needing debate in Canada are:

Economic impacts and technology divide: The economic benefits of converging sciences and technologies are anticipated to be enormous. In the USA, companies have already invested billions into these technologies. For example, the annual survey by *Inside R and D* revealed that the top 100 US companies spent more than $124 billion on R&D in 2001, up 16.2% from the previous year. Companies in the pharmaceuticals, automotive, and telecommunications sectors made the largest investments.

New generations of convergent technologies are expected to create much more efficient business practices with better margins and profits. They are expected to improve work efficiency and production. These advances also bring with them the specter of unemployment, which is an issue of great concern expressed in the EU-HLEG Report.

There is also the apprehension that new technologies may further increase the gap between rich and poor countries.

"If global economic progress in producing high-value products and services depends upon exploiting scientific knowledge, the high entry price for new procedures and skills (for example, in the medical domain) is very likely to exacerbate existing divisions between rich and poor Equally, a parallel danger that could arise if the more radical 'visions' of the promise of nanotechnologies were realised, is that enthusiasm for developing a 'technical fix' to a range of global and societal ills might obscure or divert investment from cheaper, more sustainable, or low-technology solutions to health and environmental problems."[25]

"On the positive side, molecular technologies have real possibilities to eliminate hunger, reduce the cost of energy, and ultimately, economic scarcity. However, the world has had the production capability to eliminate hunger for some time. What has been lacking is the will to do so in terms of politics, economics, cultures, and conflicts. In spite of their powerful potential, biotechnologies and nanotechnologies face these same realities. People, organizations, and governments will make important decisions by design or default." [26]

"By 2015, the world market for all steps of Atomtech will exceed US$1 trillion …Though its impact will be felt first in the North, Atomtech -like biotech before it- will have early economic and environmental consequences for developing countries."

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[25] The UK-RS&RAE Report: op.cit., Ch. 6, 2004: http://www.nanotec.org.uk/report/chapter6.pdf
[26] Spence et al. op. cit.

"Civil society organizations with a history in biotech will experience an immediate and intense déja vu when they hear the claims that Atomtech will be a major benefit to the poor. As with biotech, it is theoretically possible that, in a just and gentle world, Atomtech could have a role to play. In the absence of such a world—as ever—the control of the technology will accrue to those with power and the commercialization of the technology will inevitably give them greater monopoly control."[27]

Human enhancement and human identity/normality: Eleanora Masini and Thierry Gaudin[28] stress how modern technologies might unify cultures. They make clear that identity cannot survive in a monoculture. Conversely, CSTs, given their distributed characteristics could increase diversity within a given nation to the point where national identity is lost. Both authors worry about the impact of convergent technologies on the physical body and mind. They fear the end of societal identity and the self.

"A problem arising from visions for perfecting humans through NBIC is the ethical question of the acceptance of imperfection, such as disabilities of physical or mental nature, i.e. a "right to imperfection" which is being debated in philosophical circles."[29]

Biodiversity and sustainable development: Converging sciences and technologies are expected to have many health and environmental benefits. However, there is concern that the very properties of nanomaterials, for example, might also have negative health and environmental impacts. Will nanomaterials accumulate in the environment? Will they be biodegradable? Furthermore, will the ever greater ability to manipulate the genome lead to a loss of species diversity? These are all unanswered questions.

The ETC group warns that CSTs will:

"…profoundly affect national economies, trade and livelihoods – in countries of both the South and North. Human security and health – even cultural and genetic diversity – will be firmly in the hands of a convergent technocracy. Atomtechnology will also have profound implications for global food and agricultural production."[30]

The authors of the UK-RS&RAE Report take a more moderate view; while they counsel caution, they points out that nanoparticles exist in the environment at present. However they states that:

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[27] ETC Group: *Atomtech - Technologies Converging at the Nano-scale* http://www.etcgroup.org/documents/TheBigDown.pdf

[28] as quoted in the SIG-2 Report

[29] Coenen, C., Rader, M., & Fleischer, T. : (2004) *Of Visions, Dreams and Nightmares: The Debate on Converging Technologies.* http://www.itas.fzk.de/tatup/043/coua04a.htm

[30] ETC Group: The Strategy for Converging Technologies: The Little BANG Theory http://www.etcgroup.org

> *"Until research has been undertaken and published in the peer-reviewed literature, it is not possible to evaluate the potential environmental impact of nanoparticles and their behaviour in environmental media."*[31]

Civil liberties: The convergence of nanotechnologies with information technology promises to provide the basis for complex networks of devices to increase computational power. Some of these devices could be incorporated into other products, for example to achieve greater safety, for tracking and monitoring in manufacturing, for individualized healthcare. The ethical uses of such devices could bring many advantages. However, given the embeddedness of potential applications, negative consequence could (will) arise if (when) the technology is abused. One can envisage implications for surveillance, profiling, and misuse of personal information. The increased uses of surveillance:

> *"…continually seek to identify, classify and evaluate individuals according to ever more refined and discriminating forms of personal data. Sorting is a highly potent set of techniques with political and social-control implications…"*[32]

Military uses: Convergence has a huge potential for and impact on military technology. Sensor networks, implants, autonomous war systems, body manipulation, new biological weapons are likely to be there even faster than expected by civil society. A country needs to define its basic values and norms in the face of these rapid developments.

> *"The 21st-century technologies … are so powerful that they can spawn whole new classes of accidents and abuses. Most dangerously, for the first time, these accidents and abuses are widely within the reach of individuals or small groups. They will not require large facilities or rare raw materials. Knowledge alone will enable the use of them."*[33]

Unrealistic expectations: Given the hype around CSTs, the public may expect near term results which the scientific community may not be able to deliver

Many other issues are likely to arise because of the enabling nature of CSTs. Canada should address these issues within a Canadian framework of values. However, the highlights and questions raised at the Nanoethics Conference held in March 2005 in the USA could serve as pertinent beginning (see Appendix 4). This conference brought leading thinkers from around the world to debate a mix of science, policy, and ethical issues around converging technologies.

Examples of converging technologies that could be analysed[34] against these fundamental issues are:

- FabLabs – personal fabricators / volumetric printers
- Synthetic biology – writing digital circuits in protozoa
- Open Source development – software, biology, education

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[31] *Nanoscience and nanotechnologies: opportunities and uncertainties*. London: The Royal Society & The Royal Academy of Engineering, Ch. 5, 2004: http://www.nanotec.org.uk/report/chapter5.pdf

[32] Raab C.: *The Future of Privacy Protection*. (2004) www.foresight.gov.uk/cybertrust.html

[33] Joy, B.: (2000) *Why the future doesn't need us*. www.primitivism.com/future.htm

[34] All technological innovations qualified as "disruptive" e.g. robotics could be analyzed using similar sets of fundamental issues (See appendix 8 for details)

- Evolutionary computation – evolution to silicon for Artificial Intelligence
- Autonomous vehicles – aerial, underwater, space applications

6 BENCHMARKING INTERNATIONAL FORESIGHT APPROACHES ON S&T CONVERGENCE

The group tried to understand the processes whereby countries and/or regions developed and implemented policies regarding CST and how CST foresight exercises were carried out by identifying what process were undertaken. In particular, recent activities in the USA[35] and the EU[36] were examined. As well, policies and practices used by a number of developing Asian[37] economies for establishing priorities were studied.[38] This section provides a comparative overview of the genesis, processes, philosophies and strategies adopted by the USA and the European Union when planning and implementing CST foresight activities and their likely impact on S&T policies. These are used to benchmark Canada's current practices and future efforts.

6.1 TWO GROUND-BREAKING REPORTS

At the request of the National Science and Technology Council (NSTC),[39] Subcommittee on Nanoscale Science, Engineering, and Technology (NSET), the NSF organized a workshop in September, 2000. A report followed, which incorporated the views expressed by leading experts from academia and government and the private sector who participated in the workshop. The ensuing report[40] was a significant driver of international work in convergence. It stated that:

> *"Over the next 10 to 20 years, nanotechnology will fundamentally transform science, technology, and society. However, to take full advantage of opportunities, the entire scientific and technology community must set broad goals; creatively envision the possibilities for meeting societal needs; and involve all participants, including the general public, in exploiting them."*

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[35] The US-NBIC Report: op. cit. See Appendix 4 for details on the USA

[36] The EU-HLEG Report: See Appendix 5 for details on the European Union

[37] See Appendix 6 for details on Asia

[38] In addition, an overview of how some developing countries are capturing the power of CT is provided in Appendix 7.

[39] NSTC is the principal means for the U.S. President to coordinate science, space and technology policies across the Federal Government.

[40] Roco, M. & Bainbridge, W.S. Eds: *Societal Implications of Nanoscience and Nanotechnology*. http://www.wtec.org/loyola/nano/NSET.Societal.Implications/

The first major step in the US nano-bio-info-cogno (henceforth NBIC) convergence project was the Workshop held in December 2001 and jointly sponsored by the NSF and the Department of Commerce (DoC), the proceedings of which were published in 2002 (the US-NSF Report).[41]
This report advanced an integrative approach for converging science and engineering (S&E) from the nanoscale, information and system levels, with

- a re-focussing on people and a commitment to responsible development.
- new NBIC platforms for science and technology.
- co-evolution of new technologies and human potential.

In March 2000, the European Union (EU) Heads of States and Governments agreed to make the EU "the most competitive and dynamic knowledge-driven economy by 2010."[42] Current European industrial policy calls for an integration of research efforts in the highly competitive sectors of information and communication technologies, biotechnology and nanotechnology, aeronautics and hydrogen energy technology.[43] European science policy also demands a substantially increased investment in nanotechnology so that it can focus on its two "most challenging aspects, in particular, knowledge-based industrial innovation (nanomanufacturing), integration at the macro-micro-nano interface and interdisciplinary ('converging') R&D."[44]

The European Commission (EC) and its member states soon recognized the novel potential of CSTs to advance the Lisbon Agenda and wished to encourage wise investment in CSTs to stimulate science and technology research, strengthen economic competitiveness, and address the needs of European societies and their citizens. They requested that a study of CSTs be undertaken under the sponsorship by the European Commission Directorate-General for Research. The Report *"Converging Technologies – Shaping the Future of European Societies"* (the EU-HLEG Report) was published in 2004.

6.2 SIMILAR PROCESSES

In the USA, a planning meeting was held May 11, 2001 at the National Science Foundation to develop the agenda for the December 2001 NBIC workshop and to identify key participants from academia, industry, and government.
The participants, who were scientific leaders and policy makers across a range of fields prepared and submitted more than 50 written contributions - statements describing what exists then and their vision for what could be accomplished in ten or twenty years. The Workshop was to examine the potential in six different areas of relevance:

- **Overall potential of converging technologies**
- **Expanding human cognition and communication**: e.g., learning how to predict human cerebral function; push back the limits of cognitive complexity; improve sensory and social communications with the aid of CSTs; appreciating the consequences of fully understanding cerebral function.

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[41] The US-NBIC Report: op.cit.
[42] The "Lisbon Agenda" http://en.wikipedia.org/wiki/Lisbon_Strategy#The_Strategy
[43] Communication from the Commission: (2004) *Science and Technology, the key to Europe's future – Guidelines for future European Union policy to support research* COM 353, section 1.2., prop. 5, p. 2.
[44] Communication from the Commission: (2004) *Towards a European strategy for Nanotechnology* COM 338, section 3.1.1., p. 10.

- **Improving human health and physical capabilities**: e.g. Brain-machine interface; human-machine interface – neuroprostheses to increase human performance; artificial brains and natural intelligence; physiological self-regulation; self-diagnostics tools
- **Enhancing group and societal outcomes**: Improvements in communications, group efficiency and creativity; betterment of knowledge and social change organizations: memetics, the coding of culture
- **National security**: Super-performing war planes; non-drug induced improvements in human performance; man-machine interface; unmanned combat vehicles; means of anticipating threats.
- **Unifying science and education**: Education vision for K-12; Biological modeling of language, convergence of computational linguistics and biological chemistry.

Following the USA NBIC Conference, the EU decided to constitute a High Level Expert Group (HLEG). In December 2003, a 25 member group was drawn from a variety of countries and disciplinary backgrounds. The group met formally four times and submitted its report in July 2004.[45]

The HLEG was charged with exploring in breadth, the potential and risks of converging sciences and technologies (CSTs). Instead of simply developing a European response to the US-NBIC report, the expert group was to consider the limitations of previous approaches to NBIC convergence. Therefore, it had to delineate areas of interest and fields of application for CSTs, and to relate CSTs to the European environment and policy goals. The aim of the report was to provide advice to the Commission and Member States on the opportunities and challenges presented by the convergence of key enabling technologies. The HLEG developed scenarios for Europe in 2020.

6.3 DIFFERENT PHILOSOPHIES

The US views CSTs as the synergistic combination of four major technologies (NBIC) each of which is currently progressing at a rapid rate. They foresee that accelerated scientific and social progress can be achieved by combining research methods and results across these technologies in duos, trios, and the full quartet. This convergence is expected to create more functional paths to technology exploitation, instead of the less organized one that exists at present.

According to several critics,[46,47] the US-NBIC initiative is technology-driven, is influenced by a perspective of national security that emerged after 9/11 and by a vision of competitive security and defence for the US. The betterment of mankind does not transpire as a preoccupation. There is little acknowledgment that the scientific and technological capabilities needed to achieve the anticipated technical breakthroughs do not yet exist and may not be on hand in the foreseeable future. Cognitive science is crucial for achieving much of the technological vision but its opportunities and limits are least addressed. Considerations of ethical, legal or social and moral issues related to NBIC are to be addressed *a posteriori*. Also missing are considerations of risks

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[45] The EU-HLEG Report: op. cit.
[46] Coenen, C. op.cit
[47] 2100. org: http://www.2100.org/Nanos/NSFUE.rtf

and issues. The technocratic understanding of society and culture and the vision of a perfect future are also cited as problem areas.

By contrast, the EU, while recognizing the potential of CSTs to advance the Lisbon Agenda, proposes a bottom-up approach to prioritize the setting of a particular goal for CST research; meet challenges and opportunities for research and governance and allow for integration of technological potential as well as recognition of limits, European needs, economic opportunities, and scientific interests.

The EU-HLEG developed its own definition of converging technologies as CTEKS, as reported in Section 3.2. The definition is broad, but nanotechnology, biotechnology and information technology have central roles. In proposing CTEKS, they ask what goals European *societies* wish to attain. This approach recognizes the need to set an inclusive agenda. It proposes drawing on the enabling ability of the social sciences and humanities to deliberate on the limits of C*TEKS* and of technical approaches to societal problems. By including cognitive science within social sciences and humanities, it softens the deterministic approach.

The EU group's approach stresses the importance of preserving Europe's cultural diversity and to create economic opportunity. Social sciences and humanities should provide orientation where CST could disrupt traditional ways of life, serve as intermediaries between political actors, CST researchers and society, and help to assess risks. The methodological and theoretical diversity of social sciences and humanities is appreciated as a reflection of diversity of modern societies. These disciplines are also viewed as enablers of human-centered and demand-driven CST applications.

The EU-HLEG favours an move towards CST that emphasizes engineering *for* the mind as opposed to engineering *of* the mind. It is sceptical about technological enhancements of mental and physical capabilities that might create a divide between enhanced and non-enhanced humans - with the latter being increasingly perceived as "imperfect" or inferior. The impact on identity of transforming the body by technological means is also viewed with some trepidation.

The EU approach has not been without its critics,[48] who argue that however noble the CTEKS vision, its implementation will not be easy. They claim that the lack of communication between the technologist and ethicists at the EU conference bodes ill for the future of CTEKS.

