NRC·CNRC

From Discovery to Innovation...

Science at work for Canada

National Research Council Canada

Looking Forward: S&T for the 21st Century

Foresight Consolidation Report
NRC Renewal Project

August 2005

National Research Council Canada | Conseil national de recherches Canada

Canada

Looking Forward: S&T for the 21st Century – NRC Renewal Project Consolidation Report

Prepared by: NRC Renewal Futures Team

Sponsor: Sherif Barakat

Lead: Diane Isabelle

Team Members:
Martin Brooks
François Dubé
Michel Dumoulin
Dave Ghosh
Tom Jackman
Barry MacDougall
Raj Selvaraj
Andy Storer

Other Resources:
Sherif Barakat
Marielle Piché
Donna Viger

External Resources:
Foresight Canada
Thorington Corporation

Foreword

This document is a consolidation of the most critical material from working papers written by the NRC Renewal Global to Local, Industry Perspective, Government Perspective and Futures Teams, and takes into account discussions resulting from the presentation of that material at the NRC Consolidation Workshop.

There is a tremendous wealth of material in the source documents produced by the Teams that provide an extensive overview of the environment of which NRC must be cognizant as it moves forward with its Renewal. This report attempts to organize that background information under four overarching themes: the global context, the global challenges impacting Canada, the global economic competition facing Canada, and the evolving role of science and technology.

This Consolidation Report is one of two final reports produced as part of Phase 1 of the NRC Renewal Project. The second report is entitled The Insights Report.

EXECUTIVE SUMMARY

Introduction

The global changes now taking place are far more profound than might generally be understood. It appears increasingly likely that the future we are planning for – of business as usual – is not the future we will get.

The nature of the global tensions is increasingly complex, and is altering rapidly. These tensions include the balance between global freedoms and openness versus security and protected domestic "norms"; advancing (or protecting) economic well-being versus disruptions to social well-being; and accommodating the increased consumption of growing populations and economic development versus environmental degradation and resource insecurities.

It is possible for Canada to become the most influential mid-sized nation in the world by understanding the drivers and dynamics drifts of the new world order, by building on its strengths and transforming into a leading society and economy. This report begins to explore some of those drivers and dynamics, illustrate Canada's situation and advantage, and highlight how science and technology (S&T) will make a difference.

GLOBAL CONTEXT

Ours is a complex world. A 15-year window into the future is not very long. However, if the conditions are right, dramatic and even history-altering changes can take place in this relatively short period of time. Significant mutually reinforcing trends that have been developing slowly and quietly have gone critical and can intensify in this time frame. In this context, the following trends are explored as backdrop to the global challenges affecting Canada, global competition and S&T:

1. Changing Demographics
2. Geo-Political and Social Challenges
3. Changing Societal Context
4. Demanding Enhanced Security

Changing Demographics

The various impacts of changing demographics range from economic to social: changing consumer expectations; increasing demands on natural resources; accelerating health-care demands; changing the workforce composition; and evolving societal values, religious beliefs and cultural norms. Some of the changes in demographics that are expected include:

- The world's population will increase by approximately 2 billion to 8 billion by 2020, with most of that growth taking place in today's developing countries – notably China, India, and Indonesia. Asian culture will profoundly shape global interactions, societal values and behaviours.
- By 2015, for the first time in history, a majority of the world's population will live in cities and by 2030, 60 percent of the population is expected to live in cities.
- A host of factors will boost global migration through 2020, making even the most homogenous states more diverse: increased privatization and foreign investment, trade liberalization and enhanced communications.
- There is broad agreement that the world's inhabitants are getting older at a rate unprecedented in history. By 2050, the number of older persons globally will exceed the number of young (under 15) for the first time in history.

- In contrast, some parts of the world, notably developing countries, will face a "youth bulge". With their large youth populations, these countries may experience political instability, reinforcing the difficulties to generate economic growth.
- With their growing economic prosperity and demand for highly qualified personnel (HQP), China, India and Eastern Europe are increasingly repatriating their emigrants and deflating the desires of their brightest young people to leave – even starting to attract other countries' emigrants.

Geo-Political and Social Challenges

A global governance crisis is looming. Worldwide, the number of democracies is growing, while the number of dictatorships is decreasing, and more people will vote this year than ever before in history. At the same time, there are approximately 50 failed nation-states. These forces of rapidly mutating complex conditions feed on and reinforce each other, sometimes producing unexpected forces for which we are almost wholly unprepared – conditions with which we do not know how to cope. For example, the nation-state is seen to be losing ground to trade and religious groupings as a primary source of identity. Societies are unprepared and governments are unequipped.

Changing Societal Context

In the 20th century, it was widely assumed that the future would be owned and defined by Western Industrial Culture – by our technologies, economies and world views. Such assumptions are no longer a "safe bet". Alternative models of trade – fair trade – coupled with the demand to use economic systems to alleviate poverty and hunger (i.e. increasing sense of social responsibility) and also deal with environmental concerns will grow.

Typically, changing human awareness or consciousness has been ignored as a driver of change, yet *"our perspective on the worldetermines how we behave."* There are several shifts in the way we think about the world emerging in the early 21st century and contributing to a loss of confidence in both the institutions and leaderships in every Western society. Most existing societies, including Canada, are well-designed for stability, not for profound societal change. However, the reality is that we face emerging conditions that are both fundamentally new and crucial. This mismatch is the single most pressing issue facing Canada in the 21st century.

Demanding Enhanced Security

Rapidly increasing global interdependence brings new threats and vulnerabilities with the new choices and opportunities. There appears to be a new age of anxiety, caused by endemic poverty, convulsive economic transitions that cause growing inequality and high unemployment, the spread of deadly armament, large-scale population movements, recurring natural disasters, ecosystem breakdown, new and resurgent communicable diseases, and rising competition over land, water and other natural resources.[1] Moreover, the world increasingly faces conflicts defined along religious lines – dominated by struggles between religious fundamentalists. There is no doubt that eroding state capacity and the privatization of conflict is weakening the security of the world.

Not surprisingly, the world today is obsessed with security – or the lack thereof. To some extent, "security" is driving how we perceive the world, and how we react within it.

[1] World*watch Institute website:* http://www.worldwatch.org/features/security/

GLOBAL CHALLENGES

Among several issues facing the global community in the coming years, three emerge as the most critical themes on which the world will be focused over the next 5-15 years: energy, the environment, and health and wellness.

Energy

Some would cite energy as the number one problem facing humanity in the next 50 years[2]. As other economies gain strength, global competition for energy supplies will increase. Serious energy security concerns could emerge.

While there is a consensus that the world's supply of fossil fuel will be adequate to 2020, there is nonetheless a focus on improving the efficiency and cost of its extraction, while also decreasing the environmental burden of those activities. There is likely to be a resurgence of nuclear power as a supply response to growing energy demand, with China and France already embracing these technologies. Worldwide, the technologies needed for solar, wind and wave power are being developed. Fuel cell technology is advancing. The development of these new technologies marks the beginning of a greater awareness of sustainability, environmental impact and energy security.

In this global landscape, Canada ranks as the fifth-largest energy producer in the world – only the United States, Russia, China, and Saudi Arabia produce more.[3] Canada's oil reserves, totalling 180 billion barrels, are second in the World. While demand for energy is growing in Canada, our vast natural resources will provide secure energy supplies for many years to come.[4]

We are also among the leaders in energy responsibility. Canada has signed the Kyoto accord and thus committed to reducing our greenhouse gas emissions to 6% below 1990 levels. Significant efforts will be devoted to reducing our energy consumption and major investments will be made supporting Canadian innovation in cleaner fossil fuels and hydrogen fuel cells**.**

Environment

Environmental S&T are fast gaining prominence globally, as humankind reaches the "tipping point" in its concerns about environmental health – climate change, global warming, water, pollution, natural disasters, etc. A discussion of two of these challenges follows.

- **Water:** With populations and the per capita use of water increasing, water for all uses will become more and scarcer and lead to growing tension among competing demands. Hence, there will be intense competition for access to water. The struggle to control water resources will shape human political and economic history. Many believe that water is about to become the strategic resource of the 21st century.

