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The STFD operates as a collaboratively structured partnership activity within the Canadian Government. We undertake national and international projects with multiple partners and stakeholders from federal and provincial governments and agencies, universities and the private sector. Partnerships are developed around specific themes or projects. We use foresight tools and methodologies to stimulate longer-term thinking, develop horizontal linkages and build shared R&D awareness and capacity to better prepare Canadian and global S&T and policy communities for new challenges.

This report is the property of those who participated in the processes described herein, and therefore reflects the combined views of the participants and the best wisdom and creative thinking stimulated by the foresight process.

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We regard foresight as contingent research that examines plausible futures that we may have to contend with and as a wise investment in public preparedness.

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

> *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 5 – 25 years.*

S&T Foresight is necessarily speculative, creative and analytical. It relies on both the interpretation of S&T change drivers and on how, if and when these drivers could become significant factors in emerging social, economic and political realities. Since these are highly uncertain, foresight is inherently about attempting to understand and reduce – or at least prepare for – significant risks.

Because of this context of inherent uncertainty, foresight participants and stakeholders should not regard this report as fact or prediction. It represents collaborative research that was conducted primarily for learning purposes, with the understanding that emerging consensus around some elements might warrant a further, more detailed examination. This is the nature of foresight – creating a range of plausible future scenarios that in their diversity should alert readers to the kinds of issues and perspectives that they may not have considered in initial research planning and contingency thinking.

In foresight, 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 indicate how various foresight approaches and tools can be applied to help readers become better prepared or at least more capable of contingent planning and action in these turbulent times.

General Report
Prospective Applications for Converging Technologies in Nano-Bio-Info Systems (PACT-NBIS)
Scoping Meeting: March 19-20 2007

Report prepared by The Centre for Innovation Studies (THECIS)
March 30, 2007

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I. EXECUTIVE SUMMARY

This report summarizes the first of a series of intended meetings across Canada and the US during 2007 to consider how convergent nano, bio and information technologies may evolve over the next 15 years. The project is based upon a foresight process developed by the S&T Foresight Directorate of the Office of the National Science Advisor. This process draws on expertise from multidisciplinary groups knowledgeable in technology foresight and the ways that bio, info and nanotechnologies are converging to meet industry needs, advance human potential and provide ecological systems solutions to environmental, health, security and sustenance challenges.

Converging technologies are applications having new and combined features derived from the intersection or combination of different enabling technology platforms. This new space will provide new capabilities and functionalities, providing enormous potential for established businesses as well as new entrepreneurial opportunities for re-combinations of new and existing technologies, in new and established markets. Re-combinations are major drivers in modern industrial economies, and the convergence of nano-bio-info systems could therefore be the next major source of economic growth. Indeed, many believe that these technologies and applications will be important for addressing major cross-cutting societal issues, and whoever applies them to satisfy global demand will have significant economic and social leverage in the 21st century.

Drawing on a Foresight exercise and open discussions with academic, government and industry association experts, we explored the technological and commercial feasibility of bio-nano-info convergent technology applications, as well as likely policy implications. We also conducted an analysis for Canadian industry, specifically exploring the prospective areas of application, products and impacts, how these should be stewarded, and what steps should be taken to accelerate their development.

Workshop participants recognized that while innovation is the main driver of modern economies, it also involves trade-offs and compromises among a wide range of interacting stakeholders. It was also recognized that social and environmental considerations must be addressed at the early phases of technology development. Our belief is that Canada is well placed to understand and develop many of the prospective capabilities and functionalities associated with convergence, as well as to manage and avoid potential detrimental social and environmental side affects. A broadly based imaginative and rigorous foresight exercise focused on the nano-bio-info convergence is therefore an appropriate strategic national priority for 2007.

We conclude that convergence represents a new way of viewing cross and multi-disciplinary possibilities, and it will provide major recombination opportunities for business and entrepreneurs. It may also present unintended social consequences. A diverse private – public partnership, combining key organizations is required to explore the convergent landscape, the potential opportunities as well as the unintended negative implications. The federal-provincial-university and diverse sectoral industry structure enables multiple, plausible outcomes to be examined, and should be used to align their interests in a national strategy leading to productive entrepreneurial outcomes. The diverse technology fields, sectors and new convergent interfaces make this a very dynamic domain and an excellent target for S&T collaborative foresight.

II. INTRODUCTION AND CONTEXT

The world of global technological innovation is moving fast and in challenging directions. One of these directions is toward convergence. Converging technologies are applications having new and combined features derived from the intersection or combination of more than one enabling technology platforms. This new space, where new capabilities are revealed (e.g. think of Google Earth, or nano-bio sensors connected by information networks that some are calling smart dust) is about how and where new functionalities are emerging from more familiar platform domains such as nanotechnology, information technology, biotechnology and design, collaboration and cognitive technologies. Such new capabilities and functionalities provide enormous potential by providing established businesses and new entrepreneurs opportunities for re-combinations of new and existing technologies for established and new markets. Re-combinations have long been recognized as a major driver of modern industrial economies, and the convergence of nano-bio-info systems could therefore be the next major economic driver. Indeed, many believe that these technologies and applications will be important for addressing major cross-cutting societal issues and that whoever gets to apply them to satisfy global demand will have significant economic and social leverage in the 21st century.

In addition to providing business opportunities and policy benefits in the form of national economic growth and improved social well-being, innovation dynamics from new technologies sometimes create detrimental side-affects. For example, the initial phases of the industrial revolution caused considerable labor hardship, while environmental impacts from more recent industrialization processes have become a pressing concern for industry and governments worldwide. Innovation thus involves trade-offs and compromises, as well as the interaction of a wide range of stakeholders, and social and environmental considerations must be recognized at the early phases of technology development.

Our belief is that Canada is well placed to understand and develop many of the prospective capabilities and functionalities associated with convergence into applications, as well as managing and avoiding potential detrimental social and environmental side affects. A broadly based imaginative and rigorous foresight, focused on the nano-bio-info convergence dynamics and applications in particular is therefore an appropriate strategic national priority for 2007. The project is based upon a foresight process developed by the S&T Foresight Directorate of the Office of the National Science Advisor. This process is designed to assemble multidisciplinary groups of experts knowledgeable in technology foresight and the ways that bio, info and nanotechnologies are converging to meet industry needs, advance human potentials and provide ecological systems solutions to environmental, health, security and sustenance challenges.

This report summarizes the first of a series of intended meetings across Canada and in the US during 2007 to consider where these convergent technologies may be in their development and application looking ahead to 2017 and beyond. We explored which prospective nano-bio-info and bio-nano-info convergent technology applications industry and government will need to pursue to ensure that Canadian prospers in the future global economy. What are the prospective areas of application, what will be the key products and services and what may be the scope of intended and unintended impacts, how should these be stewarded and what steps should be taken to accelerate or manage their development?

The workshop was organized by THECIS, the Centre for Innovation Studies, with advice from the Office of the National Science Advisor. Funding was provided by Agriculture and Agri-Food Canada; the Canadian Biotechnology Secretariat, CMC Microsystems, and Environment Canada.

Workshop Format and Methodology

The format used in this first workshop included stimulus presentations, followed by a foresight exercise and open discussions with experts from across Canada (and a few from the US) from academia, the government and industry associations. Appendix A Table 10, lists the expert participants.

Foresight is a methodology widely used in Europe and Japan but relatively little used in Canada so far. It brings together key people, knowledge and ideas to look beyond normal planning horizons to identify potential opportunities from new science and technology. The choice of converging technologies in the nano-bio-info space is based upon a belief that this will become a pervasive field of new technologies that it is critical for Canadian industry to master in order to maintain its international competitiveness. The foresight exercise focused on the areas of health-life sciences; energy-environment; agrifood-bio-products and public safety-national security.

The ultimate purpose of this foresight exercise is to develop information to enable Canadian companies to enhance their international competitiveness in nano-bio-info technologies that emerge from convergence of nano-technology with biotechnology. The foresight exercise will later unfold through a series of workshops in Canada and the USA using an Expert Panel methodology to explore different aspects of the convergence. An important follow up to the workshops will be the communication of the consensus results to user communities.

The first workshop (reported here) was intended to define the scope and boundaries of the exercise and generally set the stage for the subsequent workshops. The objective was to establish the intellectual framework for the foresight exercise, by for example, reaching conclusions on the following:

- Where should we set the boundaries of the exercise?
- How much technical depth is needed?
- How should we measure success?
- What are the main fields to explore?

The first day of the workshop involved four overview/stimulus presentations, followed by three team breakout sessions to assess the technical feasibility and commercial feasibility of multiple technologies and applications in a) Energy & Environment; b) Food, Water & Bio-Products and c) Health & Life Sciences. (note that for reasons of focus and time efficiency, the safety-security area was not included as a break out topic for this workshop – it will be the focus of a separate meeting in 2007-08.)

