Bio-Systemics Synthesis

STFPP Research Report # 4

SCIENCE AND TECHNOLOGY FORESIGHT
PILOT PROJECT

A Research Report of the Science and Technology Foresight Pilot Project:
A Partnership of Federal S&T Organizations

Bio-Systemics Synthesis

By Raymond Bouchard
June 2003

SCIENCE AND TECHNOLOGY FORESIGHT PILOT PROJECT

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Acknowledgements

The BioSystemics Scoping Workshop and Technical Panels could not have been completed without the talent and effort of many people. First and foremost I would like to thank the participants who contributed their valuable time and energy

Dr. Lee Baudette - Environment Canada
Mr. William Coderre - Natural Sciences and Engineering Research Council of Canada
Dr. Arthur Cordell - Industry Canada
Ms. Jennifer Davidson - University of Ottawa
Dr. Walter Dermott - CytoBioTechnics Inc
Ms. Nicole Dusyk - Environment Canada
Ms. Susie ElSaadany - Health Canada
Mr. Philip Fleming - Industry Canada
Ms. Andra Forney - Youth Science Foundation
Ms. Sandra Gabler - Canadian Food Inspection Agency
Dr. Gary Glavin - Health Canada
Mr. Neil Gordon - Canadian Nanobusiness Alliance
Mr. Geoffrey Gurd - Health Canada
Mr. Peter Hall - Agriculture and Agri-food Canada
Mr. David Harries - National Research Council
Dr. Mary Alice Hefford - Health Canada
Mr. Ole Hendrickson - Environment Canada
Mr. Harry Hirvonen - Natural Resources Canada
Mr. Robert Hoffman - Robbert Associates
Ms. Lise Hughes - National Research Council
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Mr. Michel Poulin - Canadian Museum of Nature
Dr. Laurian Robert - Agriculture and Agri-Food Canada
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Mr. Kenneth White - Acton White Associates
Dr. Norm Willis - The Norm Willis Group

Suporting the effort, and making contributions in their own right, was the project team: Thanks go out to Mr. Jack Smith of the National Research Council for his leadership and to the other members of the team:

Ms. Line Brabant - LINE International
Dr. Allen Chong - National Defence
Mr. Kevin Cliffe - Natural Resources Canada
Mr. David Crabtree - Canadian Space Agency
Mr. George Emery - National Research Council
Ms. Carol Fairbrother - Natural Resources Canada
Mr. Peter Kallai - Keystep
Mr. Keith Langille - Texec Inc
Mr. Glen Milne - Glen Milne & Associates
Ms. Catherine Morrison - Morrison and Associates
Dr. Fonda Munro - Canadian Food Inspection Agency
Ms. Lynelle Spring - Spring Works

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SCIENCE AND TECHNOLOGY FORESIGHT PILOT PROJECT
2005 to 2030

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 project originated with a proposal made by NRC to the community of federal Science Based Departments and Agencies in March 2002, offering NRC's support for a collaborative pilot project 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 federal S&T community should be better prepared.

Thirteen federal Departments and Agencies joined together to create a limited duration (i.e. six months) partnership that sponsored close to 20 events. The partners and their colleague networks of scientists and industry-academic collaborators contributed over 400 days of professional time to developing the Project's methodology, panel and workshop events and in drafting and reviewing the STFPP findings.

It is useful to recall the definition of S&T Foresight that was used to define the scope and focus for this Pilot Project:

> *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 and when these could become significant factors in Canada's prospective social economic and political realities. Since these are highly uncertain, foresight is inherently about attempting to understand, dimension and reduce or at least prepare for significant risks.

The following statement has been used to caution foresight participants and stakeholders not to take these reports as fact or prediction. They represent collaborative research that was conducted primarily for learning purposes, with the understanding that if a consensus emerged regarding possible application of these insights, then one or more of the domains studied might eventually warrant a further, more detailed examination in that context.

> *The approach we are taking relies upon consulting a wide range of expertise, with the expectation that through our collective experience, imaginative abilities and interactive knowledge of technological development pathways, we can begin to construct a coherent view of some of the major developments that can be anticipated within a 10-25 time horizon. Foresight is therefore research that can inform the reality of planning, policy and strategic*

choice amidst uncertainty. This is the nature of foresight - creating a range of plausible future elements that in their diversity should alert readers to the kinds of issues and perspectives they may not have initially considered in longer term research planning and contingency thinking. Accordingly, this report reflects the combined views of the participants, and the best wisdom and creative thinking that we could stimulate with the tools of foresight, but it clearly does not represent an official view of the Government of Canada or any of its Departments and or Agencies.

Because this was a pilot project, each player, sponsor or participant takes away some collaborative learning and experience that is tacit and more deeply resonant than the descriptive or analytical accounts contained in the reports. These more explicitly detail the initial findings and processes employed during the STFPP. We also discuss in the reports how various foresight approaches and tools could help readers become better prepared or at least more capable of contingent planning and action in these turbulent times. Finally, this work is the result of a team in which significant learning occurred that could assist our efforts going forward.

Please contact us if you would like to become part of the network of S&T foresight professionals that will be contributing to this area in the future.

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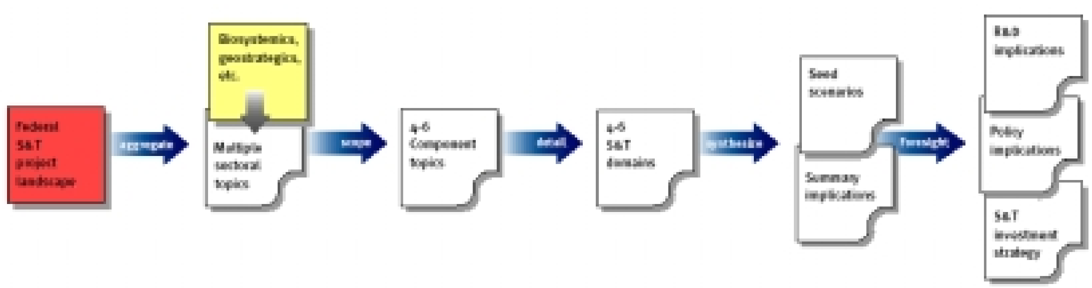
SCIENCE AND TECHNOLOGY FORESIGHT PILOT PROJECT
2005 to 2030

Executive Summary

Prospecting the Future:

- Exploring prospective impacts on society of S&T developments
- Identifying emerging factors driving change
- Identifying areas of scientific research and technological development likely to influence change and yield the greatest economic, environmental and social benefits over the next 10-25 years
- Developing a foresight context for potential application to policies, agendas and investment strategies for S&T and R&D
- Improving horizontality through better understanding of where and how to collaborate among departments, agencies and other stakeholders
- Creating robust networks of collaboration among Canadian and international experts in selected S&T domains and prospective future sectors of national concern
- Providing a collaborative learning environment for strengthening the inclusion of S&T input to the policy process



Participating Federal Science Based Departments and Agencies:

Agriculture and Agri-food Canada, Canadian Biotechnology Advisory Committee, Canadian Food Inspection Agency, Canadian Space Agency, Communications Research Centre, Defence R&D Canada, Environment Canada, Fisheries and Oceans Canada, Health Canada, Industry Canada, National Research Council Canada, Natural Resources Canada, Natural Sciences and Engineering Research Council

SCIENCE AND TECHNOLOGY FORESIGHT PILOT PROJECT
2005 to 2030

1. Background

The Science and Technology Foresight Pilot Project (STFPP) is a planning activity designed to explore the long term future of technology as it relates to the S&T activities of science based departments and agencies (SBDA) in the Canadian federal government.

In the course of a series of meetings of federal science-based departments and agencies, it was generally acknowledged that a strategic focus had to be directed to BioSystemics, defined as follows.

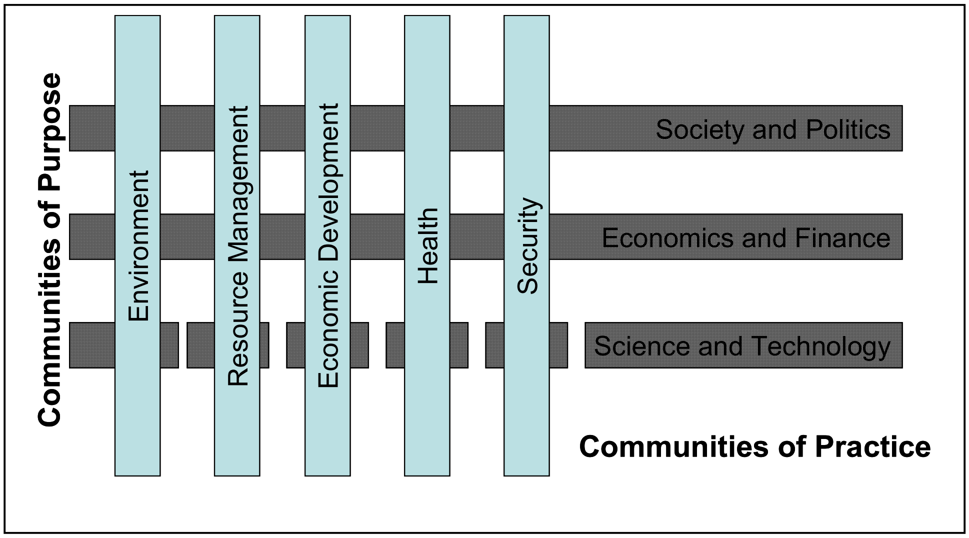
Bio-Systemics
The convergence of nanotechnology, ecological science, biotechnology, information technology and cognitive sciences, and their prospective impacts on materials science, the management of public systems for bio-health, eco and food system integrity and disease mitigation.

The BioSystemics component of the STFPP focused on the following question.

The BioSystemics Reference Question
How can the Federal Government – via FINE (Federal Innovation Networks of Excellence) departments and agencies - better understand the complexities and interdependencies of Canada’s food, health and environmental systems, and develop a 10+ year horizon of actionable intelligence for research policy in these areas, given new knowledge about emergence, behavior of populations, disease ecology, genomics, etc.?

The interest in undertaking the pilot project comes from two sources. First, there is a sense, at least in scientific circles, that we are on the verge of discovering many new transformative, and for some disruptive, technologies. While the public at large may be acclimatized to the relentless pace of innovation, technology watchers are of the belief that the rate of innovation of the past three decades pales in comparison to what is coming down the road. *In this kind of environment, it pays to look ahead*. Indeed our main trading partner and competitor, the U.S., is well ahead in its understanding of the implications of the new technologies. They understand that technological superiority is the key to continued U.S. preeminence, and security, and all that it brings.

The second source of interest lies in the concern that the Canadian government may not be approaching S&T strategically enough. Scientific knowledge and technological capability are powerful forces in the shaping of modern economies and societies. Without them, we would be operating at a much more primitive level. Yet, as is shown in the chart below, the government does not use technology as strategically as it could.



This graphic indicates the interwoven communities of purpose and communities of practice.

The communities of purpose, shown as vertical bars, focus on what must be done. The activities of these communities gravitate into clusters in which a common interest and expertise is shared, be that environmental protection or security. Their goals and requirements may at times conflict, strategically and tactically/financially, but their issues eventually get negotiated and resolved, via what are shown here as communities of practice.

Communities of practice are shown horizontally and reflect the *way* in which issues are resolved and problems solved. They are domains of expertise that sort out priorities, although they may not do it in a totally disinterested fashion. These communities also drive their own definition of what success looks like. The Society and Politics community views the world in terms of values, what is socially or politically important. Decisions in this community are made within Cabinet and executive levels of the government. The Economics and Finance community views the world in fiscal terms. Treasury Board and the central agencies make allocative decisions; lower levels of the bureaucracy execute them. There is a continuous tension between social priorities and financial ones.

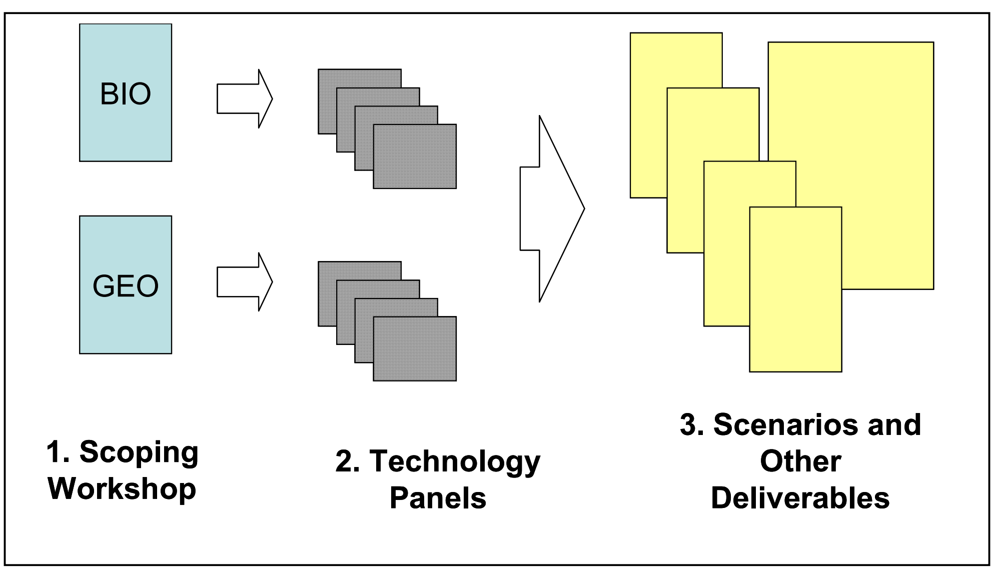
The S&T community of practice is based on knowledge. Outside the policy decision-making space it forms an integrated, well-structured body of knowledge (at least compared to other bodies of knowledge). Inside policy space it is used on an ‘as required’ basis, usually in the most rudimentary, technical and fragmented way. The challenge is to build bridges between areas of S&T expertise in order to get a MUCH greater contribution to overall public sector innovation as well as to public policy.

Process and Methodology

The dual interest in identifying important technology trends and in fostering a horizontal scientific community of practice drove a number of design decisions for the project.

1. In order to build a cross-departmental network of scientists and policy advisers the STFPP used a series of workshops and panels to bring together individuals to poll them for their thoughts on visions, capabilities and impacts. In addition to this consultative process a course on scenarios, as well as a two day meeting of science managers in the public service was held in October 2002.
2. The knowledge managers also engaged in independent research to identify material that has already been published on S&T futures.
3. A working group was established with representatives from sponsoring SBDAs to ensure that an initial set of topics was chosen that would be of interest and value.

Ultimately, two broad topics were chosen: BioSystemics and GeoStrategics. As shown in the diagram below, these two topics were investigated independently. Both had an introductory scoping workshop in which overall parameters of the topic were explored. These were followed by technical panels which probed issues more deeply. The ways in which the Geo and Bio meetings proceeded were, however, different. This report covers only the BioSystemics meetings up to the end of the technical panels. As we enter into the next phase, the production of scenarios, we intend to share and combine materials from both topic streams.



The material that follows is comes from two sources:

1. A literature review on prospective trends and implications. This was provided to participants as a knowledge base before the workshops.
2. Observations and comments made by participants at the sessions.

Bio-Systemics Technology

The term Bio-Systemics is coined to describe the combination of a number of science disciplines and their associated technologies. These disciplines: biology and biomedicine, including genetic engineering, proteomics and metabolomics; nanoscience and nanotechnology; information technology including artificial intelligence (AI), advanced computing and networks; cognitive sciences, including the neurosciences; and integrative system sciences are currently converging and overlapping in ways that are producing significant synergies.

This convergence has provoked widespread interest and enthusiasm, described in terms of a "New Renaissance" and "Threshold Technologies". The possible capabilities that could be generated include:

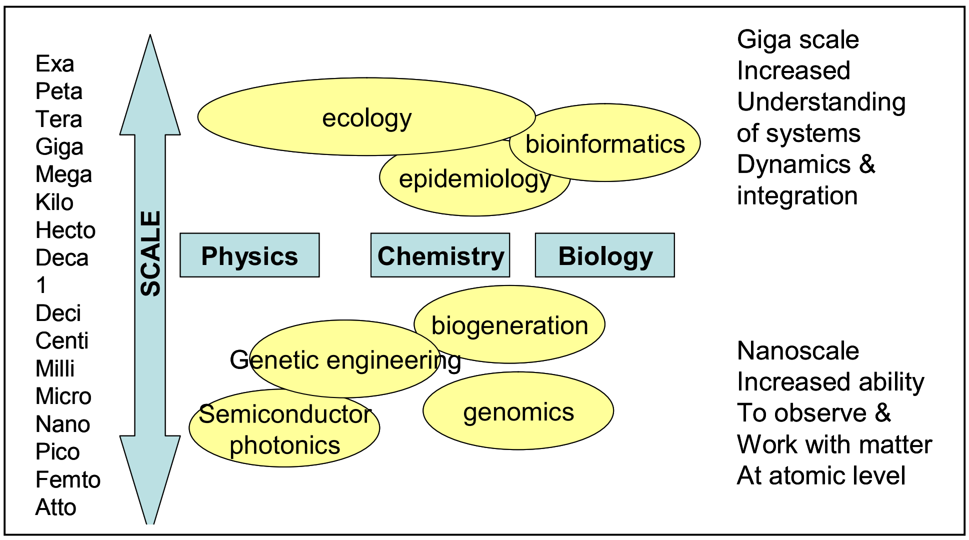
- Exceptionally strong and light new materials
- Tiny bio-sensors that could reside in and monitor the human body
- A better understanding of ecological systems (species adaptation, nutrient systems and bio threats)
- Direct linkages between brain and machine, then brain-to-brain.
- Gene therapy and the general ability to control the genetics of humans, plants and animals
- Highly targeted pharmaceuticals specifically designed for an individual host and released on an as-needed basis to the appropriate body part.
- Sustainability priorities for industrial and social practices
- Personalized health profiles and intelligent systems predictive modeling
- Bio-remediation and regenerative medicine under various societal scenarios

Some of these promising technologies are very speculative, others have prototypes in labs. The next two decades will ultimately be the only way of knowing how BioSystemics technology will evolve. What is known is that R&D spending in these areas has accelerated. The US in particular sees these converging technologies as the key to continuing technological superiority and they do not intend to fall back.