[48] see for example: Sandberg A.: (2004) Shaping the future of Europe through appending prefixes. http://www.eudoxa.se/content/archives/2004/10/shaping_the_fut_1.html

6.4 STRATEGIES

The strategies proposed by the US-NBIC Report consist in:

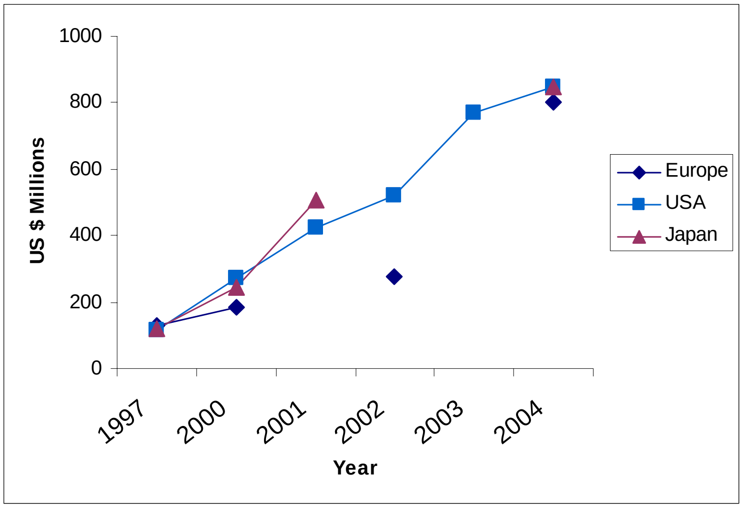
- Preparing key organizations for the social and economic changes induced by convergence
- Organizing activities that will accelerate technology convergence toward improved human performance
- Ensuring full utilization of CSTs in education systems and for life-long learning
- Experimenting with all novel ideas to mobilize researchers around multidisciplinary projects
- Centering programs on multidisciplinary projects, such as the Human Cognome Project, to maximize the impact of teams and organizations.

The EU-HLEG Report proposes to use CTEKS to:

- Identify important technologies and knowledge systems in engineering, natural, social and human sciences at the regional, national et European levels
- Define characteristics and create geographic and conceptual roadmaps
- Identify important links
- Stimulate research to respond to the European needs in health, education, environment, etc. as catalysts for convergence
- Specify CTEK solutions in response to the needs through requests for proposals from researchers in the public and private sectors
- Construct detailed roadmaps including needed social, technical, economic resources; barriers to implementation; timelines; social costs and benefits
- Use normative, ethical and social evaluation to allow comparison of the technical solutions proposed by CTEKS against non- technical solutions.

6.5 IMPACT ON POLICIES

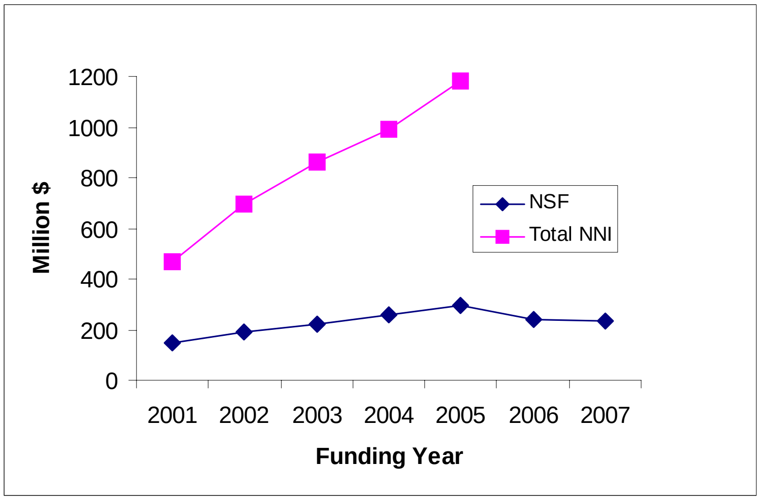
Figure 1: Governments expenses for R&D in nanotechnology



The impact of these studies on policy can only be assessed using proxy measures, given that CSTs are a relatively recent development and that most databases do not capture investments in CSTs as such. The investments of nations or regions in nanotechnologies were used as to gauge their will to go forward with the plans outlined in the studies. As shown in Fig.1,[49] it is estimated that in 2004, the USA, Europe and Japan together expended more than 2.8B$ for R&D in nanotechnology. Other countries together expended another 700 M$. The total rose from an estimated 450 M$ in 1997 to about 3.8 B$ in 2004. In the USA investments have more than doubled since 2001, and in Europe they have almost tripled.

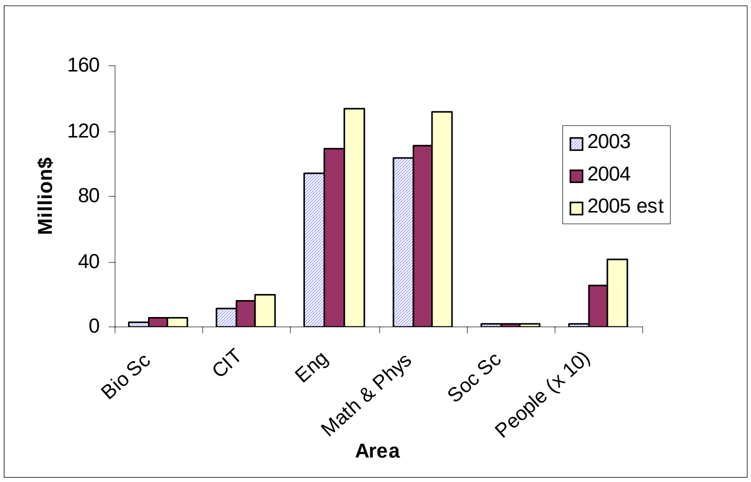
[49] Sources: Bio-Nanotechnology in Japan - Venture Capital, Public Policy and Results; US National Nanotechnology Initiative, Supplement to the President's FY2004 budget; M.C. Rocco March 2005 (NSF estimates)

Figure 2: Actual and expected nanoscience funding by NSF and NNI



The NSF in the US currently has four priority areas: Biocomplexity in the Environment. Mathematical Sciences, Human and Social Dynamics and Nanoscale Science and Engineering (NS&E). The year 2007 will be the final year for the NS&E priority area, hence the decrease in funding shown in Fig. 2 (note that the data for 2005-07 in Fig. 2 are estimates).[50]

Figure 3: NSF nanoscale S&E funding by area



NSF funding in NS&E is distributed among various areas, as shown in Fig. 3.[51] Engineering and Mathematics and Physics receive the most funding, whereas Biological Sciences and Computer and Information Technology (CIT) receive considerably less. Very little funding in this area is directed towards the Social Sciences. People (scholarships, salary awards counted for even less: Actual amount has been multiplied tenfold to appear in Figure 3.

NSF funding is a relatively small proportion of the total funding for nanotechnology in the US. The National Nanotechnology Initiative established in 2000 is a federal R&D program established to coordinate the multi-agency efforts in nanoscale science, engineering, and technology. Twenty-three federal agencies participate in the Initiative, 11 of which have an R&D budget for nanotechnology. Other Federal organizations contribute with studies, applications of the results from those agencies performing R&D, and other collaborations. The NNI will invest more than 1.2 B$ in R&D in 2005.

Funding for the Societal and Educational implications of nanotechnology (health, environment, etc) is equal to 15% of total NNI funding. This includes research and regulatory activities in health and all fellowship programs.

[50] Source: ibid

[51] Sources : NSF FY 2005 Budget Request to Congress (NSF); NSF estimates M. Roco 03-2005 (NNI)

In the EU, the difference between the funding for the Sixth (FP6) and Seventh (FP7) Framework Programs was used as another proxy. This is represented in Table 1

NBI (as opposed to NBIC, Cogno being considered among the Social Sciences) were a large part of FP6 (more than 50%) and will remain at the same level in FP7. One of the major differences between FP6 & FP7 appears to the much greater concerns for the socio-ethic components of ICT, Health, Nanotechnology, etc. and the factors that impact on human behaviour. Whether the research will actually translate into policy remains to be seen.

Table 1: A comparison between the sixth (FP6) and seventh (FP7) Framework Programs[52]

FP6 Themes Total	€ 12.4m	**FP7 Themes** Total	€ 44.4m
Information society technologies	28.5%	ICST	32.0%
Life sciences, genomics, biotechnology for health	20.2%	Health	18.7%
Sustainable development, global change, ecosystems	18.7%	Transport (incl. Aeronautics)	13.4%
Nanotechnologies, Materials, Processes Devices	11.5%	Nanoscale, Nanotechnologies, Materials, Prod. Technologies	10.9%
Aeronautics and space	9.5%	Security and Space	8.9%
Food quality and safety	6.1%	Energy	6.6%
Citizens and governance	2.0%	Environment (incl. Climate Change)	5.7%
		Food, Agriculture, Biotech	5.5%
		Socio-Economic Sciences & Humanities	1.8%

52 http://www.cordis.lu/fp7/themes.htm

Figure 4: Distribution of government R&D appropriations (1998 or 1999

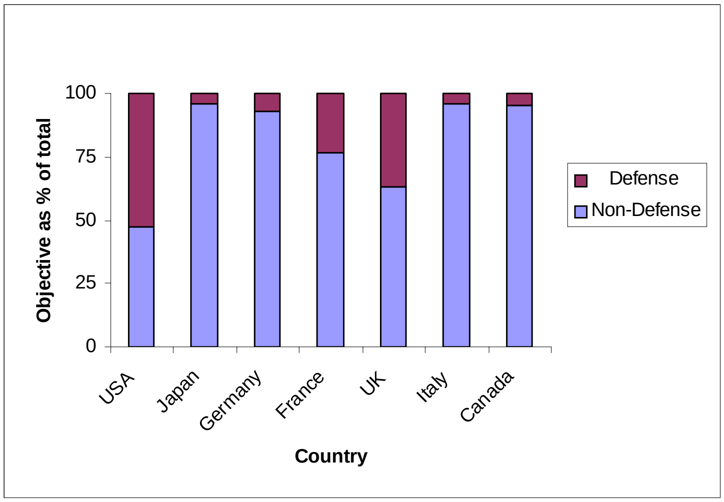


Fig. 4[53] shows the distribution of governments R&D appropriations by objective[54] (defence and others). Data are for 1998 for Italy and Canada and for 1999 for the other countries. The USA does not have a detailed R&D policy. However, its policies may be inferred from the distribution of research funding: More than 50% of government research funding in the US is for defence-related areas.

6.6 CANADA

6.6.1 Technology foresight at the federal level

In 2002-2003, the Office of Technology Foresight at the National Research Council of Canada carried out a Science and Technology Foresight Pilot Project (STFPP) involving 13 federal Departments and Agencies in an exploration of S&T foresight with a view to better understanding some of the longer term, integrative and horizontal challenges and opportunities that the federal S&T community might have to cope with, looking ahead to 2015 - and beyond.

From June-October 2002, NRC proceeded to enlist science-based departments and agencies (SBDA) nominees and expertise in the creation of an Interdepartmental Working Group (IWG) to design the process for exploring the application of foresight tools. The STFPP was launched in October 2002, after four months of preparatory work. Two topic areas (Bio-Systemics and Geo-Strategics) were eventually selected through a collaborative process that arose from the preparatory stages.

The ***Bio-Systemics area*** included scientific research and emerging technologies based on convergence opportunities involving: genomics and proteomics, nanoscience and technology; bio-informatics, bio-computing; the intersection of cognition and information science; environmental sciences and human ecology; disease systems and spread factors.

> *"The NBIC initiative has also attracted the attention of [the USA] northern neighbour, Canada, which concerned itself with convergence in its own pioneer*

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[53] Source: NSF Science & Engineering Indicators 2004, Table 4-49
[54] Adapted from the NSF Science & Engineering Indicators, 2002
http://www.nsf.gov/sbe/srs/seind02/append/c4/at04-43.xls

foresight study on "Biosystemics", the Canadian variant of convergence, which gives special attention to ecological science in addition to the NBIC quartet."[55]

The Geo-Strategics area included potential geo-spatial future applications, technical developments, scenarios and S&T pathways derived from technological advances expected in: land, sea and space based sensing, robotics and wireless data infrastructure; advanced imaging capabilities, pattern interpretation, location-based functionalities; intelligent systems, emphasis on real time identification and decision-making; prospective new tools for monitoring and managing Canada's environment, resources, and agriculture; understanding disease network structures and threats; emergency and security implications drivers.

As a pilot project, the ***process*** was directed towards and restricted to SBDAs within the Canadian Government. It included:

Scoping workshops and Expert panels: these were designed to solicit submissions from participating departments and identify unifying topics.

Scenarios: Scenarios are most useful when the external environment is complex and uncertain and the internal decisions involve major long-term investment or have long-term consequences. Ten scenarios were considered

- *Agility Canada - Canada makes good.*
- *Apocalypse Redux - Environmental and social collapse.*
- *Insecure Cocoon - Crime and terrorism on the upswing.*
- *Muddling Along - Business as usual.*
- *O Say can you C (Merger USA) - Canada becomes a de facto U.S. state.*
- *Techno-Ban - Backlash against technology*
- *Techno-Ethics - Life in balance: appropriate and sustainable technology*
- *Techno-Mania - Anything goes, as long as you can pay for it*
- *Virtual Avatar - Cyberspace becomes dominant for human interaction*
- *You Are What You Invent - Skunk-works group, designing technology*

Reports: The results of the exercise are embodied in several reports.[56]

The ***philosophy*** was first and foremost to bring the various actors together to enable horizontal approaches to the solutions of complex issues and thus, maximize benefits. It was designed to identify broad thematic areas/societal needs that might galvanize collaborations among the various potential participants and organize a research community around them that is capable of carrying out foresight activities such as surveying capabilities and specific roadmapping.

6.6.2 Technology foresight in Québec

In 2003, the "Conseil de la science et de la technologie" in Québec undertook the foresight exercise "Perspectives STS (science, technology, society)" with three major objectives: 1) to

[55] Coenen, C. op.cit
[56] See http://www.techforesight.ca/content/STFPP-general.html

make Québec society aware of the importance of S&T in solving socio-economic problems; 2) to invite the scientific community to become partners in using S&T to pursue social and economic aims, where appropriate; and 3) to ensure that Québec's socio-economic development partners are involved in the identification of and solution to the major socio-economic challenges that are anticipated in the course of the next two decades.

The project is divided into two phases:

Phase 1: identify the challenges perceived by Québec's society at large and the scientific community through:

- Consultation with the public through focus groups followed by a questionnaire to discover the principal preoccupation of Quebeckers over the next two decades
- A foresight workshop with 100 policy and decision makers to establish a list of about 40 likely socio-economic challenges likely to arise over the next 20 years.[57]
- A consultation with the research community to reduce the list to ten of the challenges where the contribution of S&T is likely to be have the most impact.
- The production of reports on the various themes that have been identified through the process.

In Phase 2, the foresight and strategic analysis phase, the CST will seek partners from the various sectors to define objectives and establish the best strategies to meet them.

6.7 CANADIAN POLICIES

Canada does not have a national science policy. However, several provinces (e.g. Quebec, Alberta and Ontario) have declared research priorities. Compared to European countries, for example, foresight activities in Canada are recent. Quebec is probably the most advanced among Canadian jurisdictions in using foresight methods to identify areas of priority. The process described in Section 6.6.2 has identified six major themes under which the 40 most important challenges can be grouped.

- Health & lifestyles
- Environment & resources
- Economy, research & innovation
- Education
- Demography & communities
- Culture & society

Alberta identifies Energy, Information and Communication Technologies and Life Sciences as priorities,[58] whereas Ontario's Ministry of Economic Development and Trade has identified similar ones: Materials, Life Sciences, Energy and Emerging Technologies and the province has invested heavily in Health and Education.

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[57] Rapport sur l'atelier de prospective organisé par le Conseil de la science et de la technologie: *Construisez leur avenir : 40 grands défis pour le Québec*

[58] cf: http://www.innovation.gov.ab.ca/

Health, the economy, the environment, energy, and education appear to be general concerns in many jurisdictions in North America, Europe and Asia (see appendices). Many, if not all, of these areas could benefit from the advances made in CSTs and the intellectual space created, to improve the planning and monitoring of their development.

7 GOING FORWARD IN CANADA

A foresight exercise focused on converging technologies could be of benefit to Canadian society at large and, if they partner with a federal exercise, could help the provinces focus their investments in the specific areas that they have identified as their major challenges.
Therefore, it is essential for ONSA to develop the partnerships necessary to deploy Phases 2-4 of the proposed foresight exercise (Phase 2 Workshops to identify key questions; Phase 3: Scenario development; Phase 4: Expert Panels to determine final contents) and engage the provinces, the granting agencies, the research community, civil society and the private sector in those exercises.
ONSA needs to select the appropriate foresight tools in consultation with partners, leading to the eventual implementation of Phase 5, the development of recommendations.