The Rand Matrix (assessing technical feasibility and commercial feasibility), modified to consider the public policy dimension was used, with the results discussed during a plenary session. In Day 2 teams returned to the technology/applications to determine Canada's potential role in each technology. Although possessing a sophisticated nano-bio-info sector, it was recognized that Canada is likely to be a relatively small global player and will need to focus on specific niches where excellence and market access can be assured. All three areas were then discussed in a plenary session. The workshop concluded with an open discussion and personal perspectives on what technology/ application would profoundly affect the individual participants' world.

In the next sections, we summarize the speaker presentations and the findings from the breakout workshops (Energy & Environment; Water, Food and Bio-Products; and Health and Life Sciences).

II. SUMMARY OF THE STIMULUS PRESENTATIONS

Throughout history, there have been inventions or developments that have had fundamentally changed how humans exist, such as the wheel, the printing press, the discovery of the double helix and the genetic code, and the invention of the transistor, which led to the micro-electronics industry and the internet. The convergence of nano/bio/info technologies may be the next major driver of technological change. Converging Technologies are applications having new and combined features derived from the intersection or combination of more than one enabling technology platform. New functionalities become evident from combining platforms such as nanotechnology, information – advanced computation technology, systems biology with human innovations that enhance the design, facilitate collaboration and enable the delivery of new technological capabilities affecting human performance and our ecological relationships with the world.

The specific areas of technology discussed in this workshop include those concerned with information and communication, biotechnology/health and energy & environment. Convergent enabling technologies include nanoscience and nanoengineering; materials science; photonics/electronics; and genomics/proteomics/metabolomics. Potential benefits from convergence include, for example, autonomous vehicles that displace manned vehicles; and enhanced safety, surveillance & security. It can also increase productivity, by employing technologies such as advanced navigation and communication systems, collision avoidance systems, intelligent sensor networks, real-time adaptive controls, modeling, and simulation techniques. Manufacturing will potentially shift from inflexible assembly line, fixed output systems to those more adaptive, self-configuring and allowing for customized output. More sustainable power generation can be developed through better generation, storage, distribution and "smart" end-users, potentially resulting in green house gas (GHG) emission reductions, improved air quality and partial or complete autonomy from the grid (e.g. two way grid). These benefits can potentially be achieved through improvements in a mix of alternative energy sources, such as fuel cells, solar, wind (large and small), biofuels, improved nuclear and hydrogen generation.

Converging technologies could also vastly improve Information Technologies through quantum cryptography and computing by augmenting and/or replacing the microelectronic industry, allowing for solutions for currently insolvable problems (e.g. weather forecasting, drug design, etc) and replacing security protocols (e.g. in the military, e-commerce, medicine and banking). Photonics, Spintronics and Molecular electronics could facilitate the integration of communications, computations and information storage, displacing the silicon microelectronic industry.

The convergence of technologies such as computational science, modeling & simulation, molecular electronics, nanostructured materials, diagnostic technologies, bioinformatics and protein engineering in health care can lead to a better understanding of living systems, provide point-of-care, individualized and universal/equitable service, a simplified, sensitive, cost effective, responsive and continuously monitored system.

A more specific outcome of the convergence of nano/bio/info technologies is the development of machines/artifacts that mimic human intelligence – smart technologies that will play a role in the so-called 'smart economy'. There are varying degrees of 'intelligent levels' how these technologies will emerge:

1. Adapting: modifying behaviour to fit the environment (e.g. adaptive networks, GPS, directory services, collaborative filtering, humanized interfaces, etc).
2. Sensing: bringing awareness to everyday things (e.g. smart badges, smart bricks, smart bridges, smart levees, smart cement, packaging, smart cameras, smart doors, etc.
3. Inferring: Drawing Conclusions from Rules and Observations (e.g. expert systems, knowledge bases, inference engines, fuzzy logic, basic AI, etc)
4. Learning: Using Experience to Improve Performance (e.g. subfields of advanced AI; case based reasoning (CBR), neural nets, genetic programming, intelligent agents, AUV's, exoskeletons, etc)
5. Anticipating: Thinking and Reasoning about (e.g. What to Do Next - goal-directed systems, robots, artificial life software, smart mind-controlled wheelchair, etc.)
6. Self-Organizing: Self-generating and self-sustaining at the cellular or nano-technology level (e.g. self-organizing systems, complex awareness, cognition, self-reproduction and self-healing, etc.)

The impacts and consequences of smart technologies are likely to be pervasive, ubiquitous and disruptive, although it may be creeping up silently on society rather than an abrupt change with obvious as well as hidden effects. The problem with such transformative technologies is that it is difficult to predict where and when they might occur, as well as what actual technologies will be employed. For example, we expect a transformation in information technologies and the human machine interface over the next 20 years but we do not know if quantum information will play a role.

Table 1: Smart Technology Trends

1. From Nano to Macro
2. Man-made objects mimic Bio
3. External Power to Self-Generated Power
4. Single Function to Integrated Systems
5. Smart Objects to Smart Processes
6. Expect Big Surprises
7. Big Shift; Silicon to Non-Silicon MEMS
8. Convergence Bio+Inorganics
9. Hobbyists give Smart Technology a push
10. Domestic Robots usher in Smart Technology Age
11. Designing Viable Systems
12. Just because it's smarter, is it better?

Some applications will improve current products or services, whereas major social pressures such as climate change and the need to deal with overburdened public infrastructure will drive others. Some Smart Technology Trends are listed in Table 1. Like other early phase technology platforms, there remain crucial questions concerning what controls do we have over adoption, the need for standards and regulations, as well as how the currently fragmented market will evolve. Currently, the media have grasped the significance of this yet, and there is perhaps an erroneous assumption that everything will be positive.

There will also be national and regional differences in the emerging Smart Economy. Canada currently has an emerging scientific and industrial based in the sector, yet it remains to be seen how Canada's mixed record in promoting science & technology can help industry exploit this initial expertise, emphasizing the importance of understanding and improving Canadian commercialization practices. Indeed, the public (adults & students) do not view science as important or necessarily in a positive light, and views range from cynical to ambivalent, yet these technologies and markets are likely to dominate future growth, and will be essential tools for dealing with tough problems Canada will face: energy, climate change, health, and security. Moving from "hewers of wood and drawers of water" up the knowledge value chain requires examining assets in a new context, and Canada's existing structures, budgets and expertise domains may be insufficient to the task. However, there is an opportunity to be proactive about which technologies are supported/ investigated/ funded by first identifying technologies that address pressing societal needs. Public acceptance is a key dimension, and there will be a need to address issues regarding incorporating life cycle assessment in a risk analysis framework generally, and specifically for nanoscale materials.

Key Innovation Concepts

Schumpeter recognized that technical change was the primary driver of modern industrial economies. He defined the categories of innovation as the "new method of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates"[1]. He explicitly noted that innovation involved the commercialization of invention, initially recognizing the role of the entrepreneur linking new scientific breakthroughs to the market (and later the ability of large bureaucratic organizations to create and commercialize their own inventions through Research & Development (R&D) investments. In addition to new scientific breakthroughs ('technology push'), innovation can also be triggered by market need – 'market pull'. Market or social pressures predominately drive some industries, whereas others are technology driven, although it should be emphasized that these dynamics are context-specific, and increasingly an interactive process[2].

Schumpeter emphasized that innovation is often composed of ***re-combinations*** of existing technologies rather than purely novel technological breakthroughs, typically involves the synthesis of knowledge from a diversity of fields. The concept of re-combinations highlights the potential for economic growth through the convergence of nano-bio-info technologies. More specifically, the convergence of such enabling technologies such as nanoscience and nanoengineering, materials science, photonics/ electronics and genomics/ proteomics/

metabolomics may transform the information & communication, biotechnology & health and energy & environment sectors.

Figure 1: The THECIS perspective on innovation[3]

	Business Implications	Public Policy Implications
Opportunities	Main source of competitive advantage (*Schumpeterian Rents)*	Primary source of economic wealth, quality of life
Challenges	Main source of competitive disruption, failure; risks due to uncertainties, complexities	Main cause of social and environmental disruption, social inequalities

Although innovation is the main source of competitive advantage for firms and a primary source of economic wealth and quality of life, it is also a main cause of competitive disruption and firm failure, as well as social and environmental disruption (See Figure 1). Indeed, innovation presents considerable conflicting pressures. For example, new technological developments and more generally entrepreneurial activities are often seen as a panacea for economic growth. Baumol[4] distinguishes three types of entrepreneurial outcomes; productive, unproductive and destructive. *Productive entrepreneurship* is where business activities lead to a net social benefit. There are winners and losers, but ultimately the overall outcome is positive. *Unproductive entrepreneurship* is where business opportunities are created through rent seeking activities such as lobbying, cartel building, market protection – there are winners and losers, but no net social gain. *Destructive entrepreneurship* is a situation when business opportunities lead to a net social loss e.g. organized crime. A challenge for policy is to encourage productive entrepreneurial outcomes.