The convergence of these technologies is not a coincidence. It occurs as result of our expanding ability to observe and understand natural phenomena. The expansion takes place at both ends of the measurement scale, from the very small to the very large.

The diagram below illustrates this point. The standard disciplines (physics, chemistry and biology) occur at what could be called human scale. This is the directly observable world as it would have been observed by everyone and anyone until fairly recently. Developments in optics opened up the scale of what is observable, with telescopes letting us see larger more distant objects and microscopes letting us observe nature at the cellular level.

We can now observe matter down to the atomic scale. The ability to observe and work with energy and materials at these smaller and smaller scales has resulted in a convergence, and to some extent an integration of sciences. At the nanoscale atoms, circuits, DNA code, neurons and bits become conceptually interchangeable.

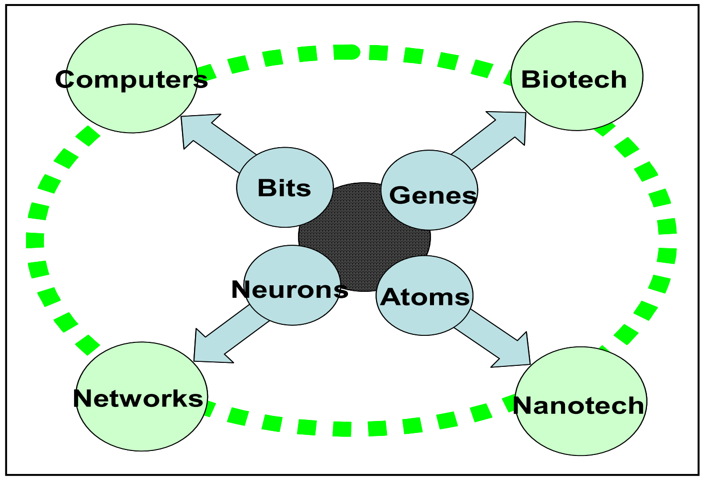


Similar advances have been made at the gigascale. The expansion of science has meant that we can observe not only local weather, but weather systems. The spread of influenza can in principal be traced and mapped. The tools of gigascale science are computers, databases, networks and satellites, which permit us to capture and analyze large amounts of data.

At both the nano- and gigascale new disciplines are emerging that cross traditional boundaries. At the nanoscale level, technologies to build semiconductors can be adapted to build medicines. At the gigascale, graphical information systems designed to monitor weather can also be used to observe oceans, forests, and crops.

What we are in fact observing is a convergence of diverse technologies based on material unity at the nanoscale and technology integration from that scale. At the nano level genes, bits, neurons, and atoms all started looking like the same thing.

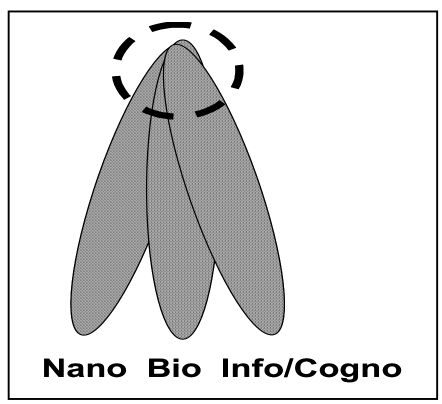
Horizontal integration across either the nano- or gigascale is not the end of the story. Advances in information technology also bring the promise of integration from nanoscale up to gigascale. Developments in combinatorial modeling and artificial intelligence show the way to understanding the behaviour of large complex systems by combining the known interaction of their component parts.



Information technology exists on multiple levels, rather than along a continuous scale. At its lowest, material level - circuits and semiconductors - IT integrates directly into the physical world at the nanoscale. Beyond that material level, circuit states are understood in terms of bits, which in turn are manipulated and understood as either data or programs. As Hofstadter pointed out in his popular 1979 work, *Gödel, Escher, Bach* the difference between data and programs is very local. At a higher level, the program becomes data for a compiler, and this process can repeat itself indefinitely. Within IT the simple manipulation of bits is extensible into sophisticated levels of computation, simulation, and artificial intelligence.

More recently, Stephen Wolfram has pointed out how very complex systems can be built up from primitive cellular automata executing very simple rules. Programs (the rules) do not always have to be complex to produce complex results. Discoveries at the nanoscale about how atoms and molecules, DNA and genes, interact open the door to modeling their behaviour at much higher levels of aggregation.

This combining of essentially different theoretical systems into one creates a unity of knowledge. This combining is called Consilience.



At a superficial level, using graphics that represent entire theories and disciplines as little boxes that somehow combine together, it seems simple enough to understand what the BioSystemics topic is all about. In reality it is unlikely that human civilization has every been poised on the threshold of so many important transformative changes that are important in their own right, but also reinforce each other in powerful ways.

The Science and Technology Foresight Pilot Project has only been able to scratch the surface of this transformation. We have managed to review a great deal of material and discovered many prospective individual technology developments and their related impacts. Seen up close it would make an impressive list. Seen at a distance it is even more impressive. The individual events that we see potentially unrolling in the future form part of a much bigger, interactive whole.

2. Principal Findings

The findings of this process are laid out below in three groupings:

1. High level general observations that apply to the entire field of BioSystemics, including broad trends, implications and impacts, and consequences for government S&T policy.
2. More specific implications for each of the four technology groups, including plausible technological milestones, impacts and implications.
3. Specific commentary that applies to individual departments. The focus of the STFPP was to identify S&T trends that could apply to all departments, however in some cases a trend had very significant relevance to a select few organizations and it is worth capturing these ideas.

General Observations

There appears to be a ”slipstream” of scientific discovery and technological progress that is directing and giving energy to new discoveries. It can be described in terms of 6 components.

1. <u>The IT juggernaut</u>. Amazingly, the progress of computer technology has not slowed down since the 50s. Indeed it shows signs of continuing at a more furious pace. The digitization and virtualization of the world has extended our ability to communicate, visualize and control beyond any natural human ability.
2. <u>Biotechnology</u>. Our expanding ability to study cell, organisms, and their relation to their environment continues to bring success in an area of great complexity. This new understanding of self-organizing, self-replicating objects is creating knowledge in the unrelated areas of IT and nanotechnology. We have created the potential to engineer life forms, something that touches on the very meaning of existence.
3. <u>Nanotechnology</u>. We are on the threshold of building structures at the atomic and molecular level, structures that we cannot see, feel or smell. Yet these structures can have amazingly useful properties. It is expected that this field will enable us

to devise instruments of exceptional sensitivity which will greatly expand our ability to view and understand the biological world.

4. Medical Science will be revolutionized by these new technologies through the use of non-invasive monitoring techniques, highly directed drugs, and much more effective prosthetics.
5. Cognitive Sciences. The ability to understand neural functions may well have profound effects on human performance and well being. There will likely be a cross-fertilization with the IT sector as we train computers to think like humans.
6. Systems Science. An understanding of fundamental material process, combined with new mathematical work in the area of chaos theory, cellular automata, small world networks, and game theory will likely enable us to understand and better manage a wide range of complex systems.

These large scale trends will feed and support each other. The quote below, from the National Science Foundation's report on Converging Technologies for Human Performance [1] (p. 10) describes the interaction.

> "It is possible to identify a number of areas for fundamental scientific research that will have especially great significance over the coming twenty years for technological convergence to improve human performance. Among these, the following four areas illustrate how progress in one of the NBIC (nano-bio-info-cogno) fields can be energized by input from others.
>
> - Entirely new categories of materials, devices and systems for use in manufacture, construction, transportation, medicine, emerging technologies and scientific research. Nanotechnology is obviously pre-eminent here, but information technology plays a crucial role in both research and design of the structure and properties of materials, and in the design of complex molecular and microscale structures. It has often been pointed out that industries of the future will use engineered biological processes to manufacture valuable new materials, but it is also true that fundamental knowledge about the molecular-level processes essential to the growth and metabolism of living cells may be applied through analogy to development of new inorganic materials. Fundamental materials science research in mathematics, physics, chemistry, and biology will be essential.
> - The living cell, which is the most complex known form of matter with a system of components and processes operating at the nanoscale. The basic properties and functions are established at the first level of organization of biosystems that is at the nanoscale. Recent work at the intersection of biotechnology and microelectronics, notably the so-called gene-on-a-chip approach, suggests that a union of nanotechnology, biotechnology, and computer science may be able to create "bio-nano processors" for programming complex biological pathways on a chip that mimic cellular processes. Other research methodologies may come for

[1] This report, often referred to as the NBIC report, can be found at the following link: http://wtec.org/ConvergingTechnologies/

the ongoing work to understand how genes are expressed in the living body as physical structures and chemical activities. Virtual reality and augmented reality computer technology will allow scientists to visualize the cell from inside, as it were, and to see exactly what they are doing as they manipulate individual protein molecules and cellular nanostructures.

- Fundamental principles of advanced sensory, computational and communications systems, especially the integration of diverse components into the ubiquitous and global network. Breakthroughs in nanotechnology will be necessary to sustain the rapid improvement of computer hardware over the next twenty years. From biology will come important insights about the behavior of complex dynamic systems, and specific methods of sensing organic and chemical agents in the environment. Cognitive science will provide insights about how to present information to human beings so they can use it most effectively. A particularly challenging set of problems confronting computer and information science and engineering at the present time is how to achieve reliability and security in a ubiquitous network that collects and offers diverse kinds of information in multiple modalities, everywhere and instantly at any moment.
- The structure, function, and occasional dysfunction of intelligent systems, most importantly the human mind. Biotechnology, nanotechnology and computer simulations can offer powerful new techniques for studying the dynamic behavior of the brain, from the receptors and other structures far smaller than a single neuron, up through individual neurons, functionally specific modules composed of many neurons, the major components of the brain, and then the entire brain as a complex but unified system. Cognition cannot be understood without attention also to the interaction of the individual with the environment, including the ambient culture. Information technology will be crucial in processing data about the brain, notably the difficult challenge of understanding the mature human brain as a product of genetics and development. But it will also be essential to experiment with artificial intelligent systems, such as neural networks, genetic algorithms, autonomous agents, logic-based learning programs, and sophisticated information storage and retrieval systems."

This is all speculative of course. We can not with certainty know the future. The approach taken in this project is best summed up in the words of Arie de Geus, Principal in the Royal Dutch Shell Group Planning, and Architect of Energy Futures Scenarios

The only relevant discussions about the future are those where we succeed in shifting the question from whether something will happen to what would we do if it did happen"

3. Biotechnology Observations

For the purposes of this study, we adopted a broad definition of biotechnology. The term encompasses the sciences, technologies, organizations and regulatory groups that have as their goal the understanding, alteration, and functional modification of organic cells – including plants, animals and humans. It also includes the possible work on non-cellular life forms (e.g. viruses) at which point biotechnology overlaps with nanotechnology.

Some of the specific topics that were considered include:

- Biosensors
- Pharmacogenomics and personalized medicine
- Proteomics
- Predictive medicine
- Gene therapy
- Monoclonal vaccines
- Genetically modified organisms
- Stem cells
- Cloning
- Agriculture and food genomics
- Genetically modified organisms
- Animal genomics
- Aquaculture
- Environmental technology, including bioremediation
- Industrial biotechnology
- Biomaterials
- Fuel sources

Technologies and Capabilities

One of the most important observations to come from these studies is that much impressive technical advancement could happen relatively soon. The following table lists some technologies that are technologically possible, along with prospective early arrival dates.

(Caveat: The prospective early time frames were made based on information in 2001 – 2002. The key assumptions behind them were: (1) some organisation was pursuing the goal, and (2) it was properly funded. These therefore represent feasible, but not inevitable, technology. Changing economic conditions, or for that matter new regulatory frameworks, could alter the arrival times. Specific details aside, it illustrates that the drumbeat of innovation is fairly quick.)

Approximate Date	Technology
2004	PDMAs – personal digital medical assistants can measure a broad range of health indicators, provide information and advice, and be capable of electronically connecting with medical professionals
2004	Genetically modified Elm trees resistant to Dutch Elm disease
2004	Biosensors available to monitor and measure *in situ* bioremediation. They can be applied to pollutants that are difficult to measure or are in hard to reach locations.
2005	Gene Chip available that may include markers for all human genes and could test for over 100,000 conditions. It will be used by professionals in selected applications.
2005	Many new and older drugs could be prescribed after screening a patient's genetic profile to estimate safety and efficacy. New drug prescriptions could include a screening kit.
2005	Birth of first human cloned baby deemed plausible
2005	Therapeutic cloning of embryonic stem cells an accepted practice.
2005	Technical refinements can eliminate most abnormalities and deaths in cloned livestock.
2005	Bioengineered microorganisms available as biocatalysts for industrial use. E.g. produce lysine from sugar for use in animal feed.
2006	"Green" genetically modified plants may use altered genes from the original plant, rather than the introduction of foreign materials.
2006	Milk containing vaccines can be produced by transgenic cows and approved for human use.
2006	Early use of genetically modified organisms, GMOs to remove difficult-to-degrade materials.
2010	Gene Chip (see 2005) could be cheap and widely available. It would be used within health care systems and in some cases by individuals using it for self-care.
2010	Drugs designed for specific genotypes and phenotypes may begin appearing on the market. Pharmacogenomics accelerates both the discovery and the approval process. Drug economics will shift from the production of 'blockbuster' drugs to specific target drugs.
2010	Comprehensive genetic, behavioral and environmental screening will be capable of predicting degree of disposition of most major chronic diseases.
2010	Gene therapy may be commonly used to treat some genetic diseases.
2010	Stem cell will be matured in cells capable of producing dopamine to treat patients with Parkinson's disease.
2010	GM crops valued at over $30 billion annually seen as possible.
2010	World aquaculture exceeds beef production.
2010	Global environmental technology worth $2 trillion. 20% could be for bioremediation.
2010	Consumer pressure and environmental concerns accelerate transition to

	environmentally sustainable bio-manufacturing in the chemical, textile, paper, food, and industry sectors.
2010	Bio-fuel represents 5% of automotive fuel in Europe.
2011	Computer model of "virtual plant" can be used to understand plant physiology and selected genetic modifications.
2013	Biomarkers can be used by most individuals with cancer or at risk of getting cancer. They will monitor early development, identify tumor subtype, pinpoint treatments, monitor responses, and estimate prognosis.
2013	First preventative vaccine for a specific cancer possible.
2013	Transgenic pig organs that reduce human rejection can be used for heart, kidney and liver transplants.
2014	50% of all new drugs could be based on genomics. They are specifically designed for a target subset of the population.
2015	Pharmacogenomic tools can reduce the cost of drug development and approval by 30%. The time from discovery to regulatory approval can be cut by 50%.
2015	Comprehensive legislation in Europe and North America may define protections against 'discrimination' based on predictive medicine.
2015	Molecular nanotechnology can be used in the manufacture of molecular compounds for use in bio-engineered medications.
2015	First major chronic disease can be prevented at the molecular level by a genetically engineered drug.
2015	Bio-based economy begins with agriculture producing significant sources of energy and natural resources.
2015	Commercial production of hydrogen from water using genetically modified algae is used for fuel cells producing electricity.
2025	50% of world fishery protein comes from aquaculture.

As these prospective early technologies lead us in to the foresight time frame (2015 – 2025), we can see the emergence of some key technology drivers.

- Capability to specifically build genetic sequences and proteins.
- High level of capability to monitor and measure phenomena at the molecular level and in remote or hostile environments.
- Ability to substitute industrial processes with sustainable agricultural processes.
- Much higher understanding of the specific causes and specific remedies for a wide number of illnesses. There will be a much improved predictive capability for "at risk" individuals.

Impacts and Implications

The impact of these drivers is extremely dependent on the scale at which they are implemented. It is easy to point to technologies that are possible now, but which have no impact because they are not widely available. How, and at what level, technologies get used will be more widely explored in the context of the scenarios. Jumping ahead though, it is safe to speculate on some impacts.

- The ability to detect and monitor key illnesses could create a greater reliance on “out-patient” approaches to health care delivery.
- New drugs and new procedures, along with predictive capabilities would create an increase in demand for health care products.
- Bio process to replace industrial ones could increase, rather than decrease, environmental stresses as the agricultural sector grows.