- **Climate Change:** It is generally accepted that, as a result largely of increased greenhouse gas emissions, our world is experiencing a global warming trend and noticeable impacts on our environment. Our oceans are more acidic, with corresponding consequences for marine life; vast areas of forests have experienced droughts; and catastrophic forest fires are now

[2] R. E. Smalley, Rice University, presentation at the 27th Illinois Junior Science and Humanities Symposium, April 3, 2005, http://cohesion.rice.edu/NaturalSciences/Smalley/emplibrary/040305%20Illinois%20Science%20Symposium.ppt
[3] http://www.locationcanada.com/art_5.htm
[4] http://www.locationcanada.com/art_5.htm

an annual event; just to mention a few of the already exhibited impacts. Humankind recognizes that we must address the root cause of these problems.

Health and Wellness

Worldwide, we are already experiencing significant challenges to public health systems. Declining fertility rates and increasing lifespan are causing an increase in the median age of the world's population. The world is facing an onslaught of diabetes and an epidemic of obesity. The world is also facing pandemics, the rise of communicable diseases, and a resurgence and new strains of old diseases. The global HIV/AIDS pandemic continues to be one of the greatest challenges of our time.

World poverty is a significant factor in health and wellness. More than 800 million people go to bed hungry every day, 300 million of whom are children. Progress in poverty reduction has been concentrated in Asia, and especially East Asia. In *all the other regions*, the number of people in extreme poverty has increased.

Against these challenges, many of the necessary "cures" are notionally available, but their implementation counters other strong societal values. For example, we struggle to judiciously balance free-trade rights against the moral obligation of ensuring access to life-saving medicines for developing countries.[5] World agriculture produces enough to feed everyone in the World; however, many people in the world not have sufficient income to purchase food, or land to grow it. As well, genetically modified crops carry the potential of lowering pollution and increasing economic yield, yet genetically modified organisms (GMOs) are strongly resisted in some economies, including the developing countries.

As a result of an increasingly burdened society, health-care costs are steadily rising. To ease the health-care burden, global realities show a need to emphasize disease prevention, lifestyle changes, and alternative health-care systems.

GLOBAL ECONOMIC COMPETITION

The Changing Global Market System

We are in the midst of major changes in the shape, structure, and dynamics of the global economy. World trade has grown from about US$580 billion in 1980 to a projected US$6.3 trillion in 2004, an 11-fold increase.[6] Trade is expected to continue growing impressively, increasing 80% by 2020 over 2000 levels.[7] Money, technology and raw materials move ever swiftly across national borders.

By 2020, given present trends, China will have an economy that rivals that of the United States in size. India will achieve this mark sometime in the 2040s and Russia may again emerge as a major player.

A country's place in this new world order is highly dependent on its social and economic well-being. Even by 2020, the benefits of globalization won't be global: gaps will widen between

[5] *A Fair Globalization: Creating Opportunities for All,* Report by the World Commission on the Social Dimension of Globalization, February 2004 http://www.ilo.org/public/english/fairglobalization/report/index.htm
[6] *Long Term Global Challenges for Europe*, released March 2005 http://www.hm-treasury.gov.uk/documents/international_issues/int_global_index.cfm
[7] *Mapping the Global Future*, Report of the National Intelligence Council's 2020 Project, http://www.foia.cia.gov/2020/2020.pdf

those benefiting countries (economically, technologically and socially) and under-developed nations. Increasingly, there is a stronger recognition that S&T is required to survive in the world and that the stronger economies must use their capacities (e.g. S&T) to assist less-fortunate nations – to combat the many "divides" in the world.

In general, the liberalization of international markets presents both an opportunity and a challenge for Canada. Historically, Can (GDP) dependent on trade is higher than any other Organization for Economic Co-operation and Development (OECD) nation. However, Canada faces the real potential to be reduced to insignificance or even irrelevance in the global marketplace.

Industrial Challenges

Taken together, the effects of technology and globalization accelerate the competitive pressures to lower costs and increase productivity. Innovation in products, processes, and services has become a determinant for success,[8] shaping the competitive position of nations. According to Statistics Canada, in 2004, Canadian businesses recorded their worst performance in labour productivity growth in eight years. As the U.S. is increasing its productivity, Canada is falling further behind.

Beyond just "knowledge creation", S&T's contribution to a nation's competitiveness will only arise when the S&T is sustainably applied to new products or services in the marketplace. This, in particular, is where Canada's predominately small and medium-sized enterprise (SME) economy becomes most apparent. Canada's private sector is dominated by SMEs, 98% of which have fewer than 100 employees. Generally, SMEs spend one-third what comparable U.S. firms do on research and development (R&D), have limited receptor capacity to absorb R&D advantages and have a limited capacity to adjust to rapid liberalization of the economy.

EVOLVING ROLE OF S&T

Impact of S&T

By supporting responses to the world's challenges, new science and technology can shape the foundations of our collective abilities to address global challenges (climate change, resources and energy, health), the competitiveness of countries (quality of life, economic productivity, increased recognition of the importance of a knowledge economy) and the structure of competition in whole industries.

Throughout history, "waves" of innovation, many of them based on developments in S&T, have been diffusing through, and significantly impacting on, the global economy. These waves are becoming more disruptive and the current wave, information and communication technologies, will continue to have considerable transformative influence to 2020. The next wave, expected to be biotechnology, will on its own have considerable impact in the areas of gene function, and molecular, cell and systems biology.

Primary Transformative Technologies

The primary transformative technologies to 2020 are expected to comprise Information and communication technologies (ITCs), biotechnologies, and energy and environmental technologies.

[8] *Manufacturing in America : A comprehensive Strategy to Address the Challenges to US Manufacturers*, US Department of Commerce, January 2004

- **Information and Communications Technologies:** The transformative power expected of information and communication technologies is already under way and is expected to be even more profound. By 2020, we will have computing power that is ubiquitous, and part of the fabric of daily living.

- **Biotechnologies:** It is believed that the transformative nature of biotechnology eventually will impact most sectors of the global economy. Biotechnologies are often regarded as the most significant S&T of the current century, with impacts exceeding those of information and communications technologies.

- **Energy and Environmental Technologies:** The development and diffusion of energy and environmental S&T are fast gaining prominence globally. Early signs suggest that this innovation wave has already begun to take hold and will have a growing impact over the years to 2020.

Primary Enabling Sciences and Technologies

In today's reality, most advances are only made possible by complementary advances in other enabling sciences and technologies. While there are a host of sciences and technologies that are important, those mentioned below are some that are expected to see significant advancement to 2020.

- **Nanoscience and Nanoengineering:** The prospective impact of nano-science and nano-engineering technologies is expected to be the most profound of all. Nanoscience – materials science on the scale of the atom and molecule – will change the very fabric of society in the long term.

- **Materials Science:** Materials science is a multidisciplinary field focusing on functional solids, whether the function served is structural, electronic, thermal, chemical, magnetic, optical or some combination of these.

- **Photonics:** Photonics refers to science and technology based on and concerned with the controlled flow of photons, or light particles. As a tool, optics is making its way into virtually every field of science and technology.

- **Microfluidics:** Microfluidics is perhaps the future of the wet lab. It may be thought of as the miniaturization of the cell culture laboratory, with the ability to control complex combinations of interactions between test molecules and individual sites on individual cells.

- **Quantum Information:** Quantum information has the potential to revolutionize many areas of science and technology. It exploits fundamentally new modes of computation and communication because it is based on the physical laws of quantum mechanics instead of classical physics.

Converging Technologies

Converging technologies are sciences and technologies that enable each other in the pursuit of a common goal. Increasingly, themes of "convergence" will dominate S&T development. New technologies will often be a blend of two or more disciplines and advances in one field will enable advances in another (e.g. the influence of informatics on genomics research). The convergence of nano-bio-info-cogno-technologies is expected to produce significant advances in human health, security and industrial applications to name a few.