Managing the conflicting pressures of innovation means that innovation requires trade-offs and compromises. Nobel Laureate Herbert Simon recognized the problems of dealing with such complex environments. He argued that, because of complexity, a situation with many interacting variables, it is infeasible or impossible for managers to know everything (what he called "bounded rationality"). Under complex environments (the norm for innovation, and certainly the case for the convergence of complex technologies such as bio/info/nano) managers should be looking for satisfactory solutions rather than attempting to find optimal solutions. An outcome of complexity and the need for compromise is that basic architecture of product or process that becomes the accepted market standard (what Utterback[5] calls a dominant design) are often not better than alternatives, such as the IBM PC.

A constraint on innovation is the level of *absorptive capacity*, the limit to the rate or quantity of scientific or technological information that a firm can absorb. In other words, knowledge is needed to absorb more knowledge. High absorptive capacity is needed to incorporate externally generated technical knowledge, and will be crucial for exploiting the opportunities presented by the convergence of nano-bio-info technologies. However, the possession of knowledge alone does not necessarily lead to innovative success, *alertness* to business opportunities is also crucial[6]. The converse of alertness is myopic behavior, an inability to see opportunities that are not directly related to the individual's knowledge-base. We suggest that myopic behavior may be a major inhibitor to exploiting the convergence of nano-bio-info technologies, as a high level of expertise in one area may hinder the recognition of recombination opportunities in other areas. Does too much expertise lead to myopic behavior? The dilemma of needing world class specialized expertise on the one hand and respect for other disciplines has long been recognized as a difficult innovation challenge. More specifically, competency enhancing incremental innovation that builds on previous knowledge bases is generally seen as more attractive than the more difficult and risky competence destroying radical innovation that requires a very different knowledge base (i.e. new paradigm). While the convergence nano/bio/info technologies provide millions of opportunities for 're-combinations', are our current competencies holding us back?

In addition to complexity challenges, innovation also involves considerable risk, especially because it involves novelty and thus is idiosyncratic. We distinguish between 'true risk' (where variables and probabilities are known), uncertainty (where variables are known, but not probabilities) and ambiguity (where neither variables nor probabilities are known)[7]. The degree of risk can thus be conceptualized as ranging from high degrees of perfect information (true risk) to low levels (ambiguity). Innovation, particularly competency destroying innovation based on new scientific paradigms involved high degrees of complexity, uncertainty and often ambiguity, yet our current heuristics (and training) typically does not address these characteristics.

A particularly complex and ambiguous aspect of innovation concerns the social implications, the detrimental side-affects such as environmental impacts, health concerns, labor disruptions and increased social exclusion of vulnerable groups. Typically these concerns involve externalities and secondary stakeholders (those not involved in the market relationship, but stakeholders that can have affect, or be affected by the firm's actions)[8]. In recent years, technology developers have had major difficulties dealing with secondary stakeholders such as NGOs and advocacy groups. For example, Monsanto's technological success in genetically modified technology was hampered by social pressures from a wide range of NGOs for health, safety and environmental concerns, as well as demands for consumer choice in Europe and concerns over social impacts on subsistence farmers in the developing world.

Such challenges have been called Stakeholder Ambiguity,[9] a situation where it is difficult to identify key stakeholders, some of which have disparate goals, demands and opinions, or may interpret the same situation differently. Stakeholder concerns often emerge after the fact, or change when concessions are offered or scientific evidence is presented, so traditional risk assessment techniques may not work. Stakeholder ambiguity is playing an increasingly important role in new technology development, and the workshop participants overwhelmingly emphasized the need to consider the social impacts of technology development. Table 2 lists some of the generic ethical, environmental, economic, legal and social impacts that may emerge.

Table 2: Ethical, Environmental, Economic, Legal and Social Impacts ("E3LS)
• What are the realistic time scales for development of convergence technologies? Value proposition? • Individual versus societal rights • Acceptance of new technologies – public knowledge of risks • Policy, regulation, legislation • Unforeseen consequences – how do we deal with them?

Evaluating new technologies: The Rand Feasibility Matrix and the TCOS Framework

As discussed above, innovation is the successful commercial application of an idea or invention. The evaluation of a new idea thus must demonstrate technological and commercial feasibility, the two constructs of the Rand Feasibility Matrix used in this workshop. However, it was also recognized that there are also policy implications that may hinder the acceptance of a technology. Furthermore, there are organizational implications, specifically whether or not Canadian business can appropriate the benefits from their technological benefits. The TCOS Framework[10] encapsulates these concerns, where uncertainties associated with Technological, Commercial, Organizational and Social factors must be overcome before an invention will likely become a successful innovation:

1. **Technological uncertainty:**
    - Does it work?
    - Relatively non-complex and unambiguous (interacting variables can be identified and outcomes tested)
    - Domain of scientists, engineers, e.g. Popperian scientific methodology (conjecture-refutation approach) appropriate
2. **Commercial uncertainty**
    - Is it commercially viable?
    - More complex than technological uncertainty, but relatively unambiguous (i.e. market demand can be estimated)
    - Domain of marketing, advertising
3. **Organisational uncertainty**
    - Can your organisation appropriate the benefits?
    - Based on intellectual property protection regime and complementary assets
    - Domain of the Strategists
4. **Social Uncertainty**
    - Is it acceptable to civil society?
    - Generally most complex and ambiguous (some interacting variables such as secondary stakeholder concerns are often difficult to identify or have have disparate goals, demands, opinions and may interpret the same situation differently or emerge after the fact, change when concessions are offered or scientific evidence is presented).
    - Current organizational structures typically do not have heuristics to deal with ambiguous nature of social uncertainties (e.g. scientific conjecture-refutation methodology inappropriate - incremental Popperian ‘piecemeal social engineering, analogical reasoning skills, etc. needed).

The TCOS uncertainties can be regarded as a series of hurdles, but they can also be regarded as potential sources of competitive advantage/ disadvantage – i.e. competencies in one area compensate for deficiencies in another. Canadian industry typically lacks technological and market scale economies, but are sometimes sensitive towards social uncertainties could compensate for these deficiencies, especially in the early (and usually most controversial) phase of technology development. Social implications emphasized during the workshop could thus be a competitive advantage for Canadian firms, particularly because they require non-traditional risk assessments and involve tacit managerial skills – they are thus difficult to copy and can thus be a source of competitive advantage.

In the next section we summarize the three team breakout sessions that assessed the technical and commercial feasibility of multiple technologies and applications in a) Health & Life Sciences; b) Energy & Environment; and c) Food, Water & Bio-Products. The Rand Feasibility Matrix, modified to consider the public policy (social uncertainty) dimension as well as Canada's role in each technology area was used.

III. GLOBAL FORESIGHT WORKSHOP

Summary of the Methodology

After the stimulus presentations, workshop participants self-selected themselves into three groups, where they participated in a Foresight exercise to analyze the impact of technological convergence in the year 2020. Foresight is a methodology that brings together key people, knowledge and ideas to look beyond normal planning horizons to identify potential opportunities from new science and technology. The exercise focused on the areas of health-life sciences; energy-environment; agrifood-bio-products and public safety-national security. Twelve technologies/applications (henceforth referred to as technologies) were identified in the literature for all three areas, all of which were believed to describe prospective convergence of nano-bio-info, usually embedded in a system. Using the Rand Feasibility Matrix modified to incorporate policy issues (Table 3), the exercise was to identify, analyze, elaborate and speculate how these new technologies, their innovative functionalities and public partnership-stewardship implications may affect a selected set of sectoral activities. The first day analysed the general technological, commercial and policy feasibility, while the second focused on the implications for Canada's future.

Table 3: Rand Feasibility Matrix used to assess each technology/application

Commercialization Feasibility							
Global Market Size?		Small/Niche		Moderate		V. Significant	
Public policy Issue?		Minor	Major	Minor	Major	Minor	Major
Technical Feasibility	Highly Feasible						
	Feasible						
	Uncertain						
	Unlikely						
	Very Unlikely						

Members of each of the three groups were supplied with a coded list with a brief description of the 12 technologies. As a team, each technology was discussed and positioned on the RAND Matrix for the year 2020. Members then individually identified where they believed the technology would be on the Rand Matrix. The team then determined the 'centre of gravity' for each technology. Members were informed that this is a brainstorming session, and there are no 'right' or 'wrong' answers. The technology was only assessed for the breakout sector. The focus of this first exercise was global, and members were informed that they would be considering Canadian perspectives in the second phase.