4. Nanotechnology Observations

Nanotechnology refers to research, technology development and eventually the production of products which used materials engineered at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometre range. Nanoscience refers to the fundamental understanding of phenomena and materials at the nanoscale. On a larger scale, nanotechnology research and development includes controlled manipulation nanoscale structures and their integration into larger material components, systems and architectures

Some specific topics included in the discussion of nanotechnology are:

- Nano-sensors
- Semiconductors
- Materials
- Micro-electro-mechanical systems
- Lab-on-a-chip
- Nanomedecine

Technologies and Capabilities

Nanotechnology is in a much early stage of development than biotechnology. Many of the promising applications are still in very early stages of development, and therefore it is highly speculative to propose arrival dates. With that caveat, the following timelines have been suggested for certain events in the area of nanotechnology.

Approximate Date	**Technology**
2004	Development of carbon nano tube (CNT) laminates, structures and devices
2004	Manufacture of high temperature CNT composites
2004	Low power CNT electronic components
2004	New materials based on SiC, GaN
2004	Develop materials for sensing and monitoring structural health
2005	Design and fabrication of self-healing materials
2005	Development of multifunctional CNT structures
2005	Devices using quantum dots
2005	Pyro-electric micro-thrusters
2005	Some deployment of super micro-electro mechanical systems (MEMS)
2005	Testing of nano sensors
2005	Testing and use of nano coating and materials
2005	Tech transfer of information from Human Genome Project to create

	biological approaches to nanotechnology
2006	Assembly of micro-mirror arrays
2007	Quantum navigation sensors
2010	Self assembling, multi-functional materials
2010	Micro-opto-electro mechanical systems (MOEMS) assemblies
2010	Multiple sensors on single chip with integrated logic functionality
2015	Biomimetic material systems
2015	Biological computing
2015	Nano-electro-mecahnical systems (NEMS) flight systems
2015	Many super-MEMS products tested and in use
2015	Entirely new classes of materials and processes can be prevalent in everyday use.
2015	Nano diagnostic products may enter commercial marketplace
2015	Early communicating and/or programmable nano-systems
2015	Very early work on nanobots
2020	Availability of communicating and/or programmable nanosystems
2020	Nanobots may be working in labs and being tested, evaluated, and fielded for various specific applications
2020	Nanomedicine could replace older forms of medicine such as surgery, traditional pharmaceuticals, rational drug design
2020	Universal assemblers still not available

Within the foresight time frame (2015 – 2025), we can imagine the following key technology drivers.

- New structural materials with new design characteristics – notable impressive mass to strength ratios, but also electrical and memory properties
- Continuation of circuit density in semiconductors and bit density in storage devices.
- Emergence of nanosensors: to detect chemicals in the environment as well as in biological organisms; to detect mechanical properties (tension, torque, inertia, position, velocity) in robots.
- Integration of nanosensors with circuit logic
- Custom production of complex chemicals for use as pharmaceuticals and enzymes.

Impacts and Implications

Although we view nanotechnology as being new, it is in fact an established technology if we include the semiconductor and IT manufacturing industry as a subset. For decades, IT has been transforming not only industrial and commercial process, but social processes as well. Moreover the pace of innovation shows no sign of slowing down. If anything it is accelerating.

Within nanotechnology as a “new” discipline, although many of the foreseeable technologies are in the very early stages of experimentation and development, they nevertheless are expected to have huge potential. Estimates are that the worldwide market size will exceed $US1 trillion annually in 10 to 15 years. Components of this global market are:

- Nanostructured high performance materials $US340 billion
- Nanotechnology in electronic devices within the semiconductor industry $US300 billion
- Pharmaceuticals production could account for $US180 billion
- Nanostructured catalysts in the chemical processing and pharmaceutical industries could contribute $US100 billion
- High use is expected in the transportation sector for infrastructure and vehicles. In aerospace alone nano components could contribute $US70 billion.
- Nanotechnology is expected to make major environmental impacts not only in improving agricultural yields, but also in water filtration and desalination. Advances in lighting alone could save $US100 billion in the forecast timeframe.
- There will be significant health care benefits.

5. Information and Cognitive Technology Observations

The information and cognitive technology theme puts together two disciplines that are completely separated in the physical world, but are related in a conceptual world.

Information technology is a mature industry in some ways, yet continues to re-invent itself. Even in the simple world of mechanical calculation and sorting of cards, the potential for thinking machines, or “mechanical brains” was there. The IT topics included in this theme are broad and will likely change themselves over the next 10 years. They include items dealing with both hardware and software and point to what has been called “spiritual machines”.

- Semiconductors
- Photonics
- Storage
- Batteries
- Displays
- Networks
- Wireless
- Integrated and embedded devices
- Software engineering
- Artificial intelligence (expert systems, fuzzy controls, neural networks)
- Peer-to-peer

The second part of the Information and Cognitive Technology theme deals with the biological brain. Advances in imaging technology (including holography) and improvements in sensors are creating the capability to discover what the brain does when it thinks. Not only are there medical and psychological possibilities in these technologies. There is also (although long-term) the possibility of reverse engineering some brain functions, thereby enabling the creation of hardware devices that perform some brain functions. The cogno sub-theme includes:

- Neuroscience
- Neuromedicine
- Sensory augmentation and enhancement
- Cognitive sciences
- Brain-machine interfaces
- Artificial emotion, sociable technologies

Technologies and Capabilities

Technology writers have been fairly comfortable about predicting the evolution of IT hardware, as the table below shows. One reason is the relentless march of Moore's law which predicts the doubling of the number of transistors on a chip every 18 months.

While it stands to reason that sooner or later the law has to run out of steam, its demise has been unsuccessfully predicted many times in the past. It just keeps marching on. This success is a prime example of a dominant technology driver. The continued growth of computer power forms a "technology slipstream" into which many other technologies get a free ride.

It is much more difficult to make reasonable forecasts about software development. Even though great sums of money are spent writing code for applications, nevertheless extremely important applications or concepts can emerge from seemingly nowhere to totally realign the computing world. As an example, the simple modification of GML to HTML, combined with a pre-existing network and dataset, was enough to launch the internet in its current form.

Approximate Date	**Technology**
2010	Highest paid celebrity could be synthetic
2010	Nano (chemical + direct) mood control
2011	Molecular computing
2012	Single chip real time translation
2013	Low-power PCs run for one year on batteries
2015	Biochips – 1012 bits/cm^2
2015	Sensory chips – taste, smell, sound
2015	Photonics replaces electronics
2015	Ethical computer
2017	Tele-presence (primitive halodeck)
2020	Cyberspace covers 75% of populated world
2020	Functional mind-machine interface
2030	Robots mentally, physically superior to humans

Impacts and Implications

Within the IT sub-theme the impacts of a continuing decline in hardware costs point to a continuation of the trend to virtualize everything. We will capture increasing amounts of data and have a use for it. This will have important implications for:

- Process control in all phases of manufacturing
- Transportation systems, including the movement of inventory from supplier to consumer
- Service delivery within the government sector
- Maintenance of histories for everything from automobiles and aircraft to humans and livestock.

Computing technology will play the role of the microscope or telescope in previous eras. Basic science will provide us with accurate models of building blocks of nature (cells, neurons, molecules). Models will provide us with rapid ways of interacting with them. From the point of view of scientific experimentation, time will speed up.

Networks will increase communication not only in terms of quantity of data, but also in terms of number of reachable nodes. This is leading to concepts which are difficult to evaluate such as pervasive computing or grid computing.

The wild card will be the extent of the activity of software agents operating within the context of a pervasive/grid world. We may never know until it has happened. Much of our data gathering is measured in terms of human use (how many PCs, how much e-mail). Independent software agents could be extremely active without anyone being aware of it.

AI will continue to be used. Its human-oriented systems (expert systems, translation, data-mining) will just improve over time. These could well find use in resource allocation applications (e.g. for environmental reason). They are currently being used in such things as credit checks. It will be used more and more in control systems. Indeed we can expect many more such systems to get beyond human control.

The sub-theme of cognitive and neural sciences is more speculative, but important advances are being made.

6. Systemic Technologies Observations

The Systemics theme addresses the integration of theories, mostly through the use of models and simulations. It is expected that data and basic observations about material at the nanoscale can be modeled to predict the properties to the material once it is aggregated at a larger scale. For example, the astronomical observations of Kepler and others were put together to form a theory of the law of gravity by Newton (and others).

The development of Systemics technologies could easily move forward with the development of the bio-nano-info/cogno sub-themes. Moreover, its development should be vigorously encouraged, for two reasons. The first is that Systemics technologies would greatly enable the investigation of holistic solutions to a broad range of problems. The second is that the radical and revolutionary bio-nano-info/cogno technologies could easily create new problems themselves. Systemics would enable us to anticipate these a bit better.

It is possible that all kinds of behaviors could be modeled.

- Extensions of epidemiology to include a much broader range of environmental variables
- Models of plants or cells to predict their reaction to a broad range of stimulations
- Predictive models of the impacts of genetic modifications
- Network models that could simulate the flow of traffic and information in the presence of multiple, independent, software agents.
- Predictive models for social behavior, including such things as ethics as independent variables.

Technologies and Capabilities

The table below gives an indication of some the possibilities in the area of systems science. It is not possible to pin down a date on these since their appearance and success is a highly subjective matter. To some extend these capabilities are here already. The question is, how advanced are they?

Technology
Using environmental parameters, predict the movement of new diseases.
Accurate and effective methods of assessing human impacts on the environment – climate, water, forests, fish stocks
Ethical computers can used in evaluate disputes in finance, insurance
Economic models (e.g. input/output) that extend to environmental resources

Impacts and Implications

Many foreseeable developments in the area of Systemics are both useful and necessary. They are useful in the sense that an understanding of whole systems acts as an accelerator for the acquisition of new knowledge. This is particularly true when major bodies of theory begin to overlap.

They are necessary because they greatly help in understanding the impacts of new technologies. We *should* be able to understand, explain, and predict issues surround GMOs and climate change.

The hitch, of course, is that it is very unlikely that Systemics R&D will come out of the private sector which is mainly concerned will producing products and services that have a commercial payback. Systemics are by and large a public good S&T.

7. Government S&T Investment Postures

The reach and range of likely S&T advances over the next 10 to 20 years is extensive.

There are many ways in which they can be used to advance government programs and policies. The following is an approach to categorizing them for use in scenarios. The approach is based on how the technologies are adopted or implemented.

Strategic Technology Posture. This refers to technologies that are critical to delivering the government's portfolio of services. In many cases, these technologies will receive little or no investment. Private sector companies will not do the R&D because there is no possibility of selling the product or service in the consumer market. Environmental technologies are an example as are some of the systemic technologies.

A special case is medical technology. It is conceivable that investment in this technology will follow a reward model dictated by the U.S. system of service delivery. This may not be appropriate for the Canadian health system. It is entirely conceivable that we can develop technologies that are more appropriate to a universal health care system (focus on wellness, for example).

Reactive Technology Posture. This refers to a situation in which evolving technology puts a system at serious risk. Thus, for example, xenotranplantation, the use of non-human organs and tissues for transplantation in humans, would eliminate the waiting time for transplants and dramatically increase the number of people expecting them. This alone could bankrupt the health system.

If we add the following list of possible new medical interventions to an essentially unlimited demand for them and add in the expectancy that they will be provided at no cost to the user, it is easily seen that there would be substantial pressure on the health system.

Intervention Level	Key Advance	Timescale	Life Extension
Human	Noninvasive diagnostics	5-10 years	Lifesaving for some conditions
	Cognitive assist devices	15-20 years	Higher quality of life for several years
	Targeted cancer therapies	5-10 years	Reduction in cancer deaths by up to 30%
Organ	Artificial heart	0-5 years	2-3 years awaiting transplant
	Neural stimulation or cell function replacement	5-20 years	10-20 years extra if successful for neurodegenerative patients

Cell	Improved cell-materials interactions	0-15 years	Lowering of death rates on invasive surgery by 10% and extending life of surgical implants to patient's lifetime
	Genetic therapies	30 years	Gains in the fight against cancer and hereditary diseases
	Stem cells	5-10 years	Tissue/brain repair Life extension of 10—20 years
Molecule	Localized drug delivery	0-10 years	Extending life through efficient drug targeting
	Genetic interventions	0-30 years	Life extension by targeting cell changes and ageing in the fight against disease. Likely to be a very complex environment to successfully manipulate.
P. Connolly, NBIC Report, p.167			

Opportunistic Posture. In this case, governments are in a position of being able to use technology developed in the private sector at, essentially, the average cost of production. IT technology is an example. It will likely be funded and used by the commercial sector such that it can be bought "off the shelf" by government departments. Some, but not all, sensor devices will fall in this category.

Threat Posture. Not all technologies will be beneficial. Some will create problems. The miniaturization and cost reductions inherent in the new technology may move many capabilities out of institutions and commercial labs and into the hands of private individuals. This could no doubt create significant security problems (i.e. if criminals can manufacture bio-toxins in their basements.)

8. Recommended Scenario Structure

Due to the broad definition of BioSystemics there are many possible drivers or "Issue Vectors". [A note on scenario architecture is attached as Appendix 2. This note is excerpted from the Drachma-Denarius paper on scenario management.]

There are a number of possible issue vectors which we could consider, including:

Technical Functionality. Does the technology perform as intended? Are discoveries made quickly or do the breakthroughs just not happen. Are there any unanticipated complexities or negatives, i.e. difficult to manufacture?

Market Acceptance. Is there a demand for the technology? Do people want it and can they pay for it? Is the delivery price acceptable, compared to alternatives? Is the government a major purchaser of the technology?

Business and Production. Is there a source of investment for the technology? Will it disrupt/displace earlier investment? How well does it complement existing infrastructure. Is the government a possible producer or investor in the technology?

Social Context. Are there any cultural or risk issues with the technology, e.g. GMOs? Are opponents to the technology mobilized? How highly do social values apply? Is there a government led initiative behind the technology?

Environmental Issues. Will the technology cause problems in the greater environment, either as a direct pollutant/toxin, or as a result of production, or due to some ecosystem complexity.

Governance and Regulation. Are there any regulatory issues (intellectual property, regulations written for similar but different technologies)?

Geo-Political. Are there any international competitive issues arising as a result of globalization? Are there national reasons for participating in the technology?

Some scenario possibilities are as follows:

	A	B	C	D	?
Technical Functionality	Works	Works	Complex	Some	
Market Acceptance	Moderate	Good	Low	Some	
Business and Production	Govn't	Business	Risky	Some	
Social Context	Moderate	Moderate	Low	Some	
Environmental Issues	Few	Some	Many	Some	
Governance & Regulation	None	Some	Many	Some	
Geo-Political	Critical	Global	None	Some	

Scenario A is one in which the government views aspects of the technology as being critical and invests in it, greasing the track for others along the way. There are critical national reasons for investment.

Scenario B is private sector driven. There is market acceptance but some adverse environmental resistance. It is conducted in a globalized trade environment.

Scenario C rejects the technology. It is too complex to build or manage and too expensive to buy. There are just enough environmental problems to regulate it to death

Scenario D is the unexciting scenario. In some situations, but not all, the technology is usable and acceptable. The process of overall discovery is slow as is its adoption.

These suggestions are mentioned to stimulate thinking. The actual process of driver and scenario selection should use a methodology similar to the one outlined in Appendix 2.

9. Summary and Conclusion:

Bio-Systemics is a word coined to describe a combination of emerging technologies. These include:

- Biotechnology. A fairly broad definition of biotechnology was used in the study. The term encompasses the sciences, technologies, organizations and regulatory groups that have as their goal the understanding, alteration, and functional modification of organic cells – including plants, animals and humans. It also includes the possible work on non-cellular life forms (e.g. viruses) at which point biotechnology may well overlap with nanotechnology. The term included genomics, pharmacogenomics, proteomics and metabolomics.
- Nanotechnology. Here we were concerned with the study and manipulation of material at the nanoscale. The term includes the technologies of the semiconductor and photonics industries. It also includes whole new areas relating to new materials with properties unavailable until now.

- Information and Cognitive Technologies. This topic area considered the use and manipulation of information in a most general sense. The topic includes the standard computing, telecommunication and software disciplines. It also included AI, and control systems. It was intended to include the neurosciences as well, but due to a lack of available expertise we did not make much headway in this area.
- Systems Sciences. The systems science topic included knowledge and methods that could be used to integrate information about behavior at a low level and integrate it into an understanding of the behavior of complex systems – such as ecosystems.

While this may seem to be a diverse and broad list of topics, there are good reasons to consider them together. There was a general understanding that these technologies had properties in common. Their importance and urgency derives from five characteristics of these new technologies.