Factors that may Impact on the Development and Acceptance of S&T

Several factors will impact the timely development and deployment of S&T. These factors pose a major challenge not only to the research community, but also to policy-makers and societies. Some of the more important factors include:

- **Multidisciplinary collaboration:** In this day of S&T convergence, no technology succeeds on its own but depends on other enabling technologies. Interdisciplinary collaboration may represent the most important challenge facing the future of S&T development to 2020.

- **Coping with the pace of S&T developments:** S&T is changing faster than regulators' ability to "keep up".

- **Acceptance:** Reliance on S&T must prevail over fear of technology as science input is increasingly needed for sound decision making. This observation underscores the importance of education and open debates on the philosophy of science.

- **Breakthroughs and tipping points:** History has shown us that many truly transformative sciences and technologies were not foreseen (at least not their importance nor timing).

CONCLUSION

Reponses to today's complex and interrelated global challenges require the collaboration and multilateralism of many nations – no society can work alone. This is particularly true of trading nations such as Canada. Our priorities are shaped by what goes on in the world. With technology's ability to help cope with or affect many of these challenges, S&T's transformative influence can be profound. Consider how recent advances in information and communication technologies have fundamentally changed the ways people organize, communicate, collaborate, and produce goods and services.

The "global experience" is forcing the emergence of new social, cultural, political and business models for the 21st century. Not only will these changes be remarkable in their depth and breadth, they will occur with great rapidity and redistribute power, knowledge and resources. Together, these social pressures will encourage innovators to focus their talents and skills on specific questions, given the promise of sizeable returns for their innovations.

Table of Contents

Foreword **2**
EXECUTIVE SUMMARY **4**
PART 1 – THE GLOBAL CONTEXT IN WHICH WE OPERATE **12**
Changing Demographics 12
Geo-Political and Social Challenges 16
Changing Societal Context 17
Demanding Enhanced Security 19
PART 2 – GLOBAL CHALLENGES IMPACTING CANADA **22**
Energy 22
Environment 25
Health and Wellness 28
PART 3 – GROWING GLOBAL ECONOMIC COMPETITION **32**
The Changing Global Market System 32
Industry Challenges 33
PART 4 – EVOLVING ROLE OF S&T **40**
Innovation Waves: A Lesson from History 40
Primary Transformative Technologies 41
Primary Enabling Sciences and Technologies 42
Converging Technologies 44
Factors that may Impact on the Development and Acceptance of S&T 44
CONCLUSION **47**

PART 1 – THE GLOBAL CONTEXT IN WHICH WE OPERATE

All religions, arts and sciences are branches of the same tree. All these aspirations are directed toward ennobling man's life, lifting it from the sphere of mere physical existence and leading the individual towards freedom - Einstein

Ours is a complex world. A 15-year window into the future is not very long. However, if the conditions are right, dramatic and even history-altering changes can take place in this relatively short period of time. Significant mutually reinforcing trends that have been developing slowly and quietly have gone critical and can intensify in this time frame. These trends include globalization, resource constraints, education levels, human security, inappropriate organizational forms, and courageous and insightful leadership. Other trends, such as a return to domination by big powers, climate change, societal change, and the disintegration of identity and community, may well go critical by 2020.

In this context, the following trends are explored as backdrop to the global challenges affecting Canada, global competition and S&T:

1. Changing Demographics
2. Geo-Political and Social Challenges
3. Changing Societal Context
4. Increasing Concern with Enhanced Security

Any S&T organization in the process of renewal must be cognizant of the potential impacts of these forces to better position itself for success.

Changing Demographics

Changing global demographics will have various and significant impacts, including economic changes; changing consumer demands; increased demands on natural resources; changing migration patterns; changing societal values; significant health-care demands; and the changing composition of workforces to name but a few.

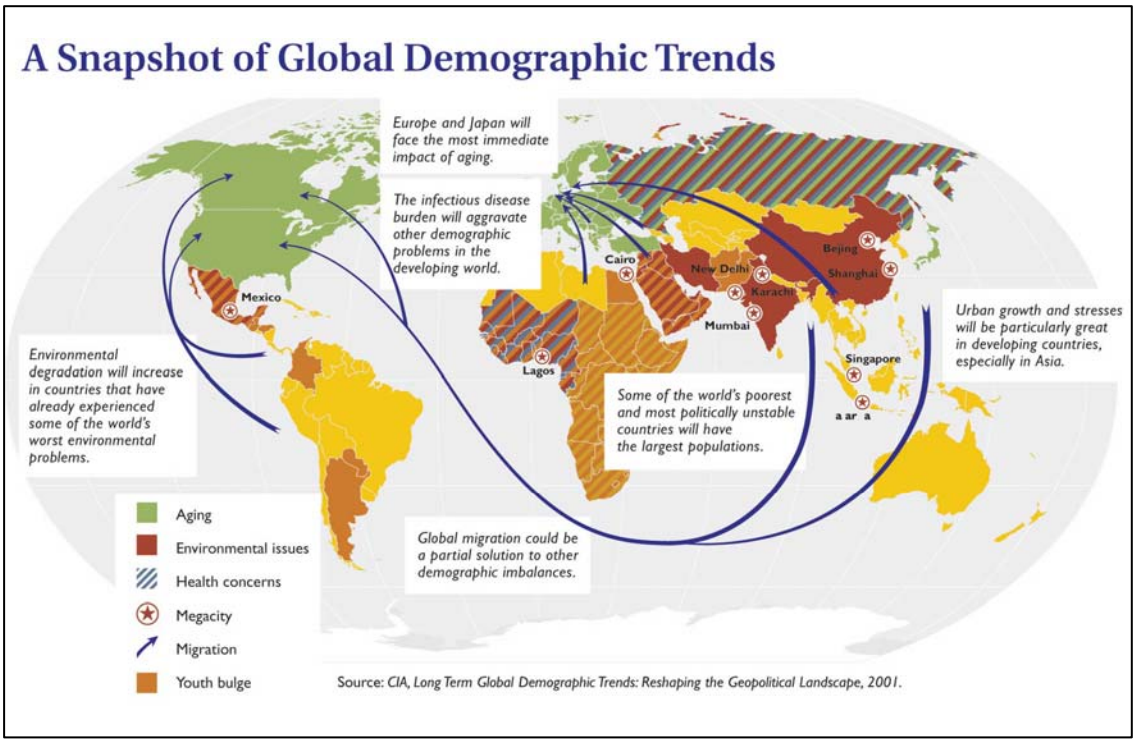
Population Growth and Mix

The world's population will increase by approximately 2 billion to 8 billion by 2020, with most of that growth taking place in today's developing countries – notably China, India and Indonesia. Asian culture will profoundly shape global interactions, societal values and behaviours. By 2015, for the first time in human history, a majority of the world's population will live in cities and by 2030, 60% of the population is expected to live in cities. The diagram below depicts the changing face of the world.

Telescoping the Population of the World

To truly appreciate what the projected population of the world's more than 7.8 billion people would look like by 2020, we have projected their mix into 100 people:

- Fifty-six of them would be from Asia, including 19 Chinese and 17 Indians.
- Thirteen would be from our hemisphere, including four from the United States.
- Sixteen would be from Africa, including 13 from Sub-Saharan Africa.
- Three would be from the Middle East.
- Seven would be from Eastern Europe and the former Soviet Union.
- Five would be from Western Europe.



As noted in the above diagram,[9] migration is expected to be a significant factor in shaping the face of the globe in the coming years. A host of factors will boost global migration through 2020, making even the most homogenous states more diverse: increased privatization and foreign investment, trade liberalization and enhanced communications. Democratization in many developing countries may loosen state control over migration, and immigration laws in receiving countries may give priority to family reunification. The growth of powerful ethnic communities in those countries will boost pressure to increase immigration of certain ethnic groups.

[9] *Long Term Global Demographic Trends: Reshaping the Geopolitical Landscape*, CIA, 2001. Note of caution: this report was produced pre 9/11.