Energy and Environment
The following figure 2 summarizes the Energy & Environment Working Group's assessment on the Rand Feasibility Matrix:

Figure 2. Energy-Environment Rand Feasibility Assessments							
Technical Feasibility	*Commercialization Feasibility*						
	Niche/Small		*Moderate*		*V. Significant*		*Global Market Size*
	Minor	*Major*	*Minor*	*Major*	*Minor*	*Major*	*Public Policy Issues*
Highly Feasible					•EE 8 •EE10 •EE7	• EE8	
Feasible	•EE1		•EE1 •EE12	•EE9	•EE12		
Uncertain	•EE3 •EE5						
Unlikely	•EE4 •EE11 •EE5 • EE2 •EE12	•EE3	•EE4				
Very Unlikely					•EE 8 • EE10 •EE7	•EE8	

The following Table 4 lists the code, PACT title and details of assessed technologies/applications supplied to the Work Group, as well as the Group's assessments regarding technological & commercial feasibility and likely public policy implications for the energy & environment Foresight exercise.

Table 4. Energy-Environment Applications Overview			
Code	***PACT Title***	***Details***	***Tech. & Comm. feasibility; Public policy implications***

EE-1	**Self-Powered Nanodevices (SPND)** or nanosystems via nanopiezotronics.	• When piezoelectric material is squeezed, twisted, or bent, electric charges collect on its surfaces. • Nanopiezotronics refers to generation of electrical energy at the nanoscale such as bending of a zinc oxide nanowire, transforming that mechanical energy into electrical energy. • This approach has the potential of converting vibration, biological mechanical energy, acoustic/ultrasonic vibration energy, and biofluid hydraulic energy into electricity, enabling self-powering wireless nanodevices and nanosystems. • **Current stage: Proof of concept; demo stage**	- There were doubts whether there was convergence - Overall minor public policy issues - Bi modal wide* – depending on the application
EE-2	Novel **Organic Thermo-electric Materials (OTEM)** for radically improved cooling, energy production based on nanoparticles.	• Organic thermoelectricity (direct conversion of latent heat to electricity, known as Seebeck effect) • Various new designer meta-materials such as new organic molecules linked to one atom thick plates of gold can generate micro-electric charges from a latent heat source • **Current stage: Proof of concept**	- Target cluster - Technologically unlikely, but potentially wide market
EE-3	**Self-assembling Nanobatteries (SANB)**	• Batteries could one day assemble themselves inside micromachines. • Researchers have deposited charged particles of the electrode materials lithium cobalt oxide and graphite on a surface. Like types of particle then electrostatically attracted each other to form electrodes or possibly more advanced designer functional materials • **Current stage: Proof of concept**	- Potentially wide market - Politically bi model – depending on the specific application
EE-4	**Nano Enzymatic or Industrial conversion of CO2 to Methanol (NEIE)**	• Strategies for conversion of CO2 to methanol offer promising new technologies not only for recycling of greenhouse gas but also for an efficient production of fuel alternatives. • Traditionally, this is done by industrial catalysts: heterogeneous catalysis, electrocatalysis, and photocatalysis. Oxide-based catalysts are used for industrial fixation of CO2. • A unique approach involves the use of enzyme catalysts for conversion of CO2 to methanol. This is appealing since it provides a low temperature route for generation of methanol directly from gaseous CO2. Future engineered nano-catalysts promise greater efficiency. • **Current Stage: Research started in 1999; now in Lab development (from R to d)**	- *Nano dynamic issue: where does the energy come from? - Technologically unlikely - Minor public policy concerns
EE-5	Credit-card sized **Microreactors** convert vegetable oil & alcohol to **biodiesel**. **(BDMR)**	• Using microfluidics, this smart credit card sized bio-reactor can turn vegetable oil & alcohol instantly into biofuels in microliter amounts • Imagine a suitcase size container full of these bioreactors, just like we place batteries in series to get more power • **Current stage: Proof of concept-prototype**	- Technologically unlikely, and no clear market - Why bother?
EE-6	C02 free process for **biofuels + Hydrogen production & storage**	• This novel process could meet all of the USA's & Canada's transportation fuel needs; • Computer simulations have identified new class	- Not rated: two ideas lumped together

	from **biomass (NBHP)**	of hydrogen-storing nanomaterial , metal-diboride nanotubes, with a large hydrogen storage capacity • **Current stage: Proof of concept**	
EE-7	New High efficiency flat light source (organic light emitting diodes) **OLED**s & future **Nano Particles Light Harvesting (NPLH)**	• Almost any surface in a home, whether flat or curved, could become a light source: walls, curtains, ceilings, cabinets or tables with OLEDs • Solar cells+ nanobattery as one integrated unit • Nanoparticles have also been created that enhance artificial photosynthesis • Combining these two technologies, enhancement mechanisms could be used to design artificial light-harvesting systems. • **Current stage: Proof of concept + prototype**	- Huge market potential: could replace 15 nuclear reactors - Public policy issues depends on life cycle management - Where & eventual disposal key.
EE-8	**Nano-biosensors** that detect toxins and contaminants in the environment **(NBES)**	• Called smart dust, these sensors will be interconnected, forming in effect, a regional or global network or nervous system; • **Current stage: field trials**	- Huge market potential - Principle has been proven (technologically feasible) - Excluding smart dust - “Big brother” public policy issue: right to privacy, surveillance concerns, etc
EE-9	**Plastic Electronics + GPS + RFID Nano-polymer package monitors (NPPM)**	• Practical application of polymer electronics (sensors & monitors) integrated into products & packaging, which will make it possible to monitor the general condition and history of foods and goods during processing, transport and storage • **Current stage: field trials**	- Smart packaging - Not clear who benefits: consumers or distributors - Where does the benefit arise in the global supply chains? - Excluded the food safety aspect
EE-10	**Nano-systems** that break down pollution; nano photonic reactive systems **(NPRS)**	• Smart cement (and other nano-stystems) that have nano-particles of photo-reactive TiO2 that break down pollution near the surface of the cement or structure • **Current stage: field trials**	- Minor convergence angle - Big potential - Large scale use in Japan - T1O2 paint used since 1930’s
EE-11	**Nano-Scrubber Atmospheric Vortex Engine (NAVE)** harnesses waste heat converting it back into electrical energy and traps CO2 pollution	• A controlled Tornado-in-a-box vortex at a nuclear or hydro power or coal or cement plant with a nanosrcrubber (possibly made of metal organic frameworks (MOF’s)that sequesters CO2 can be used as an atmospheric pollution collector and energy generator • **Current stage: Proof of concept**	- Small convergence angle - Good alternatives exist - Likely policy concerns
EE-12	**Precision Nano Materials for Energy Saving Processes (NMEP)**	• Contour Crafting for building homes and structures; Robots that “print” homes in one day with quick drying nanocement • Modular home construction from prefab • Green” nano cement production • Precision Farming • **Current stage: Field trials**	- Week convergence - Could first be applied in Africa, other areas with high housing demand but low infrastructure, restrictive construction codes, etc. - Most varied ranking of all the EE technology - 3 spots identified

Water, Food and Bio-Products:
The following Figure 3 summarizes the Water, Food & Bio-Products Working Group's assessment on the Rand Feasibility Matrix:

Figure 3. Water, food, Bio-Products Rand Feasibility Assessment

Technical Feasibility	*Commercialization Feasibility* •WFB8 [general purpose technology]						
	Niche/Small		***Moderate***		***V. Significant***		***Global Market Size***
	Minor	*Major*	*Minor*	*Major*	*Minor*	*Major*	*Public Policy Issues*
Highly Feasible			•WFB6		•WFB6		
Feasible		•WFB7	•WFB4	•WFB7 •WFB1 •WFB2		•WFB10 [Smart release]	
Uncertain		•WFB3 •WFB5 •WFB12 •WFB11		•WFB12 •WFB11			
Unlikely							
Very Unlikely							

The following Table 5 lists the code, PACT title and details of assessed technologies/applications supplied to the Work Group, as well as the Group's assessments regarding technological & commercial feasibility and likely public policy implications. Additional topics discussed (but not analyzed here) included livestock therapeutics, nanotags for species validation (id preservation) and smart packaging.