1. Convergent. The technologies overlap in many areas. Technology designed initially for the semiconductor industry,, such as the scanning tunneling microscope, can be used to observe genomic structures. Genetic and neural models get adopted by AI researchers do develop learning systems. Data mining applications, developed for commercial research, get used to mine abstracts of pharmaceutical research. Faster, more powerful, computers and software enable the simulation of experiments, taking them "off the bench" and thereby permitting "experiments" that might otherwise be too costly or dangerous.
2. Fundamental. The technologies tinker with very fundamental processes. Biotechnology modifies life forms. Nanotechnology permits the direct manipulation of atomic structures to create previously unknown chemicals and materials, not to mention amazingly small devices. Information technology mimics, and in some cases surpasses, human intelligence.
3. Replicant. Each of these technologies has some capability to "reproduce" itself. Modified life forms reproduce in the normal biological manner. Nano-devices are likely to duplicate themselves via nano-assembly. Computer code has the ability not only to duplicate itself but also to modify itself in a primitive (so far) learning process.
4. Distributed. All of these technologies can be used by individuals. Unlike the big, centralized industrial technologies of the 20th century these operate at a low, distributed level. This gives them both power and the possibility of misuse.
5. Public Interest. There is interest and concern in the general public over the use and misuse of these technologies. There is a sense that these technologies will hold much promise, but at the same time be very disruptive.

The rollout of Bio-Systemics technology is attracting considerable policy attention. In June 2002, the U.S. National Science Foundation and the Department of Commerce published *Converging Technologies for Improving Human Performance*.[i] This report was the culmination of a series of workshops which were intended to assess the state-of-the-art in a number of scientific disciplines that showed signs of having broad strategic importance. The report was significant in that it revealed, in one place, just how wide the technology pipeline is. The new technologies are transformative and possibly disruptive on a scale not previously encountered in human history.

The U.S. NSF is not alone in identifying the importance of NBIC (Nano-Bio-Info-Cogno) research. It confirms what other S&T policy analysts had found, for example:

- The RAND Corporation published a study on the outlook to 2015 of converging technologies.[ii]
- French futurist Joel de Rosnay wrote an overview of the biotechnology revolution.[iii]
- In addition to their report on converging technologies, the U.S. National Science Foundation produced two other reports on the importance of nanotechnology [iv] and the societal impacts of nanotechnology [v]
- The U.S. Department of Energy took a normative approach and attempted to see how the new technologies would help them achieve specific goals. [vi]
- Information technology continues to drive innovation in many areas. The European Commission has prepared a foresight study on the prospects for IT, including a roadmap.[vii]

The level of interest among policy makers is reminiscent of the focus in the 1970's on the semiconductor industry ("The Chips are Down"). Then, as now, there was an understanding that a major industrial revolution was underway and that each nation had to both create a niche for itself and protect its intellectual assets from international poaching.

Summary of Key Findings

The STFPP was set up to take a long-term outlook of science and technology. It drew information from a number of sources:

- A review of existing literature on trends and impacts.
- Exploratory workshops using a combination of subject matter experts and policy generalists.
- Scenario-building to explore a wide range of policy implications.

As a result of these design choices, the conclusions and findings of the STFPP are neither purely speculative nor particularly authoritative. They represent a view of the future that is a blend of scientific literacy and an awareness of what is currently on the public policy radar. The future is unknowable, but it is not incomprehensible.

General Capabilities

At the base of the interest, excitement, and concern about the new technology lays a set of new capabilities that are being developed. For example:

- Capability to specifically build genetic sequences and proteins.
- High level of capability to monitor and measure phenomena at the molecular level and in remote or hostile environments.
- Ability to substitute industrial processes with sustainable agricultural processes.
- Much higher understanding of the specific causes and specific remedies for a wide number of illnesses. There will be a much improved predictive capability for "at risk" individuals.
- New structural materials with new design characteristics – notably impressive mass to strength ratios, but also electrical and memory properties
- Continuing improvements in circuit density in semiconductors and bit density in storage devices.
- Emergence of nano-sensors: to detect chemicals in the environment as well as in biological organisms; and to detect mechanical properties (tension, torque, inertia, position, velocity) in robots.
- Greatly extended knowledge of basic phenomena along with a capability to simulate many experiments rather that performing them physically.
- Integration of bio-nano-sensors with circuit logic
- Custom production of complex chemicals for use as pharmaceuticals and enzymes.

More, Faster, Sooner

These capabilities are being pursued with some measure of success. The drive to develop them is often being done with some application in mind. One of the most important observations to come from the STFPP studies is that much impressive technical advancement could happen relatively soon. The following table lists some technologies that are considered technologically possible, along with prospective early arrival dates.

[Caveat: The prospective early time frames were made based on information in 2001 – 2002. The key assumptions behind them were: (1) some organisation was pursuing the goal, and (2) it was properly funded. These therefore represent feasible, but not inevitable, technology. Changing economic conditions, or new regulatory frameworks, could alter the arrival times. Specific details aside, it illustrates that the drumbeat of innovation is fairly quick.]

Technologies possible in the next 5 years
Biosensors available to monitor and measure *in situ* bioremediation. They can be applied to pollutants that are difficult to measure or are in hard-to-reach locations.
Manufacture of high temperature carbon nano tube (CNT) composites
Low power CNT electronic components
New materials based on silicon carbide (SiC), gallium nitride(GaN)
Gene Chip available that can include markers for all human genes and can test for over 100,000 conditions. It can be used by professionals in selected applications.
Many new and older drugs can be prescribed after screening a patient's genetic profile to estimate safety and efficacy. New drug prescriptions can include a screening kit.
Birth of first human cloned baby
Therapeutic cloning of embryonic stem cells gains acceptance in some locations
Bioengineered micro organisms available as biocatalysts for industrial use. E.g. produce lysine from sugar for use in animal feed.
Design and fabrication of self-healing nano materials
Development of multifunctional CNT structures
Initial devices using quantum dots
Some deployment of micro-electro mechanical systems (MEMS)
Testing of nano sensors
Testing and use of nano coating and materials
Tech transfer of information from Human Genome Project to create biological approaches to nanotechnology
"Green" genetically modified plants used altered genes from the original plant, rather than the introduction of foreign materials.
Early use of genetically modified organisms (GMOs) to remove difficult-to-degrade materials.

In the medium term, the following technologies are expected to build on the list above.

Technologies possible in the next 5-10 years
Drugs designed for specific genotypes and phenotypes will begin entering clinical trials. Pharmacogenomics accelerates both the discovery and the approval process. Drug economics can shift from the production of 'blockbuster' drugs to specific target drugs.
Comprehensive genetic, behavioural and environmental screening can be capable of predicting degree of disposition to most major chronic diseases.
Gene therapy can be commonly used to treat some genetic diseases.
Stem cells can be matured in cells producing dopamine to treat patients with Parkinson's disease.
GM crops valued at over $20 billion annually are likely.
Global environmental technology worth $2 trillion. Up to 20% is bioremediation.
Consumer pressure and environmental concerns accelerate transition to environmentally sustainable bio-manufacturing in the chemical, textile, paper, food, and industry sectors.
Bio-fuel represents 5% of automotive fuel in Europe.
Self assembling, multi-functional materials begin to appear
Micro-opto-electro mechanical systems (MOEMS) assemblies
Multiple sensors on single chip with integrated logic functionality
Computer model of "virtual plant" can be used to understand plant physiology and selected genetic modifications.
Biomarkers can be used by most individuals with cancer or at risk of getting cancer. They can monitor early development, identify tumour subtype, pinpoint treatments, monitor responses, and estimate prognosis.
First preventative vaccine tested for a specific cancer
Transgenic pig organs that reduce human rejection start to be used for heart, kidney and liver transplants.
Low-power PCs run for one year on batteries

All of these technologies have aspects that can require regulation both to prevent harm and to promote the underlying infrastructure needed to capture benefits.

Longer-range technologies with more uncertain horizons for deployment are suggested below. While this may be long-range foresight, it is not that far away in terms of legislative eras and government "lifetimes". The preparation of new laws, including consultative processes, can easily take five years or more.

Technologies possible in the next 10 to 20 years
50% of all new drugs may be based on genomics. They would be specifically designed for a target subset of the population.
Pharmacogenomic tools can reduce the cost of drug development and approval by 30%. The time from discovery to regulatory approval can be cut by 50%.
Molecular nanotechnology can be used in the manufacture of molecular compounds for use in bio-engineered medications.

First major chronic disease can be prevented at the molecular level by a genetically engineered drug.
Bio-based economy begins with agriculture producing significant sources of energy and natural resources.
Commercial production of hydrogen from water using genetically modified algae is used for fuel cells producing electricity.
Bio-mimetic material systems
Nano-electro-mecanical systems (NEMS) flight systems
Many super-MEMS products tested and in use
Entirely new classes of materials and processes are in everyday use
Nano diagnostic products enter commercial marketplace
Early communicating and/or programmable nano-systems
Biochips – 1012 bits/cm^2
Sensory chips – taste, smell, sound
Photonics replaces electronics
Availability of communicating and/or programmable nanosystems
Nanobots are working in labs and being tested, evaluated, and fielded for various specific applications
Nanomedicine may be replacing older forms of medicine such as surgery, traditional pharmaceuticals, rational drug design
Cyberspace covers 75% of populated world
Functional mind-machine interface
Robots mentally, physically may become superior to humans

Although this is an impressive list, is not presented to predict what is going to happen. It is meant to illustrate that there is a wide technology pipeline that is likely to produce many fundamentally new applications and products. Specifics aside, it is clear that we are going to see a qualitative and quantitative change in the technology landscape.

General Impacts and Implications

Given rather conservative assumptions about the ability to deliver on some of the capabilities and technologies mentioned above, it is safe to speculate on some impacts they might have on everyday life. The following statements on impacts have been published, as examples:

- The ability to detect and monitor key illnesses could create a greater reliance on "out-patient" approaches to health care delivery.
- New drugs and new procedures, along with predictive capabilities would create an increase in demand for health care products.

- Bio-process to replace industrial ones could increase, rather than decrease, environmental stresses as the agricultural sector grows.
- The total market size for nano-products will exceed $US1 trillion annually in 10 to 15 years. Components of this global market are:
    - Nanostructured high performance materials $US340 billion
    - Nanotechnology in electronic devices within the semiconductor industry $US300 billion
    - Pharmaceuticals production could account for $US180 billion
    - Nanostructured catalysts in the chemical processing and pharmaceutical industries could contribute $US100 billion
    - High use is expected in the transportation sector for infrastructure and vehicles. In aerospace alone, nano components could contribute $US70 billion.
- Nanotechnology is expected to make major environmental impacts not only in improving agricultural yields, but also in water filtration and desalination. Advances in lighting alone could save $US100 billion in the forecast timeframe.
- Information technology and networking will continue to expand, creating a significant economic and security dependency on the system. This would create a new exposure to crime terrorism and war. Some of these dependencies would include, as examples:
    - Process control in all phases of manufacturing
    - Transportation systems, including the movement of inventory from supplier to consumer
    - Service delivery within the government sector
    - Maintenance of histories for everything from automobiles and aircraft to humans and livestock.

Application Areas

The scoping workshop and the technical panels focused specifically on technologies. The discussion broadened somewhat in the scenario writing exercise. A number of themes were discussed. To some extent, these centered on current policy areas, even though the scenario process permitted some creative liberty to define totally new priorities.

Health Care Delivery

Background
The discussions on health care delivery focused on the current model in Canada. Widely believed (by Canadians) to be one of the best systems in the world, its predominant paradigm is one of medicine directed to individuals. Treatment is curative if possible, palliative otherwise. The patient-doctor relationship is direct and private.

The system is not without its problems. There are no systemic elements to limit growth – patients have no incentive to stay away from seeing a doctor, doctors have no incentive to reduce tests or referrals. The system is a ready-made *tragedy of the commons*. In theory, if there is resource, the system will expand until it reaches a point of stability; i.e., the funding and service level get to the point where supply meets demand. The tragedy occurs when resource is exhausted. This appears to be likely as more and more social issues become medicalized. Also there is a phenomenon known as "normative creep" by which acceptable service standards (such as mean waiting time) are expected to improve over time.

Failing a natural convergence to stability, the system will soon exhibit resource shortages (e.g., of doctors) and have reduced service levels (e.g., longer waiting times).

Attempts to manage the situation may result in gridlock. New technology is not quickly accepted in this environment as it is seen as an additional cost. Even pharmaceuticals, which are seen as reducing a more costly option (hospital beds), are under scrutiny as they become an increasingly important line item in the overall health care delivery budget. Indeed, new tests and new cures are seen by some to be a significant risk to the sustainability of the current health care delivery model

Technologies
Many technologies were discussed in relation to conventional health care:

- "Boutique" medicine – the ability to custom design medications based on an individual's genetic profile
- Stem cell research – with its capability to replace/repair defective organs
- Transgenic xenotransplantation
- Artificial intelligence in diagnostics
- Improved data visualization
- Logic circuits imbedded in the body and
- Real-time portable health monitoring.

Implications
Converging technologies were seen as having many implications on the health care system, in its current model of delivery.

- The main implication was seen as cost. Xenotransplantation, for example, would permit heart patients to get transplants immediately. This would certainly stress other parts of the medical system too – a shortage of heart surgeons possibly. There was some debate on this, however. It was not known if some technologies would create cost early, but result in savings later.
- The many new discoveries create a cascading list of possibilities. Artificial hearts could be replaced by xenotransplantation, which in turn could be replaced by stem cell therapies. This would create a very short life cycle for some technologies.
- Big implications were seen on the testing/regulation side for individualized medicine. Current statistical test methods over large sample populations would no longer apply. Similarly, sophisticated logic circuit implants could create problems of maintenance and calibration.
- There were questions about fundamental values. Universality as a principle tries to treat everyone the same. Technology is becoming more and more personal, more specific to the individual. This may open the way to a wide level of standards of care being applied.

R&D Questions
A number of questions were raised that point to a need for further research if public policy in the area of health care delivery is to be effective.

- How do we get better statistics on survival rates for current treatments and procedures? How will we know if new technologies really are better in the long run?
- How do we assess and invest in R&D when technologies have such a short life cycle, when they become obsolete in a few years?
- The current system resists new technologies. They are viewed as a cost factor. How do we create a system that accepts innovation more readily, that has a more continuous flow between the lab and the end user?

Public Health

Background
A public health system was outlined as an important option or addition to the current delivery model. The public health vision seeks to improve overall public health by

addressing broad social, environmental and psycho-social factors. The focus goes beyond curing disease to improving wellness – not just of individuals but of entire communities.

Proponents of this vision have as an article of faith that a systemic approach to community wellbeing will, overall, reduce health care costs since it costs far less to avoid illness than it does to cure it. This is very plausible since it is well known that environmental factors contribute to illness, as well as to recovery rates. However, these factors may not be understood well enough to create a manageable system.

There is a strong shift in values in this model. It is no longer enough to eliminate suffering. We are now trying to increase quality of life in both a preventative and supportive way. It will involve the broad cooperation of entire communities.

Technologies

The technologies to get to public health seemed to come from a mix of biotech and non-biotech sources. Note that these technologies would be needed for a full blown vision of an all-embracing public health system. In practice, many public health measures can be undertaken using very simple processes. Some technologies that were considered are:

- Small, highly distributed nano-sensors that could collect data on individual health status as well as environmental conditions.
- Bioinformatics that would help establish the link between health problems and the conditions that create them. Moreover, such systems would serve to establish that actions taken are in fact effective. An important development would be a data platform useful for modeling.
- Eco-epidemiological population modeling that would be predictive and provide the basis for managing a public health system.

Implications

The implications of a public health model are contingent on a number of considerations, notably whether or not it exists in parallel with the current delivery model. Some of the highlighted implications are:

- These technologies should permit us to take a broader, long-term view of health. They also will require us to develop accounting systems (for outcomes and money) that will enable us to balance costs, risks, and benefits that occur among separate stakeholders at different points in time.
- Large, complex administrative systems, particularly if they are top-down bureaucracies, are often non-adaptive. Once the IT systems are programmed, they often have to be worked around to achieve change.
- The roles of people will change. There will be more social workers possibly. Doctors will become data collectors.

- Public health, while supported by technology, is more of a social innovation. People will be expected to behave differently.

R&D Questions

Although public health measures are not new, the scope and scale envisioned by some of the participants raised a number of questions.

- How do we get the evidence-based data needed to properly design a comprehensive public health system?
- How do we model the inter-relationships between drivers and stakeholders in the system?
- What new testing/regulatory processes would we need in going from curative to preventative methods?
- Do we run the risk of health care being based on circumstances such as location (postal code health)?
- How do we manage social factors? What happens if people don't co-operate?
- What becomes of privacy in a community-based health system?
- Will private sector innovation be able to respond to the needs of this system?
- Are we putting too much faith in information technology?
- Who actually owns/controls medical data for health care purposes?

Security

Background

The area of security has rapidly grown as a public policy priority in the last few years. Not only are more funds being devoted to this issue, but other priorities and values are being transformed by security imperatives – privacy and civil liberties, for example.

Part of the reason for this is the terrorist attack on the World Trade Center. This not only heightened our perceptions of being at risk, but also triggered a major and sustained response to "global terrorism" by the U.S. and others.

Another reason for concern lies in the nature of the new technologies. Network communications, peer-to-peer computing, and biotechnology enable the creation of small organisations (criminal or terrorist) to have global communications and organization, as well as weapons of mass effect, while at the same time remaining invisible.