8 TOOLS FOR FORESIGHT IN CONVERGING SCIENCES AND TECHNOLOGIES

Processes and tools for understanding the future of converging sciences and technologies can be adapted from those widely used in foresight exercises *examples include*:

8.1 PROCESSES

Processes refer here to the planning, implementation and outcomes dissemination of approaches-used individually or in combination- aimed at triggering participative "futures" thinking leading to decision making. The more "open" and "inclusive" approaches has been reported to ease the "buy in" of potential outcomes and community involvement in the development of positive avenues and the prevention of negatives ones. Approaches used more frequently in reviewed foresight exercises are:

Scoping workshops: Selected attendees assist the project sponsor and developers in defining the boundaries of the scope for the intended project and for prioritizing requirements within the scope. These can be preceded by broader consultations, where appropriate. More precisely applied to CSTs, the scoping workshops would determine key questions around convergence as it relates to stakeholders and subfields of science and technologies that are of greatest interest to them.

Expert working groups or panels: Experts in different areas are asked to define specific contents, methods and policy. Such panels would develop an ongoing convergence dialogue centering on key convergence areas that Canada may wish to develop or in which it already has strengths.

Scenario building exercises are a method of "anticipating the future – actually plausible, diverse futures" that rely on a series of assumptions about alternative possibilities, rather than on simple extrapolation or existing trends.[59] Such an exercise could uncover the potential opportunities and challenges that convergence will afford to Canada.

Web-based consultations: Given Canada's geography and limited means, an "open foresight" process should be considered, taking its cue from the process used by the EU to plan the 7th Framework Program (FP7). Before undertaking the FP7 exercise, the EU came to the conclusion that a more general planning process was needed. The EU believed that foresight exercises could enhance a learning process based on experience sharing, and developing a "European distributed strategic intelligence system" for future-oriented participative activities. For these reasons, they undertook an open online consultation "EU Science and Technology Foresight in FP7." The target groups were the Foresight community, policy-makers at national and regional level, research organizations, universities, industry, international organizations and associations.

> *"… the WEB-based consultation highlighted that participants appreciated mutual learning and exchange of experiences in Foresight. However, they particularly pleaded for EU-wide issues to be tackled in Foresight as well as global views and global monitoring. A combination of both "disseminated Foresight" and "specific focused horizontal activity" in FP7 seems to be the favourite option for a large majority, the main argument behind that an integrated approach combining both horizontal and vertical approaches is necessary for synergy."*[60]

Web & video conferencing could also be used in Canada to join the various partners together in foresight activities without the disruption and costs of travel. However, these "distance" activities need to be built on a climate of trust among all the participants as well as impeccable planning of the activities to be undertaken.

8.2 TOOLS

Various tools can be used, regardless of the selected process to help structure collective thinking on multi-faceted topics or issues. The tools introduced below are provided by the STFD group as templates or examples of tools to be tailored to specific objectives and needs of the various foresight exercises.

[59] www.nap.edu/openbook/0309072786/html/113.html
[60] http://europa.eu.int/comm/research/foresight/07/article_2402_en.htm

Figure 5: An example of Roadmap

Issue - application driven technology roadmaps: Roadmaps describe a future environment, objectives to be attained within it and plans for achieving the objectives over a given period. Roadmaps provide a framework for understanding how the parts of intricate systems fit together, interrelate and develop and the time scale over which they do so. Roadmaps are best constructed by teams of people who will carry out the plans and are a way of achieving consensus and buy-in.

According to The Albright Strategy Group[61], roadmaps for CSTs, teams should define applications and related technology areas, identify trends, and refine architectures. In the case of CSTs, it is particularly important to identify areas where there is important interaction among the fields, that is, where technologies from multiple fields can come together to solve real-world problems.

> *"There are many questions teams might seek to answer about the future of the converging technologies. What inventions will be practical enough to become innovations, and when? How will the fields interact to produce innovations? What customer and market drivers and development actions will be needed for commercialization? What are gating factors to innovations and how can they be satisfied? What are the risks to innovation?"* [62]

Domain matrices: It is possible to make concrete one's thinking on convergence by considering how one technology domain might contribute to one or several others. The domain-domain technology matrix proposed in Table 2 is a preliminary and partial attempt to classify some specific technologies which are the result of using one domain's techniques or thinking in a new field.[63]

For each CST a contributing domain and an extended or assisted domain are identified. Each application area is the result of using the contributing domain at left to assist or extend the assisted domain labelled across the top. For instance, nanoarrays use nanotechnology (nanomanufacturing) to aid or improve biotechnology (the ability to sense and identify millions of different types of molecules).

Similarly, biotechnology is assisting and extending nanotechnology through the technology of synthetic biology. Synthetic biology is the "art" of taking a simple digital logic circuit, coding it

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[61] http://www.albrightstrategy.com/converging_technologies.html
[62] Albright, R.E.: *Roadmapping Convergence* *http://www.albrightstrategy.com/papers/Roadmapping_Convergence.pdf*
[63] See appendix 8 for further definitions

in genetic material, and inserting it into a unicellular organism. For instance, bacteria have been genetically programmed to use a 1-bit memory circuit to "remember" if they have been exposed to bright light. They demonstrate their "memory" by expressing GFP, a green fluorescence protein. The "genetic circuit" thus formed produces what could be called a "bacterial photography". This was vividly demonstrated by printing a mask with the text "Hello, World" cut out from it, and shining light from a projector onto an agar plate infected with immobilized bacteria. When later exposed to ultraviolet light, the bacteria illuminated with light shone green, repeating the traditional computer science test message. Synthetic biology is an excellent example of technology convergence, as digital circuit design (information technology) is being applied in genetic systems (biotechnology), often to produce behaviour at the nanoscale (nanotechnology). Accordingly, synthetic biology appears in two positions in the domain-domain matrix shown in Table 2, both as information technology extending biotechnology and as biotechnology extending nanotechnology.

Of course, a full analysis would fill out the full 4-tensor enabling all combinations of technology domain linkages.

Table 2: Example of domain-domain matrix

Contributing Domain	***Extended or Assisted Domain***			
	Bio	***Nano***	***Info***	***Cogno***
Bio		• synthetic biology • RNA scaffolded nanostructures	• DNA & RNA nanotags • DNA computing	• evolutionary computation • cognitive-enhancing drugs • biorobots
Nano	• nanobiosensors • nanoparticles for smart drug delivery • nanoarrays		• single molecule transistors • nanowires for integrated circuits • nano memory	• nanoelectrodes • nanocomputers • real-time brain nanosensors
Info	• protein structure prediction • metabolic pathway discovery • proteomics and other analyses • synthetic biology	• molecular dynamics simulations • nanophysics modelling • ab initio calculations		• brain augmentation • collaborative filtering: Google & Amazon • avatars & software agents • personal networking
Cogno	• automatic algorithm generation for bio-applications • bio-data mining	• EC for force field optimization • machine optimization of nanodevices	• swarm intelligence for network optimization • software agents for network threat discovery	

Technology impact matrices: These can be constructed using combinations of CSTs to assess or vision their potential impacts on selected subjects, such as the environment, economics, public safety or health. Many other subjects of interest could be added such as governance, cultural diversity. The example below (Table 3) uses pairs of technologies, but more complex combinations could also be used. For each subject, some of the technologies likely to arise for nano/bio and info/cogno convergence can be rated as positive (+), negative (-), neutral (+/-), or unknown (?). Any rating assigned will depend on the perspective, outcome and even the identity of the evaluator. For example, the production of synthetic life through nano/bio convergence could be viewed as neutral, positive, or negative, depending on the point of view, the application and the likelihood that the impact on the environment could be irreversible. Such an exercise is aimed at forcing the participants to express their views and the reasons for them and can be used as a method of assessing risks and benefits of CSTs and taking appropriate action.

Table 3: Technology impact matrix

Impact on	***Nano / Bio***	***Info / Cogno***
Environment	Nano-particles Energy-efficient machines Synthetic life CO2 scrubbers	Reality browsing / Sensor nets Integrated landscape models
Economics	Personal fabrication, volumetric printing and manufacturing	IP and brands become the central repository of value IP more easily violated through invasive, invisible sensor technology
Public Safety	Gray goo GM hazards	Disaster response platform Info-security, privacy
Health	Nano-medicine Expensive, proprietary medical solutions available primarily to the rich of the world Pharmacogenomics, slowdown of aging	Health Informatics and analysis - Privacy concerns for personal genomes Genetic predeterminism and prejudice as new social ills
Governance	Fast brain : machine interfaces Expanded creative abilities Improved learning skills	Communications across barriers of language, distance, etc. Instantaneous access to information Organizational structures based on fast communications

Both the domain-domain matrix (Table 2) and the table of negative and positive impacts of convergence on possible domains of application (Table 3) could be used to discover what new science is involves and where Canada is able to benefit by focusing its research investments.

The next steps of the project will focus on the elaboration of the matrix cells in the two preceding tables and their prospective implications and impacts in Canadian society.

9 CONCLUSIONS

In this work, the Science and Technology Foresight Directorate has attempted to introduce a preliminary framework to delineate Canada's Foresight on Science and Technology Convergence. It suggests some definitions, principles and prospective instruments to support the planning and implementation of further analyses and foresight work. It focuses on NBIC (or BANG) technologies with a particular lens on ethical issues and social empowerment. This framework is inspired from a review of foresight practices and perspectives regarding CST in countries/regions where work on CSTs is developing at a rapid rate.

The value to society of successful CSTs applications will be measured in improved health, better environmental protection, economics, and in increases in human comfort, ability, and dignity. However, Science and Technology convergence also poses the challenge of shifting boundaries and new winners and losers. The ethical implications of many CST applications are significant. Early indications lead to the conclusion that there is a need to bring ethical debate into the realm of public discourse. Issues extend from maintaining privacy rights of citizens to the sorts of human enhancements society is willing to allow. This means involving a wide variety of voices in the discussion: from scientists and economists to law and policy makers, ethicists, opinion leaders and the public.

Doing foresight on science and technology convergence requires accepting uncertainty as a norm. Incorporating the best evidence and considering current trends and current research can offer valuable insights into multiple plausible contingencies of the future. Foresight can offer new ways of thinking about the convergence of technology domains. Not all possible future technologies are equally accessible, feasible or indeed desirable. Looking forward 20 years, it could be envisaged that some of the technologies that are currently thought of as being in the realm of science fiction may become realities. Therefore, it is important to capture what is known today about possible future convergent technologies to inform our thinking as a nation. It is also important to be aware of international trends in this area.

Technology convergence is a global phenomenon, and Canada is and will remain a modest piece of the global picture. On the other hand, Canada has significant leverage afforded by its high per-capita income, a strong educational system, and its social commitments to universality and respect for diversity. Canada has an opportunity to select appropriate areas of CST applications in which it could position itself strategically, as well as establishing itself as a world leader in thinking about the ethical, legal and social challenges posed by CSTs and their applications.

Canada is lagging behind European nations in adopting foresight methodologies to select priorities and mitigate the perceived and real risks of emerging technologies and their applications. In this context, ONSA could play a critical role in catalyzing partnerships among various jurisdictions/groups to carry out a foresight exercise to make recommendations on issues such as: the exploitation of particular niches from which Canada and/or provinces could derive socio-economic benefit and the timely design of policies (e.g. legal, ethical).

ONSA could also be a leader in fostering the development of innovative mechanisms to inform policy, such as the creation of a risk bureau, a federal CST applications centre and collaborative simulations for exploring policy options.

ONSA has made some progress toward a more active societal engagement strategy for the uncertainties associated with convergence. It continues to be invited by the European Commission to participate in their converging technologies deliberations, and represents Canada on the international forum for the responsible use of nanotechnology.

10 APPENDIX 1 - LIST OF ACRONYMS

BANG	Bits, Atoms, Neurons, Genes
CBS	Canadian Biotechnology Secretariat
CTEKS	Converging Technologies for a European Knowledge Society
CSTs	Converging sciences and technologies
CTTs	Convergent Transformational Technologies
DRDC	Defence Research Development Canada
EU	European Union
FP	Framework Program
HLEG	High Level Expert Group
IDB	Industrial Development Bureau
ITRI	Industrial Technology Research Institute
MDEIE	Ministère du Développement Économique, Innovation et Exportations
MEXT	Ministry of Education, Culture, Sports, Science & Technology
MOEA	Ministry of Economics Affairs
MOST	Ministry of Science and Technology
NBIC	Nano-Bio-Info-Cogno
NNI	National Nanotechnology Initiative
NRC	National Research Council of Canada
NS&E	Natural Science and Engineering
NSERC	Sciences and Engineering Research Canada
NSF	National Science Foundation (USA)
NTRM	National Technology Road Map
OECD	Organization for Economic Cooperation and Development
ONSA	Office of the National Science Advisor
SBDA	Science-based Departments and Agencies
SSHRC	Social Science and Humanities Research Council
S&TC	Science and Technology Convergence
SCJ	Science Council of Japan
STFD	Science & Technology Foresight Directorate
TRMs	Technology Road Maps
UCFP	Understanding Convergence 2005-2025 Foresight Project
US	United States of America

11 APPENDIX 2 - A BRIEF OVERVIEW OF THE NBIC TECHNOLOGIES[64]

NANOTECHNOLOGY

Nanotechnology is defined as the manipulation of objects with a characteristic size of 100 nanometres or less, approximately the size of a single virus particle, which take on new properties due to their small size. Many interesting behaviours happen at the nanoscale: from optical effects (being smaller than a wavelength of light makes most nanoparticles transparent) through effects on strength (nanosized domains make most metals and alloys much stronger than bulkier forms.) For instance, nanotubes have a strength-to-weight ratio about 80 times better than steel in tension.

Many macroscale devices beg to be optimized by nanotechnology, such as the conversion efficiency of thermoelectrics, insulation, and light gathering. Nanotechnology could lead to efficient batteries, solid-state refrigeration, lighter and less bulky clothing, and "spray-on" solar cells.

Perhaps more interesting, nanotechnological "devices" can be used to do things on command. For instance, nanoparticles of gold can be bound to sulphide-terminated cDNAs, allowing the detection of one specific DNA sequence among millions. "Smart" drug delivery – depositing the drug where it is required and nowhere else – is envisioned through nanoparticles of various types.

Computers are already stretching to the nanoscale with line widths of 90 nm becoming common in new work. This is not considered nanotechnology since the behaviours are qualitatively similar to those at larger scales. However, at line widths around 13 nm and smaller, new techniques such as molecular transistors will be required .

The most obvious convergence already exists at the nanoscale: Cells are efficient factories; their proteins and RNA autosomes, for example, are natural liquid-phase nanomachines. They work with atomic precision and perform one carefully specified function. By pursuing nanotechnology research, the hope is that many useful nanoproducts and nanotools can be manufactured with equal precision without requiring that cells make them.

Quantum dots, for instance, allow light to be made at a nanoscale in a tuneable manner that is impossible to achieve with bulk materials – essentially creating new substances with unique optical properties. In these, light can be slowed down, emitted, or converted to electricity at high efficiencies.

Much is unknown at the nano scale – from the toxicity and bioaccumulation profiles of nanosubstances to the detailed behaviour of new materials. Clearly, much more research and significant consensus are required to ensure the safety of researchers and the general public.

[64] Contributed by Steffan Christensen and Hassan Masum

BIOTECHNOLOGY

Biotechnology is interpreted here as the application of technology to living entities and materials. The completion of the human genome project has given information biotechnology a massive boost. Genes are routinely sequenced and the larger problem of puzzling out the "proteome", the "catalog" of proteins and interactions among them that give rise to life, is underway.

Biotechnology is turning out useful products, mostly through recombinant DNA. For example, recombinant insulin has been produced from transfected *Escherichia coli* since 1982. Natural insulin from cadavers would cost over $5000 per vial, according to one source. Beef and pork insulin is much less expensive, due to supply, but initially purification was a problem and adverse reactions occurred. Now a 1000 iu vial of recombinant human insulin sells in the United States for $31, in Canada for around $14 and in India for $7. The stories of human growth hormone and interferon are similar.

The production of nutriceuticals, such as lycopene, pharming, which is a way of engineering plants to produce non-plant compounds, such as the production of oil-soluble drugs in safflower are other examples of the use of biotechnology. In addition, a bioproducts industry is emerging, based on using biological agents to produce non-health products. Examples include the use of unused straw to make ethanol for fuel, biopolymers for consumer materials, food additives such as agar, pectin and carrageenan and the manufacture of enzymes for natural cleaning, bleaching and biodegradation.