Table 5. Water, Food & Bio-Products Applications Overview

Code	***PACT Title***	***Details***	**Tech. & Comm. feasibility; Public policy implications**
WFB-1	**Nanotags** for food safety/tracking applications **(FSNT)**	Millions of unique sequences of nucleic acids which can be injected or dusted on products to identify them for copyright or identification purposes	- Emerging management system could be positive for industry - Identity/history tracking highly useful - Importance of contamination/class mix control\database/proprietary issues - Precedent of cattle ear tags - (UC) microbial evolution impact - Date stamp relevance
WFB-2	**Nanofilters** for	Carbon nanotubes have a very	- Almost here or early markets

	water and food purity **(NFWF)**	large surface area to volume ratio, enabling filtration as with graphite filters, but requiring a negligible pressure. Can be very small as well.	- Scalability issues important - Various combinations (titanium oxide e.g.) - Major impact potential on potable water e.g. sewage recycling (etc.) - Regenerative catalytic potential - End use "outcome" remains to be confirmed - Possible new side effects on water/food
WFB-3	Nanoscale **biocidal coatings (NBCC)**	Nanoparticles of zinc and copper can be toxic to bacteria, as distinguished from bulk metal samples. These may be useful in food preservation and preparation applications.	- Add in situ genetic ID markers (may not need nanotags) - Includes smart packaging / smart biocides pathogen focused - Beyond emerging "saran wrap" - Insect targeting - Toxicology assessment will be required
WFB-4	**Nanoarrays** of oligonucleotides for disease detection **(NODD)**	Nanoarrays of oligos can measure the quantities of thousands of specific compounds at once, enabling early disease detection from very small quantities of extracted blood, solvent	Not assessed
WFB-5	Functional nanoimaging for efficient cloning **(FNIC)**	Cloning of mammals is very inefficient. Epigenetic factors causing low efficiency may be determined by in vivo nanoscale functional imaging of the host cell	- Epigenetic factors very complicated - Info load/mgmt ratio high - Strong public opinion issues - Competitive market niches (race horses etc) - Image machinery opportunity could be high (new industry) and embryonic food/species (highly mechanized) selection - genetic factors almost for free Public Policy control of selected genetic stocks = few companies control vs public ownership of gene stock (super beef) - Start with niches?
WFB-6	Real-time **bionanosensors** for waterway monitoring **(BNWM)**	Radio-linked sensors capable of detecting low concentrations of pollutants provide real-time information on stream toxins	- Now in use (nano) - Cost issues/scale (capability-cost-deployment spectrum) - Bio persistence issues - Flexible target capacity (can shift) Real time cost – deployment factor may be critical - Not necessarily a public policy focus
WFB-7	Nanoarrays for directed evolution chips **(NDEC)**	Nanoarrays can sense tiny quantities of solute; these can be used to screen bacterial clones in parallel to direct evolution towards beneficial bioproducts while minimizing side reactions	- (Can do now but 2020 scale up possible) - Selected 2020 characterization/chip for directed evolution/scaleable/different generations of bio-products - Motivating bacteria - Accelerated breeding/measurable e.g. Yeasts/H2 generator/H4/proteins - Green industrial production "catalyst" - IP issues/medium – large firms most likely sponsors - Bio – terror potential / weapons? - PC – Bio Hacker potential /

			decentralized model (social questions) - Developed vs undeveloped nation issues
WFB-8	Bio-nano-composite new materials **(BNCM)**	Biocomposites such as bone combine the strength of minerals with the elasticity of collagen. Adding nanotubes to the mix would enable superstrong, supertough materials	- Bio-mimetic /polymer/fabrics - "breakdown" properties maybe critical: need to engineered - Nano-natural materials (bone patch, micelle food additives) - GM already has day composites (nano potential) - Ocean engineering possibilities Nutraceuticals/lots of prospective applications - Molecular diversification for product diversification\nano element (separate) - 2020: do we see any limits on this? - Scaleable/engineering challenges)
WFB-9	Synthetic biology information systems **(SBIS)**	Synthetic biology makes genetic circuits in bacteria and yeast, programming them as in digital circuits. Useful in sensing and intelligent bioproducts	Not assessed
WFB-10	Nanoporous materials for ag-bio systems conrol **(NMSC)**	Materials like zeolites can be manufactured with nanoscale pores; these can be used for the gradual release of water, fertilizers, and pesticides in agriculture applications	- Smart release / membranes/ large applications (conditional) - Synthetic self assembly of zeolite type for wide spread applications - Includes packaging / farming - Issues of ready availability – like agriculture (land mines?) - Needs to demo us safe as current fertilizer (e.g. Anti soy rust/pine beetle)
WFB-11	Real-time bionanosensors for precision farming **(PFBS)**	Radio-linked sensors deployed in a plot can detect biochemicals such as insect pheromones from pest species, plant ripening and plant stress chemicals	#11 & 12 analysed simultaneously - Fly over/spray on precision bio sensors can be easily deployed - "Photonic"/"pheremonic" - Fluorescence efficiencies - New element is the nano-visibility resonant response for sensor - Tuneable /resilient (e.g. Opium poppies/coca plants detection) - Need to demo sustainability
WFB-12	Ultralow-cost bionanosensors (flags) **(ULCB)**	Very simple, very cheap sensors that detect a specific chemical and then signal the chemical by fluorescence. Can be sprayed on fields and detected by nighttime overflights.	

Health and Life Sciences

The following Figure 4 summarizes the Health and Life Sciences Working Group's assessment on the Rand Feasibility Matrix:

RAND Feasibility Matrix: Health, Life Sciences

Figure 4. Health-Life Sciences Rand Feasibility Assessment

Technical Feasibility	*Commercialization Feasibility*						
	Niche/Small		***Moderate***		***V. Significant***		***Global Market Size***
	Minor	*Major*	*Minor*	*Major*	*Minor*	*Major*	*Public Policy Issues*
Highly Feasible				•HLS9			
Feasible	•HLS11	• HLS3	• HLS2 •HLS7		•HLS5	•HLS10 • HLS 1	
Uncertain				•HLS4 •HLS12			
Unlikely				• HLS 6			
Very Unlikely		•HLS8					

The following Table 6 lists the code, PACT title and details of assessed technologies/applications supplied to the Work Group, as well as the Group's assessments regarding technological & commercial feasibility and likely public policy implications. This workgroup discussed general issues for the Health & Life Sciences sector, concluding that the majority of technologies/ applications (75%) would likely encounter major policy issues (as would be expected due to the health related nature). They also recognized that it was a challenge to think forward to 2020, not incrementally from 2007-03-20. They also recognized concerns about focusing on technology push. Speed and size of commercialization would be strongly impacted by a world card effort. The Work Group also thought it was challenging to think globally, not through a socially – respectful Canadian perspective, and thus decided to focus their assessments on three areas applicable to the Canadian context.

Table 6. Health & Life Sciences Applications Overview

Code	*PACT Title*	*Details*	**Tech. & Comm. feasibility; Public policy implications**
HLS-1	**Bio-Nano replacement parts (BNRP)**	Made using stem-cell derived tissues: initially cartilage (knees), teeth, eventually heart valves, retinas, entire organs. Made using patient's own tissue, hence no rejection issues. *Bio:* Stem cells/bioengineering, *Info:* 3d-imaging and design, *Nano:* 3d printers, tissue 'scaffolds'	
HLS-2	**Continuous health**	Bio-sensors built into clothing, HVAC	- Being pulled by concerns over air

	monitoring using bio-nano sensors (HMBS)	systems or ingestible, that continuously monitors user's health and specific risk factors in individuals, buildings etc.. Data processed locally or uploaded to a doctor's office. *Bio/Nano:* Smart-dust biosensors *Info:* diagnostic software, mesh networking	testing, aerosols and water usage. - Security implications - Potential cross-over applications with agricultural applications - Current production costs a barrier, plus no infrastructure
HLS-3	**Bio-Nano electrodes for brain pacemakers (BNBP)**	Treatments for depression, epilepsy, Parkinson's and a broad range of addictions, using neurological implants. Also functional enhancement/behavioural modification. *Bio/Nano:* nano-electrodes, bioelectric devices *Info:* implanted computers	
HLS-4	**Smart (Telemedicine) implants for sensing & delivery - (SISD)**	Telesurgery, remote diagnosis and remote intervention. Active rather than passive, could perform drug calibration, defibrillation, clot-busting and stent placement. Includes smart implants for drug delivery. *Bio/Nano:* in-body microbots/nanosensors *Info:* implanted computers	
HLS-5	Medical "tricorder": **Bio-Photonic images and diagnostics – (BPID)**	Improvements and miniaturization of medical imaging technologies. "Lab in a box" applications for doctor's office. Early diagnosis through cheap and easy medical imaging. *Bio/Nano:* Biophotonics, bio-nanosensors *Info:* image analysis and diagnostic software	- Likely to be driven by rapid diagnostic capabilities, thus providing cost advantages - "a Radiologist in a box" - Infrastructure concerns remain - Could be resistance from clinicians.
HLS-6	**Brain-machine interface – telepresence (BMIT)**	Artificial limbs and thought-control of computers (see **Emotiv Systems**' Epoc game interface). True telepresence because the limb you are controlling does not have to be attached to your body or on same continent. *Bio/Nano:* Nano-biosensors *Info:* signal interpretation software	
HLS-7	**In Vitro NanoVaccinology and on-time vaccine/drug development (IVNV)**	Development of new flu vaccines within days of outbreak; drug delivery using nanoparticles. *Bio/Nano:* Genomics, proteomics *Info:* DNA analysis, massive parallel simulations	- Generic vaccines (not just flue) – nano materials + speed -Automation is moving very quickly
HLS-8	**Metabolic prosthesis nanosensor modeling (MPNM)**	Monitoring, analysis and intervention in metabolism of cells using tailored nanoparticles and nanosensors. *Bio:* synthetic cells/mitochondria/viruses *Nano:* nanoparticles *Info:* complete real-time cellular metabolic modeling	
HLS-9	**Bio-nano supported personalized medicine (BNPM)**	Treatment customization from DNA/medical imaging profiles; disease prediction based on DNA/MRI/genomics, biochip experimentation using patient's own cell lines. *Bio/Nano:* DNA arrays/biochips,	