Technologies

A number of NBIC technologies were identified as being of use in security operations:

- Micro-sensors capable of identifying compounds (viruses, proteins, chemicals) at the zepto-mole range.
- Mesh networks of low powered transmitters creating a pervasive computing environment.
- High use of cheap RFID tags to keep track of materials. Added functionality if these are GPS capable.
- Greater understanding of disease epidemiology and capability to track it.
- Intelligent (AI) decision support systems of disaster and crisis management.
- Capability to modify human behaviour using nano-bio monitors and drug delivery systems.
- Advances in genetics and proteomics that would enable rapid identification of pathogens.

Implications

Security is in many ways a game with two side playing – the good guys and the bad guys. Thus means that technologies to fight crime can also be used by criminals. Some of the main implications:

- Much higher levels of surveillance. Greater amounts of personal data available to a wider range of people,
- Wider range of threats due to greater integration of systems.
- Possible new bio-threats as development and production capabilities become more distributed.
- Greater reliance on personal systems to monitor security.
- Possible pervasive computing.

R&D Questions

The actual technologies supporting security issues may not need to be complex. R&D questions may in fact center on designing them to unobtrusive or unavailable to the wrong people.

Economic and Industrial Development

Background
Economic development was an important consideration in a number of the scenarios. It was widely believed that these technologies would not only be profitable on their own, but that they would also drive an industrial engine that would be critical to the competitiveness of the economy. Moreover, without the industry engine, many solutions will never get developed. Once developed, companies have to have some way of collecting revenues.

The value proposition (apart from making money) would lie in having a Canadian innovation system that was able to respond to Canadian needs and would capitalize on Canadian strengths (viewed as being primarily in the biotechnology arena). It would also create a Canadian S&T infrastructure that would support the health delivery system.

Technologies
All NBIC technologies were included in this topic. Moreover, there was a recognition that some technologies would be disruptive.

Implications
The implications cover the whole range of the production spectrum, from development, to production, marketing, and support infrastructure, all the time creating conditions to make the whole flow profitable in a free market system. The challenges are formidable and it is likely that the commercialization potential, rather than technical potential, will determine the shape of new technology.

- A rapidly evolving technology scene means that the assessment and regulatory systems must be nimble. Product life cycles are too short to be waiting for approval.
- There is no "commercial play" in a number of prospective markets - the health system, the environment, defence. There is one dominant customer – the government. This creates a risky, all-or-nothing, environment that makes venture capitalists nervous.
- In the bio-economy sector, the potential is huge, but so are the entry costs. In the case of bio-fuels, there are often large infrastructure investments needed to get to industrial production levels.
- Many of the technologies are disruptive and will displace established industries. Economic development plans which promote new technologies will also have to figure out what to do with the old ones.

R&D Questions

- Is there a unique Canadian value proposition that would determine which R&D initiatives will best use Canadian capabilities and which will drive benefits of specific interest to Canada?
- What are the sources of funding for projects in risky public sector markets?
- How do you capture R&D costs when product life cycles are so short?
- Can Canadian companies compete in international markets that may be dominated by government customers looking after the interests of local national companies?
- How do we sell products that provide a system-wide benefit if the customers are only responsible for benefits in their own department?

International Alignment

Defining Characteristics
The R&D communities, underlying industrial infrastructure and markets for the new technologies tend to be international. The view is that "one's genome is everyone's genome." There needs to be focus on the benefits of collaboration internationally, particularly with respect to testing, regulation, and the development of comprehensive data platforms.

While there are clear benefits to this approach, there was the risk that we could overlook the national agenda.

Technologies
Specific technology characteristics that were international in nature include:

- Data gathering on a global scale that would provide early warning of new diseases and epidemics (e.g. West Nile, SARS, Mad Cow Disease).
- Standards and architectures that would enable new devices to interface.
- Standards that would form a common base for measuring health and environmental outcomes (e.g. are all nations reporting SARS incidents in the same way?).

Implications
There are already many mechanisms in place in the international arena to deal with technology transfer and standardization, although at times commercial or national interests may try to co-opt them. There are extensive considerations that need to be dealt with in order to manage impacts.

- In an international system, we may wind up having shared regulatory jurisdiction.

- Knowledge of an impending global pandemic would require some kind of global risk management system.
- There would have to be a balance between Canadian and international interests.
- There would have to be better linkages for co-operation, particularly when some nations (US) would have predominantly private sector R&D, while others would have more public/academic sector R&D.

R&D Questions
Beyond the selection of "best"

- How do we deal with fundamentally different paradigms for program delivery (e.g. public vs. private approaches)? Political agendas form a strong overlay on many problems such as health and the environment.
- Can Canada really be a world leader in a particular field?
- Is there a sufficiently robust forum for global regulation?

Next Steps

The STFPP achieved a number of objectives. It pulled together a broad group of scientists and policy analysts to explore the frontiers of science and policy. In doing so it created an informal network of several hundred people. It was able to communicate the importance of technology to Canadian society and members of the TFPP core team were invited to provide further presentations to the Canadian Biotechnology Advisory Committee, to the Canadian Centre for Management Development, and to the Privy Council Office.

Moreover, this was all done on a budget shared among participants – a good example of horizontal policy analysis.

The STFPP was designed to be a foresight exercise. As such, its purpose was to make us think about the long-term future so that we can have a clearer idea of how to prepare ourselves now. What has this foresight given us?

Threats
The first item of note is that not all technologies will be beneficial. Some will create problems. The miniaturization and cost reductions inherent in the new technology may move many capabilities out of institutions and commercial labs and into the hands of private individuals. This could no doubt create significant security problems (i.e. if criminals can manufacture bio-toxins in their basements.) There is a general level of concern in the public mind about many of these technologies.

At a minimum then, the government S&T community must be prepared to assess the scientific basis for these perceived threats. For over a decade there have been concerns expressed about genetically modified organisms. Why is it that we do not yet have answers to these concerns? If we know now that antibiotic resistance will soon exhaust our defenses against bacteria and disease what is the public R&D response? It is worth noting that decisions will eventually be made, with or without scientific input,

The foresight activity has very generally pointed to a number of threats. As a next step we should consider pinpointing them and defining responses in collaboration with a lead sponsoring department. Consider for example the following table taken from the NBIC study. It shows a number of possible technical advances and estimates the impact on life expectancy.

Intervention Level	**Key Advance**	**Timescale**	**Life Extension**
Human	Noninvasive diagnostics	5-10 years	Lifesaving for some conditions
	Cognitive assist devices	15-20 years	Higher quality of life for several years
	Targeted cancer therapies	5-10 years	Reduction in cancer deaths by up to 30%
Organ	Artificial heart	0-5 years	2-3 years awaiting transplant
	Neural stimulation or cell function replacement	5-20 years	10-20 years extra if successful for neurodegenerative patients
Cell	Improved cell-materials interactions	0-15 years	Lowering of death rates on invasive surgery by 10% and extending life of surgical implants to patient's lifetime
	Genetic therapies	30 years	Gains in the fight against cancer and hereditary diseases
	Stem cells	5-10 years	Tissue/brain repair Life extension of 10—20 years
Molecule	Localized drug delivery	0-10 years	Extending life through efficient drug targeting
	Genetic interventions	0-30 years	Life extension by targeting cell changes and ageing in the fight against disease. Likely to be a very complex environment to successfully manipulate.
P. Connolly, NBIC Report, p.167			

This single table has tremendous implications for the Canadian health care system. As a next step there should be efforts made to validate such numbers and estimate quantitatively their effects on Canada.

Opportunities
Many technologies will be critical to delivery of the government's portfolio of services. In many cases, these technologies will receive little or no investment. Private sector companies will not do the R&D because there is no possibility of selling the product or service in the consumer market. Environmental technologies are an example as are some of the systemic technologies.

A special case is medical technology. It is conceivable that investment in this technology will follow a reward model dictated by the U.S. system of service delivery. This may not be appropriate for the Canadian health system. It is entirely conceivable that we can develop technologies that are more appropriate to a universal health care system (focus on wellness, for example).

Where there is technology that will further social priorities, and particularly if there is little likelihood that the privates sector will independently develop these technologies, the government should pursue them as a strategic priority. A next step for the STFPP could be to identify these R&D opportunities in greater detail.

Appendix 1: Contributions from Technical Panel Participants

This appendix contains the 'raw material' produced by the workshops. It provides many useful ideas that could be incorporated in the next task, scenario writing.

Scoping workshop:

Participants were asked to brainstorm visions and capabilities that could occur in the foresight timeframe. No distinction was made between capabilities that were driven by technical momentum and those that were desirable and therefore could occur because it was likely someone would successfully want to build them. Some responses were:

Visions and Capabilities
• Social review of any pervasive bio-molecular change • Micro atlas nation-wide – geology, biology & ecology • Intelligent question answering from data bases • Real-time mass monitoring of pathogens by city and by food supply • Identify every gene interlink to form a crop unique to Canada • Syntax-level machine translation • Full market evaluation of ecosystem services • Real-time environmental bio-monitoring • Accelerate/enhance understanding of aquatic biology to develop cheap energy • Individual allergen/pathogen detection systems at the consumer level • Develop aquatic solutions to human protein deficit • 100% waste recycling – no more landfills • Strategies to prevent/methods to repair radiations damage to permit human space exploration • Self replicating wound healing technologies • Nano-machines that float in body – bio-molecular machines • Increase average human intelligence by a factor of 10 – drugs, systems, etc. • Real-time personal health monitoring • Integration of wastewater management and its ecological effects • Develop new drugs & therapies to treat shock • High-grade dietary meals analysis • Extend human life span x 25% • Application of network-structure math and rules to decision making • Neutraceuticals and pharmaceuticals derived from aquatic environment • Hydrogen driven energy grid • Quantum computing – problems will undermine cryptology

- Ensure no invasive plants/animals enter Canada
- Cancer prevention through bio-engineered substances & genomics
- Understand protein interactions between humans and all other organisms

In order to create context (and also to help define parameters for future scenarios) participants were then asked to suggest catastrophic headlines that could appear in the forecast range. The following ideas were generated:

Imagined Catastrophic Headlines

- Life style choices become greatest health hazard
- Great Lakes drop 6 meters
- Greenhouse gasses increase exponentially
- Collapse of Canadian forest sector
- AIDS mutates and is airborne
- Global cocooning from viral threats
- Sulfur-based life forms vs. carbon-based life forms
- New dark ages… anarchy
- Teenaged bio-hackers make new life forms
- Terrorist network takes over CNN & reports elimination of Toronto/Montreal/Vancouver
- Narco-virtual reality (addictive fantasy media vs. real reporting)
- Cancer-causing virus with 15 year latency in Toronto water supply
- Environment sterilized by wild nano-robots
- Pandemic disease affects world grain crops

The participants were then asked to identify a few drivers:

Drivers

- Scientific curiosity
- Globalization of trade
- Fear of uncertified association
- Demographics
- Communications/computing costs heading to zero
- Ownership of information
- Social acceptance of change
- Availability of nano-materials
- Regulatory environments
- Global wealth distribution

The material seemed to fit into the following four “clusters”. Participants broke into facilitated breakout sessions to further explore the clusters.

1. Science and Society
2. Environment & Energy
3. Intelligence: Systemic, Cognitive & Artificial
4. Food & Health

Breakout Group 1 – Science and Society

This group focused on public values as a driver. The felt that public debate/dialogue was needed to determine Canadian values about science. This, in turn drove a requirement for the public to have/build knowledge about science and understand its value and role in society. In their view, public objectives should be derived from informed debate.

The Mechanisms to achieve this informed consensus included:

- Governance and engagement
- Public education in the areas of:
- Fostering of critical thought
- Social skills
- Literacy, both scientific & social

The group also identified a number of issues, obstacle, or challenges the could require attention, including:

- Building public trust and gaining legitimacy for both science and government
- Differentiation between science for “public good” and “private good”
- Information
- Reliability
- Ratification
- Preservation
- Cataloguing
- Intrusion
- Liability
- Management systems… moving from command and control to network management models
- Managing or reintegrating the disenfranchised
- Risk Management and informed choice
- Dependency on technology and technological systems

The identified two “priority action items”

- Creation of “The Observatoire” - an institution to access the direction and impacts of science

- Development of mechanisms for public debate on S&T

Breakout Group 2 – Environment and Energy

This group asked whether Canada could be a leader in the bio-economy, and at the same time address some current and upcoming "bio-gaps". This would possibly entail the following:

- Need baseline data of Canada's ecosystem structure and functions – "Biological Survey of Canada"
- Need to understand toxins & biological interaction, and what parts of these are unique to Canada.
- Need the intellectual capacity to take on this work
- Need an Ecosystem Valuation/Accounting mechanism that can assign value to bio-diversity.
    - Need to measure in order to protect.
    - Bio-Survey can drive Bio-Prospecting
    - Need to differentiate between personal value and "shadow pricing"
    - Need a framework for a sustainable approach, including tools that incorporate socio-economic research evaluation framework and socio-environmental indicators

The group identified some "Quick Hits", i.e. action that could be started immediately and have early payoffs:

- Tools to identify, detect, monitor & analyze any species in complex mixtures
- Alternative energy – biofuels, ethanol, bio processes, more efficient use of fossil fuel
- Reducing bio-corrosion
- Industrial Ecology
    - Integrated approach to input & output on industries/sectors to other uses
    - Industrial complexes:
    - Cascading
    - Co-generation
    - Process step elimination
    - Process integration
    - Zero waste/minimal water use
    - Smart & intelligent biosensors/systems
    - Bio-Air/water purification cleaning – "living walls"

In further commentary, the group noted that:

- Difficulty is managing the biomapping systematically & horizontally – linking supply and demand sides
- There is no real world leader in this field… the U.S. has backed off, creating an opportunity for Canada. We need focused "biomatics" capacity.
- "The 21st Century will be the Age of Biology"

Breakout Group 3 - Intelligence: Systemic, Cognitive & Artificial

This group built an approach to discussing the subject matter. In their view it could best be studied using the following structure which maps four subject matter categories against two opportunity areas.

	Socio-economic Benefits	**Horizontal Collaborative R&D Opportunities**
Future Computational Systems	Optical, biological & DNA computing	Self-replicating systems Biological Artificial (Von Neumann)
Knowledge Management Systems & Agents	Syntax level translation	Intelligent Q&A from databases – text mining
Cognitive Advancement	Smart wearable systems, e.g. health advisor	Network structure math – for complexity
Networked Intelligent Decision Systems	Real-Time monitoring – health, etc.	Robotic colonies – robotic cooperation

Breakout Group 4 - Food & Health

This group approached their task form the perspective of a vision: eliminating disease in a holistic manner that considered, among other things the human dimension – lifespan, behaviour, prevention vs. technological solutions

Capabilities needed to do this fell into a number of categories:

- Preserving antibiotic effectiveness
    - Monitoring current use
    - New vaccine development (e.g. edible vaccine)
    - Search for new types of antibiotics
- Canada's role in agriculture
    - Increase productivity with/out negative environmental outcomes
    - Increase non-traditional uses of agriculture
    - Insecurity and regulatory issues
    - Bio-goods – better productivity
- Diagnostic dimensions
    - Biomarkers (smart wrapping)
    - Early detection and response
    - Wellness monitoring/vitals/feedback
    - Detection of disease agents, land, air, food, wildlife
- Treatment
    - Xenotransplantation
    - Self-replicating wound treatment

- Artificial organs
- Personalized drug delivery
- Bio-containment
- Nano-robotic micro surgery

Their "quick hit' suggestion was the development of biomarkers for food, water and medical purposes

Vision and Capabilities	Optimistic World	Pessimistic World
	Nanotechnology	
Nano manufacture: machines – self replicating capacity cost effective/pervasive, e.g. o Personal health machines o Less labour need per unit (goods) o Security droplets/ nanobots/cameras/sensors New matter/materials	o 2025 – 25 hour work week o cheap goods, closed cycle systems o clean environment, more programmable custom design and variety o health improvements o economic equality o real security planetary flexibility enhanced	o Bill Joy grey goo scenario – digesters o Nano-management/totalitarian techno fascism/security o Terrorists assisted o Techno priest-hood – nano divide Mutation, bugs, unwanted evolution
	AI and Computing Systems	
o Net experience one of AI entity ---agents of intelligence/access o Productivity gains (info context not industrial)	o More productive, more creative o Better quality of life: entertainment, community o AI "friends", "advisors: o Able to model complex social, economic systems o Self selected communities & virtual associations	o Totalitarian government o Social inequality o Machines take over o Bugs – machines fail o Virus – machines vulnerable to attack o Loss of human self-esteem
	Industrial Ecology	
o Little waste/closed loop production/tracking/nano profiles o Nanobot assembly systems counter 3rd world labour manufacture o Waste treatments by nano	o Ecological systems become pervasive o Remediation of 20th century possible o Sustainability assured o Longer life spans	o Benefits only to the techno wealthy societies o Trade & migration based on exclusions o Quality of life down o Ecological priesthood reigns supreme/green

extractors in landfills etc.		fascism
Genomics/Proteomics		
o Personal data/authorization profiles o Genetic diseases progress/cures/therapies o Boosters: vision/ intelligence/features (eye colour)/health determinants o Artificial: organs/nutrients & new foods o Selective breeding of plants, use of water	o Better health o Better agriculture o More choices about health and appearance o Reduced health costs o Economic efficiencies from sNA arrays/chips for wide-transactions o Disease tracking/migrations	o Discrimination by insurance companies, etc. o Parents choosing child's features based on fad and fashion o Unwanted side-effects of genetic treatments o Unwanted side-effects of new organisms
Society/Privacy		
o Tradeoffs between privacy and economy and security multiple directions (privacy as a 21st century externality that most choose to barter for security/comfort, etc) o Advances in tech embed surveillance in infrastructure – well accepted for public good o Changes to personal actions and accountability	o Stability & less fear o New community of open knowledge o More accountable behaviours	o Big Brother has arrived o Wealth disproportional to security masters o Privacy seekers as non-conformists/outcasts o Privacy for wealthy only
New Information Economy		
o Every burden has a registered tax or price/benefit o Ecological accounting is embedded o Social costs & distributive benefits related to risks/time of day & situational factors… complex models for individual payments & balances in services (health, traffic, noise, etc.) - Smart, local,	o Cleaner environment o Better communities o Personal decisions aligned with public good	o Models with flaws may lead to bad decisions o Models may be skewed or biased by special interest groups or power groups

distributed controls tied to load factors on systems/needs - Energy services - Service priorities - Feedbacks from inanimate objects - Appropriate federal solutions		

Biotechnology Panel:

Participants were asked to identify some plausible or prospective "future events" in the bio-technology area.