Biotechnology is also likely to be used in new ways, to make nanofibers such as synthetic spider silk, anti-nerve toxin agents such as butyl-choline esterase. Synthetic biology, where entire digital circuits are manufactured and inserted into bacteria or yeasts, is a promising avenue is. This has already been used to perform bacterial photography and to sense one of three concentrations of caffeine in water. The possibilities of biotechnology seem virtually boundless.

INFORMATION TECHNOLOGY

Advances in information technology have spread to even remote corners of the globe. A million fold increase in processing power has brought capabilities that used to be the province of mainframes into the reach of personal computers, and even pocket devices. Communications have similarly advanced greatly – affordable bandwidth and ubiquitous wireless access have made international communications commonplace. Combined with open standards, this has led to the formation and rapid uptake of the Internet.

Powerful processing and communications technologies have become readily available to the average person. It is possible to communicate with one another, write a document, print a poster, calculate an orbit, publish a Web page, store photos and music, and do any of a thousand other activities which once were the province of experts rapidly and efficiently thanks to modern computer equipment. What more does the future hold?

The forward march of bandwidth and processing speed will continue, but may be utilized more effectively - by adaptive technologies, for instance, which allow computational agents to learn and be flexible in response to their users or environments. "Good enough" machine translation could lower linguistic and cultural barriers. Videoconferencing and broadband collaboration platforms have the potential to radically increase the effectiveness of all group-based activities, from engineering to business interactions, from policy planning to the democratic process itself.

Even more progressive possibilities lie on the near horizon. For example, a marriage of information technology and advanced mechanical design may lead to autonomous robotic agents sooner rather than later.

COGNITIVE SCIENCES

The workings of the brain are still understood only in the broadest brushstrokes. Will science manage to decode the neural patterns of the brain, and become capable of reading the moods, intentions, and thoughts of people by means of sensing devices? Will it ever become possible to alter those features?

One imagined application: "the reliable truth machine" could have immense impacts on society.[65] Would social or political actors be required to make their platform statements while using the machine? Would it become mandatory for witnesses and the accused in trials? Is society ready to move toward a world where honesty is scientifically testable?

Medical applications will be another key driver. Already, paralyzed patients have had sensor arrays implanted, enabling them to exert some control over a computer input device[66] - and hence to communicate, control their movements, call for help, engage in work, and independently do a myriad of other activities essential to a full life. Similarly, experiments in animals indicate potential for direct brain-computer command signalling. Understanding the brain's workings will also assist the treatment of mental and behavioural disorders. However, this poses the question of whose definition of "normality" should be enforced.

There is also the "potential" to directly enhance human performance. Direct brain-machine interfaces are only the most obvious possibility: augmenting and supporting human intelligence in more subtle ways could have far-reaching effects. One can imagine the power of increasing human attention span, intuition level, or even speed of thought. Whatever it is that makes human kind, would having more of those qualities make it more truly human - or lead to a dystopian nightmare?

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[65] Halperin, J.: (1996) *The Truth Machine* Ivy Press
[66]" Page, R.M.: (2003) *Mind Control*, Wired, 13.03, 05/03 - www.wired.com/wired/archive/13.03/brain.html

12 APPENDIX 3 - DEFENCE AND SECURITY APPLICATIONS OF CONVERGENCE[67]

12.1 BACKGROUND

Understanding the relevance and potential impact of emerging technologies is integral to providing state-of-the-art science and technology leadership within the defence environment.[68] To ensure that the Canadian Forces (CF) remain technologically prepared and relevant in a future defence environment, it is essential to follow the emerging technologies with the potential for the provision of new and innovative defence capabilities.

To engage the defence community in understanding the role of emergent and potentially disruptive technologies, Defence Research and Development Canada (DRDC) sponsored a symposium in 2003.[69] Presentation covered various aspects of convergence along with specific technologies of interest to defence such as stealth, communications, autonomous intelligent systems and encryption.

12.2 INTRODUCTION

The unpredictable and often disruptive effect of technological advances is particularly important when two or more of the technologies merge, as is the case with the convergence Nano, Bio, Information and Cognitive (NBIC) technologies, to create new opportunities. The convergent technologies can spawn new applications but, equally, they can be used in an innovative fashion that significantly alters established practices. The defence communities in many industrialized nations see great potential for NBIC convergence especially as a means for improving performance and the safety of soldiers and first-responders. To find how the CF might be affected by these developments, DRDC sponsored a study to look at the potential defence applications of NBIC convergence.[70]The study found that, indeed, the synergy arising from a combination of NBIC technologies is expected to lead to enhanced human capabilities. The likely results of convergence are increases in sensory-cognitive capabilities, improvements in human-machine interfaces, and reduction of physical and cognitive decline. All of these are expected to contribute to human performance and personal safety.

12.3 SOME ENABLERS

The exact means by which NBIC convergence will change the defence operations are still not clear since much of the science and technology related to NBIC convergence is still in its early development. What we can talk about at this stage is some possible areas that will influence the future conduct of the CF.

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[67] Contributed by Afaq Ahmad
[68] The US-NBIC Report, op.cit
[69] See: http://www.drdc-rddc.gc.ca/newsevents/events/st_sympo_e.asp
[70] MacKenzie, S., Chong, A., Romet T. and Thomas, K.: NBIC Disruptive Technology Watch, DRDC and CAC Project Number: 510-2844 (April 2003).

The capabilities listed in Table 4 below are conjectural and far from being exhaustive but they give a flavour of what to expect in the future as the products and services based on NBIC convergence graduate from the lab to the marketplace.

Table 4: Possible new capabilities and their enablers

CAPABILITY	ENABLERS
Expanded human cognition and communication enabled	Brain implants, new drugs, rapid learning and direct brain-to-machine interfaces
Improved human health and physical capabilities	Nano-biosensors to monitor and repair bodily functions, and systems that enhance human sensors
Nano robots for surveillance and medical applications.	Nano-fabrication, genomics
Responsive and collaborating autonomous intelligent systems to support decision-making	Global information systems, Nano-robots

12.4 ENHANCED HUMAN PERFORMANCE-EXAMPLES

An integrated helmet is a specific defence capability that could be enabled by combining developments in nanotechnology, information and cognitive technologies. Such an helmet would have tuneable hearing, night vision, communication systems, physical and auditory protection providing tactical awareness and cognition of "in-field" activity. Another example is integrated wearable, wireless miniaturized sensors, communications and computers woven into the fabric of uniforms/body armour. The uniforms for field personnel could be made from self-sterilizing organic and inorganic hybrid materials. The same type of material would make sterile/clean surfaces available in field situations.

12.5 CONCLUSION

The mission of DRDC is "…to ensure that the Canadian Forces remain technologically prepared and relevant". To accomplish this in the future, DRDC is engaged in multi-faceted R&D that often crosses the boundaries between the life sciences, engineering, information technology and the physical sciences. In recent years, applications based on NBIC technologies have been evolving at a rapid rate. This presents Canada and its Allies with both opportunities and threats forcing them to look at exploiting NBIC convergence to stay ready and able to face the peace and security challenges of the new century.

13 APPENDIX 4 - SCIENCES AND TECHNOLOGY CONVERGENCE IN THE UNITED STATES[71]

13.1 INTRODUCTION

The September 2001 report entitled “Societal Implications of Nanoscience and Nanotechnology,”[72] was a significant driver of international work in convergence. The report drew from work done in 1999-2000 on the idea of convergence and divergence in mega-trends in science and engineering. However the first major step in the US-NBIC convergence project was in “Converging Technologies for Improving Human Performance,” (the US-NBIC Report)[73] published in 2002.

This report advanced an integrative approach for converging science and engineering (S&E) from the nanoscale, information and system levels, with

- a re-focussing on people and a commitment to responsible development;.
- new NBIC platforms for science and technology;.
- co-evolution of new technologies and human potential.

The expected outcomes of this approach include:

- revolutionary tools and products;
- improvement of everyday human performance: work efficiency, accelerated learning, better use and increase potential for individuals, groups and society at-large to lead happier, healthier and more productive lives;
- changing societal relationships, organizations and businesses;
- reshaping infrastructure;
- improving science and technology (S&T) governance.

13.2 APPROACH AND SCOPE

A planning meeting was held May 11, 2001 at the National Science Foundation to develop the agenda for the December workshop and to identify key participants from academia, industry, and government.

The NBIC convergence project draws heavily from the workshop on Converging Technologies to Improve Human Performance, which took place on December 3-4, 2001. In response to the workshop, participants submitted more than 50 written contributions - statements describing what existed then (2001) and visions describing what could be accomplished in ten or twenty years. Many of the recommendations of the NBIC project were concretized and funded under the aegis of the National Nanotechnology Institute (NNI). While certainly not all of the visionary ideals promulgated in the Converging Technologies workshop report have been undertaken to date, the primary funding and focus of US research in this area is through the NNI and ancillary networks.

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[71] Contributed by Steffen Christensen

[72] Roco, M.C.; Bainbridge, W.S. (eds.): 2001, *Societal implications of nanoscience and nanotechnolog*y, (Proceedings of a workshop organized by the National Science Foundation, September 28-29, 2000), Kluwer, Dordrecht [available online at http://itri.loyola.edu/nano/societalimpact/nanosi.pdf]

[73] The US-NBIC Report: op cit

13.3 DEFINITION AND KEY PRINCIPLES OF CT

The NBIC report defines "convergent technologies" as "the synergistic combination of four major NBIC provinces of science and technology, each of which is currently progressing at a rapid rate:

- **n**anoscience and nanotechnology;
- **b**iotechnology and biomedicine, including genetic engineering;
- **i**nformation technology, including advanced computing and communications; and,
- **c**ognitive science, including cognitive neuroscience.

This seminal document's focus is explicit in its title: "Converging Technologies for Improving Human Performance." It also emphasizes that in order to attain the maximum benefit from scientific progress; the goal[74] can be nothing less than a fundamental transformation of science and engineering.

13.4 ELEMENTS OF THE US APPROACH TO THE DEFINITION OF GOALS

Relation to R&D strategy

The express goal of the US NBIC initiative is the immediate restructuring of research and development work towards the satisfaction of NBIC convergence goals. It is acknowledged that in many areas, it will be necessary to build scientific communities and research projects nearly from scratch. Many strategies have been identified and are being pursued:

- Prepare key organizations and social activities for changes made possible by convergence;
- Organize enhancing activities that accelerate convergence of technologies for improving human performance;
- Ensure that education and training at all levels use converging technologies and prepare people to take advantage of them;
- Experiment innovative ideas to focus on and motivate multidisciplinary developments;
- Concentrate multidisciplinary research programs, such as the "Human Cognome Project" and a "Communicator" system to optimize human teams and organizations;
- Provide flourishing communities of NBIC scientists and engineers with a variety of multiuser, multiuse research and information facilities;
- Establish a shared culture that spans across existing fields to integrate sciences
- Find ways to address ethical, legal and moral concerns;
- Accelerate developments in medical technology and health-care to obtain maximum benefit from converging technologies

Relation to "values" of the country

The NBIC program designers have always sought to ensure representation of the public interest in all major NBIC projects. They have called for incorporation of ethical and social-scientific

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[74] Roco M.C. & Bainbridge, W.S. (2002): op. cit. page 9

education in the training of scientists and engineers. Ensuring that policy makers are thoroughly aware of the scientific and engineering implications of the issues they face is an issue of importance as well.

The US economy has benefited greatly from the rapid development of advanced technology, both through increased international competitiveness and through growth in new industries. Convergent science and technology is considered as having the potential to further help transform some low- into high-technology fields, thereby increasing the fraction of an economy that is both growing and preeminent in the world.

13.5 AREAS OF INTEREST AND FIELDS OF APPLICATION

The NBIC report underlines several broad, long-term implications of converging technologies:

Societal productivity, in terms of well-being as well as economic growth;
Security from natural and human-generated disasters;
Individual and group performance and communication;
Life-long learning, graceful aging, and a healthy life;
Coherent technological developments and their integration with human activities;
Human evolution, including individual and cultural evolution.

Six areas of relevance were identified at the December 2001 workshop:

- Overall potential of converging technologies;
- Expanding human cognition and communication;
- Improving human health and physical capabilities;
- Enhancing group and societal outcomes;
- National security;
- Unifying science and education.

13.6 GENERAL CHARACTERISTICS OF LIKELY CT APPLICATIONS

It is believed that the unification of sciences and technologies can yield results over the next two decades on the basis of four key principles:

- The convergence of diverse technologies is based on material unity at the nanoscale and on technology integration from that scale;
- Revolutionary advances at the interfaces between previously separate fields of science and technology are ready to create key NBIC transforming tools, including scientific instruments, analytical methodologies, and radically new materials systems;
- Developments in systems approaches, mathematics and computation in conjunction with work in NBIC areas allow for the first time the understanding of the natural world and cognition in terms of complex, hierarchical systems;
- Improvement of human performance becomes possible.

13.7 ASSESSMENT OF RISKS

According to the NBIC report authors[75], the NBIC approach strongly opposes transhumanist ideas because its focus is to preserve and serve human nature. The report specifically underlines the need to serve people, to develop an "intelligent" environment for helping people, and specifically states that NBIC aims to protect human nature and develop anticipatory measures to do so.

Risks such as those presented by Bill Joy[76] with regards to nanotechnology were examined with a call to treat these concerns responsibly. Studies have been conducted and coordinating offices have been established at the national level, to track and respond to unexpected developments, resulting from CST, including public health and legal aspects. The NBIC report agrees that while all possible risks should be considered, the need for economic and technological progress must be placed in the balance. The main aim of the national research initiatives is to develop the knowledge base and to create an institutional infrastructure to bring about broader benefits for society in the long term. It is recognized that involving the entire community from the start, including social scientists, will be necessary to maintain a broad and balanced vision.

Risks are being assessed in the NBIC project through dedicated investment of expert groups[77]. Funding made available under the National Nanotechnology Initiative (NNI) for ethical, legal and social implication (ELSI) work amounted to US$400K in 2001, US$900K in 2002, US$3.4M in 2003, US$5.5M in 2004 and a projected US$7.4M in 2005. In 2005, US$34.5M is budgeted for basic environmental R&D and implications of nanotechnologies (not including applications); US$43.3M for basic health R&D and implications and US$46.6M for education, not including fellowships. For fiscal year 2005, 0.63% of the total NNI budget of US$1,181M is allocated for ELSI, 2.9% for environmental issues, 3.7% for health impacts and 3.9% for educational initiatives.[78]

[75] Roco, M. Personal communication
[76] Joy, B. op.cit.
[77] One example: the Nanoethics conference that took place at the University of South Carolina in spring 2005 was supported by the National Science Foundation
[78] Roco, M. Personal communication

Table 5: Some of the societal impacts projects to date

Title	Agency
Nanotechnology and its Publics	
Public Information, and Deliberation in Nanoscience and Nanotechnology Policy	Small Grants for Exploratory Research (SGER)
Public Information, and Deliberation in Nanoscience and Nanotechnology Policy	SGER
Social and Ethical Research and Education Agrifood Nanotechnology	Nanotechnology and Interdisciplinary Research Initiatives (NIRI)
From Laboratory to Society: Developing an Informed Approach to natural sciences and engineering	NIRI
Social and ethical dimensions of nanotechnology	
Ethics and belief inside the development of nanotechnology	Faculty Early Career Development (CAREER) Awards
Societal implications components inside the nanotechnology centers: the National Nanotechnology Infrastructure Network (NIN) and the Network for Computational Nanotechnology (NCN)	
Citizen Learning, Deliberation, and Reasoning in Internet-Mediated Technology Policy Forums	
An Integrated Approach to Teaching Nanotechnology and Society	National Union for Educators (NUE)
Nanotechnology: Content and Context	NUE
Undergraduate Exploration of Nanoscience, Applications and Societal Implications	NUE
Assessing the Implications of Emerging Technologies	Integrative Graduate Education and Research Traineeship (IGERT) program

13.8 ANTICIPATED CHALLENGES AND OPPORTUNITIES

Human potential and technological development are coevolving, and quality of life has greatly increased with technological advancements. However, there is a perceived tension between society and technology, perhaps due to the high and accelerating rate of change and/or the larger benefits and risks as stake. Technology implications are perceived as global issues that need to be addressed through collaboration among nations.