		genomics *Info:* patient-specific data modeling	
HLS-10	**Bio-nano environmental medicine (BNEM)**	Pervasive monitoring of environmental health factors; remediation of environmental pollutants using mesh sensors, nanofilters, targeted neutralization of airborne/waterborne toxins. From industrial to household scale. *Bio/Nano:* biosensors, filters, synthetic enzymes *Info:* mesh networks, 'smart dust,' real-time environmental analysis	
HLS-11	**Dorian Gray applications – genetic – sensor whole person aging models (WPAM)**	A sort of diet-planner on steroids, eg. a picture of yourself that shows what you'll look like in ten/twenty/thirty years according to your genetics, diet, habits etc. *Bio/Nano:* biosensors, genomics *Info:* smart patient records, massive simulations	
HLS-12	**Pathology linked smart health records (PLSH)**	Patient health record that is an active process, almost like a computer worm. It integrates with personal biosensors (see HLS-2) and contains logic and "triggers" to do everything from prompting the booking of follow-up appointments to cross-checking clusters of symptoms for patterns of pathology. *Nano/Bio:* smart-dust biosensors *Info:* data-mining, planning/scheduling, diagnostics	

IV. IMPLICATIONS FOR CANADA

Summary of Methodology

Work teams returned to the technology/ commercialization matrix to determine Canada's role in each technology area. Although possessing a sophisticated nano-bio-info sector, it was recognized that Canada is likely to be a relatively small global player and will need to focus on specific niches. Each team was therefore asked to identify key technologies applicable to Canada, and indicate the role (e.g. science incubator, technological developer, application developer and/or producer) and degree (no role, major, intermediate, minor) that Canadian industry may play.

Energy & Environment

The Work Team determined that the main driver in the energy & environment sector would be mostly problem/application driven, and thus 'pulled' by market need or social pressures. Four areas of concern for Canadian industry were identified: Clean Coal, Biomass/Bio-fuels, Biosensors, and CO2 Sequestration. Table 7 lists these areas, correlated with the target technologies analysed in the previous section, the stage of development Canada would likely play, and the role Canada might play. The percentage numbers represent the percentage of the group voting, so in EE-4 73% of the group voted that they believed Canada's likely role would be as a science incubator. The columns at the right [major role, intermediate role, minor role] represent whether Canada will be a user of the technology. So for EE-4, 100% of the group believed Canada would be a major user of this technology.

Table 7: Identified Roles in Energy and the Environment

Target	*Area or Title*	*Science Incubator*	*Tech. Developer*	*Application Developer*	*Producer*	*No Role*	*Major Role*	*Inter. Role*	*Minor Role*
EE-4	Clean Coal	73%	18%	5%	5%	0%	100%	0%	0%
EE-6	Biomass/ Biofuels	0%	9%	55%	36%	0%	60%	10%	30%
EE-8	Biosensors	0%	9%	27%	64%	0%	75%	25%	0%
EE-11	CO2 Sequestration	0%	27%	50%	23%	0%	80%	10%	10%

Clean coal has been recognized as a means by which the vast reserves of coal in Canada and elsewhere (e.g. China) can continue to be used without the detrimental side effects associated with Climate Change. Canada could play a major role, particularly at the incubator level. Currently it is not clear if there are major convergence opportunities, but bio, nano approaches should be established by 2020. Conventional technologies are currently being studied, and these approached can be improved with nano-bio technologies. The technology associated with clean coal was EE-4:Nano Enzymatic or Industrial conversion of CO2 to Methanol (NEIE), determined to be relatively uncertain in the previous section. Clean coal is thus best characterized as a problem looking for a solution. Clean coal will therefore require heavy investment, and there well likely be a need to collaborate or import key technologies with other leading areas such as the US. A high absorptive capacity is thus needed to keep the technological options open.

Bio Sensors (EE8) that detect toxins and contaminants in the environment were identified as a potentially promising area for Canada. Unlike the other energy and environment applications, bio sensors appear to be driven more by both technological developments rather than predominantly market need. Relatively low barriers to entry may allow PhD students and small cottage industries to emerge, which fits with Canada's small and medium-sized (SME) strengths. Currently there are already significant research strength in Canada, and there are promising data management/ mining tools available that could be re-combined with emerging bio-sensor technologies. One question is whether Canada can play a role in setting standards, and whether Canadian industry can appropriate the benefits of early investments (thus an emphasis on a role down-stream and an application developer or producer). Canada may play a larger role of they become a leader in international standardization and privacy legislation. Civil society concerns could thus be crucial to Canadian success.

Biomass and bio-fuel production was identified as an important sector for Canada, although the majority of participants recognized application development as the main role for the country. Canada is already a major player, but many emerging economies have inherent advantages such as better climate/longer growing seasons, cheaper labour, etc. For example, Brazil, currently one of the world's leading developers and producers of biofuels, has had considerable technological and commercial success, but mixed experiences concerning social impacts such as social equity; ethanol from sugar cane has been a social failure, but recent policies towards social inclusion have created a different dynamic for bio-diesel. By 2020, Canada will likely be drier, so Canada will need to explore crops that are more appropriate. Currently there are varying provincial and federal strategies, while bio-fuel initiatives have been accused of being a 'front' for rural/farm lobbies. Other fuel systems may be overall more efficient with lower impacts, while the use of waste products as feedstock could be better used to maintain soil quality. Techniques such as environmental life cycle assessments (LCA) will be needed. The technology identified from the previous section, EE-6: C02 free process for bio-fuels + Hydrogen production & storage from biomass (NBHP) was recognized as being too broad.

For ***CO2 sequestration***, it was recognized that Canada was under considerable pressure to reduce CO2 emissions, and that by 2020 Canada will need the ability to manage a large land mass to exploit opportunities for sequestration benefits. By this time the Bio economy will also be larger. Canada could play a major role in terms of technology and application development, and could sell to other countries that will also be under pressure, such as China. They could also be an application developer of technologies developed elsewhere. However, the question remains if Canadian industry has a sufficient entrepreneurial culture willing to take the risks to do it ourselves. Partnership between industry and government could be the key, and oil sands development in Alberta could be a model for such an initiative (this sector also has a major interest in sequestration due to huge CO2 emissions). The target technology analysed the prevfious day, EE-11, Nano-Scrubber Atmospheric Vortex Engine (NAVE) to harness waste heat and converting it back into electrical energy and trapping CO2), was not recognized as a feasibly technology, so other technologies would have to be identified.

Water, Food & Bio-Products

The Work Team determined that the main driver in the energy & environment sector would be mostly problem/application driven, and thus 'pulled' by market need or social pressures. Four areas of concern for Canadian industry were identified: Clean Coal, Biomass/Bio-fuels, Biosensors, and CO2 Sequestration. Table 8 lists these areas, correlated with the target technologies analysed in the previous section, the stage of development Canada would likely play, and the role Canada might play.

Table 8: Identified Roles in Water, Food and Bio-Products

Target	*Area/ Title*	*Science Incubator*	*Tech. Developer*	*Application Developer*	*Producer*	*No Role*	*Major Role*	*Inter. Role*	*Minor Role*
WFB-1	FSNT	56%	44%	0%	0%	0%	0%	88%	13%
WFB-4	NODD	13%	25%	38%	25%	0%	88%	0%	13%
WFB-6	BNWM	0%	25%	63%	13%	0%	71%	29%	0%
WFB-7	NDEC	25%	38%	25%	0%	13%	0%	75%	25%
WFB-10	NONSC	0%	63%	0%	38%	0%	50%	0%	50%

Nanotags for food safety/tracking applications **(*FSNT*)** was recognized as a promising technology to preserve food sources through smart labelling. Canada could play an intermediary role at the nincubator and technology development stage. N60 positioning on Nano Tags will be a key factor (+privacy), while some S&T integrity issues regarding quality and relevant time issues will be important. Canadian industry will need to compare against alternative tracking measures (e.g. spectrometry). Other ancillary applications could be inventory management /bio security and other non – food applications. One advantage is small quantity detection/intervention privacy characteristics. Canada will need to play a smart regulatory support role, and public perception will be a major factor, especially for the initial industry leaders.