The CIA[10] cites the following four types of large-scale demographic shifts that will contribute to social stress:

- Age cohort differences, such as the widening youth bulge in the developing world
- Population growth exacerbating environmental degradation in some areas
- Movements from rural to urban areas
- Destabilizing effect of migratory population flows in the developing world

Given 9/11, protectionism, security and defence of trade interests could be added to this list.

The Changing Face of Canada

In 2000 Canada's population was estimated at 30.7 million. In 25 years, it is expected to be around 35 million. From 1901 to 2001, the Aboriginal ancestry population increased tenfold, while the total population of Canada rose by a factor of only six.[11] Whereas 50 years ago, most immigrants to Canada came from Europe, today most are from Asia. Between 19% and 23% of the nation's population could be members of visible minorities by 2017 – giving Canada between 6.3 million and 8.5 million citizens with cultures, values and religions quite different from those upon which the country was founded.

The Population is Aging in Several Parts of the World

Although demographic projections should be viewed with caution (e.g. the US Census Bureau recently changed its two-year-old projections for South Africa from gaining 6 million people by 2025 to losing nearly 9 million people due to the AIDS virus), there is broad agreement that the world's inhabitants are getting older at a rate unprecedented in history.

By 2050, the number of older persons globally will exceed the number of young (under 15) for the first time in history, with nearly 16% of the world's population 65 or older compared with 7% in 2000. Currently, the population over 65 represents 20%, with 30% of the population aged 20-64 in G7 countries. This ratio will reach 35% to 50% by 2030 and 40% to 70% by 2050 if current trends continue.

Several areas of the world such as Europe, Japan, Russia and China, are facing the most immediate impact of aging. In addition to increased political instability and significant cultural changes, this will potentially result in slower economic growth, with capital market, investments and trade most affected. Even the youngest regions, Latin America, Asia and Africa, will have substantial elderly populations.

In Canada, by 2026, one in five Canadians will be 65 years of age or older – up from one in twenty in 1921 and one in eight in 2001.[12] In the coming decades, Canada's population is expected to age more rapidly than that of other industrialized countries. Over the next four decades, growth of the seniors' population will account for close to half the growth of the overall Canadian population. Canada's population growth will stagnate and may even decline by 2026 if our immigration rates do not increase significantly.

[10] ibid.
[11] Statistics Canada at http://www12.statcan.ca/english/census01/products/analytic/companion/abor/canada.cfm
[12] Health Canada in collaboration with the Interdepartmental Committee on Aging and Seniors Issues, *Canada's Aging Population.* Ottawa: 2002.

The societal influence of the Big Generation[13] will greatly increase. By 2020, they will range in age from 54 to 68. Many will be retired, but most will still be working. They will have become the psychologically dominant generation in Canada, with the most assets, power and influence, and the first generation in history to have a majority of its cohort graduate from high school. The Big Generation will facilitate the transformation of the Canadian culture into a post-Industrial form as they will be more inclined to let go of the past in ways that older generations find impossible.

More than 40% of the owners of Canadian SMEs – about 400 000 people – plan to retire in the next five years, and less than a third have formal succession plans. These often family-run businesses make up almost half of the Canadian economy and the changes could disrupt two million jobs across the country.

How countries deal with their aging trends will be heavily affected by how active and productive the elderly population will be in the workforce. If advances in biotechnology and health-care continue, and the elderly are given the right incentives to continue to be active, then this group (especially the youngest of the old who are less than 80 years of age and are generally healthier) could actually be a new set of consumers (or savers) with a longer productive life. This would lead to additional economic growth and continued prosperity, not to mention enhanced quality of life.

Changing demographics will result in changing consumer demands, particularly in terms of transportation, agri-food (interest in nutraceuticals, functional foods and bio-farming driven by consumer appreciation of the link between diet and health and the aging population), construction (increased urbanization, better second-home construction, rise in the number of smaller houses required), information technology (IT) (a large aging population and a vocal youth market, both with divergent needs but a large influence in an increasingly fragmented market) and Health/Pharma.

Other Parts of the World are Experiencing Youth Bulges

The world's poorest and often most politically unstable countries – including among others Afghanistan, Pakistan, Colombia, Iraq, Gaza and Yemen – will have the largest youth (15-29) populations through 2020. Most of these countries lack the economic, institutional or political resources to effectively integrate youth into society. Sub-Saharan Africa will have the worst youth bulges through 2020. With fertility rates remaining relatively high, pressures will continue on education, health-care, sanitation and economic infrastructures. It will be harder for global economies to prosper without improvements in education and economic reform in countries with large youth populations.

The International Labor Organization estimates that the global labour force will increase by nearly a billion over the next decade, with most growth coming from the developing world. This will put significant pressure on already weak economies to create hundreds of millions of new jobs for this younger population. Political instability will make it difficult to generate economic growth and encourage the foreign and domestic investment needed to generate such jobs. The shortage of professional entry-level jobs will be a particular concern. Unemployment in the Middle East, for example, is most severe among young semi-educated city dwellers that have received enough education to raise expectations and aspirations and are reluctant to take manual low-status jobs.

[13] By this term, John Kettle refers to the 400 000 persons born in Canada in each year from 1952 to 1966. It is much more precise than the more common term 'baby boomers'. See *The Big Generation*, 1980. McClelland and Stewart Limited, Toronto.

The Developed World's Demand for Labour Will Affect Patterns of Mobility

Changing demographics will require several developed countries to seek substantial growth in immigration from China, India, Pakistan, the Philippines and other transitional economies. Migration from some countries (e.g. India) will slow, as working and living conditions improve in these countries and more opportunities are created for virtual work.

Governments with aging populations will have difficulty balancing the need for new immigrants with domestic political resistance to the societal changes caused by that greater immigration. For example, Japan will have the greatest demand for immigrants, but will face the greatest political hurdles to increasing immigration because of its traditional emphasis on ethnic and cultural homogeneity. Governments in developing countries also are likely to face political opposition to excessive emigration to developed countries, as emigration will drain them of their already small pools of highly educated elites, making it more difficult for these countries to generate higher growth and "catch up" to the developed world. On the other hand, if China, India and Eastern Europe continue on their present course, there will be greater domestic opportunities for the brightest young people. Canada could therefore experience a brain drain of both highly skilled immigrants back to their homelands and of Canadians. These are typically young people, so this situation would intensify the aging of Canada.

Changing patterns of settlement will have far-reaching cultural and social impacts (shifts in language use, religious beliefs and cultural norms) in several countries, including the US (by 2020, one in 5 U.S. residents will be Hispanic) and Canada.

Geo-Political and Social Challenges

Canada's Place in the World is in Decline

Our place in the world is central to our social and economic future. Canada has historically punched above its weight internationally. We have had more influence than our size or performance alone would indicate. Our influence has been a function of our "family" connections with the U.K. and the U.S. and our capabilities – human, institutional, technological and financial. Our "family" connections have now weakened and we are in danger of becoming an international street child. For instance, Canada is poorly positioned for a potential serious struggle between China and the United States.

New investments by Canadians are required to re-secure our place in the world for at least three reasons. First, the number of effective international players – governments, agencies, corporations and non-governmental organizations (NGOs) – is growing. Without offsetting action, as time passes our voice will be more and more muted. Second, Canada is failing to secure leadership roles on critical issues, further eroding our reputation as a reliable partner that can be counted on to keep its commitments. Third, Canada is coming to be treated as an incubator for both high-quality people and effective corporations that then move and develop elsewhere. If these trends are not addressed, the best and brightest of the world may have no reason to come and our best and brightest may have no reason to stay.

Religiously-based Claims may Change the Society

Although the nation-state will continue to be the dominant unit of global order in 2020, it is losing ground to trade and religious groupings as a primary source of identity. The "modern secular" West has not yet internalized how much its hegemony will be explicitly challenged by other identities, be they Christian, Islamic, Confucian or other, that will impact on the way the West

will develop in the period to 2020. The debate over the place of traditional Islamic law – *sharia* – is an example.