Table 6: Some of the opportunities identified by the NBIC workshop expert group

Fast direct interfaces between the human brain and machines
People from all backgrounds and ranges of ability learning skills more reliably and quickly
More durable, healthy, energetic, easier to repair, and aging resistant human body
Treatment or eradication of many physical and mental disabilities
Genetic control of humans, animals and plants to benefit human welfare
Expanded creative abilities for engineers, artists, architects and designers
Improved awareness of the cognitive, social and biological forces operating individual lives
Wearable sensors and computers to enhance awareness and safety
Robots and software agents that operate on principles compatible with human goals
Communication and cooperation across barriers of culture, language, distance, and specialization
Instantaneous access to information from anywhere in the world in a form tailored for most effective use by the individual
Increased effectiveness of administrators through new organizational structures based on fast communications
Machines and structures built of materials with precisely needed properties, such as energy efficiency, durability and communications abilities
"Intelligent environments" for the combined benefits of mass production and custom design
Strengthening of national security by lightweight, info-rich war fighting systems
Realization of the promise of outer space by means of efficient launch vehicles and robotics
Increased agricultural yields and reduction of food spoilage through advanced sensors
Safe, cheap, and fast transportation due to improvements in materials and information technology
Revolution in the work of scientists by importing approaches pioneered in other sciences
Transformation of formal education by a curricula based on hierarchical paradigms for understanding the architecture of the physical world.

13.9 ACTORS

The National Science Foundation's NBIC and National Nanotechnology Institute (NNI) projects engage members from diverse sectors in convergence and nanotechnology research. This section discusses largely US research and investment in nanotechnology; however, the majority of the existing research, development and outreach programs incorporate a significant biotechnology, information technology or cognitive technology component.

13.10 SHORT AND MEDIUM TERM STRATEGIES

The Second Nanotechnology Institute Strategic Plan (2006-2010)[79], lists four main goals for the next 5 years:

- Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology (supporting R&D for active nanostructures and nanosystems);
- Facilitate transfer of the new technologies into products for commercial and public benefit (increase funding for technological innovation and multidisciplinary R&D platforms);
- Develop educational resources, a skilled workforce, and the supporting infrastructure and tools needed to advance nanotechnology (provide access to research facilities and educational opportunities in nanoscale science and engineering for half of the undergraduate and graduate students by 2010);
- Support responsible development of nanotechnology through societal, environmental and health implications R&D, and interaction with the public (address sustainability and life cycle of products).

With respect to environmental, health and other societal implications, the goals are to:

- Align R&D investment with societal implications
- Evaluate and implement regulatory standards
- Coordinate measures for environmental, health and social implications (EHS) and ethical, legal, and social implications (ELSI)
- Periodic meetings for grantees, setting research targets, and interactions with industry and the public
- International collaboration through the International Dialog for Responsible R&D of Nanotechnology (ONSA provides a Canadian representative)

[79] http://www.nano.gov/NNI_Strategic_Plan_2004.pdf

Through the Converging Technologies Bar Association (CTBA):

- Dialogue with legal community;
- Education and reference material for the legal system;
- Source of information on implications of converging technologies form the nanoscale;
- Public awareness;
- Advocate policies, regulations and legislation;
- Anticipatory measures for the implications of NBIC;
- Prepare reference materials and position papers;
- Evaluate and implement regulatory standards.

Through the North-South dialogue on nanotechnology:

- Identify key application opportunities: healthcare, energy, water filtration, food, communication;
- Identify suitable technologies: nano-biotechnology, solar cells, use local resources;
- Develop partnerships: regional alliances, industry, international organizations;
- Long-term view and plan of action: education, converging technologies, infrastructure, economy/jobs, human development, international interaction between developed and developing countries.

13.11 FUNDAMENTAL ISSUES

Societal implications were first addressed in the September 2001[80] report, "Societal Implications of Nanoscience and Nanotechnology." Follow-up items include:

- Making support for social, ethical, and economic research studies a priority;
- Define a new theme in the NSF program solicitations;
- Create centers with societal implications programs;
- Begin an initiative on the impact of technology, NBIC convergence, and human and social development (HSD;)
- Charging the White House National Nanotechnology Coordination Office (NNCO) to communicate with the public and address Environmental, Health and Safety issues, and unexpected consequences[81] ;

[80] Roco, M. & Bainbridge, W.S. (2001) op. cit.
[81] see, for instance, http://research.musc.edu/inklings/0601/nsf_0601.htm

- Establishing the Nanoscale Science, Engineering and Technology (NSET)'s Nanostructures Environmental and Health Issues working group in October 2003;
- Organising a Workshop with the European Community (2001); Links to Europe, Americas, Asia; international dialogue with 26 countries, with NSF sponsorship.

Moreover it was strongly recommended that:

> *"NSET develop a new funding strategy to ensure that the societal implications of nanoscale science and technology become an integral and vital component of the NNI."* [82]

It recommended also that NNI allocate funds directly to the NSF Directorate for Social, Behavioural and Economic Sciences (SBE), to help to assure this result. Finally, although NSF award activity on societal dimensions was minimal in fiscal years 2001 and 2002, it increased in fiscal year 2003. Changes in eligibility requirements have been designed to generate additional applications from investigators in the social and behavioural sciences, ethics and values studies, research on science and technology, and science and technology studies in fiscal year 2004.[83]

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[82] The National Nanotechnology Initiative: Supplement to the President's 2006 Budget (p. 3, pp.48-9) http://www.nano.gov/NNI_06Budget.pdf

[83].Hollander, R.D.:.*NSF and the Societal Dimensions of Nano-science and Technology* http://www.nano.gov/html/facts/societyHollander.html

14 APPENDIX 5 - SCIENCES AND TECHNOLOGY CONVERGENCE IN THE EUROPEAN UNION[84]

14.1 BACKGROUND

In March 2000, the European Union (EU) Heads of States and Governments agreed to make the EU "the most competitive and dynamic knowledge-driven economy by 2010."[85] Current European industrial policy calls for an integration of research efforts in the highly competitive sectors of information and communication technologies, biotechnology and nanotechnology, aeronautics and hydrogen energy technology.[86] European science policy also demands a substantially increased investment in nanotechnology so that it can focus on its two "most challenging aspects, in particular, knowledge-based industrial innovation (nanomanufacturing), integration at the macro-micro-nano interface and interdisciplinary ('converging') R&D."[87]

14.2 APPROACH AND SCOPE

Following the USA NBIC (Nano-Bio-Info-Cogno) Conference,[88] the EU decided to constitute a High Level Expert Group (HLEG) to define a European Union's position on CST. In December 2003, a 25 member group drawn from a variety of countries and disciplinary backgrounds was formed. The group met formally four times and submitted its report in July 2004.[89]

The expert group was charged with exploring in breadth, the potential and risks of converging technologies (CTs). Instead of simply developing a European response to the US report, the expert group was to consider the limitations of previous approaches to NBIC convergence. Therefore, it had to delineate areas of interest and fields of application for CTs, and to relate CTs to the European environment and policy goals.

> *"The aim of the report is to provide advice to the Commission and Member States on the opportunities and challenges presented by the convergence of key enabling technologies."*

In support of the work of the HLEG project, a Workshop was held to develop scenarios. It was decided at the start to create 2 or 3 realistic, self consistent scenarios (using Porter's definition, not a forecast but a possible, credible outcome). The process ended up with four scenarios[90]:

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[84] Contributed by Nicole Bégin-Heick
[85] The "Lisbon Declaration"
[86] Communication from the Commission: Science and Technology, the key to Europe's future – Guidelines for future European Union policy to support research" COM (2004) 353, section 1.2., prop. 5, p. 2.
[87] Communication from the Commission: Towards a European strategy for Nanotechnology," COM (2004) 338, section 3.1.1., p. 10.
[88] The US-NBIC Report: op.cit.
[89] The EU0HLEG Report: op. cit.
[90] New Technology Wave – Scenarios for Europe in 2020
http://europa.eu.int/comm/research/conferences/2004/ntw/pdf/scenarios_report_en.pdf

Competitive Europe represents the "official future" as expressed at the Lisbon summit. Here, Europe would use science and technology to modify old industries and create new ones, focusing on export opportunities

Alternative Lifestyles focuses on industries facing structural change, using research to take them to a new totally sustainable economic model.

Global Capitalism concentrates research on export opportunities of capability, innovation and specialist products.

Regional Calm focuses on promoting inclusiveness
The lag time from demonstration of capability to introduction is typically 5 years (new materials, health sector, pharmaceuticals), and for those in agriculture and energy, 10 years. The effect on society in economic terms is likely to be several years later. This list in figure 17 therefore focuses on capabilities demonstrable in the laboratories now

In defining these scenarios, the Workshop participants were looking for:

- clarity on key issues
- two or three differences between a European and North American converged NBIC technology world
- the link between the technology and economics
- an ability to formulate research questions for the 7th Framework Program
- the adoption of a common technology roadmap
- application of the Principles guiding the overall project

The approach assumed the existence of a series of technology road maps to 2020, and focused on the social and economic environment, and hence the implications of NBIC where these road maps converge. Assumptions were made about 2020, about the world **(**Global Environment, Demographics, and European Economy**)** and about NBIC.

Table 7: European Assumptions on NBIC

BIOTECHNOLOGY
Pharmacogenomics and personalized medicine – these will accelerate the approval; process and shift attention from block-buster drugs;
Bioterrorism [viruses] – something will happen, we do not know the exact form or when;
Bio-based agricultural economy (e.g. modified algae to generate hydrogen);
Nanobotic laboratory with lab techs replaced by robots;
Bio-engineered bugs e.g. to monitor or counter pollution.

NANOTECHNOLOGY
Computer based/invasive monitoring and treatment of health and disease [effect on need for hospitals];
Cheaper energy sources e.g. from photovoltaic cells;
Convergence of food, cosmetics and pharma technologies e.g. generation of tailored foods as well as medicines;
Designer leisure drugs;
Materials science produces more bio-degradable products;
Thin screens and broadband impact leisure and household management;

INFORMATION TECHNOLOGY/COGNITIVE SCIENCE
DNA to assemble circuits for IT: contenders for new implementation technologies (processors, storage) will cause market confusion;
new generation of computer products: themes are miniaturization, multimodal input including natural speech, images becoming more important;
Artificial intelligence is very powerful in a much wider range of tasks, more intelligent than humans: but software of complex systems to support failure conditions lags;
Sensor networks, surveillance, data gathering by governments;
Personalized/localized personality broadcast, digital pheronomes: use of wireless technology dominant;
Convergence of bio & IT instrumentation in the skin/artificial skin & smart coding in the skin - tagging by states and monitoring for health problems by individuals;
Nano scale intelligent autonomous agents for medical repair e.g. cleaning out arteries, stomach operations.

14.3 DEFINITION AND KEY PRINCIPLES OF CT

The HLEG defined CTs as “enabling technologies and knowledge systems that enable each other in the pursuit of a common goal.”[91] It introduced the notion of Converging Technologies for a European Knowledge Society (C*TEKS)* as a uniquely European approach to CTs. This approach focuses on the need to set agendas or common goals for convergence.

[91] ibid, p. 12

The expert group identified four likely characteristics of CT applications. Each of these presents an opportunity to solve societal problems, to benefit individuals, and to generate wealth. Each of these also poses threats to culture and tradition, to human integrity and autonomy, perhaps to political and economic stability.

Embeddedness**:** CTs will form an invisible technical infrastructure for human action – analogous to the visible infrastructure provided by buildings and cities. The better they work, the less we will notice our dependence on them or even their presence.
Unlimited Reach*:* Nanotechnology's dream to control everything molecular follows upon information technology's increasing ability to transform everything into information.
Engineering the Mind and the Body*:* Some proponents of CTs advocate engineering *of* the mind and *of* the body. Electronic implants and physical modifications are to enhance our current human capacities. The expert group proposes that CT research should focus on engineering ***for*** the mind and ***for*** the body.
Specificity*:* Research on the interface between nano- and biotechnology allows for the targeted delivery of designer pharmaceuticals that are tailored to an individual's genome in order to effect a cure without side effects.

14.4 ASSESSMENT OF RISKS

While each of the characteristics of C*TEKS* represents economic and scientific opportunity, each also represents a category of risk.

Embeddedness: The most direct and profound effect of C*TEKS* is therefore to change traditional boundaries between the self, nature and social environment, where the social environment includes people, groups of people, informal and formal institutions. It also includes arenas and places, both physical and informational, where goods and beliefs are traded and transformed.
Unlimited Reach: The notion regarding the total constructability of humanity and nature is matched by the suggestion that CTs may provide a technological fix for every problem.
Engineering the Mind and the Body: Whether of or for the body and mind, CTs raise legal and philosophical issues regarding human inviolability, dignity, and autonomy. For example, how neutral or socially coercive is the decision of individuals to gain an advantage for themselves or their children through artificial enhancement? Inversely, when entire environments are engineered to structure human action, do individuals have a legally and socially protected choice to opt out?
Specificity*:* The invisibility of CTs raises questions as to their absence or presence. It also raises issues of control and social justice.

14.5 ELEMENTS OF THE COUNTRY/REGION APPROACH TO THE DEFINITION OF GOALS

Relation to R&D Strategy

As stated above, the European exercise on CTs (or C*TEKS*) was shaped by the Lisbon Agenda and the acknowledgment that the early recognition of the opportunities and challenges offered by

CTs might enable Europe to invest wisely and to develop strengths in harmony with its own societal values.

The European approach to CTs prioritizes the setting of a particular goal for CT research. This presents challenges and opportunities for research and governance alike, allowing for an integration of technological potential, recognition of limits, European needs, economic opportunities, and scientific interests.

It recognizes that only careful agenda-setting can bring them together in viable and socially beneficial research. C*TEKS* exploit the potential of nano-, bio-, and information technologies. They also include the social sciences and humanities, and other enabling technologies and knowledge systems; explicit awareness and study of CTs' limits, e.g., with respect to cognition; and an orientation towards common goals formulated within a European policy framework.

Relation to "values" of country/region

The HLEG wished to gain a historical understanding of the social dynamics of innovation processes and to clarify the civil and societal benefits of CT research and put Europe in the position of being able to exploit its positive social aspects. In particular, Europe prizes diversity, social justice, international security, and environmental responsibility.

14.6 AREAS OF INTEREST AND FIELDS OF APPLICATION

The HLEG believes that agenda-setting for C*TEKS* research should remedy the disproportionately small private sector involvement identified, for example, in the EC's Communication on Nanotechnology.[92]

The expert group recommends that C*TEKS* should be focused initially on the research topics that are valued highly and for which a positive impact is expected under any European scenario. These are the areas of **health, education** and **ICT infrastructure**. C*TEKS* are also expected to make powerful and important contributions in the areas of **environment** and **energy** which should also be included in the design of CT initiatives.

14.7 SHORT AND MEDIUM TERM STRATEGIES

Documents reviewed introduce two short and medium term strategies:

Mobilizing knowledge for CTEKS (Convergence Discovery)

- Identify enabling technologies and knowledge systems in the engineering, natural, social, and human sciences on regional, national, and European levels.
- Characterize and place on conceptual as well as geographic maps.
- Identify or construct connections and complementarities between various endeavors.

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[92] The EU-HLEG Report: op. cit.

Stimulating research through CTEKS (EuroSpecs process)

- Identify European needs in general areas of health, education, the environment, etc. as identified in the Millennium Declaration, Lisbon Agenda, or forthcoming European policy initiatives and use them as catalysts for convergence
- Offer design specifications for C*TEKS* solutions that address these needs: Requests for proposals from public and private sector researchers to submit design proposals.
- For the best entries, develop detailed road-maps specifying conceptual, economic, and technical resources and obstacles towards implementation, time-lines, social costs and benefits.

14.8 ANTICIPATED CHALLENGES AND OPPORTUNITES

Three major challenges were identified at the onset of the process:

- Establishing CTEKS: Vision and strategy.
- To use the potential of CTs to develop ambitious research programs and thereby advance European social, economic, and research policy goals.
- To swiftly create multidisciplinary communities of CT researchers for the development of scientifically feasible, economically attractive, and socially beneficial C*TEKS* proposals.

These challenges turned into the need for new research agendas and the development of a framework for CTEKS through an appropriate research and support environment.

Harnessing the Dynamics of Convergence: New research agendas.