Prospective Future Events – with "plausible" dates
1. BASIC KNOWLEDGE
• (2020) definition of "life relevant to space discovery & exploration" • (2030) search for extraterrestrial intelligence (SETI) advanced civilization detected in milky way galaxy • Population level—genetic info (genetic relief maps) • Transfer of consciousness on genetic chemical basis • (2015) mathematics of complexity discovered
2. ENVIRONMENT
• (2013-2018) remote sensing network convergence of biosensors… enviro-social • Ecological and supply side integrity of all biological starter materials necessary to fuel the future life sciences agenda of the federal govt/Canada • Pollution resistance in plants • Managed biocomplexity in place of biological control * • (2018) biosensors in framework of socio biogeo logic environmental networks • Simulated micro-(aquatic) ocean environment • "invasive species" include escaped transgenics & mass extinction of native species
3. BIO-TOOLS
• Biosensors to trigger need for nutritional supplements when in vicinity e.g. vending machines detect -—delivery mechanism to your requirements e.g. detect viruses • Airport biosensors for keeping foreign diseases out • Bio-scavengers search and destroy specific microbes * • We may have the technical capacity to detect, identify, monitor microbial consortia in complex/extreme environments in real time * • Home based genomics technologies (genome sequences at Toys 'R us • Micro organisms better equipped to decompose plastics, garbage, etc. • Microbial consortia,.evolving systems • computer model and visualization of virtual cells • genetic engineering on large scale to produce ideal combat troops—in rogue states • designer life forms – animals, plants, human, microbial and bio tools • understanding of gene functions • Understanding of gene relationships and plasticity

- emergence of genetic libraries
- genetic markets
- complete proteomics maps of specific cell types
- (2015) tracking of genetic “release level” (like software) as code sequences go through versions

4. **FOOD**

- High percentage fish consumed produced through aquaculture
- Gene banks for all marine organisms
- Teleproduction—biodegradable—life cycle
- Plants resistant to drought and other environments
- Multi-functional (use) designer plants e.g. root-tube tomato (fruit foliage)
- More plant based protein food to replace animal based protein
- Alternative protein sources from GM crops
- Plants with built in sensors and responses can tell you what they need!
- Food produced from building blocks –animals not used
- Food replicators (soylent green meets Star Trek)
- GM animals/plants to provide a wide / larger range of nutrients
- Beef=protein (complete) and vitamins (from plant genes) and mineral supplements
- Photosynthetic animals or autotrophs

5. LIFESTYLES

- sub-20 min 10 km runners 1:55 marathon
- “genetically enhanced undetectable”
- Slowing the “biological clock”—stay young and energized
- Designer symbiots
- Landscape plans designed to complement unique personality styles and moods
- Society splits into techno-accepters or –techno-rejecters
- Genetic testing at Olympics (first genome scandal!?)
- “cloning” of deceased person (new meaning to born again)
- safe drugs to enhance human intelligence *
- (2020)cloning of extinct species
- (2025) Genetic cosmetics (re-do yourself)

6. HEALTH & DISEASE

- Dramatic decrease in colds, flu
- Complete nutritional supplements individually prepared re diet, age health, etc. *
- Immortal cells—prevention of aging (telemeric research) *
- Memory enhancing or IQ augmenting drugs, symbionts or implant *
- Non-invasive gene therapy—oral?
- Edmonton Protocol perfected in 2010 and diabetes eliminated worldwide 2020

- human genetic manipulation—prenatal, socially acceptable, used widely
- Tissue, limb organ regeneration (just like new)
- Non-specific immunization versus vaccines
- Prevention of animal disease not treatment
- halt ageing process
- Vaccines for animals in plants as delivery, e.g. forage
- Limitations to genome based approaches appreciated *
- Disease suppression to stop spread
- Chip implant for multiple diseases for animals to detect antigen (bacteria/virus) at extremely low levels
- Prediction of plagues in large populations—animals, fish, people
- 90% world population eliminated following escape of bioterrorist agents
- all forms of cancers are preventable
- (2020) biochemical repair agents for radiation damage to human genetic material—application space travel *
- (2015) all possible antibiotics in production

7. ENERGY & FUELS

- A food waste energy converter—food scraps to fuel
- Complete replacements of fossil fuels through bioengineered fuels
- Population explosion, world disease,
- People living longer, more older people
- Improve health and welfare
- Alternative energy sources
- Narrow gene pool
- Animals, plants, humans due to cloning designer organisms
- Biopharms produce pharmaceuticals

8. INDUSTRIAL PROCESSES

- Complete elimination of family farm in industrial countries
- 100% food produced in biofactories for food *
- Method to achieve sterilization of food prior to release to retail level
- Increase in private research (underground)
- Wealth gap increases, private research in forbidden gene technologies cloning, stem cells, human reproduction
- Waste disposal decreased by 95%
- Recycle
- Bioremediation
- nano industrialization
- Reduction in mass *
- 25% of our consumer products based on biomaterials
- industrial scale of production of 100’s of input materials through bio-mimicry type

processes • industrial products, production can be reduced by bio-products 50% • First bio car commercial production possible
9. BIOINFORMATICS
• Comprehensive micro-databases tracking all genetic heritage and potential • reduction in prediction / control leads to increase in sensing, info sharing technologies • "e-mortality"—human machine inter-faces at the Central Nervous System level of integration * • (2020) Bio mathematics genetic process becomes form of abstract algebra
10. GOVERNANCE
• Reduction of emphasis on techno-fixes in order to address distributive, equity issues • Global cooperative governance of technology for human benefit • we find to ways to effectively simplify complex issues, model impacts e.g. genetically modified foods • Canadian biodiversity in extreme environments (such as deep sea, arctic, contaminated sites) will be routinely identified, evaluated, documented, protected, stored and or utilized in a socially responsible and sustainable manner • Strict control of human, animal & plant reproduction • We will have assessment framework (similar to the current federal regulatory framework for bioproducts processes) that offers the additional capacity to evaluate performance, efficacy, benefits, society acceptance and overall sustainability of biotechnology products.

The themes identified in the morning session were clustered into three groups:

1. Basic Knowledge, Bio-Tools, Bioinformatics
2. Environment, Energy & Fuels, Industrial Processes
3. Food, Health & Disease, Lifestyles

It was discussed and agreed that the tenth topic "Governance" spanned all 9 themes and was therefore not included as a separate item.

Participants were assigned to a group and tasked with identifying biotechnology "drivers", defined as "forces that make events happen".

Biotechnology Drivers		
Basic Knowledge, Bio-Tools, Bioinformatics Drivers		
	Basic Knowledge	
		• Fundamental human tendencies to explore and understand the world • Discovery of the unexpected a critical driver • Applications of basic discoveries – most discoveries have multiple applications • For basic research to be competitive with other sectors, need to explain the payoff… emphasise that solutions link back to basic research • Human traits – human one-upmanship and competition • Governments willingness to continue to support basic research • Many items reflect a reductionist view… the need to move to a complex model • "What is life? - new definitions driven by biotechnology and the human/spiritual links • demographics – population explosion – environmental refugees
	Bioinformatics	
		• Basic human need to track, trace and identify things • Public acceptance of tracking capability • Basic human desire to measure and quantify • Databases – huge amounts of information drive the technology for manipulations and extraction of more information more quickly or in real time • Need for information to be accessible
	Biotools	
		• Desire to extend life • Need to respond to market demands • Desire to kill • Desire to save life • Need for entertainment • The environment
Environment, Energy & Fuels, Industrial Processes		
	Policy (personal/government/industrial)	
		• International trends (e.g. another country banned gasoline) • Trade regimes • Consumer pressure • Regulatory decision • Resource expenditures
	Knowledge	
		• Trends • Compilation of baseline data • Radical technology breakthrough

		• Crisis – knowledge about, causes, effects (e.g. acid rain)
	Infrastructure	
		• Natural, physical, social economic • Degree of entrenchment or willingness to change
	Demographics	
		• Population growth • North/south divide • Development trajectories (e.g. China) • Wealth distribution • Urbanization
Food, Health & Disease, Lifestyles		
	Demographics	
		• Population growth • How/where/clustering • More disease • Wild cards
	Loss of farmland	
		• Decrease of biodiversity • New food sources • Need to look to the oceans
	Oceans as the "new frontier	
		• Psychological driver • Pharmaceuticals • Platform for energy harvesting
	Climate change	
		• Change society • Food supply decrease in land mass
	Social dichotomy based on whether to accept/reject biotechnology	
		• How is risk communicated • Reality is that there always will be pros & cons • Without a mechanism to deal with this reality, we will be immobilized
	Disappearance of national boundaries/sovereignty (as we move to the oceans)	
		• results in global consideration of human needs and the cooperation required to act on that
	Increase in social stress (air/road rage)	
		• Resources taken away from biotechnology • Creates a greater need for biotechnology to deal with and detect outcomes of stress-related disease and conditions
	Assuming we overcome lack of acceptance of biotechnology, the sector will grow with concomitant economic growth	
	Social acceptance will become a driver	
	Need for "life cycle" in product development, with biotechnology as a means to achieve this	

The Impact Space model was introduced as a tool to help identify ways in which inter-relationships between future events and technology developments might be mapped. Impacts of an event/technology can be linked to opportunities, change and threats, and viewed horizontally across social and government structures.

A few examples of specific events and their impacts follow:

Designer life forms (single cell)		
Opportunities	**Changes/Issues**	**Threats**
• preserving foods, • probiotics (medicine), • bioremediation—span all areas • environmental protection • making industry cleaner	• Containment - unintended release & tracking it • knowing there in the first place • terminator technologies (automatically shuts down, sunset clause on life)… • risk assessment… microbes into food processing…will we even know that it relates back to food?	• "can be used for good or evil" • also used for • military purposes… e.g. microbe could make oil products useless and destroy fleets, mobilization capacity of armies • unintended release

"Genome on a disk" (disk issued at birth)		
Opportunities	**Changes/Issues**	**Threats**
• health management • custom drugs • personal blueprint	• Privacy – who should know? Government? Insurance companies? Your family? • Data ownership – do the parents own the child's data? • Potential impacts – schools, health care system, etc. • Jurisdiction	• How to deal with classifications – normal vs. not normal • Enhanced risk of genetic discrimination • People categorized by genotype

Food waste to energy (bioconversion of solid food wastes)		
Opportunities	**Changes/Issues**	**Threats**
• environmental	• how to encourage buy-	• environmental wastes

protection – reduction of landfills • reduce use of fossil fuels • new technological innovation – enzymes, systems control, fermentation • health benefits – CO_2 and smog reduction • Waste conversion – need to re-design food to facilitate conversion	in to program • new regulatory requirements • who to target? Producers? restaurants? • health policies – e.g. in composting - intensive presence of micro organisms	• escaped microbes • leachates • Greenhouse gas emissions

Managed bio-complexity (using bio-control agents in the context of environmental complexity)		
Opportunities	**Changes/Issues**	**Threats**
• reduced threats endangered species or foster recovery e.g. sterile pine beetles instead of pesticides, herbicides… • able to use to counter bioterrorism • new forestry practices, • reduce reliance in pesticides, - using bioagents to reduce dependence on pesticides and fertilizers • smart modeling of (all natural systems…start from best knowledge, acknowledge complexity start to lose sureness on grip of understanding)	• many more horizontal linkages, integrated • sustainable development ecosystem approach *"When you acknowledge system complexity you lose sureness of prediction"*	• bioterrorism, • food system effects • new invasive

Virtual model of the cell (both science to create virtual model & effects of having model)		
Opportunities	**Changes/Issues**	**Threats**
• access info in coordinating proteomic, genomics; • new preventative therapies • targeted treatments	• Decision models become large scale, multi-institutional collaborative, horizontal • Need a policy shift to incorporate new ethics	• targeted treatment gets out into the environment • false extrapolation, negative outcomes

Biopharming vaccines		
Opportunities	**Changes/Issues**	**Threats**
• Health improvements	• risk assessments, • risk management & communication • develop standards	• transgenic escape… • Xeno-tranplatation diseases • Bio-terrorism/sabotage • Transplant organs… latent disease develops in human wasn't present in animals

Gene mapping		
Opportunities	**Changes/Issues**	**Threats**
• Natural resource management • Epidemiology • Identification of diseases of genetic origin • Genetic counselling • Gene therapy • Biodiversity inventory	• regulations re information and privacy • allocation of resources – change in health care expectations…	• privacy, • bioterrorism, • genocide - target races

Nanotechnology Panel:

Prospective Future Events – with "plausible" dates
1. HEALTH
• (2008) Nano-markers to ID infection on a real-time basis • (2010) Development of artificial skin replicating human sensory characteristics (cosmetic surgery through nanotechnology); biometric artificial skin • (2012) Customized, integrated health care delivery, including monitoring, medication, therapy • (2015) Genetic screening for definitive prediction of disease; genetic mechanisms to prevent development of disease ante-natal. • (2020) "Foolproof" immune monitoring to prevent foreign body (viral, bacterial, parasitic) invasion • Genetic material to over-ride Alzheimer's disease; reduce tangled brain cells, regenerate brain cells • Bio-switches to over-ride aging in human cell growth, repair cells • Guided "pills" containing diagnostic elements, possibly driven by "cilia motors" • UN agrees on a charter of ethics for medical use of nano-devices • Nano-tissue self repair: heart, lung, skin • Individual genetic or proteomic chips • Artificial livers, kidneys based on "smart membranes" and filters; synthetic organs from MEMS devices and nano-materials • Implanted devices to monitor health status by body chemistry • Specific and efficient drug delivery devices based on CNT and nanoparticles; drug delivery using nano-pumps • Nano-manufacturing of specific drugs or proteins as needed • Artificial virus, injectable into DNA, for cell repair • Neuron re-growth guided by nano-tubes
2. COMPUTING
• (2012) Quantum computing – massive parallel, ultra high-speed computing • molecular computer • "neuronic" computers built from "grown-in" neuron structures • nano-hub, driver, simulator for everything; nano software, hardware development • Nano-chips, full function computer built to nano scale • Virtual representation (modelling, prediction) of cellular molecular interactions and structures; not only see the molecular players, but "see" what they look like
3. MATERIALS
• (2015) A nano-level "block and tackle) or "windlass" for hauling nano-level masses • understand biological processes in atomic and molecular assembly • Design of specific catalysts

• Self-healing, self-repair structures and materials • Actuators based on chiral CNT – Robotics • Nano-coating/nano-phase super hard materials, 2D superconductivity, superalloys • Silicon "Bucky Balls" and tubes with unique properties; also made from III-V compounds
4. **BIO-ENGINEERING**
• (2005) Feed fish nano-sensors as a tagging mechanism • (2005) DNA chips • (2005) Nano-membranes (chemical separation) • (2010) Nano-interface to control artificial limbs • (2010) Canada's last abandoned mine neutralized via nano-particle remediation • (2012) Nano-controller to monitor and deliver medication • (2015) A major oil spill is completely neutralized using nanotechnology • (2020) bio heat pumps • Re-design molecular interactions, e.g., designer regulatory and functional genetic elements • Rebuild/re-engineer single cell organisms for specific purposes, e.g., bioremediation, protein production • Mass "in-vitro" machines – parallel molecular devices to produce "high value" molecules • Nano-sensors embedded in humans and animals • Nano-bio- molecular machines • Reproduce and improve natural structures fro membranes to organelles to specific cells • Artificial cellular components, e.g., photosynthesis, Nitrogen (N_2) fixation
5. ENERGY
• (2015) Nano-electron catalysis→hydrogen→fuel cells • (2025) Nano remediation that converts waste to fuel • (2050) Majority of transport is based on hydrogen, remainder is largely hybrid • Hydrogen economy • Solid state power generators • Advanced thermoelectric materials
6. CONSUMER PRODUCTS
• (2008) Personal security: biometric sensor, home security and financial security with nanotechnology • Personal sensors, detectors: alarm for hazardous materials, signal location for the elderly, miners • Universally available water purification devices • Home diagnostics systems continuously monitoring water, air, food and safety
7. OTHER EVENTS