All Countries Will be Challenged to Find New Forms of Governance

A global governance crisis is looming. The forces that are driving change are creating rapidly mutating complex conditions that feed on and reinforce each other, sometimes producing unexpected forces for which we are almost wholly unprepared – conditions with which we do not know how to cope. Societies are unprepared and governments are unequipped.

Much hangs on the choices Canada makes. In its 2004 review of *The Challenge of Long Term Policy Analysis,* the Rand Corporation said: *"Our World confronts rapid and potentially profound transitions... It is increasingly clear that today's decisions could play a decisive role in determining whether the 21st century offers peace and prosperity or crisis and collapse."* Today's decisions are setting the tone of the (human) security our future will "enjoy"**.**

Changing Societal Context

Most existing societies, including Canada, are well-designed for stability, not for profound societal change. However, the reality is that we face emerging conditions that are both fundamentally new and crucial. This mismatch is the single most pressing issue facing Canada in the 21st century.

There is reciprocal interplay between a culture and the patterns of consciousness by which those in the culture live; as one evolves, so does the other. In the 20th century, it was widely assumed that the future would be owned and defined by Western Industrial Culture – by our technologies, economies and world views. Such a view is no longer a "safe bet" in a global world. For example, anti-globalization and anti-capitalism movements have gained ground during the last decade. Alternative models of trade – fair trade – coupled with the demand to use economic systems to alleviate poverty and hunger (i.e. increasing sense of social responsibility) and also deal with environmental concerns will grow.

Human Awareness and Aspirations as a Driver of Societal Change

Typically, changing human awareness or consciousness has been ignored as a driver of change, yet *"our perspective on the world determines how we behave."* Unconscious changes to human consciousness happen, for example, when a new technology is accepted into a culture – a technology that carries a consciousness that is in some way at odds with the culture's existing state. The emergence of the Internet in our own culture and its impact on China provides examples. Peer-to-peer and open-source computing will be a major source of consciousness change in the 21st century and is just beginning to emerge.

The following shifts in the way we think about the world appear to be emerging in the early 21st century:

- **From piecemeal to systems/ecologies:** The default position of cultures is to deal with things one at a time, in a serial order, but the world is increasing in complexity, requiring a systems approach.

- **From community-defined to individuals with choices and interdependent:** As long as our roles and behaviours were tied to unchallengeable traditions, we had little choice in how we behaved. However, the drift has been to greater and greater participation in the

definition of one's roles and even one's self. It is a necessary step to working with and through others, as interdependent beings, co-creating our society and our future.

- **From static to dynamic and from single truths to multiple perspectives:** What was once true, may not be true at a different time in history. The upside to this is that trend need not be destiny; our future is more open that we have ever dared to believe. We must view what we know from as many perspectives as possible.

- **From linear to non-linear change:** Linear change means that we can figure out just where we are and what to expect next. Non-linear change means that we have to give up the illusion of control, that we must anticipate what will happen, but not know when. There will be more non-linear change in our future than in our recent past.

- **From surface to multiple depths:** Einstein's famous quote "We can't solve problems by using the same kind of thinking we used when we created them" is an invitation to develop multi-layered views of the world. New science and technologies – stem cell research, for example – challenge us to recognize the complex social implications of discovery.

These shifts are contributing to the loss of confidence in the leaderships and in the institutions of every Western society.

The Drivers of Changing Awareness

Each of the following drivers of change in human awareness or consciousness tends to reinforce the shifts mentioned above:

- **Education:** Sustained education in late high school and early college years nurtures a sense of psychological independence and a capacity for reflexive thinking. For the first time in history, the generation that wields the most influence and owns the most assets will be markedly *less* likely than any generation before them to argue for keeping things as they are, just because that is the way they have been. This could translate into greater understanding of S&T, but also stronger concerns about societal impacts of new technologies.

- **Science:** Evolution of the hard sciences and of the philosophy of science away from certainty will continue to be a primary driver of societal change.

- **Global Communication Technologies:** Already, communication is truly distance-independent. Our routine reach is beyond our community, ethnic group and country. Global citizens cannot emerge in significant numbers without cheap and easy global communications. Now we have both. This will only intensify and accelerate the arrival of a new consciousness.

- **Global Travel:** Travel tends to broaden one's mind and soften one's judgements of others. This alone is enough to encourage it. Travel is one of the fastest growing activities and will accelerate during the period 2005-2020.

- **Communities of Interest:** Given the above, those who are coming to share a particular interest or point of view can find one another with relative ease. Different ideas and new information are now more likely to be explored, challenged or embraced.

- **Knowledge-driven Economy:** Sustained success now requires the reflexive capacity to determine whether the knowledge that one is putting to use is adequate to the task at hand in light of the best knowledge that is available and the quality of the knowledge utilized by one's competitors. A knowledge-driven economy will challenge every institution such as NRC to look afresh at the consciousness by which it conceives its future.

- **Personal Experience:** This last driver of change in human consciousness is the sum of the foregoing drivers. Human consciousness is deeply personal. A powerful experience is often enough to dislodge old conceptions and convictions. A growing number of persons are seeking to make a difference for themselves and their community of interest.

Demanding Enhanced Security

Rapidly increasing global interdependence brings with it new threats and vulnerabilities as well as new choices and opportunities. In the past decade and a half, the international security landscape has changed – we have entered into "new world instability". Many ethnic and religious tensions have erupted. Increasingly, our environment is becoming more volatile. We are facing threats of pandemics and diseases such as HIV/AIDS. There is likely to be increased conflict over dwindling natural resources. Trans-national organized crime is on the rise. Hostile cyber-activity is increasing. Not surprisingly, the world today is obsessed with security – or the lack thereof. To some extent, it is driving how we perceive the world, and how we react within it.

Continued Threats to Security Challenge our Notion of Risk and Stability

The United Nations (UN) cites six "clusters of threats" with which the world should be concerned in the decades ahead:[14]

- war between states;
- violence within states, including civil wars, large-scale human rights abuses and genocide;
- poverty, infectious diseases and environmental degradation;
- nuclear, radiological, chemical and biological weapons;
- terrorism; and
- transnational organized crime.

These threats are echoed in *Securing an Open Society: Canada's National Security Policy,*[15] tabled in Parliament on April 27, 2004. However, other strategic studies present different findings, with war between states, for instance, nowhere near the top of the list.

More states will appear from the many more "nations" that exist and have democratic rights to be self-determining. Many of these nations are fighting for statehood and these fights often pose security issues. Nuclear devices and arms are seen as significant threats to security. Decaying nuclear devices (e.g. Russia) are also a source of concern.

Eroding state capacity to deal with the privatization of conflict (terrorism) is weakening the security of the world in spite of the fact that a large proportion of the world's workforces are engaged in security-related activities (estimated at between one twelfth and one eighth of the

[14] *A More Secure World: Our Shared Responsibility*, Report of the UN Secretary General's High-level Panel on Threats, Challenges and Change, 2004. http://www.un.org/secureworld/

[15] For the National Security Policy, refer to http://www.pco-bcp.gc.ca/default.asp?Language=E&Page=publications&Sub=natsecurnat&Doc=natsecurnat_e.htm

world's workforces). Modern warfare is now less about troop deployment and more about intelligence gathering and fighting a different kind of enemy.

As Security Issues Become More Prevalent, Tensions Become More Evident

There appears to be a new age of anxiety, caused by endemic poverty, convulsive economic transitions that cause growing inequality and high unemployment, international crime, the spread of deadly armaments, large-scale population movements, recurring natural disasters, ecosystem breakdown, new and resurgent communicable diseases, and rising competition over land, water and other natural resources.[16] Moreover, the world increasingly faces conflicts defined along religious lines – dominated by the conflict between religious fundamentalists.

Megacities typically grow faster than local governments anticipate. High population density, uneven income distribution and mismanagement of social services, all prevalent in megacities, are considered breeding grounds for social upheaval.