New research agendas were to be defined on the basis of the consolidation and support of multidisciplinary CT research, allowing for focused and sustained technical developments. The conduct of background research necessary for the scientific, economic, historical and normative assessment of CTEKS proposals; and the assessment of the prospects and limits of CTEKSs were viewed as essential. Such assessment would require scientific research in cognitive science, evolutionary anthropology, economics, philosophy and ethics.

Developing a framework for C*TEKS*: The research and support environment.

This framework is structured on three key elements:

- Ethics and social empowerment;
- An effective monitoring and assessment system that is adequate to the potential of CTEKS and their specific mode of development ; effective monitoring of C*TEKS* and societal feedback to the agenda-setting process requires accompanying research alongside science and technology R&D (*Begleitforschung)*
- A regulatory process that is appropriate to CTs

14.9 DEALING WITH CTEKS: ETHICS AND SOCIAL EMPOWERMENT

Europeans have adopted an original approach to addressing fundamentals issues such as ethical and societal issues and intellectual property issues. This approach is based on a series of principles and translated into specific recommendations from the HLEG.

Principles

- To ensure the consideration of ethical concerns from the beginning and in advance of the developments of norms for CTEKS development through the EuroSpecs[93] process.
- To promote in Europe engineering for the mind and improvements of the cognitive environment instead of the type of approaches that consider engineering of mind and brain.
- To pursue CTEKS as a tool for the development of local solutions that foster natural and cultural diversity instead of the type of approaches to CTs that promote an increasingly homogeneous technical culture.
- To balance CT-based solutions against low-tech or no-tech policy alternatives.
- To promote sustainable development, environmental awareness, precautionary approaches.
- To empower citizens and consumers to understand, use, and control CTs and to maintain a sense of ownership.

In addition to the scientific and research community and decision makers, NGOs and ethicists were to be involved. The HLEG report recommended that steps be taken to ensure buy-in by the public and the inclusion of CT issues in the educational process:

- *Recommendation #15: Member and Associated States are encouraged to stimulate national discussions of CTs and the CTEKS perspective*.

Beginning with conferences that survey national CT research, national research councils and funding agencies can contribute to the Widening Circle of Convergence (WiCC) initiative and the development of prototype CTEKS research. They should join together in a European Empowerment Campaign Knowledge Year Europe (KEY) 2020. The campaign provides a forum for educational initiatives, idea competitions, and public debates that develop visions for the contribution of key technologies to Knowledge Europe Year 2020.

- *Recommendation #16: CT modules should be introduced at secondary and higher education levels to synergize disciplinary perspectives and to foster interaction between liberal arts and the sciences*.

This was to be stimulated through European competitions for students and teachers. European Centers of CTEKS Excellence and particular CTEKS research programs and projects should engage in educational activities ranging from public outreach to the introduction of postgraduate

[93] The development of European design specifications for converging technologies.

summer schools and programs. In analogy to computer literacy, standards of CT literacy need to be developed through the EuroSpecs process.

Furthermore, the HLEG prepared several recommendations for addressing ethical and societal issues:

- *Recommendation #11: That a strict line be maintained between military ambitions for CTs and their development in Europe.*

- *Recommendation #12: Upon advice from the European Group on Ethics (EGE), the mandate for the ethical review of European research proposals should be expanded to include ethical and social dimensions of CTs. Funding organizations in Member States are asked to take similar steps.*

- *Recommendation #13: In the face of new models for participatory research governance, transparent decision making processes need to be developed and implemented.*

- *Recommendation #14 of the European Report deals with the question of intellectual property rights and proposes that they be addressed proactively and on an international level.*

Finally the HLEG proposed Actions for Monitoring and Regulation of CTEKS:

- Recommendation #8 reads: **"***A permanent societal observatory should be established for real-time monitoring and assessment of international CT research, including CTEKS"*.

- Recommendation # 9 reads**:** *"That the Commission implement a "EuroSpecs" research process for the development of European design specifications for converging technologies, dealing with normative issues in preparation of an international "code of good conduct."*

15 APPENDIX 6 - SCIENCES AND TECHNOLOGY CONVERGENCE IN SELECTED ASIAN COUNTRIES[94]

15.1 INTRODUCTION

The Asian countries whose policies/practices were investigated for this report (Japan, Korea and Chinese Taipei) are three of the four Asian economies that have invested heavily in R&D in the past decades and, as a result, are becoming important competitors in the knowledge economy.

Figure 6: Gross expenditure in research and development (GERD) as % of gross domestic product (GDP)

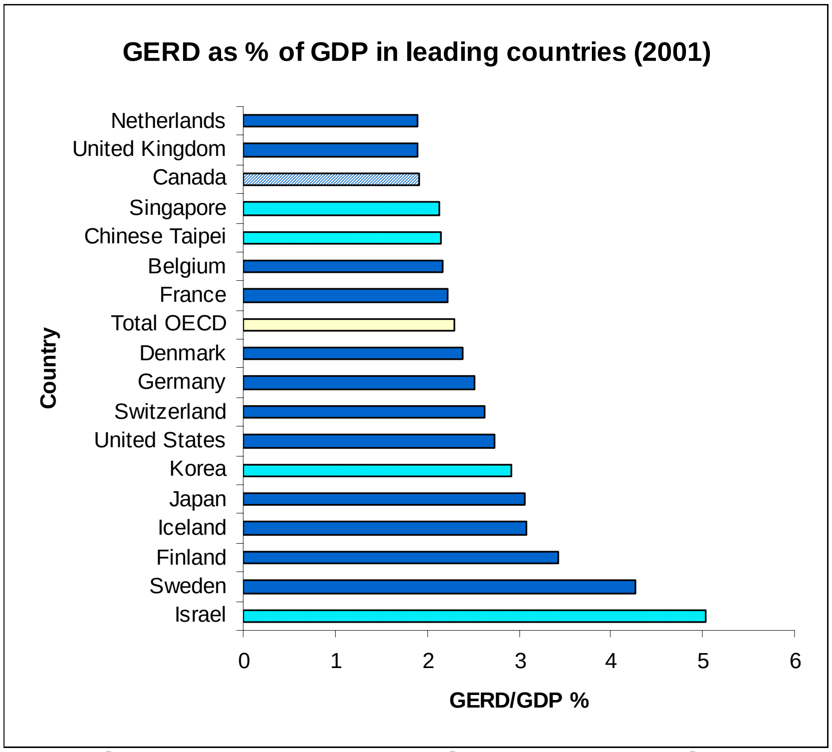

Fig. 6 shows the ranking of the leading countries in gross expenditures on research and development (GERD) as a % of the country's gross domestic product (GDP). Canada's performance is indicated by the hatched bar. Non-OECD countries are represented by stippled bars and the average for all the OECD countries by a clear bar. This graph shows that Japan, Korea, Chinese Taipei and Singapore are ahead of Canada according to this indicator.

The most recent documents exist only in the country's language.[95] The documents cited below indicate that Foresight exercises on NBIC (at least in some combination) are being conducted in Japan[96] as well as in Korea and Chinese Taipei.

[94] Contributed by Nicole Bégin-Heick
[95] It typically takes 2-3 years before English translations of official documents are available
[96] See for example http://asia.stanford.edu/events/spring02/

15.2 KOREA

Korea aims to be among the seven world leaders in technology by 2025
SCOPE OF FORESIGHT

Korea has carried out eight Foresight exercises since about 1960. There are also frequent exercises carried out within or across ministries.

A large-scale technology Foresight activity was performed in the mid-1980s to establish the Long-range Plan for S&T Development toward the year 2000. More than 800 experts were involved in the Plan. Another example of large scale Foresight activities is the Long-term Vision for S&T Development toward the Year 2025. About 200 experts participated in this exercise that lasted one year.

So far, with the support from the Ministry of Science and Technology (MOST), there have been two large-scale technology forecasting activities in Korea. The first study was undertaken in 1993, it included three-round Delphi through three stages: preliminary activities, pre-foresight and main foresight. This survey included 1, 174 participants[97] in total and the forecasting period was from 1995 to 2015. After the survey, a comparison was made with advanced countries such as Japan and Germany. The second study was done in 1998, with the same methodology as the previous one. It dealt with total 1, 155 items and the forecasting period was extended to 25 years from 2000 to 2025 so that the results could be compared with Japan and Germany.

In 2002, Korea established a National Technology Road Map (NTRM). The purpose of this exercise was to analyze industrial transformation and technological trends at home and abroad; to find out promising products and core technologies that are essential to secure global competitiveness 10 years forward; to draw up a technology roadmap at the national level for promoting strategic research and development projects.

NTRM was carried out in two stages: The first stage was to identify the technologies for which NTRM will be drawn up. It explored the vision of the national S&T development for the up-coming 10 years and the elements to be secured for industrial competitiveness. It forecasted general technological and nontechnological elements to be strengthened and defined key technologies to be developed for enhanced global competitiveness by 2012. The results of this first stage were produced in the first half of 2002.

The second stage drew up Technology Road Maps (TRMs) for the key technologies identified in the first stage. It derived future visions related to key technology areas and marked milestones of technology development to achieve the vision. It found out technological alternatives in each technology area, which is necessary for attaining the target technological capacity and explains how to reach the target through presuming the process and using time coordinates. The results of the second stage were released in the second half of 2002

[97] the actual word used is “item”

AREAS OF PRIORITY

The areas of S&T priority that came out of this staged process are:

- Building an Information-Knowledge-Intelligence Society

- Meeting a variety of human needs in all areas of life by making IT services more intelligent, mobile, and user-friendly and to build a wealthy society. Fourteen 'Strategic Products or Functions' to realize this vision were identified.

- Aiming at Bio-Healthpia (sic): To meet the increased demand for high-quality therapeutic agents. To supply diagnosis, prevention & therapy in a timely manner. Thirteen 'Strategic Products or Functions' were identified.

- Advancing the E2 (Environment and Energy) Frontier: To provide for an efficient and stable energy supply & utilization system in line with international environmental regulations and global issues and to build a society that recycles and lives in harmony with nature. Five 'Strategic Products or Functions' were identified.

- Upgrading the Value of Major Industries of Korea Today: To pursue sustainable economic growth through strengthening the international competitiveness of current main industries and the infra industry. Eleven ‘Strategic Products or Functions' were identified.

- Improving National Safety and Prestige: To build the world's 10th aerospace technological capability and to establish national self-sufficiency in food supply.

ELEMENTS OF THE COUNTRY/REGION APPROACH TO THE DEFINITION OF GOALS

Relation to R&D Strategy

A review by the Organization for Economic Cooperation and Development (OECD) found gaps between scientific research, applications research and commercialization of technology in Korea. It also found that most Korean production technology is imported and for many of big chemicals and food processing businesses, biotechnology is only a sideline.[98]

Korea believes that this leaves considerable room to increase the level of research and to capture more value than the research currently underway.

[98] A.Toffler: Biotech Evolution Emerging in Korea
http://iranscope.ghandchi.com/Anthology/TofflerKorea/Toffler05.pdf

AREAS OF INTEREST AND FIELDS OF APPLICATION

Although the S&T policy of the Korea's MOST stresses NBIC technologies individually, there is little to indicate a convergence agenda

Korea's goal of raising biotechnological capabilities to the level of the world's leading countries by 2007 will depend on its ability to build on and move beyond successes such as fermentation technology, antibiotics, diagnostics, and Hepatitis B vaccines to such fields as "farm-aceuticals," the attempt to harvest human antibodies from genetically altered plants grown cheaply on an agricultural scale.

ANTICIPATED OPPORTUNITIES AND CHALLENGES

The government would like to have scientific policy satisfy more of the private sector's needs and is accordingly more open to that sector's views.[99]

Furthermore Korea considers it important to enhance S&T awareness among the general public. Its S&T policy is silent on the issue of ethics, intellectual property and monitoring and regulation. The main challenges therefore are the legal framework and the educational system.

SHORT AND MEDIUM TERM STRATEGIES

The 21st Century Frontier R&D Program was launched in 1999 to develop scientific and technological competitiveness in newly emerging areas. The government planned to invest a total of US$3.5 billion over a period of ten years in this program that would comprise twenty-three projects in new frontier areas, such as bioscience, nanotechnology, space technology, and so on.

Twenty-three projects had already been launched as of September 2003: Functional analysis of human genome ('99); Biological modulators ('01); Proteomics technology ('02); Tera-level nanodevices ('00); Nanoscale mechatronics technology ('02); Nanostructured materials technology ('02); Applied superconductivity technology ('01); Proton engineering technology ('02); Sustainable water resources research ('01); Industrial waste recycling ('00); Carbon dioxide reduction and sequestration ('02); Plant diversity ('00); Crop functional genomics ('01); Stem cell ('02); Microbial genomics & applications ('02); Smart unmanned aerial vehicle technology ('02); Advanced materials processing technology ('01); Intelligent microsystems ('99); Advanced information display technology ('02); Ubiquitous brain project ('03); Intelligent robotics ('03); Brain research ('03); Hydrogen energy ('03)

The most outstanding feature of the program is that each project director is given full autonomy in managing the program. The project director is responsible for designing the details of the research projects, supervising sub-projects, and allocating the funds.

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[99] M. Johns: Science and Technology Overview 2002: Republic of Korea
http://www.infoexport.gc.ca/science/KOR_2002-en.htm

The Creative Research Initiative (CRI) launched in 1997, symbolizes the policy shift in S&T development in Korea "from imitation to innovation." It aims to strengthen the national potential for technological competitiveness through creative basic research.

The National Research Laboratory (NRL), which was launched in 1999, aims at exploring and fostering research centers of excellence, which will play a pivotal role in improving technological competitiveness.

With an ambitious vision of becoming one of the leading nations in the world in this field within the next ten years, the government launched the **Nanotechnology Development Plan** in 2001 under the framework of the national R&D program. In order to establish and expand the R&D infrastructure in this field, the government has also launched several action plans, including the establishment of a Nano-Fabrication Center, human resource development, etc.

15.3 JAPAN

SCOPE OF FORESIGHT AND AREAS OF PRIORITY

Japan's current S&T plan available in English covers the period 2001-2005. This plan proposes several areas of priority:

- **Life sciences** fields that contributes to preventing/treating diseases in aging society with a falling number of new born babies and to solving the food problem;
- **Information and telecommunications** field that is advancing rapidly, and leads directly to the construction of advanced information and telecommunications society and expansion of the information and communications industry and high-tech industry;
- **The environment field** that is indispensable to maintaining human health and conserving the living environment as well as sustaining the foundations of human existence;
- The **nanotechnology and materials** field that makes spin-off effects to a broad range of other fields, and in which Japan is at advantage.
- Energy, manufacturing technologies, infrastructure and frontiers

Convergence of info-bio-nano technologies and underlying sciences exists but is not acknowledged per se in the documents consulted.. However some likely CT applications are quoted: Carbon nano-tubes, research, applications and patents as well as DNA computers.

ELEMENTS OF THE COUNTRY/REGION APPROACH TO THE DEFINITION OF GOALS

Relation to R&D Strategy

The government, universities and research institutes and the public at large are the key actors involved in the definition of goals. Japan sees itself at an advantage in nanotechnology and sees the impact of nanotechnologies in many areas

Relation to "values" of country/region

The Japan Perspective, a document published by the Science Council of Japan (SCJ) provides a road map of the path that humanity should take in the 21st century. It offers a broad-based look at the various problems that confront the human species, clarifies the fundamental nature and structure of such problems, and proposes a direction for humankind to take over the next 30 to 50 years.[100] It represents the views and values of the group of scientists that make up the SCJ to provide a path to a sustainable society, but there is no documentation showing that these values have been espoused by the Japanese government.

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[100] The Japan Perspective: The role of scientific information in society
http://www.scj.go.jp/ja/scj/perspective/pdf/eiban.pdf

AREAS OF INTEREST AND FIELDS OF APPLICATION

The government of Japan has declared bio-nanotechnology as one of the focus areas on which hope is placed for Japan's future economic expansion. Consequently research funds are channelled into the bio-nanotechnology area.[101]

Nanotechnology and information technologies are viewed as strengths upon which to build future advances. The creation of an appropriately educated workforce and environmental issues and restoring Japan's economy are viewed as particular challenges. Japan trains relatively few PhDs in Science. Creativity needs to be enhanced.

The Ministry of Education, Culture, Sports, Science & Technology (MEXT) views the following projects as contributing to economic revitalization:

- In the **Life Sciences**: personalized medicine based on the genetic make-up of individuals; regenerative medicine through stem cell therapy; simulation of living cells and organisms through bio-info-nano-technologies; bio-photonics.