- (2005) Nano radio frequencies to track shipment of goods
- (2005) Anti-nano lobby groups thriving thanks to media negativity
- (2010) Unexpected nano-scale degradation causes dramatic cancer increase in some group
- (2010) Artificial nano-level chain reactions; self-starting nano-level evolutionary processes
- (2010) Nano-plants that adapt to hostile environments
- (2010-20) increasing numbers of third-world countries adopt Open Source Biological Manufacturing
- (2012) personalized micro-environments
- (2015) Training programs (universities) organized on integrated themes, rather than faculties and departments

<table>
<tr><td colspan="3">Nanotechnology Drivers</td></tr>
<tr><td colspan="3">Biology</td></tr>
<tr><td></td><td colspan="2">Wildcards</td></tr>
<tr><td></td><td></td><td>• Nano hackers
• New generation of nano-bugs</td></tr>
<tr><td></td><td colspan="2">Drivers</td></tr>
<tr><td></td><td></td><td>• Scarce resources, need for alternatives
• Regulatory environment: smart/proactive/innovative or oppressive/ unrealistic
• Public awareness/acceptance of nano-bio-technology – fear, need (GM food issue a good example); Risk communication – clear scientific knowledge must be communicated
• Harsh industrial environment requiring amelioration through nanotech
• Maturity of companies
• Technology itself in a push-pull dynamic; would the technology create demand, or would there be pre-existing demand
• Ethics – who would inject? Scientist, engineers, entrepreneurs?
• Competitiveness
• Consumer demand and spending
• Demographics (aging population)
• Overall vs. short-term cost</td></tr>
<tr><td colspan="3">Physics/Engineering</td></tr>
<tr><td></td><td colspan="2">Drivers</td></tr>
<tr><td></td><td></td><td>• Certain kinds of basic science issues to be resolved: e.g., algorithms about how computing devices actually work
• A foundry/workbench operation to enable:</td></tr>
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people networks, standards, rate of information/technology exchange
modelling, visualization, simulation
fabrication
MEMS exchange, prototype, beta-testing

No mechanism for a national focus on nanotechnology
Public acceptance
Convergence, for discovery of natural models
Killer App needed – consumer or industrial
No major industrial player
S-curve: the importance of all drivers changes as you move up the S-curve, e.g. Standards, Killer App become more important as you move up the curve
Importance of niche markets – knowledge, research, applications, specialty industries
Japan sees drivers of nanotech at 2010 to be, in order of importance: IT, materials, the environment, space.
The pace of discovery in nanotech may be too quick for investors to keep up with.
Application areas that will be drivers:

Climate, energy, new ways of using energy
Health
Environmental concerns
Security
Consumer – clothing, electronics, cosmetics

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<tr>
<td colspan="3">Environmental sensors in GM fish and water (For tracking and monitoring fish and water in aquaculture cages.)</td>
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<tr>
<td>Opportunities</td>
<td>Changes/Issues</td>
<td>Threats</td>
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Ability to monitor fish and water
Create large amounts of protein to feed the world and overcome the environmental threats that are currently preventing this; production of beneficial by-products, such as Omega 3 oils
Canada well positioned to be a net exporter
Early detection of

</td>
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Environmental protection legislation to encourage aquaculture protection and more fish farms
Health policy changes

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Sensors may enter the food chain
Aesthetics – people don’t want to smell fish farms
Effect of fish waste on water quality
Fish diseases
Invasive species

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problems • Biomass→fish food		

Personal Movement and Physiology Detector Remote sensors that detect where a person is and his/her physiological state.		
Opportunities	**Changes/Issues**	**Threats**
• Tracking criminals, children, alien security risks, ill people • Detecting disease status, improves chance of solving problems, reduce costs • Extended life means increased knowledge pool, new post-retirement opportunities for older people to contribute to society, post-retirement-related industries • More information to better manage society, resources	• Regulations and policy essential in health, privacy and security areas	• Privacy compromised; citizens become a number • Social prejudice against those not complying • Costs • Quality of life issues • Impact on natural resources, environment of more people living longer

Nano-roach/ enviro-bug A nano-level entity that can act everywhere, has high mobility, can communicate with other nano-level entities, can be under a central control or autonomous, can be used for both positive and negative purposes.		
Opportunities	**Changes/Issues**	**Threats**
• No more secrecy • Quality control • Know how environment works; environmental tracking • Identify polluters • Mathematics of complexity; computational biology	• Regulation of information overload, privacy issues • Selective use in innovation and development • Decision support • Statistical voting to reduce information density	• Roach hackers • Nano-counter measures • Death of secrecy/privacy/security • Evolution of external machine intelligence • Information overload • Wrong data proxies • Too many loose devices

Nano-pill Defined as a flexible entity that would do imaging, chemical analysis, would be steer able		
Opportunities	**Changes/Issues**	**Threats**
• Incapacitate the enemy • Specificity and customized delivery of medication • Early assessment of disorders; healthier population, increased longevity • Fewer chemicals in the water	• Ethics, Geneva Convention • Re-training for medical profession; need for doctors reduced • Regulation of acceptable levels	• Psychological/physical control • Too complex • Aggravate aging problem; overpopulation • Nano-waste

Info/Cognotechnology Panel:

Prospective Future Events – with "plausible" dates
1. DISTRIBUTED COMPUTING/EMBEDDED HARDWARE POWER COMPLEXITY
• (2010) global "phone" directory; all Canadian health records can be put online • (2010) metadata for geographic information is ubiquitous; find restaurants, social groups, etc. close to you • (2015) simulation software and spreadsheets will routinely use evolutionary computational models (e.g. for optimization) • (2015) ubiquitous web/grid/cyberspace interfaces through portable, wearable, wireless devises of multiple configuration (clothing, implants, watches) voice activated and DNA security validated • (2020) global mind; computer assisted network problem solving • (2020) automatic language translation • (2025) computers with enough power to telescope time in simulations of complex historically-bound systems • Rapid identification of bio/chemical/radiological nuclear agents for "first responders" to terrorist attacks • Query tools to access and link genetic species and ecosystem data • Communications dominated by computer to computer talking • Demographic delineation to allow deeper, broader, wiser policy creation with virtual fencing for division, containment, protection, compliance • Data archives in space – distribute caching • Globalization becomes "glocalization"; communities of interest world-wide.
2. HEALTH-BIO INTERFACE
• (2015) human cognome project – mapping of human brain • (2015) consumers carry sensors to detect freshness in food, chemicals, personal preference • (2015) detectors at airports – sensory chips replace detector dogs • (2020) rapid, accurate, thorough analysis of individual DNA chips for personal ID, counter-terrorism, "patient bio-electronic chart" • (2025) computers help to understand complex systems • Small scale tools for accessing and sequencing combinatorial DNA • Identification tools using DNA micro array technologies • All species "bar-coded" by specific gene sequence identifiers • Whole body/mind scanners/sensors that can determine health status • Body as battery – energy from body N-powered converter - heat/blood mobility/physical activity • Chips individually tagged on humans to track location • All tools for the deaf, blind and cognitively impaired give 80-100% function • Using photonics in medicine – individual and social • Human cloning devices for human senses

• DNA computers that enable all living matter to be linked into intelligent networks for R&D and computational purposes, but with moral, ethical controls embedded • Neuro-stimulators to harvest memories w. their social context
3. INTELLIGENCE SYSTEMS/AI (SOFTWARE)
• (2004) voice to print technology that doesn't have to be trained to voice recognition; digital audio files with multiple voices can be converted directly to print • (2015) innovation monitors: goods/ services that allow publicizing/sharing of organizations and individuals, situations that are ripe for innovation • (2025) machines to read the electromagnetic structure of though and feed back to the thinker • (2025) cognitive alignment bio-computers whereby we switch into brain-web alignment patterns for defined periods to motivate fast learning, info intake, complex expression: no more hard-wired • (2040) robots are smarter than humans but Hans Moravic is wrong - robots attack human civilization and cyberform earth to their own needs (do we need the Joy manifesto?) • (2040) Hans Moravic is right – robots are smarter than humans but they take care of human civilization benevolently • Early warning of opportunity and change as crisis software • AI teachers and at-home learning with AI mentors √√ • Cars travelling at the same speed in specific lanes due to programmable chips √ • AI doctors office – consultation, diagnosis, treatment without seeing another human √√ • Effective collaborative interaction between humans and intelligent machines/systems in military/counter-terrorism scenarios • Virus resistant IT systems • Voice-activated interactive control of pre-programmable vehicles communicating with other interoperable vehicles • Autonomous intelligent systems in unmanned combat vehicles • Computer systems that augment or sense of context by showing a larger or smaller scale of interactions – applied ecological thinking • Systems dynamics and knowledge management tools built into elementary and secondary school curricula √√ • AI-based agents who could represent you in other environments to double your experience • New global spoken language that builds in tools such as critical thinking and innovation √
4. OTHER/MISC
• (2020) cognitive research can monitor processes at work in the scientific ind as it discovers new knowledge • (2020) optical E.T communications (off-axis lasers) are sensed, but not understood • (2025) we will know of thousands of earth-like planets but none will have intelligent life • (2025) small-scale artificial islands of durable, constructed/assembled molecules

using nano manipulation (new spaces, places/realties)

- Exo-bilogy
- Cross-species genetic mixing √
- Ethical It tools for consistent judgments √√√√
- Direct links to human mind to enhance physiological learning state √√

5. ACROSS CATEGORIES (DRIVERS?)

- (2010) discarding of privacy rules; large core data for everyone available in one database globally
- (2012) government bilingualism policy changes due to real-time translation
- (2015) standards established for bio-nano-IT interfaces √
- (2020) US may admit to greenhouse warming; it will be one of Earth's biggest industries √
- (2020) sufficient numbers of multi-disciplinary trainees/young researchers to enable and employ IT
- (2020) artificial wisdom is a more desired goal than AI √
- First indirect evidence of SETI
- "Cyborgs" are everywhere – wearable processing jewellery
- Innovation is built into all disciplines from pre-kindergarten onward √√
- Simulating problems in real world to embrace trans-disciplinary understanding; efficient, effective education

Info/Cogno Drivers

DISTRIBUTED COMPUTING

Wildcards

- Intelligent virus (fungal growth)
- Equilibrium/balance, possibility of collapse
- Physical destruction
- Human element; used for destructive purposes
- N/W autonomous?
- International language
- Asia wiped out by AIDS

Drivers

- P2P applications
  - Cost
  - File
  - Process sharing
- Architectural issues
  - O/S vs. network bound
- Application mobility
- Machine to machine (for machine needs)
- Archival issues
- De-couple applications from hardware
- Propaganda/info control
  - indestructible and accessible
- Security
- Competence (know how)
- Backlash (Luddite)
- Changing concept of privacy
- Cash/barter economy
- Increased level of communication
- Reaction to central control
- Employment
  - Where do they go
  - Nature of work
- Self-learning systems
- Distributed computing mirrors the brain
  - Cognitive systems embedded
  - "self-awareness"
  - New forms of cognition
  - New kind of organism
  - "Rights" for computers
- Luck/change/random
  - Errors don't surface, but survive

HEALTH-BIO INTERFACE		
	Drivers	
		• Signal conversion ○ Biochem→electrical • Mapping (gene, protein, human brain) • Patents and intellectual property • Bio-terrorism • Assessment of threat (speed of evaluation) • Scientific expertise (personnel base) • Societal divide between those who accept and those who reject new technologies • Ethical debate • DNA sequencing • Still to nascent • Public resistance to interface devices • Privacy issues • Ability to read chip implants • Global warming and changes to bio-diversity • Resistance to de-compartmentalized learning, specialization • Complete evolutionary change • Products development and demand • Resistance to control by too many sensors • Personal autonomy vs. ubiquitous sensors • Zero risk tolerance for certain health threats – smoking, salmonella, e. coli • Perpetuation of risky behavior as devices diagnose and cure faster • Fears of loss of creativity, identity • More leisure and entertainment
Intelligent Systems/AI		
	Wildcards	
		• Software development (pace and complexity) is faster/slower than anticipated • Progress slows to a stop • Breakthrough in understanding how the brain works • WW III, other conflict pushers
	Drivers	
		• Interaction between man and intelligent systems • Translation systems • Neural connections; man-machine interfaces • Functional interfaces, e.g., “eye scanners” vs. surgical interventions • International travel and trade (push for translation devices) • Security – military/national defence

		• Reservation of military personnel drives development • Synergies and efficiencies enhancements – complex technologies and people working together • Tactical (competitive, military, trade, productivity) – keeping up • Technical and cognitive complexity – difficult to build, to drive • End users create demand • Human Resources, e.g. sufficient doctors and nurses – new systems required • Need for solutions for collective "prisoner's dilemma" • Push development due to inability to solve with current tools • Entertainment industry

Personalized DNA chip For health data and identity		
Opportunities	**Changes/Issues**	**Threats**
• Individualized DNA chip • Disposal of chips, compatible with human physiology • Catalogues of genetic diversity • Identify problematic genes • Identify individual cloning • Identify non-domestic flora and fauna	• Who is permitted to scan? • Privacy issues • Education of scientists, medical profession • Diseases vs. propensity to behaviour • Health cost savings, therefore smaller health system	• Self replicating machines – issue of control • Tracking dissidents, individual actions • Individual freedom/ ID chips • Negative stereotypes labelled

AI medical system Docs in a Box.		
Opportunities	**Changes/Issues**	**Threats**
• Correlation of medical data and environmental data • More data collected and stored for analysis e.g., illness and where you live • Using medical system to differentiate between real and psychosomatic	• Social • Medical education • Public vs. private medical systems • Confidentiality and privacy	• Negative impact of knowing what future sicknesses one will develop; resulting social problems • Medical liability • Earlier detection may lead to reduced costs • Nurses may be harder to replace

illness • Pharmaceutical testing • May push discovery, science • Doctors freed up to do more research • Better use of available Human Resources • Personal scanning devices • Could be learning system • Human trials improved • Economic efficiency • More clinical and financial options • May lead to preventive lifestyle changes • Detecting trends in personal health • Autonomous personal monitoring system • Gender issues; nurses, authority issues • Access to one's own medical records		• Patient confidence • Doctors; gender power, authority

Systemics Technology Panel:

Participants were asked to offer an idea for a technology or a technology system that might be available or desirable in 2025.

POTENTIAL TECHNOLOGIES OR SYSTEMS OF 2025
• Need to push the concept of economic input/output matrices to cover the natural environment, air, water, etc • Technology that can be instantly used in economic and social models to see how weather and the atmosphere will effect society and the economy • Predictive models for empathogens, in food, interactions, matrices of interactions between packaging, food, ingredients etc. • Utilization of complex ecosystems as "ecotech" technologies. Developing global scaled monitoring of the land, seal and air to scan for risks to life support. This would be coupled with interventions to restore health. "Using nature to look after nature." • Technology to rapidly and accurately detect agents of bioterrorism… the new unknowns that don't fit our current moulds. The new chimeras will be entirely new and are likely to be created in a basement lab somewhere… • Looking to see the spill-out from military programs through to emergency preparedness to general health support… Envisions a card that patients take to the dentist or doctor. A card swipe at the beginning of the visit would offer an up-front range of biomarkers, biosensors, "labs-on-a-chip" and data for everyday health and pathogens. Gives a record over time of health and could monitor pathogen spread over time. • Predictive models or systems that could integrate date from the global human and animal populations monitor population densities, movements and disease occurrences worldwide. • Two technology challenges relating to the probable loss of wild fish stocks by 2025. Given that by that time all sea-based protein will be derived from aquaculture and that nano-contaminants will be prevalent in the aquatic environment, we need: 1) technologies to detect micro-contaminants and eliminate them so that aquatic proteins are edible, and 2) mechanisms to turn waste products from large scale aquaculture into benign and beneficial nutrients. • Development of a non-invasive bio-diagnostic device – perhaps a cuff – that could provide vitals, current health status, monitor for bacteria, viral infections, etc. • We need to understand the "systems of systems" – how they interact with each other. Development of synthetic environments can have applications in defence and across the spectrum. • The ability to simulate with a deep level of understanding at the cellular level and

build on that to create accurate simulations of organisms. Also to see models and simulations of complex eco-systems. • Comprehensive database of all genes and sequences, and the functions of those genes and their effects on the environment, as well as a means of predicting/knowing natural mutation rates vs. man-made or genetically engineered mutation rates. • A non-invasive biochip that contains information from the moment we are born – baseline information – leading to detection of disease through diagnostics and perhaps gene therapy. • Cyber-organism/cyber-cells – every single metabolic pathway, protein, enzyme and detail is built so that any extra cellular stimulus can be mapped. • Looking for a cheap "lab-on-a-chip" that can be spread everywhere to assist in soil analysis, determination of optimal crops, also giving air, soil, water microbiology/contaminants & pathogens… a full picture.