Demographic imbalances are a significant destabilizing force. In countries torn by civil wars, such as Africa, the Middle East, and South and Central Asia, emigration and terrorism emerge. These countries have significant numbers of teenagers with limited educational and economic opportunities, ethnic and religious differences, and a breakdown of the social and ecological systems on which people depend, leading to social unrest. They face a typical dilemma of needing foreign investment to employ their citizens, but they are unable to attract foreign investment because their unemployed youth are fomenting dissent and creating unstable environments.

The profound sense of insecurity that has gripped the world for at least the past three years may grow even deeper in the years ahead. National security now includes more than just surveillance and control of our borders. It also includes safeguarding citizens and critical infrastructure from potential natural and man-made disasters. Global tensions will remain at the forefront of international concerns and will shape actions, many of which affect Canada. For instance, Canada is affected by U.S. decisions on security, the most recent issue being that no aircraft can fly over U.S. airspace without a complete passenger manifest having been fully disclosed to US authorities. Similar decisions have been made about border controls and passports.

The Environmental Challenges Faced by Nations Will be a Source of Conflict and Tension

The prospect that world oil production will begin a long decline within the next decade, just when large countries like China and India stake their claims to remaining reserves, will fuel tensions. Environmental causes of conflict are expected to become more significant as environmental deterioration increases the number of environmental refugees, which will, in turn, increase the number and scale of conflicts related to migration.

Cyber-threats Will Destabilise Communities and Disrupt Economies

Communities of interest are becoming vulnerable to cyberterrorism, power outages and information pollution. The probability of a catastrophic attack – global damages in excess of $100 billion from a chain of combined events – has risen from 2.5% for 2003 to 30% for 2004.[17] Security of IT systems and infrastructure (identity theft, service attacks, spread of computer

[16] *Worldwatch Institute website:* http://www.worldwatch.org/features/security/
[17] *2004 State of the Future*, Jerome C. Glenn and Theodore J. Gordon, Published by the American Council for the United Nations University (2004), http://www.acunu.org/millennium/sof2004.html

viruses and cybercrime – all growing) has a significant economic cost for all sectors of the economy, especially as forecast growth in e-commerce is 25% per annum.

Security of Financial Systems in Some Countries also a Risk

The security and sustainability of some aspects of the banking systems in some countries (including China, some Asian countries and some Latin American states) are seen as problematic by some commentators – bank failures destabilize communities and significantly disrupt patterns of trade.

Although Canada's domestic exposure to conflict-based threats and casualties should remain minimal, proximity to the U.S. may bring with it certain security challenges. Canada needs to ensure that its energy, water and natural resource systems are protected from security risks and threats.

Characteristics of S&T in 2020

What kind of science and technologies does Canada require in 2020 if it is to sustain success, in the context of the forces that are reshaping our world and the complex issues with which we will be faced?

Some characteristics that will begin to define S&T in 2020 include:

1. **Set in a social context**: developed within the context of an understanding of the evolution of science and its interplay with society and humanity.
2. **Reflexive**: disciplined, open, tested by others and critically self-aware.
3. **Varied in size and scope**: includes many different scales, scopes, intentions, tools, techniques and locations from curiosity-driven to project-based science; from "big science" to smaller projects.
4. **Focused on human development**: focus on the potential to contribute to ongoing human development.
5. **Integrated around big issues**: cross-disciplinary approach to strategic issues.
6. **Global**: work with the best in the world and to serve the wider world.
7. **Transparent**: meeting demands for greater transparency and accountability.
8. **Committed to knowledge-in-use**: commitment to get information into routine use within our society and economy, and to do so as quickly as possible.
9. **Foresighted**: practice of strategic foresight is inherent.
10. **Selectively focused**: co-operate, learn from and build on the work of others, focused on what is of importance to Canadians.

PART 2 – GLOBAL CHALLENGES IMPACTING CANADA

Globalization, the "growing interconnectedness reflected in the expanded flows of information, technology, capital, goods, services and people throughout the world," is a force so ubiquitous that it will substantially shape all other major trends in the world of 2020. Although that interconnectedness of economic growth and technology innovation has made it possible for three to four billion people to have relatively good health and living conditions today, unless our financial, economic, environmental and social behaviours are improved along with our industrial technologies, the long-term global future could prove challenging. After examining various themes on global issues as listed in the figure below, it was clear that there are three overriding critical themes on which the world will be focused over the next 5-15 years: energy, the environment, and health and wellness.

Energy

Overview

Some would cite energy as the number one problem facing humanity in the next 50 years,[18] and further suggest that once this issue is solved we will be well on the way to solving all others. According to the International Energy Agency's World Energy Outlook 2004, if governments

[18] R. E. Smalley, Rice University, presentation at the 27th Illinois Junior Science and Humanities Symposium, April 3, 2005, http://cohesion.rice.edu/NaturalSciences/Smalley/emplibrary/040305%20Illinois%20Science%20Symposium.ppt

maintain policies in force as of mid-2004, the world's energy needs will be almost 60 percent higher in 2030 than they were in 2004. Fossil fuels will continue to dominate the global energy mix, meeting most of the increase in overall energy use.[19] Some predict that Hubbert's Peak[20] will be reached by 2010 (e.g. Exxon Mobil Corporation), while others say that we have passed it already, and still others suggest that it will not occur until 2035.

Overall, the Earth's non-renewable energy resources appear more than adequate to meet demand until well beyond 2020, though it is less certain how costly and damaging it will be to extract and deliver those resources to consumers**.** As China, India and other economies gain strength, global competition for energy supply will increase. Serious energy security concerns could emerge, causing sensitivity to vulnerability of supply disruption. On the other hand, vulnerability to supply disruptions could fall as more options (ways and means) will exist for supplying it. Either way, a reliable source of energy will be critical for energy-importing countries such as the United States, China, Japan and Europe.

Additionally, current methods of energy production and usage are detrimentally affecting our environment – greenhouse gas emissions are contributing to climate change, and waste from energy production is a significant polluter. Consequently the need for non-polluting energy sources is becoming increasingly important.

Energy Production and Consumption

While there is a consensus that the world's supply of fossil fuel will be adequate to 2020, there is nonetheless a focus on improving the efficiency and cost of its extraction, while also decreasing the environmental burden of those activities.

There is likely to be a resurgence of nuclear power as a supply response to growing energy demand. China and France are already embracing these technologies (China expects to double its proportion of power supplied by nuclear generation by 2020; translating into 30 new plants). However, there is resistance to nuclear power by many environmental groups who fear the threats posed by nuclear plants to communities and the problem of nuclear waste disposal.

Worldwide, the technologies needed for solar, wind and wave power are being developed. Fuel cell technology is advancing. Geothermal and hydrology applications are also being explored. While these newer technologies are not expected to become a primary source of the world's energy by 2020, advances in their development mark the beginning of a greater awareness of sustainability, environmental impact and energy security.

Developed countries are finding it increasingly difficult to meet energy needs through large, centrally-located generating stations. It is foreseeable that we will move to distributed energy – a networked system of small (single family solar, single farm biogas), medium (bioenergy generators, small hydro) and large generating stations, with most, but not all, contributing electricity to a grid.

Numerous products and processes that result in lower energy consumption will become more prevalent: more highly insulated buildings, hybrid and more efficient vehicles, and co-generation opportunities with high-energy-consumption processes (e.g. cement manufacture).

---

[19] International Energy Agency's World Energy Outlook 2004. http://www.iea.org/textbase/npsum/WEO2004SUM.pdf

[20] The Hubbert Peak, also known as peak oil, is an influential theory concerning the long-term rate of conventional oil and other fossil fuels production and depletion. It predicts that future world oil production will soon reach a peak and then rapidly decline.

Canadian Situation

At present the energy sector is a key component of the Canadian economy, contributing over 7% to our GDP and employing nearly 300 000 Canadians. Canada now ranks as the fifth-largest energy producer in the world - only the United States, Russia, China and Saudi Arabia produce more.[21] Canada's oil reserves, totalling 180 billion barrels, are second in the world, placing Canada ahead of Iraq and Iran and behind Saudi Arabia.[22] About 40 percent of Canada's primary energy production is currently natural gas. Oil and hydropower each make up a little less than 20 percent of the market, with the remaining production split between coal and nuclear energy. We are the largest foreign supplier of energy to the U.S. While demand for energy is growing in Canada, our vast natural resources, much of which remains untapped, will provide enough energy supplies for many years to come.[23]

Canada has an advantage when it comes to nuclear power. We are one of four key nuclear providers (with the U.K., Russia and U.S./France) and research powerhouses in the world, and one of just a few countries that sell electricity-producing reactors. Domestically, nuclear power generates approximately one eighth of Canada's electricity.