Nanoarrays of oligonucleotides for disease detection (NODD) was recognized as a promising sensing technology, and electronic "litmus" test. Evolving detection priorities and animal health sensor could be the key drivers (e.g. Angus certified). A niche market with high growth potential is pathogens/food. If emphasis is on nano, then it is less likely to progress than if the focus was on the systemic integration / capacity to analyze wide range of substances. Technology is accessible and Canada is well positioned. There are also many technical barriers, but most are mostly foreseeable. Scale issues are critical, and there are many complexity challenges. Gradual prototyping may be necessary. We need to develop a Research in Motion equivalent lay 2020.

The Systems integrator role will need strong capacity, as well as strong links with the scientific community, customers and other value chain members.

Real-time bionanosensors for waterway monitoring (BNWM) was recognizing as being an important technology to deal with Canadian water problems. There remains scientific uncertainties, but these issues should be resolved by 2020. This sector may provide opportunities for SMEs as it is not capital intensive. Canada has many waterways and is increasingly under pressure to have an ecological ethic. The role of the integrator will however be important, as it is a complex integrative system. Application development could thus be an opportunity for Canadian industry, and there is a service/software opportunity. Development of the supply chain is critical, and institutional structures will need to be aligned. We will also need a global market emphasis. Government capacity to deal with water remained uncertain, although it was assumed by 2020 clean water would be a key issue (and regarded more valuable than oil). A radio linked bio-nano sensor market could be valuable. A barrier could be our current complacency/ lack of urgency regarding water issues.

Nanoarrays for directed evolution chips (NDEC) was recognized as being an important technology for Canada at all stages of the development process. This technology involved accelerated “breeding” sensors + package (RIM model), and could create a change in paradigm from low value / high performance + cost. A niche/high value application could be bio chemicals/ enzymes/ systems/ H2 with scale up capacity and ensuing efficiencies. By 2020 global demand pull to displace fossil fuels/ industrial chemicals will be high, while bio-degrade nano products could internalise sustainability issues. There will however need to address all the risks of associated links (e.g. Genomic/microbial factors).

Canada’s role in ***Nanoporous materials for ag-bio systems control (NMSC)*** was split between minor and major, with Team Members believing that we will be either a technology developer or producer. This technology may be applied for pollution recycling, but there is a concern over zeolite disposal, and the N60 role may be critical (+-). The delivery mechanism is also key to system integrity (trigger – dust-release – residue?). Many technical – application issues remain (rub offs/gene inducible expression), and a sensor release mechanism is also crucial. Fertilizer/bio- products could be a non food applications focus, and we may be able to build upon existing semi- smart practices. To establish the technology, we will need to emphasize strong environmental benefits, and there will be a need to align with 2020 agriculture commerce practices. It will probably be incremental in Canada, but can be scaled up globally.

Health Life Sciences

The work team determined that the main driver in the Health & Life Sciences sector would be mostly driven by the specific technology and how they may resolve specific needs.   Four technologies were identified (Table 9): Continuous health monitoring using bio-nano sensors (HMBS), medical “tricorder": bio-photonic images and diagnostics – (BPID) and in vitro nanovaccinology and on-time vaccine/drug development (IVNV).

Table 9: Identified Roles in Health and Life Sciences

Target	*Area or Title*	*Science Incubator*	*Tech. Developer*	*Application Developer*	*Producer*	*No Role*	*Major Role*	*Inter. Role*	*Minor Role*
HLS-2	HMBS	0%	31%	69%	0%	0%	100%	0%	0%
HLS-5	BPID	0%	0%	31%	69%	0%	57%	29%	14%
HLS-7	IVNV	25%	50%	25%	0%	0%	75%	0%	25%

Continuous health monitoring using bio-nano sensors (HMBS) was recognized as being pulled by concerns over air testing, aerosols and water usage. There could also be applications for security, with Canada having multi entry points. Note that there could be cross-over applications with agricultural applications. Canada is currently a leader in developing STD's, and there is likely to be demand from the Government as a major user, and may thus play a major role in the future. Currently industrial production costs are a barrier, and there is no industrial infrastructure, new investments and perhaps another manufacturing model will be needed to facilitate an effective industry by 2020. Strategic alliances with foreign partners will be necessary. Canadian industry will also need to be more proactive in pro-typing, with more investment going beyond science. There is also a role for smaller Canadian companies, but there will need to be assistance (e.g. teach them how to develop 'product roadmaps').

***Bio-photonic images and diagnostics* (*BPID*)** was likely to be driven by rapid diagnostic capabilities, thus providing cost advantages, "a Radiologist in a box". Information on the technology would however be available anywhere, although Canada has capabilities and a strong track record in integrating telecommunications in and IT/wireless technologies. Smaller companies could play a role, while pharmacy companies could be applications developers. The government could play a role as an early procurer, and provide an advantage by accelerating the regulation approval process, and Canada already funds major clinical trials to support these techs/apps. Manufacturing and export barriers may be smaller in this sector, and companies may develop platforms for multiple applications. However, Infrastructure concerns remain, and there could be resistance from clinicians.

Vitro nanovaccinology and on-time vaccine/drug development (IVNV) was recognized as having a potentially major role in Canada in all areas of development. Consider generic vaccines (not just flu) – nano materials + speed. Canada will need to invest in basic science, large scale fermentation and production capabilities. Furthermore, Canadian industry will have to understand what is needed – e.g. not a protein. Automation is moving very quickly already. A driver could be Canada's concern over pandemics – do we wait in line or take the lead. Canada is already a leader in nano-delivery, with considerable scientific expertise. There is however much to do, and Canada will need to be connected into global scientific communities. The Work Team agreed that this needs to be a top priority for the Federal/Provincial Governments (top – down driven), with a focus immunology prevention and government as the client. The government must therefore be committed to compensating developers and being early adopters.

V. PLAN FOR THE SUBSEQUENT FORESIGHT EXERCISE

This report summarizes a scoping workshop event conducted in March 2007 to formally launch the project *Prospective Applications for Converging Technologies in Nano-Bio-Info Systems (PACT-NBIS*). This was a landmark meeting with invited experts from across the country where key issues were identified and discussed in an open forum. Overall we suggest that the workshop was successful in examining a wide range of prospective convergent technologies applications. There was both sufficient technical expertise to conduct the scenarios, and it was also recognized that additional expertise in marketing and social concerns will be needed, as well as a more extensive industry perspective.

The scoping Foresight exercise indicated that the success of many of the technologies will be driven by not-so-obvious market need, and therefore a visionary industry presence would be ideal, perhaps through trade associations. It also recognized that in many cases the technology will be driven by social needs, such as pressures to reduce CO2 emissions and energy usage, improve water usage, agricultural output and material use, etc. Appropriate expert stakeholders in these areas should be identified to participate in the next workshops. As a result, the next more focused Foresight exercise should perhaps use 1 or 2 technologies in a narrower industrial sector, and further pre-work on a few scenarios would be appropriate.

Starting in mid April 2007, further partnership development-industry engagement will take place, and an initial S&T Advisory Board meeting will be scheduled for May or June 2007. Linkages are planned with a national nanotechnology strategy, when and if it emerges as a federal-provincial policy opportunity. A plan for briefing respective Ministers, industry stakeholders and developing strategic communications will be initiated in the late spring of 2007 once all partners are engaged. In the Fall of 2007, ONSA plans to initiate international discussions with US NSF-NNI, Nano Foresight Institute, European Commission, UK Foresight, Taiwan and S&T Trends-Netherlands.

Present plans call for a National PACT Partnership involving several provinces, industry associations and federal departments and agencies , with workshops potentially in:

- **Montreal**: bio-pharma & health systems
- **Calgary**: water & energy-environment systems
- **Vancouver**: food & bio-products, medical devices
- **Moncton** or **Halifax**: resource processing & life sciences
- **Ottawa**: public safety-security

In addition, workshops may be conducted in the US:

- **Washington**: NBIC & human security and industrial potentials;
- **Boston**: bio-medical frontiers
- **California**: nano-computational frontiers

PACT Deliverables will include the following:

- **Expert Panel Reports** that reference alignment about Canada's PACT – NBIS opportunities;
- **Applications Scouting Reports** on the state of development, sectoral prospects and applications of interest to Canada in 4 broad sectors and 20 sub sectors;
- **Observations and references** on what sorts of public policy issues, health or security *dangers or ethical dilemmas* do converging technologies share, and how to frame practical conversations about risks, opportunities and concerns?
- **Technology Characterizations**, research and analysis and expert panels summations about strategic implications of CT in the future Canadian economic and social character (BIND analysis)
- **Communications Materials**, briefings and presentations suitable for Ministers and the public

Potential PACT Success Measures include:

- CT applications tied to specific sector opportunities;
- CT applications point to new R&D areas and skills that Canada will require;
- CT applications clearly contribute to changes in the funding and organization of field or research boundaries within key institutions
- CT foresight creates a recognition that Canada needs some new federal and/or provincial policies or program instruments
- CT applications are adopted by innovative firms;
- CT applications become the focus for international recognition and discussion;
- CT applications and the foresight approach attract significant interest from the stakeholder community both within Canada and internationally

Learnings from this Scoping workshop to apply to the forthcoming foresight exercise

At the end of the Workshop, there was an open discussion of ideas to apply to the subsequent foresight exercise. Some of the main ideas expressed are discussed below.