- In **Information and Communications**: advanced information network systems; High-speed Computer Network Development Project.

- In the **Environment** field: Sustainable Management and Recycling System of Biomass, General and Industrial Wastes.

- In the **Nanotechnology and Materials field**: elemental device development; advanced semi-conductors; artificial organs; next generation analytical equipment, next generation fuel cells.

- In **Other fields**: Creation of a new industrial base in optics; early warning systems.

SHORT AND MEDIUM TERM STRATEGIES

Importance of Basic Research

To contribute to the world through the creation of new knowledge and develop the potential for technological innovations that may break new ground for the future prosperity of Japan, it is considered important to promote pioneering and creative basic research across a wide spectrum of disciplines. For this purpose, MEXT takes measures to increase the support to basic research in universities, improve research organizations and systems such as Inter-University Research Institutes, and increase competitive funding.

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[101] Eurotechnology-Japan Report: http://www.eurotechnology.com/store/bionano/ (summary only)
"Bio-Nanotechnology in Japan - Public Initiatives, Venture Capital, New Initiatives, and Impact on Foreign Corporations" http://www.eurotechnology.com/store/bionano/

Increase in Grants-in-Aid for Scientific Research

Grants-in-aid for scientific research are those provided by the government and the Japan Society for the Promotion of Science with the aim of advancing scientific research in Japan by encouraging creative and pioneering work across a spectrum of fields, from the humanities and social sciences to the natural sciences.

Creative Research for Evolutional Science and Technology Program

The objective of this program is to promote basic research with the aim to achieve strategic goals set by the government to contribute to the creation of new technologies meeting social and economic needs.

FUNDAMENTAL ISSUES

Ethical and societal issues

Japan has defined measures for Bioethics and Bio-safety. With the rapid development of life sciences, revolutionary advancements are expected in such areas as medical science. At the same time, however, this advancement is likely to give rise to bioethical issues that might violate human rights and dignity, or bio-safety issues which affect people's health and diversity in the bio-system. To ensure proper responses to these issues, MEXT formulates and operates laws and guidelines such as those which prohibit human cloning and regulate the use of genetically modified organisms, and based on the latest technological development, makes considerations for revisions.

Intellectual property issues

MEXT coordinates Business-Academic-Public Sector Cooperation and has developed an Intellectual Property Strategy102 In order to create new industries, increase international competitiveness and revitalize the economy and society, Japan considers important to promote business, academic and public sector cooperation to turn important results achieved at universities and national research institutes into practical applications, and thus return the benefits of the research to society. Cooperation and collaboration between universities and private companies are believed especially important to promote the contribution of universities to society and to advance scientific research.

Consequently, MEXT is making efforts to create a system that promotes cooperation among the business, academic and public sectors. MEXT also operates a Technology Licensing Organization (TLO) to promote technology transfer from universities and maintains centers for cooperative research in national universities. In addition, with a view to promoting the intellectual property strategy, MEXT is developing a system to manage and utilize intellectual property at universities and is nurturing expert human resources in intellectual property.

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[102] http://www.mext.go.jp/english/org/science/50.htm

15.4 CHINESE TAIPEI

SCOPE OF FORESIGHT

Chinese Taipei has been involved in R&D planning since 1979. Responding to the international innovation trend towards the knowledge economy, Chinese Taipei government drafted the "National Science and Technology Development Plan, 2001-2004" in May 2001. This plan provided a roadmap to guide in the drafting of Chinese Taipei's technological policies and the implementation of its S&T research and development.

According to the World Economic Forum's "Global Competitiveness Report, 2001-2002", Chinese Taipei ranked third in terms of Growth Competitiveness Index; it also ranked second in the world (1st in Asia) in terms of technology, and second in innovation. Meanwhile, in a national competitiveness ranking report 2003 conducted by the International Institute for Management Development, Chinese Taipei ranked sixth in terms of its overall competitiveness.[103] In the past years, the Chinese Taipei government has proposed the "Two Trillion & Twin Star Project" and the "Challenging 2008 National Development Plan"[104] to promote biotechnology to become the country's next principal industry.

AREAS OF PRIORITY[105]

The key priority determinant is what is included in the designated National Programs – see table 9 , below . A strong feature of innovation design in Chinese Taipei is the Industrial Technology Research Institute and its emphasis on rapid commercialization of technology into manufacturable products. In particular are the National Program areas that have progressed into technology innovations within the scope of the Industrial Technology Research Institute (ITRI) activities:

- **Nanotechnology** covers aspects in electronics, data storage, packaging, energy, display, photonics, biotechnology, platform technology, application in traditional industries, and facilities built-up.
- **Biomedical technology** is considered one of the most promising areas of research in the 21st century. ITRI is involved in five main research areas: genomics, medical engineering, nano-biotechnology, tissue engineering, and pharmaceuticals. Key research projects include biochips, bioinformatics, biomaterials, tissue repair, molecular devices, bio-photonics, targeting delivery, and peptide drug development.
- The technical field of **communications and optoelectronics**, is centered on technical development and applications for mobile and broadband Internet by using current wireless communications, broadband communications, information and communications design, intelligent information technology, and optical information as the foundation to advance into area like Beyond 3G networks, broadband access, intelligent optical

[103] M. Dellah: Science and Technology Overview 2003: Chinese Taipei http://www.infoexport.gc.ca/science/Taiwan_2003-en.htm

[104] http://www.itri.org.tw/eng/about/annual/annual02/annual2002e-3.pdf. Only the html version of the file is accessible

[105] http://www.itri.org.tw/eng/research/index.jsp

communications network, human-machine interface and information technology, advanced information storage, advanced flat panel display, and nanoelectronics.

- Future R&D in the **sustainable development** field encompasses advancement in many areas: clean energy utilization, high efficiency energy technology development, fuel cells, nanotechnology applied to environmentally-related subjects, clean production, waste reutilization, industrial process hazard prevention, and responsive measures, etc.

ELEMENTS OF THE COUNTRY/REGION APPROACH TO THE DEFINITION OF GOALS

In Chinese Taipei, the responsibilities of Science and Technology R&D are divided among several governmental agencies. The Executive Yuan is most important actor in the S&T development system of Chinese Taipei. Besides the Executive Yuan, the Office of the President, which is independent from the Executive Yuan, shares the power of making S&T Policies. The Academic Sinica is under the Office of the President, while the National Science Council (NSC) and several related agencies: the Ministry of Education, the Ministry of Economic Affairs (MOEA), the Ministry of Transportation and Communications, the Atomic Energy Council, the Department of Health, and the Environmental Protection Administration report to the Executive Yuan

The Ministry of Economic Affairs seems to be the key organization responsible for the definition of S&T goals through the National Science Council, which funds basic research and the ITRI, a non-profit R&D organization engaging in applied research and technical service. ITRI was founded in 1973 by the MOEA to attend to the technological needs of Chinese Taipei's industrial development. It has played a vital role in the transformation of the economy from an agriculture-based model to an industrial one. By year 2001 it has grown to a 6000 people operation, and serves as the technical center for industry and an unofficial arm of the government's industrial policies in Chinese Taipei. Backed by its broad research scope and close industrial ties, ITRI is becoming an increasingly active member in the global industrial R&D community.

Relation to R&D Strategy

Chinese Taipei’s S&T strategy is geared to using its existing competitive advantages to excel in many technology areas. The major actors in this strategy are the Government, National Research Institutes, Industry, Academia Sinica and Educational Institutions

Seven Critical Features of the National S&T Programs are identified:

- ***National Champions***: Each program is assigned a national champion, consisting of a senior, designated leader having stature, relevant knowledge and abilities and connections that can assure the participant organizations access to resources, knowledge and early integration of production capacity. This person is also very much in charge of the process of organizing the institutional partnerships and alignment and assignment of resources within the program and for positioning its future economic potentials, so there is both creativity and accountability built into these assignments.

The National Science Council actively manages the portfolio of national programs ensuring that the Champions are able to manage them with the assurance of cooperation form other stakeholders within the national governance and innovation systems.

- ***Academic Excellence***: Each program is accompanied by an academic research program element tied to the national university system and managed through Academica Sinica, which functions as a national granting council, but has a more directive leadership function insofar as the ties to other elements - e.g. industrialization are designated early and more continuously developed than they would be in a Canadian context.

- ***Industrialization Strategy****:* Prospective product or knowledge based service domains and devices - systems applications and their target eventual markets are integrated into the program from the start. e.g. in nanotechnology the plan includes the following objectives and industrialization elements:

  - Establishment of common core facilities and education programs to achieve academic excellence, and promote industrial applications.
  - Support academic excellence based in the area of the national competitive technologies and then, create innovative industrial applications.
  - Establishment of international competitive nanotechnology platforms.
  - Enhancement of advanced innovative research to speed up the commercialization of nanotechnology.

- ***ITRI and the national science and technology parks*** have been particularly effective at identifying developmental and emerging market trends and directing the commercialization of technologies through the provision of a managed environment for prototype realization, assistance with talent acquisition, and as vehicles for the provision of public sourced financial seed money that eventually gets repaid from initial earnings once a firm achieves export revenues and self reliance. e.g. The Hsinchu Science-based Industrial Park, established in 1980 by the National Science Council under the authority of the executive arm of government, Republic of China Executive Yuan, now has over 300 firms and 85,000 hi-tech workers, with annual growth rates averaging 20%, and a 10 -15 % success rate in launching public companies so that additional developmental revenues can be raised.

- ***Education + Global Competitive and Technical Intelligence***: Each national program is expected to include a set of mechanisms to provide the continuous knowledge of where one's competitors are, and where the new market opportunities can be anticipated. A key element associated with this aspect of the national programs is an active system of bilateral Memorandums of Understanding (MOUs) with S&T institutions in key western economies such as that with the National Research Council in Canada. Under these agreements, Taiwanese students and researchers are dispatched abroad on cultural and scientific exchanges and encouraged to obtain graduate education and internships from leading global universities and R&D institutes.

- ***Early Public Education and Outreach***: Chinese Taipei has developed a series of public educational videos and kindergarten to grade12 learning packages, cartoons etc. that educate and build positive receptiveness to what S&T can offer the future. These present an alternative to what has appeared to be a resistance against advanced technology in some other national circumstances where fears and hype become the polarities of public debate and innovation seems to become more constrained than in the Taiwanese culture.

- ***High Level Integrated Governance and Disciplined Exit Strategy***: Many countries have a similar system of national initiatives approximated by the foregoing elements. Where Chinese Taipei has clearly differentiated itself is in the way it has ensured not only effective coordination and integration, but also in how the really difficult and demanding decisions are made to ensure discipline and adaptation to what are fast changing global target markets.

There is a clear commitment to coordination within and across the elements of the national programs in terms of progress goals, innovation strategy and precedence of decision authority.

One of the key mechanisms is a regular dinner with key leaders, linking the National Program management with the National Science Council and Academica Sinica leadership. These dinners allow for frank and informal discussion of critical alignments and investments as well as shifts required to remove barriers or address emerging opportunities. They also provide a forum for shared intelligence about global context and collaborative priorities with organizations such as Canada's NRC.

AREAS OF INTEREST AND FIELDS OF APPLICATION

Table 7 shows (2003) activities supervised by the NSC under the National Science and Technology Development Plan (taken from[106]):

[106] M. Dellah op. cit.

Table 8: Chinese Taipei NSC Activities (2003)

Research Areas	Current Research Emphases
Natural Science Development:	
Mathematics Statistics Physics Chemistry Earth Science Atmospheric Sciences Oceanography	Nanomaterials Advanced Research Project Studies on Metal String Complexes & Molecular Metal Wires Spectroscopy and Photochemistry of Gaseous Free Radicals Program of Earthquake and Active-fault Research Research on the dynamics of typhoon genesis, intensity, and track in the Northwestern Pacific A model of Real-Time Predictions of Sea Conditions in the Strait of Taiwan High-Energy Physical Experiment / Large Hadron Collider (LHC)
Engineering and Applied Sciences:	
Civil Engineering Environmental Engineering Solid Mechanics Thermal-Fluid & Energy Automation Aeronautical Engineering Metals & Ceramics Industrial Engineering Management Optics & Photonics Micro-Electronics Engineering Computer Science & Information Engineering Communication Engineering Control Engineering Biomedical Engineering Chemical Engineering Polymer Science & Engineering Electric Power Engineering Ocean Engineering	**MEMS and Nanotechnology Promotion:** Establish & coordinate the long-term plan for R&D on Micro-Electro-Mechanical Systems (MEMS) and Nanotechnology within NSC Applied Science and Engineering Departments Promote and collaborate all aspects of the NSC-funded projects Coordinate the framework needed for international collaboration **Information Technology Research:** Human Machine Interface Natural Language Processing Micro-system Chips Biometrics Digital Life Integration of 3C Technologies (Computer, Communications, Consumer)
Life Sciences:	
Biological Science Agricultural Science Medical Science Clinical Science	Agricultural Biotechnology Research Biotech-Pharmaceuticals Research Genomic Medicine Research Frontier Science Research: -- Transgenic Technology, Embryo-Biology, Structure Biology, Neuroscience, Aging and Degenerative Diseases etc. Development of New Drugs, Development of Cancer-Preventive Agents, Breeding of Ornamental Plants etc. Tissue Engineering Research Bioinformatics Research

GENERAL CHARACTERISTICS OF LIKELY CT APPLICATIONS

- **Genomic Medicine**: The planning and implementation of the "National Research Program for Genomic Medicine" reflects results already obtained by the "Frontier Project on Medical Genomics". It will also tie in the computer industry by developing bio-information technology, will use protein science to understand gene function and pathogenic mechanisms, and will explore the ethical, legal and societal issues of genetic technology.
- **Systems on Chips:** The country has invested NT$7.6 billion in semiconductor development projects. The goal of establishing a semiconductor internet protocol industry was to resolve difficulties to systems on chip implementation and enhance the competitiveness of information technology design companies and system product manufacturers, expanding the market share of Taiwanese firms.
- **Nanotechnology**: Drawing on outstanding domestic and foreign research results and the "High-Speed Commercialization" ability of Chinese Taipei's R&D organizations, the program will transform the unique phenomena of the mesoscopic[107] world into market opportunities. With the comparative advantages of Chinese Taipei's dominant industries as a starting point, the program is aimed at expanding existing strengths into new areas, creating opportunities for innovation. The goal is to strengthen the training of innovative R&D manpower and establish core facilities.

The following Table gives the extent of investment and the deployment of Chinese Taipei's National S&T programs 1998-2008.

Table 9: Chinese Taipei National S&T Programs 1998-2008

Program Area	Time Period	Budget $ US M
1. Nanotechnology	2003-2008	633.80
2. Telecommunication	1998-2003	376.40
3. Systems on a Chip	2000-2005	226.40
4. Pharma-Biotechnology	2000-2002	32.30
5. Genomic Medicine	2002-2004	220.60
6. Hazards Mitigation	1998-2006	120.60
7. Agriculture Biotechnology	1998-2004	82.30
8. Digital Archives	2002-2006	82.30
9. E-Learning	2003-2007	117.65

[107] Small systems whose dimensions are intermediate between the microscopic and the macroscopic.

ANTICIPATED OPPORTUNITIES AND CHALLENGES

Four major sources of opportunities and challenges have been identified:

- The globalization of trade has made it harder for Chinese Taipei to use tangible or intangible trade barriers to protect domestic industry, knowledge, and technological innovation.
- Devising sustainable development strategies that will maintain the ecological balance while fostering development
- The emergence of the neighbouring Chinese market as a lower cost competitor is threatening to reduce Chinese Taipei's leading OEM manufacturing edge.
- The education system, particularly higher education, is viewed as too “exam focused” and needs some reforms.

In view of such future challenges, the Cabinet-level National Science Council drafted a plan in an aim to bring the country into the knowledge economy age through the application of technology, improve the country's international competitiveness, and transform Chinese Taipei into a Green Silicon Island. NSC is responsible for the promotion and coordination of the country's projects in the development of science and technology.