Having already faced energy constraints in Quebec and Ontario, Canada will likely accelerate its pursuit of alternative and distributed energy options. This trend will likely begin with individual or pockets of consumers installing their own energy-generating capacity to ensure their security of supply. The next phase will be for some of these sites to connect to the transmission grid. These trends have already started in Ontario.

Currently, NRC, Natural Resources Canada (NRCan), and Canadian industry are investing in, and promoting, the development of renewable energy resources, such as hydrogen as an alternate fuel. Although Canada does not yet have a national energy policy, in February 2005, Prime Minister Paul Martin re-mandated the National Round Table on the Environment and the Economy (NRTEE),[24] which he has charged with, among other things, developing advice on a long-term strategic energy and climate change policy for Canada that sets the course for the 21st century economy to 2030-2050. NRTEE's report, expected in 2006, will deal with nuclear, traditional and alternative sources of energy.

Canada has signed the Kyoto accord and is thus committed itself to reducing our greenhouse gas emissions to 6% below 1990 levels. A significant part of Canada's efforts to reach those levels will be devoted to reducing our energy consumption and major investments supporting Canadian innovation in cleaner fossil fuels and hydrogen fuel cells**.**

S&T Applications to Address Energy Challenges

Some S&T applications that are considered relevant to the energy challenges of the future are:

- Improving the productivity or efficiency of extraction and refinement processes for non-renewable energy resources;
- Reducing the amount of water and energy now used to produce non-renewable energy resources, including manufactured oil;
- Co-generation (capturing the energy from the process itself);
- Carbon sequestration – capture and storage technologies;

[21] http://www.locationcanada.com/art_5.htm
[22] The federal government's *Invest in Canada* website at http://investincanada.com/english/View.asp?t=&x=511
[23] http://www.locationcanada.com/art_5.htm
[24] http://www.nrtee-trnee.ca/eng/index_e.htm

- Advancing traditional alternatives: advanced nuclear reactor designs, nuclear fuel and hydroelectric power, and advances in fusion;
- Advancing new renewable alternatives by both stationary generation (hydrogen, solar power, wind power, biogas, tidal, and geothermal) and mobile generation (biodiesel, biofuel, fuel cells, micro fuel cells);
- Energy storage;
- Technologies that support distributed energy;
- Energy monitoring, control and management systems; and
- Reducing the amount of water needed for fossil fuels' extraction and production.

Environment

Our environment is "global". We have a responsibility to protect our shared environment and precious natural resources. Thus, it is only by working globally that we can begin to eradicate the damage already done and ensure a safe, clean and healthy environment for those who follow.

Water

"Of all the social and natural crises we humans face, the water crisis is the one that lies at the heart of our survival and that of our planet Earth".[25]

Only 2.53% of the world's water is fresh, and two-thirds of that is locked up in glaciers and permanent snow cover. Available freshwater is being significantly reduced by pollution. As with most global issues, it is the poor who are most affected, with 50% of the population in some developing countries exposed to polluted water sources which result in water-related diseases being among the most common causes of illness and death. In 2000, for example, there were two million deaths due to water sanitation and hygiene-associated diseases, and one million deaths caused by malaria. The majority of those affected are children under five.[26]

Today, agricultural irrigation accounts for 70% of all water withdrawals, but that amount is likely to increase by 14% in the next 30 years, when it is expected that all land with irrigation potential will be in use. With populations and the per capita use of water increasing, water for all uses will become scarcer and lead to growing tension among demands from the rural and urban areas, the domestic and industrial sectors, irrigation and energy production, etc. Water management of the future will have to accommodate all such competing interests.

There will be intense competition for access to water. Water will continue to be the cause of conflict between countries (as it has in the Middle East) and in big cities. The struggle to control water resources will shape human political and economic history. Scientists and experts at the Stockholm World Water Forum in 2001 concluded that shortages of drinking water could affect one-third of the world's population by 2025 and ignite hostilities between regional haves and have-nots.

Water is about to become the strategic material of the 21st Century.

[25] Koïchiro Matsuura, Director-General UN Educational, Scientific and Cultural Organization (UNESCO).
[26] "Water for People Water for Life, The United Nations World Water Development Report (Executive Summary)" (2003), http://unesdoc.unesco.org/images/0012/001295/129556e.pdf

Climate Change

It is generally accepted that, largely as a result of increased greenhouse gas emissions, our world has changed. The global warming trend (the average temperature of the earth's surface has risen by 0.6^{o} C since the late 1800s and is expected to undergo a rapid and profound change with an increase of another 1.4 to 5.8^{o} C by the year 2100), has already begun to have noticeable impacts on our environment. Several researchers however take the view that global warming will be followed by a period of significant global cooling.

Stationary fuel combustion is the largest single contributor to greenhouse gas (GHG) emissions. In terms of CO_2 production in OECD countries, the contributors are: energy production and transformation (34%); transport (27%); industry (17%); residential and commercial (13%); and other sectors (9%). In most OECD countries, the fastest growing contributor of GHG emissions is the transportation sector. Within that sector, although one of the smaller contributors, emissions from the aviation sector are the fastest growing. In Canada, large final emitters contribute 50% of GHG emissions.

Due to climate change, our oceans are more acidic, with corresponding consequences for marine life. Vast areas of forests have experienced droughts. Catastrophic forest fires are now an annual event. The ranges for disease carrying mosquitoes are expanding. Numerous plant and animal species are not expected to survive the next 100 years. And, our weather has become more severe – just to mention a few of the already exhibited impacts. Humankind recognizes that we must address the root cause of these problems.

Natural Disasters

It is expected that climate change will result in more severe and more frequent natural hazards in the future.[27] Natural disasters (i.e. those resulting from floods, droughts, storms, earthquakes, fires and other events) are on the rise – in terms of severity, numbers and economic impact. Annual economic losses associated with natural disasters averaged US$75.5 billion in the 1960s, US$138.4 billion in the 1970s, US$213.9 billion in the 1980s and US$659.9 billion in the 1990s.[28]

Pollution

Globally, there are several recurring concerns about pollution, dominated primarily by air and water pollution. In countries with a developed industrial base, the emphasis is on maintaining activities while reducing environmental impact. Airborne pollution issues are primarily the result of human activity involving cars, aircraft and power generation, although forest fires are a significant pollution concern across the Indian and Pacific Ocean countries. Europe also emphasizes water pollution as a significant issue, arising from agricultural runoff and poor industrial practices.

There are several trends that contribute to the urgency and magnitude of current environmental issues and that will have a dramatic impact on the market for environmental technologies: growing global population and urbanization, migration, the expanding global economy and increased industrialization.

[27] http://www.environmenttimes.net/article.cfm?pageID=129
[28] UN Report, Reducing Disaster Risk: A Challenge for Development, 2004, http://www.undp.org/bcpr/disred/rdr.htm

Canadian Situation

Canada has as much as 20% of the world's supply of freshwater, but we consume 350 litres of water a day per capita, second only to the U.S. as the most profligate wasters of water in the world. (A global citizen needs only between 20 and 40 litres of water a day for drinking and sanitation).[29]

Canada's Federal Water Policy, recognizing that water is becoming a critical issue and that we must begin now to plan for the future, is based on the following principles: water pricing, science leadership, integrated planning, legislation and public awareness.