It was suggested that the forthcoming workshops should have a narrow focus and involve industry and trade association participants as well as the academic and government representatives. Use of a scenario approach will be very helpful – a perspective [or more likely several perspectives] on what the year 2020 will look like. We should develop a set of open ended questions to address to the workshop participants.

We need to think clearly who the "customer" for the foresight exercise is, and tailor the process accordingly. The main customers would seem to be Canadian industry, and individuals responsible for technology and innovation policy in the Federal and Provincial governments. One aspect not to overlook is the positive role that regulation could play to stimulate demand for new technologies.

One key challenge is how to balance technology push with market pull and marketplace needs. It is a challenge because market needs are very hard to identify at the best of times, and looking 10-15 years into the future makes this very challenging. One possibility is to look at broad societal needs, as well as industrial needs. We should not overlook quality of life issues. The competition between different technologies to meet market needs should be a focus of the foresight workshops – there are other technologies beyond those that we will discuss. We also need to find out where the potential "receptor" companies are in Canada, as engaging them will be a key to the success of the foresight exercise.

We need to articulate the question clearly for the next foresight workshops carefully. One suggestion was:"Will it improve the competitiveness of Canadian industry?" Another was "What could Canada's role realistically be in 2020 to take advantage of these opportunities?"

VI. CONCLUDING REMARKS

Convergence represents a new way of viewing cross and multi-disciplinary possibilities, and it will provide major recombination opportunities for business and entrepreneurs. It may also present unintended social consequences. A diverse private – public partnership, combining key organizations driving change is required to explore the convergent landscape, the potential opportunities as well as the unintended negative implications. The federal-provincial-university and diverse sectoral industry structure enables multiple, plausible outcomes to be examined, and should use these to align its interests in a national opportunities strategy leading to productive entrepreneurial outcomes. The diverse technology fields, sectors and new convergent interfaces make this a very dynamic domain and an excellent target for S&T collaborative foresight.

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FURTHER INFORMATION ABOUT THIS REPORT

Further information about the report and workshop can be obtained from the following individuals:

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APPENDIX A

Table 10. Participants at the March 19/20 2007 Toronto Scoping Foresight Workshop

		Title	Affiliation
Ken	Andrews	Facilitator	High Impact Facilitation
Eric	Archambault Ph.D.	President	Science Metrix S & T Evaluation
Roy	Atkinson	Public Policy Consultant	Canadian Food Inspection Agency
Paul	Chow	Professor	Sr. Dept. Electrical & Computer Engineering
Steffen	Christensen Ph.D	Senior Consulting Researcher Science and Technology Foresight Directorate	Office of the National Science Advisor
Martha	Coté Ball	Executive Secretary	THECIS - The Centre for Innovation Studies
David	Creasey	Policy Analyst	Canadian Biotechnology Secretariat
Walter	Derzko		Office of the National Science Advisor
Lesley	Esford Ph.D.	Industrial Technology Advisor	National Research Council - Industrial Research Assistance Program
Brad	Ferguson	President Strategy Summit	Alberta Advanced Education and Technology
Marc	Fortin	Assistant Deputy Minister	Research Branch,Agriculture and Agri-food Canada
Dan	Gale	Vice President & Chief Technology Officer	CMC Microsystems
Jeremy	Hall PhD	Associate. Professor	Assoc. Director International Institute for Resource Industries & Sustainability Studies (IRIS)University of Calgary
Ted	Heidrick Ph.D.,PEng	Professor in Technology Management	Faculty of Engineering School of Business University of Alberta
Dave	Jackson B.Sc., M.A., M.A.Sc., Ph.D. Dip. Eng. Mgmt, M.Eng. Mgmt.	Professor (Adjunct)	Department of Engineering Physics McMaster University
Della	Johnston PhD	A/National Program Coordinator Bioproducts and Bioprocesses	Agriculture and Agri-food Canada
Peter	Josty PhD, MBA	Executive Director	THECIS - The Centre for Innovation Studies
Shana	Kelley	Professor	Faculty of Medicine, Biochemistry Faculty of Pharmacy University of Toronto
Cooper	Langford Ph.D. FRSC	Faculty Prof of Chemistry; Faculty Prof in Communication & Culture coordinator, Science, Technology & Society	University of Calgary, THECIS
Janusz	Lusztyk Ph.D.	Director of Research	National Research Council
Irene	Makar MSc.	Directoral Researcher-Nanotechnology	SPRU [Science Policy Research Unit, Sussex University]

Hassan	Masum PhD		Office of the National Science Advisor
Wayne	Materi Ph.D	Assistant Research Officer Nano Life Sciences	National Institute of Nanotechnology
Terry	McIntyre M.Sc.Ph.D., P.Ag.	Chief, Environmental Biotechnology Advancement Division Technology & Industry Branch	Environmental Protection Service, Environment Canada
Maria	Nazarowecm-White	National Program Coordinator Food Safety & Quality - Research	Agriculture and Agri-food Canada
Shane	Roberts	Policy Advisor Futures & Forecasting /	Science and Technology Policy Division Public Safety and Emergency Preparedness Canada
Mike	Rott	Research Scientist,	Sidney Laboratory Canadian Food Inspection Agency
Karl	Schroeder		Thalience Communications
Manjeet	Sethi B.V.Sc.&AH, M.V.Sc., Ph.D	Director Research & Development Science Branch	Canadian Food Inspection Agency
Jo Anne	Shatkin Ph.D	Principal	The Cadmus Group, Inc.
Jack	Smith	Director , Science & Technology Foresight	Office of the National Science Advisor
Leah	Soroka-Demkiw	Science Policy Advisor	Agriculture and Agri-food Canada
Brian	Staples, DIC, Ph.D., P.Eng., C. Mar Eng., C. Eng., CIMARE, FIMarEST		Canadian Forces (Ret'd)
Danielle	Tanguay MBA, Pdg	Chief Executive Officer	Trema Gestion Conseil Inc.
Dan	Wayner FCIC, FRSC	Director General, Steacie Institute for Molecular Sciences	National Research Council

APPENDIX B

Workshop Agenda: March 19/20 2007, Toronto

Monday March 19

9:00 – 10:00am	Registration & coffee
10:00 – 12:00pm	Welcome & introductions Meeting objectives & overview of 'convergence' Future perspectives of technology & applications from: Dan Weiner, affiliation Walter Derzko, The Smart Economy Jeremy Hall, affiliation Plenary discussion
12:00 – 12:45	Networking Lunch
12:45 – 5:00pm	Team breakout: Assess the technical feasibility and commercial feasibility of multiple technologies & applications in: a) Health & Life Sciences b) Energy & Environment c) Food, Water & Bio-Products Report & discussion in plenary
6:00pm	Workshop dinner

Tuesday March 20

8:30am – 12:00pm	Team Breakout: Review technology/commercialization matrix from day #1 & determine Canada's role in each technology area Report and discuss in plenary Personal Perspectives: "The technology/application which I believe will most profoundly impact my world will be …." Discuss a draft plan for future PACT meetings, foci and participation Next Steps & Communication
12:00 – 12:45pm	Networking Lunch

APPENDIX C

Personal Perspectives.
At the end of the workshop, participants were asked to identify their own personal "best " ideas from among those discussed at the workshop –ideas that they thought would most affect their work or private lives. This list is reproduced below. These ideas can be regarded as complements to the main conclusions of the workshop.

- Nano bio sensors - 3
  - Early warning
  - Decision support
  - Self care – health care
- Bio Products/energy
- Medical device implant technology
- Convergence of nano bio in new materials capabilities
- Smart tech – not passive – it does something
- Link bio products and new materials – bio materials e.g. New hip material
- Construction of nano machines to carry out specified chemistry
- Personalized Medical diagnostics and treatment – ethical discussions will be important
- Nano filtration for safe water
- Micro fluidic tech for cost effective diagnostics
- Nano particles for remediation of contaminants
- Intelligent fabricator for nano structure
- Smart materials for lowering emissions for carbon based energy
- Nano bio info technologies to improve the systems to minimize down stream negative emissions
- Regenerative medicines – e.g. Alzheimer; Dementia; hip replacement;
- Sensor, coatings, devices, effect industry and other factors – made off shore
- Cognitive science – e.g. Conflict resolution.
- Cognitive enhancers, to enable the brain to think better
- Sensors to enhance human sensory capacities...
- Convergence of nutrition, genomics and environment factors – sensors
- Development tools for analytical analyses at the nano level
- Safe nano materials to delivers drugs in a targeted fashion
- Social networking technologies for policy resolution
- A tool for predicting nano materials in the environment

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