Systemics Drivers		
Natural Systems		
	Wildcards	
		• Massive volcanic eruption • Asteroids • Earthquakes • Terrorists
	Drivers	
		Population • Distribution/density • Demographics • Land use, resource demand • Decrease in biodiversity • Waste generation Carbon-based economy • Wind driven pollution • Climate Loss of biodiversity • Instability • Loss of resilience • Domino effect • Loss of ecological services (e.g. NYC decided it was cheaper to go upstream for water than to clean up waste Alien invasive species

		• E.g. potato warp, MAD cow disease • Increases with international trade and travel Food security/safety • Global food reserve is only 50 days • Who will feed Third World - China/Africa? After either natural causes or catastrophe? • Will drive land-use up – more intensive usage • Require more fertilizer – less and less sustainable • Currently 20% of global grain production uses non-renewable ground water mining • Will challenge issues of political sovereignty & global governance
	Tools	

		• Forecasting tools – Natural Systems (Note that Forecasting & Monitoring are linked – expertise in one, improves efficiency in other)
		  o Weather
		  o Populations
		• Monitoring/surveillance – we are currently lacking in this technology
		  o Real-time
		  o Ground
		  o Water
		• DNA based sensors/technology
		  o Plants with novel traits
		• Bio mimicry (using nature to help us design technology) – Natural Systems
		  o Barnacles
		  o Spider webs
		• Hi-sensitivity detection techniques
		  o Metabolomics
		  o Proteomics to detect tiny amounts
		• Distributed monitoring networks (satellites and Links)
		  o Model to priorize resource use (who gets priority for resource use – an ethical issue)
		  o Communication
		  o Decision support
		• Information sharing (natural systems)
		  o Hiding information becomes an ethical issue (Democratization of decision-making assumes a willing sharing of information)
		• AI capability for analysis of data
		• Data (relevant) democratization at local level (even down to the individual)
		  o Observation & reporting – e.g. birdwatchers sending in data voluntarily
		  o S/W for analysis at individual level

		• Legislated real time surveillance of commercial harvesting of biological resources – to support conservation enforcement
Human Systems and Tools		
	Issues	

		• Need real-time surveillance & real-time diagnosis – ultimately leading to pattern recognition
		    o Eg. “Pulsenet” – couple of weeks
		    o Weakness – first patient contact to system
		    o Link animal/fish disease termination with human monitoring
		• Need an intelligent bio-diagnostic card for human monitoring
		    o E.g. – implant or breathalyser with a means of rapid diagnosis and pattern recognition
		• Need a food security system
		    o Design critical technologies
		• Need trained personnel – from epidemiologist to neural networks
		    o Need to be aware of bioterrorism and the introduction of new areas of concern – plan a detection system

	Negative Drivers	

		• Privacy Issues – voluntary vs. involuntary – ethics
		    o Insurance implications
		    o Human rights issues
		• Governance issues – modeling – real time
		• Computing power – systems required to handle data and make sense of it – real time
		• Human acceptance
		• Lack of instant diagnostics
		• Education
		    o Government
		    o Local

	Positive Drivers	
		• More productivity – fewer sick days – prevention of disease • Health care savings • Prevention of infectious and chronic diseases • Bio-informatics – availability • Most technologies should be available • True bioterrorism event
	Technology Tools	

		• Monitoring migrant health - human and animal - Biological monitoring before people enter Canada
		    o Full body imaging
		    o “Chips & Dip” - gene chips to dip in bodily fluids to check for

		presence of pathogens
		• Computing power
		  ○ Data mining tools
		  ○ Data collection
		  ○ Data extraction
		  ○ Data analysis
		• Systems to read cards plus data tools
		• Electronic noses
		• Micro-arrays
		• Biochips
		• Transfer systems
		• In sum – need rapid, accurate diagnosis methods and more computing power.

Appendix 2 – Scenario Architecture

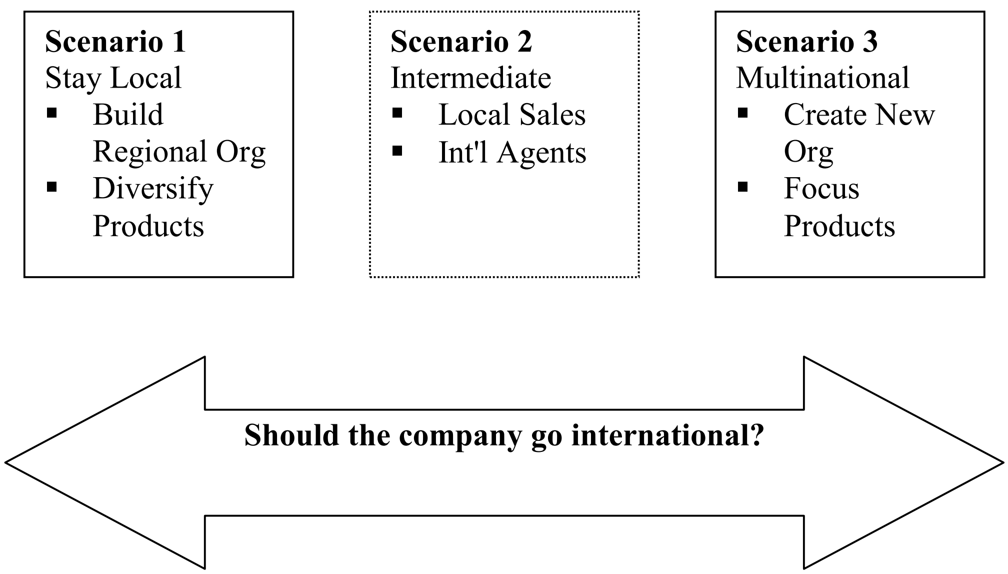
[Excerpted from Drachma-Denarius Methods Paper on Scenario Writing]

The scenario architecture stage lays out the basic definitions of each scenario. This stage is crucial. The main task in this stage is the identification of the focal issue or issues. There are number of possible ways to approach the problem.

Single Issue

If only one key issue is identified, it should represent the single most important decision facing the management team, or the single most import external change in the future.

Suppose, for example, that a firm has been successful and has fully met its goals within its home country. Its focal issue is whether it should expand into international operations. This would drive either a two- or three-scenario architecture.

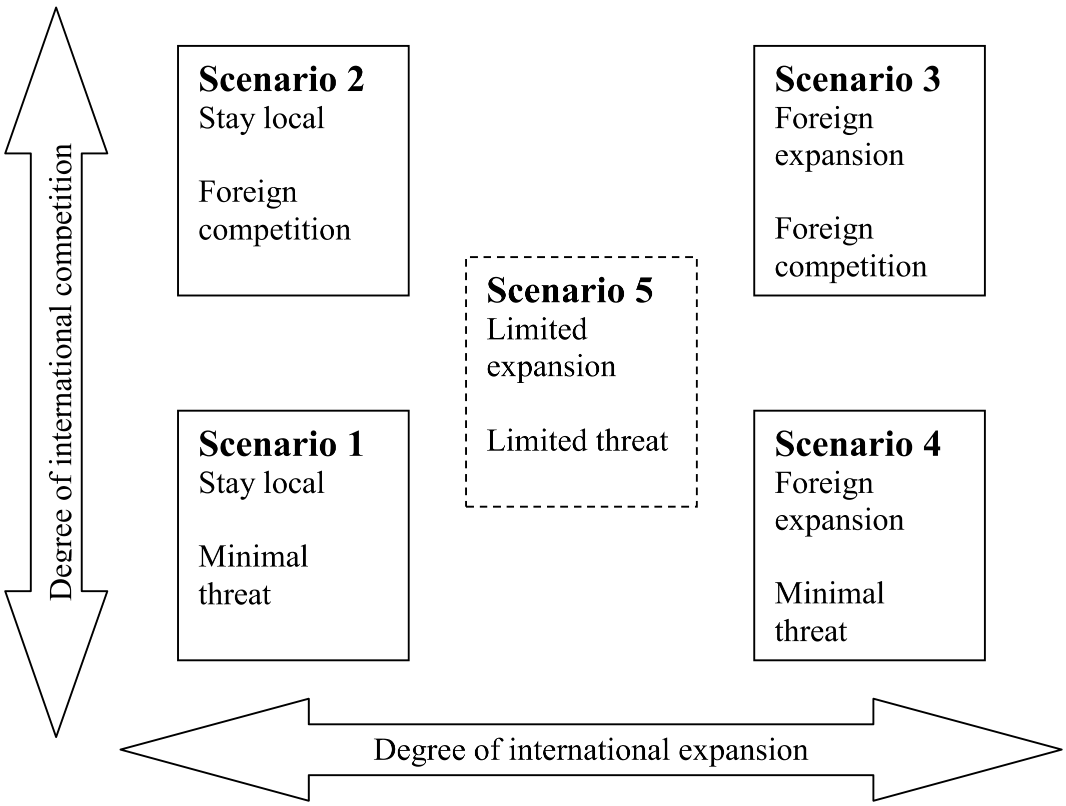


In this case the two main scenarios are that the company creates international operations or it stays strictly local. Often, an intermediate scenario is prepared, which in this case could mean the company would have export operations handled by overseas agents.

Double Issue

If two issues are identified, one should represent the single most important decision facing the management team, and the other the single most import external change in the future. This will make it easier to create a 'conceptual distance' between each scenario.(If we were to take the most important and the second most important internal issue, then the scenarios would start to look similar to each other.)

Continuing with the example above, suppose the critical external issue was the degree of competition from out side the country due to trade liberalisation or just due to an aggressive foreign competitor. This would drive a four- or five-scenario scheme.



Multiple Issues

It is possible to go beyond two issues, but this will significantly increase process complexity. Such an approach would typically be used:

- For a large problem (geo-politics)
- With sophisticated planners (military or diplomatic)
- As part of a collection of strategies

The number of scenarios can get quickly out of hand. Suppose each focal issue is defined as an Issue Vector (IV) having N possible states. For example, we could have:

- IV1, degree of globalisation = high, medium, low: N=3
- IV2, extent of global peace = peaceful, continuous war: N=2
- IV3, population growth = declining, stable, growing: N=3
- IV4, environmental health = collapse, slow deterioration, stable, some improvement, healthy: N=5

These four vectors would lead to 90 scenarios (3x2x3x5). This is far too many to deal with. In order to control this combinatorial explosion a 'manageable' subset of key scenarios is usually chosen for study.

Table 1 shows the kind of information that should be captured and documented for each of the issue vectors. Do not rush through this table. It should represent the prime issue facing management. Be sure the description describes the problem and why it is so important. Make sure that the description of each of the possible issue vector states reflects the real spectrum of choices or options, since these form the assumptions behind each scenario.

Table 2 gives thumbnail descriptions of each scenario using point form information derived from the relevant issue vector states. Each scenario has a number, and space for a name. The common practice is to assign a memorable, representative or overly cute name to each scenario. This is a good practice, but should not be done early in the process. Scenario naming is better done towards the end of the environmental scan phase. Suppose, for example, that the following names were assigned to the scenarios:

1. Easy Street
2. Eating Our Lunch
3. What Were We Thinking
4. Tourist
5. Business as Usual

The evocative titles could easily drive the selection or rejection of trend and event variables.

Table 1: Sample Issue Vector Form

<table>
<tr><td>No.</td><td>IV1</td><td>Title:</td><td>Foreign Expansion</td></tr>
<tr><td colspan="4">Description:
▪ Should XYZ Corp expand into international markets?
    ▪ Expansion in domestic markets has limited potential
    ▪ Product line competes well with imports
    ▪ Will require significant front end investment to acquire foothold</td></tr>
<tr><td colspan="4">Vector States:
▪ IV1(1): Stay local, focus on domestic markets
▪ IV1(2): Remain local, work with agents to establish export market
▪ IV1(2): Aggressively expand into international markets, establish branch offices</td></tr>
<tr><td colspan="2">State Description</td><td colspan="2">IV1(1) Domestic</td></tr>
<tr><td colspan="4">Grow within domestic market at 5% per year
Invest in follow in product line
Establish partnership alliances with downstream suppliers</td></tr>
<tr><td colspan="2">State Description</td><td colspan="2">IV1(2) Export</td></tr>
<tr><td colspan="4">Maintain focus on domestic markets
Establish internet sales, foreign demand generation through advertising
Establish channels with foreign retail organizations</td></tr>
<tr><td colspan="2">State Description</td><td colspan="2">IV1(3) Foreign Office</td></tr>
<tr><td colspan="4">Establish regional organization in US, Europe
Modify products for local standards
Set up marketing campaign</td></tr>
<tr><td colspan="2">State Description</td><td colspan="2"></td></tr>
<tr><td colspan="4"></td></tr>
</table>

Table 2: Sample Scenario Description

No: 1	**Title**:
IV States	IV1(1): local, IV2(1) no threat
Description: Domestic growth at 5% Exports low at 10% of total sales Competition form imports at 15% market share and stable	
No: 2	**Title**:
IV States	IV1(1): local, IV2(3): max threat
Description:	
No: 3	**Title**:
IV States	IV1(3): foreign expansion, IV2(3) max threat
Description:	
No: 4	**Title**:
IV States	IV1(3): foreign expansion, IV2(1) no threat
Description:	
No: 5	**Title**:
IV States	IV1(2): export, IV2(2) some threat
Description:	

Notes and Key Literature Sources

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[i] **Converging Technologies for Improving Human Performance**
National Science Foundation, US Department of Commerce

This large (400 pages) report, published in June 2002, takes a detailed look at the converging nano-bio-cogno-information technologies. Drawing on a large body of experts, it takes considers the long term outlook for these technologies and their implications for science policy. A principal area of focus is the use of converging technologies to improve human performance.

The report is a collection of over 50 papers, consisting of 'statements' and 'vision' are organized into five groups:

1. Motivation and Outlook
2. Expanding human cognition and communication
3. Improving human health and physical capabilities
4. Enhancing group and societal outcomes
5. National security

A 20-page overview gives the gist of report. Of particular note are: (1) the Newt Gingrich paper in which he describes the role of politics in the 'Age of Transitions'; and (2) the Mihail Roco paper on coherence and divergence of megatrends.
http://wtec.org/ConvergingTechnologies/

[ii] **The Global Technology Revolution**
RAND Corporation

This report, subtitled "Bio/Nano/Materials Trends and Their Synergies with Information Technology to 2015" was prepared for National Intelligence Council. It provides a capsule analysis of key technologies, including:

- Genomics
- Therapies and drug development
- Biomedical engineering
- Materials engineering and smart materials
- Self-assembly and rapid prototyping
- Molecular manufacturing and nanorobots

This is followed by a discussion of 'meta-technology trends' and the cross-facilitation of technology effects.
http://www.rand.org/publications/MR/MR1307

[iii] **From Molecular Biology to Biotics**
Joel de Rosnay

Joel de Rosnay is a French science writer and futurist noted for his writings on whole systems. This short (6 pages) article published in Cellular and Molecular Biology conveys the exciting possibilities arising from the convergence of bio, nano, and info technologies.

English version
http://csiweb2.cite-sciences.fr/derosnay/english/articles/BiolMOl_anglais.pdf

French version
http://csiweb2.cite-sciences.fr/derosnay/articles/BiolMol_francais.pdf

[iv] **Importance of Nanoscale Science and Technology**
National Science Foundation

This article takes a short term assessment of nanoscale technologies. It describes products that are currently available, then describes possible new applications and capabilities five to ten years into the futures.
http://www.nsf.gov/home/crssprgm/nano/nrconnni7_2002_nseimportance.pdf

[v]

Societal Implications of Nanoscience and Nanotechnology
National Science Foundation

This 270 page report addressees the growth of nanotechnology and pays special attention to the broader impacts of the technology. There are general sections on the goals of nanoscience and its societal interactions. Specific statements are made on such topics as:

- Economic and political implications
- Science and education implications
- Medical, environmental, space and security implications
- Social, ethical, legal and cultural implications

http://www.wtec.org/loyola/nano/societalimpact/nanosi.pdf

[vi] **Technology Roadmap for Plant/Crop-based Renewable Resources 2020**
US Department of Energy

This is a goal-oriented roadmap in that the DOE was looking for a plan to achieve specific targets for cutting back the use of non-renewable resources in the agriculture sector. Some of the methods investigated are:

- Engineered metabolic pathways to enhance the yield of specific molecules
- Design, production, and handling of dedicated crops
- New separations technologies to better handle heterogeneous plant components
- Advanced (bio)catalysts for monomeric and polymeric conversions
- Elucidation of structure-function relationships for plant constituents
- Rural development to support production, marketing, and utilization of plants.

The study goes beyond looking at technology alone. It also considers the overall industrial infrastructure.
http://www.oit.doe.gov/agriculture/pdfs/ag25942.pdf

[vii] **Information and Communications Technologies and the Information Society**
European Commission Foresight to 2015 - Information Technology

The IT business is mature and well entrenched. This article differs from the speculative materials of the other topics (above) in that it must also consider issues related to the overall management of a pervasive technology. The report addresses a set of "hot issues" and has an annex at the end with a 5-circle Venn diagram showing the relationships between major issues.
http://futures.jrc.es/panels/panel2/NewFormat4-4.pdf

Technology Map of Ubiquitous computing to 2015
ITPS Futures Project

This is a one page technology map showing the expected arrival of key technologies for ubiquitous computing. Technologies are places into the following categories:

- Semiconductors
- Storage
- Batteries
- Communications
- Display
- Artificial intelligence
- Integrated devices and applications

http://futures.jrc.es/reports/FutAPP41.pdf