.SHORT AND MEDIUM TERM STRATEGIES

In the **Nanotechnology** field, the R&D program itself was structured as a three-part, 20/60/20 portfolio. Approximately 20 percent of program resources will go to technologies that can be immediately commercialized, within one to two years (nano-powders, pigments, coatings and inks, nanotechnology-reconstituted plastics and polymers, fibers for textiles, paper products, inorganics and ceramics, metals and alloys). The middle 60 percent will go to the "major thrust" technologies. (like ICs, displays, data storage, packaging, mobile communications, optical communications, biotechnology and energy applications). Program tasks in this category will run on rigorous R&D roadmaps and stretch-targets. As nanotechnology is considered likely to bring radical advances, these major-thrust efforts will be driven by targets that are "quantum jump" or "orders of magnitude" in nature, or risk being orders of magnitude short of competing offerings. The remaining 20 percent of the program will go to the kind of nanotechnology with truly revolutionary implications, but will likely take ten to twenty years to reach commercial maturity.

FUNDAMENTAL ISSUES

Ethical and societal issues

As mentioned above, there is an early education and outreach strategy planned to diminish resistance to the implementation of new technology. No documentation was found regarding the potential risks of new technology and how they should be anticipated and mitigated.

Intellectual property (IP) issues

Chinese Taipei's IP policies are provided on the website of the Ministry of Economic Affairs[108] There is nothing specifically related to CTs. However, the document indicates a concern for issues related to the protection of intellectual property and the need to implant appropriate policies.

[108] http://www.tipo.gov.tw/eng/about/publications/publications.asp

16 APPENDIX 7 - AN OVERVIEW OF THE DEVELOPING WORLD PERSPECTIVE [109]

The very magnitude of problems faced by developing nations makes them receptive to the rapid uptake of advanced technologies - even at a faster rate than the developed world. Their perspective is therefore important to those studying S&T convergence.

Examples of such technologies include:

- Solar technologies, ranging from the simple passive solar cooker to distributed rural electrification.
- Efficient lighting: first fluorescent light now light emitting diodes (LED).
- Inexpensive computing devices: India is now domestically producing the "SimPuter", a Linux-based machine that is meant to be used by a group of people (e.g. a number of farmers in a village). Sturdy, inexpensive, and able to handle many different regional languages, the device also innovates by letting each user have a chip which stores all personal information - so the same computing device can be used by many people.
- Biotechnology applications targeting the health and nutrition needs particular to poorer countries.[110]

These are just the crest of a great wave of innovation that will be driven by many factors, including raw physical needs, competitive pressures, and the natural desire of people worldwide to secure a better life for themselves and their children.

Innovation from Larger Developing Countries

Brazil and India, for example, have been very vocal in challenging the stance of large trade organizations like the World Trade Organization (WTO) and the World Intellectual Property Organization (WIPO), arguing that their policies on intellectual property, trade rules, and agricultural subsidies are preventing the development of poorer nations. Brazil has set up a Microbe Bank, to avoid "biopiracy" from developed countries or multinationals and poorer nations are now manufacturing generic drugs, at competitive prices. Some developing nations are also turning into software and service powerhouses. India is a dramatic case study, having moved far beyond call centres to R&D labs for many of the most advanced companies, including Microsoft and Google. Brazil has a plan to improve access to computing, by leasing Linux computers with software and Internet access to millions of middle-class citizens for a fixed monthly fee – turning computing into a utility while ordinary citizens of Europe and North America still need to waste time with software licenses, system maintenance, choosing the right hardware and programs, and so forth. Such proactive attitudes coupled with an increasing supply of well-educated, technologically savvy, and motivated young people means that a growing number of information technology breakthroughs and applications are likely to come from the larger developing nations.

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[109] Contributed by Hassan Masum

[110] See report *The Top 10 Biotechnologies for Improving Health in Developing Countries* University of Toronto Joint Centre on Bioethics. http://bio.org/globalhealth/topbiotech.asp

Innovation for developing and/or transient economies

"FabLabs," are personal fabricators that could allow design and fabrication of products in one's own workgroup or home. They have already been deployed on an experimental basis to developing countries. Allowing those without access to industrial-scale machinery to easily design and test prototype devices, may enable them to develop tools, machinery, and high-tech devices adapted to local needs in the developing world. It is quite probable that such devices would start to build up Open Source object libraries - schematic blueprints like computer programs which can be fed into a "fablab," to generate devices designed somewhere else.[111] This could lead to a PC-like revolution sweeping the globe for industrial and consumer items coming from countries unable to pay for expensive company-built solutions or in need of rejuvenating less globally competitive traditional manufacturing sectors.

Information technology and the power of open collaborative projects offer radical leapfrog opportunities to developing world nations. For example, SchoolTool[112] is a project to develop a common global school administration infrastructure that is freely available under an Open Source licence. It will provide teachers and school administrators from around the world:

> *"...a robust and reliable means of managing their school or classroom, saving time on routine tasks like managing class rosters, tracking student attendance, assessment and demographic information, helping teachers coordinate their schedules and reserve resources ...SchoolTool's interface will be easily translated for use around the world and accessible to people with disabilities."* [113]

This could easily be connected to a global infrastructure of "learning objects", so that educational material could be generated, replicated around the world, and improved at low cost.

A similar but even more ambitious initiative is the $100 Laptop project from the Massachusetts Institute of Technology Media Lab[114] that aims to:

> *"...revolutionize how we educate the world's children...The $100 Laptop will be a Linux-based, full-color, full-screen laptop...it will be rugged, use innovative power (including wind-up), be WiFi- and cell phone-enabled, and have USB ports galore. Its current specifications are: 500MHz, 1GB, 1 Megapixel... Organizationally, MIT will host a consortium of a small number of companies of complementary skills to develop a fully working and manufactured laptop (50,000 to 100,000 units) in fewer than 12 months, with an eye on building about 100 million to 200 million units by the following year."*

Through necessity, progressive developing nations are open to making full use of the potential of converging technologies. They may be the places to watch for creative and low-cost applications

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[111] See FAB: The Coming Revolution on Your Desktop (Neil Gershenfeld; Basic Books, 2005).
[112] (www.schooltool.org)
[113] (www.schooltool.org)
[114] (laptop.media.mit.edu).

in the future and should be integrated as technology user and provider in open foresight initiatives.

17 APPENDIX 8 - DEFINITIONS: TECHNOLOGIES INCLUDED IN THE DOMAIN-DOMAIN MATRIX, ROBOTICS AND OPEN SOURCE TECHNOLOGIES

17.1 OPEN SOURCE TECHNOLOGY: A CONVERGING TECHNOLOGY FOR AMPLIFYING HUMAN EFFECTIVENESS?[115]

This section discusses the potential of open source and collaborative technologies (Open Source) as drivers and enablers of innovation. Advances achieved through the open source process can be considered as a platform technology that is speeding up the course of discovery in many of the other converging technologies. Open Source also has direct relevance to the foresight process itself, as a way of engaging many stakeholders in decision-making throughout a Converging Sciences and Technologies Foresight exercise – a way that could lead to better and more timely policies.

The concept

> *"Property in open source is configured fundamentally around the right to distribute, not the right to exclude."116*

Proprietary products are legally protected from copying, modification, and improvement by all but the producer. In contrast, many open source licenses explicitly allow copying and modification, as long as the resulting modified product is itself released under the same open source license.

By keeping the right to distribute and modify as a fundamental requirement for use of open source material, improvements to the material from contributors and users worldwide are incorporated in a positive feedback loop. This has led to the development of industry-leading products around which service businesses are being built, most notably in software, but increasingly in other fields as well.

Some precedents and examples

Although Open Source may seem a radical idea, it is not without precedent. Many service industries have a shared open "code", around which services are built: the legal and accounting professions are excellent examples. An even more pertinent example is the edifice of science itself.

> *“An absolutely crucial aspect of the development of modern science were the institutions, customs, and personal decisions made to disseminate discoveries widely and publicly. Such dissemination was and is essential to quality control and uncovering flaws in theory and practice, and of course it is also essential for the*

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[115] Contributed by Hassan Masum
[116] Weber, S.: (2004) *The Success of Open Source* , Harvard University Press,

"building block" aspect of science which lets each scientist build on the work of many predecessors."[117]

The software industry has a large and growing number of Open Source projects. The Linux operating system is the best-known example: it is used by many large companies in sectors including banking, finance, special effects, and R&D. Most universities and many research-oriented government agencies use the software, as do an increasing number of national and municipal governments (especially in the developing world). And many companies have made serious investments or business models based on Linux, including IBM, HP, Oracle, Intel, Dell, Sun, Red Hat, and VA Linux.

It is important to note that "Open Source" does not necessarily mean "free of charge", although it does mean "free to modify and redistribute". Clearly the vast array of for-profit companies that have bought into the open-source process believe that it is to their advantage to do so – not least because it partially levels the playing field between incumbents or monopolists and new entrants, thus leading to a more competitive market.

Aside from the well-known example of Linux, there are many other large projects, and a vast number of smaller ones. These span the gamut from Web server software (Apache) to office suites (OpenOffice) to mail servers (Sendmail) to databases, graphics packages, scientific tools, collaborative software, and many more.

While smaller projects with a handful of developers can be of uneven quality, the larger projects are robust and scalable, and useful for mission-critical applications. Indeed, many have argued that the open nature of such software is a crucial ingredient of its quality, since more users report flaws and since organizations are free to critically examine or modify the code themselves to increase its robustness for their applications.

A platform technology

Open Source is increasingly becoming a platform technology, enabling rapid advances in advanced and converging technology applications. There are many examples:

Open Source Biotechnology: Many important biotechnology tools are Open Source, and now, complete exploratory bioinformatics toolsets are being made available. These are sophisticated toolsets that may become heavily used for advanced biotechnology, especially in developing nations unable to afford proprietary solutions.

Open Source Education: The Massachusetts Institute of Technology, one of the world's leading universities, has committed to making much of its course material publicly available over the Internet.

Open Source Medicine: Pharmaceutical innovation has started to happen in the provision of funding for research into developing-world diseases, which have not been priorities of for-profit

[117] Mokyr J.: (2003) in *The Gifts of Athena: Historical Origins of the Knowledge Economy* Princeton University Press.

companies in the past. A non-profit company model is being tried out,[118] as are innovative funding models such as guaranteeing purchase of a certain amount of curative medicines in exchange for making them free of legal restrictions.

Open Source Nanotechnology and Rapid Fabrication: There has already been discussion about making blueprints for physical objects freely available. Since viruses in software for manufacturing physical objects could be far more dangerous than the familiar annoying computer viruses, there would need to be oversight on several levels – but it may become natural to share blueprints for making common objects. Indeed, this may become a near-term reality as rapid fabrication devices grow to be more widespread.

Open Source Publishing: O'Reilly and the Public Library of Science are two well-known examples: the first is a leading publisher of technical books, the second an open-access journal publisher whose journals have already become heavily cited. There is a growing movement among funding agencies to require that the results of research done using public funds be made available free of cost to the public.

17.2 ROBOTICS[119]

Dreams of mechanical servants created in the image of humanity have been around for hundreds of years. Since the word "robot" was coined[120], the idea has become an increasingly popular staple of science fiction. However the stage where robots are turning from fiction to fact is being reached and some applications might raise important ethical and security issues, even today:

Autonomous vehicles have been used to explore the ocean depths and the sands of Mars. Several Japanese companies have developed humaniform robots capable of walking. Now they are competing to give their robots more abilities, from climbing stairs to manoeuvring in busy environments to dancing and juggling.

Drone aircraft have been used for surveillance, and there is a large amount of interest in developing war-fighting robots - a development which is viewed with grave misgivings in many quarters.

At the same time, robots have potential for good, from household cleaning to assistive care of the disabled and elderly. How much intrusion will societies find comfortable, as robotic devices move out of the factory? What are the economic implications (positive and negative) of robots becoming capable of some routine activities - negative because of job loss, or positive because of their time-saving potential? Who is liable for ensuring robotic security? One can imagine the havoc that spyware and spam could play if it targeted devices in the physical world. Finally how far should governments be allowed to go in building up robotic police and war fighting devices?

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[118] Institute for OneWorld Health: http://www.oneworldhealth.org/

[119] Contributed by Steff Christensen and Hassan Masum

[120] The use of the word Robot was introduced by Karel Capek (1890-1938) into *R.U.R. (Rossum's Universal Robots)* which opened in Prague in January 1921. Robot is derived from the Czech word for forced labor or serf. In R.U.R., Capek describes a paradise, where the machines initially bring many benefits but in the end bring an equal amount of blight in the form of unemployment and social unrest.

17.3 DOMAIN-DOMAIN MATRIX CAPSULE DESCRIPTIONS

The technologies presented in the domain-domain matrix are only a representative snapshot, not a in-depth analysis of all interesting convergent technologies. As some of these may be unfamiliar to our readers, we provide the following capsule descriptions that may aid readers in learning more about these interesting convergent technologies. Much more in-depth information is available on the Internet through a search engine, or from a major science journal such as Nature or Science. Note that in some cases, the terminology has not stabilized for these technologies, so they may be called different things by different sources.

RNA Scaffolded Nanostructures

RNA Scaffolded Nanostructures: RNA is synthesized so as to self-assemble into particular shapes at the nano-level. Nanomaterials of interest are thus given the desired nanoshape

Nanotags: Millions of unique sequences of nucleic acids which can be injected or dusted on products to identify them for copyright or identification purposes

DNA Computing: Computing achieved by performing simple operations on billions of sequences of DNA at once

Evolutionary Computation, also EC: Programming a computer to use evolution to solve hard optimization problems, such as programming, routing and scheduling

Biorobots: Implanting the brains and nervous systems of lower animals in mechanical robots to provide a shortcut to trainable behaviour in robots

Nanobiosensors:
Nanoscale sensors that detect a particular compound of interest using an enzyme specific to that compound. The human sense of smell works this way.

Nanoparticles:
Tiny spheres of gold, nickel, etc. which can be chemically bound to active substances to make highly specific engineered "compounds"

Smart drug delivery:
Delivering a very tightly localized drug dose to a particular tissue to eliminate systematic toxicity.

Nanoarrays:
DNA, RNA and protein microarrays, manufactured at nanoscale densities (10 000 per linear millimetre)

Nanoelectrodes:
Electrically conducting wires that are small enough to connect to parts of an individual neuron

Nanocomputers:
Hypothetical nanoscale computers made of mechanical rods. Slower than digital computers, but likely millions of times more power efficient

Real-time brain nanosensors:
A nanosensor which is small enough to filter through the blood, which is attached to a signalling device that can be picked up by receiver machinery on the outside of the patient's brain

Protein Structure Prediction:

Determining the shape of a folded protein from its amino acid sequence

Metabolic pathway discovery:
Determining automatically which enzymatic sequences and which chemicals are involved in producing a particular substance

Proteomics:
Determining which proteins are produced by an organism and under what conditions they are produced

Other analyses: Other biological systems research, by analogy with genomics – the study of the set of genetic material produced by an organism. Includes, among others, transcriptomics and metabolomics.

Molecular dynamics:
One level of modelling chemistry where atoms are observed through a few picoseconds of simulated time. This is enough time to watch a nanogear rotate or to watch chemical reactions take place, but not enough to watch a protein fold into its natural shape

***ab initio* calculations**:
Determining what should happen in a nanoscale system by using a very accurate physical theory that is too slow to run on large or complicated atomic systems

Collaborative filtering:
An online automatic system that uses user feedback from many users for determining which information would be interesting or useful. "Feedback" can be as intrusive as user ratings or as automatic as what is clicked or looked at for how long

Avatar:
a user's representation in a virtual interactive forum

Software agent:
an autonomous program that variously searches for information or resources on a user's behalf; or negotiates and transacts with other users or agents on a user's behalf

Personal networking:
a very local-area-network, usually confined to the perimeter of a person's body and the space within about a meter of it. Will obviate wiring between small input/output devices and future portable computers

Automatic algorithm generation:
Automatically writing software for challenging domains. An example would the best-known algorithm for hydrophobicity prediction, which was written by a computer using genetic programming

Data mining:
Determining relations among predictor variables in large data sets by means of a comptuer program. The large volumes of data available makes human optimization challenging, though humans are better at determining which solutions are superior in a real-world context

Force field optimization: A common problem in protein structure prediction is that existing models of energy calculation are inaccurate. These can be improved using automatic search algorithms to augment human intelligence

Swarm intelligence: "Intelligent" behaviour produced by running very simple algorithms on interacting software agents. Ant, wasp and bee swarms use this technique to collectively solve hard problems like getting food to a colony in the face of resource depletion and introduced threats