PollutionWatch indicates that in 2002 alone, over four billion kilograms of pollutants were released into Canada's air, soil and water, representing an increase of almost 50% over 1995.[30] By far the greatest proportion of this pollution (92%) was released into the air. Brownfields, and abandoned, idle or underutilized commercial or industrial properties where past actions have caused known or suspected environmental contamination may number as many as 30 000 in Canada.[31]

In adopting the Kyoto Protocol, Canada pledged to reduce its greenhouse gas emissions by six per cent below 1990 levels by the five-year commitment period of 2008 to 2012. Recognizing that meeting Canada's Kyoto commitment will require concerted efforts on a number of fronts and that activities to date have not generated the required results, the Federal Budget 2005 allocated approximately $5 billion dollars ($3 billion of new money) to fund climate change related activities. In April, with its revised Kyoto plan, the government pledged to spend $10 billion over seven years to help Canada cut its average greenhouse gas emissions by 270 megatonnes a year in the five years 2008 to 2012. (We are producing 750 megatonnes per year). Some, however, question the plausibility of such a goal.

Canada is far from united on the appropriate Kyoto approach. Although all political parties support the promotion of alternative energy and fuel sources, there is a schism between those parties that oppose Kyoto on principle (Conservatives) but want to "initiate a review of all environment and energy initiatives, including the Kyoto Protocol"[32], and those that support Kyoto, but feel the Liberal vision doesn't go far enough (NDP) and those that call for an increased focus on new and alternative technologies (Green Party). The Bloc Quebecois produced its own Kyoto plan – emphasizing regional assets such as hydro and wind power as significant sources of clean energy. Provinces have differing views as well. Alberta, in particular, expressed strong reservations about the federal plan, released its own, and is undertaking significant initiatives to address climate change.[33]

Some S&T Applications to Address Environmental Challenges

S&T applications that are considered relevant to the environmental challenges of the future are:

- Water quality and treatments (purification, desalinization);

[29] "Selling Canada's Water", a CBC News in-depth analysis, August 2004, http://www.cbc.ca/news/background/water/
[30] http://www.pollutionwatch.org/pub/pollutionwatch%20national%20report_english_ebook.pdf
[31] Cleaning up the Past, Building the Future: A National Brownfield Redevelopment Strategy for Canada, http://www.nrtee-trnee.ca/Publications/HTML/SOD_Brownfield-Strategy_E.htm
[32] Conservative Party of Canada, Policy Declaration, March 19, 2005 – Policy 42, ii) a.
[33] http://www3.gov.ab.ca/env/climate/accomplishments.html

- Water management in Canada (evaluation, distribution, availability, quality and requirements) and water security;
- Development of rapid, reliable and sensitive analytical techniques for air, water, effluents and emissions;
- Advances in environmental modelling, monitoring and reporting with respect to climate change, biodiversity, and atmospheric and other environment applications;
- Improving alerting systems for weather and water events;
- Alternative fuel sources for public and private transportation;
- Lighter weight materials and production methods for transport;
- Developing less environmentally intrusive means of extracting non-renewable energy resources;
- Clean coal – technologies that "scrub" the emissions gases, sequester the carbon by-products;
- Bioremediation and other reclamation technologies that can be applied to brownfield sites;
- Sustainable development in agriculture and forestry, including the use of environmentally-friendly biocontrols, pesticides and herbicides, improved husbandry methods, new crops, and improved animal and aquaculture methods;
- Building design and construction technology, such as improving building techniques to minimize energy usage (particularly in light of Canada's experience in northern climate construction); and
- Waste reduction and recycling.

Health and Wellness

Aging Population, Rising Incidences of Infectious Diseases and Pandemics, and Health Determinants

The world's median age is increasing, with life expectancy at birth expected to reach 81 years for men and 86 years for women by 2041.[34] However, over 40 countries (including many African countries, central Asian states and Russia) are projected to have a lower life expectancy in 2010 than they did in 1990.[35]

Declining fertility rates and increasing lifespans are causing an increase in the median age of the world's population. That, combined with the aging of the "baby boom" generation, will result in increased numbers of persons over 65 in the period 2010 to 2030, and by 2050 the number of older persons (i.e. over 65) in the world will, for the first time in history, exceed the number of young (i.e. under 15). The greater number of people living longer and demanding better quality lives will represent a significant challenge to our public health systems. We will need to emphasize disease prevention, lifestyle changes, and alternative healthcare systems.

On the other hand, the world is facing an onslaught of type II diabetes in younger and younger people and an epidemic of obesity. Recent reports suggest that this will result in "the first time in a century that children can look forward to a shorter life expectancy than their parents". However, the Centre for Disease Control recently acknowledged that there are not yet proven scientific methods to validate such a finding. The obesity epidemic is not just in younger people. There has also been a sharp increase in obesity among people now in their sixties, which,

[34] Health Canada in collaboration with the Interdepartmental Committee on Aging and Seniors Issues, *Canada's Aging Population.* Ottawa: 2002.
[35] U.S. Census Bureau.

according to the National Institutes of Health (NIH),[36] may be one of the reasons the gains in U.S. life expectancy at older ages have been less than those in other developed countries. It is interesting to note that more than 20 other developed nations have higher average life expectancies than the U.S.

The world is also facing pandemics, the rise of communicable diseases, a resurgence of old diseases (e.g. malaria and tuberculosis) and new strains of old diseases such as cholera and meningitis. The greatest influenza pandemic (1918-919) caused an estimated 40–50 million deaths worldwide. During recent years, we have seen SARS and influenza outbreaks. Experts believe it is simply a matter of time before the next pandemic. Given the high level of global traffic, pandemic viruses can spread rapidly, leaving little or no time to prepare and resulting in 2 to 7.4 million deaths globally, with developing countries hardest hit. On the other hand, we may find by 2020 that something we think in 2005 is terrible will be the key to the prophylactic for the pandemic of the next decade.

The global HIV/AIDS pandemic continues to be one of the greatest challenges of our time. Worldwide, over 40 million people are now infected and, each day, 14 000 more are added to their ranks. We are struggling to judiciously balance intellectual property and free-trade rights against the moral obligation of ensuring access to life-saving medicines at affordable prices for developing countries.[37]

On average, over 17 million people die each year from infectious diseases, many of which are classified as emerging or neglected. Ninety-five percent of those deaths are in developing countries.[38] Since the 1970s, at least 30 new infectious diseases have emerged for which there are no effective treatments.[39] We are seeing resistant strains of bacteria – recent examples include vancomycin-resistant infections of *Staphylococcus aureus* in the United States and Japan.

World poverty is a significant factor in health and wellness. More than 800 million people go to bed hungry every day, 300 million of whom are children; and, perhaps surprisingly, only 8% of those are victims of famine or other emergency situations. In addition, worldwide every year 11 million children die – most under the age of five with more than six million deaths from completely preventable causes such as malaria, diarrhea and pneumonia. Progress in poverty reduction has been concentrated in Asia, and especially, East Asia. In *all the other regions*, the number of people in extreme poverty has increased. Poverty is an issue for some Canadians, especially amongst Aboriginal peoples and children (Canada currently ranks 19th out of 26 OECD countries in terms of child poverty).

World agriculture produces 17 percent more calories per person today than it did 30 years ago, enough to feed everyone in the world despite a 70 percent population increase. The principal problem is that many people in the world do not have sufficient income to purchase food or land to grow enough food. GM crops carry the potential of lowering pollution and increasing economic yield, yet GMOs are strongly resisted in some economies, including the developing world. With our agricultural production capabilities, our transportation systems, and our

[36] *Obesity Threatens to Cut US Life Expectancy, a New Analysis Suggests,* NIH Press Release, March 16, 2005, http://www.nih.gov/news/pr/mar2005/nia-16.htm
[37] *A Fair Globalization: Creating Opportunities for All,* Report by the World Commission on the Social Dimension of Globalization, February 2004 http://www.ilo.org/public/english/fairglobalization/report/index.htm
[38] *Biotechnology and Sustainability: The Fight Against Infectious Disease*, OECD Report, 2003, http://www.oecd.org/dataOECD/23/23/2508407.pdf
[39] *Ibid.*

commitment to the Millennium Development Goals, the world could potentially eradicate this problem.

The Coping Capacity of the Health-care Systems

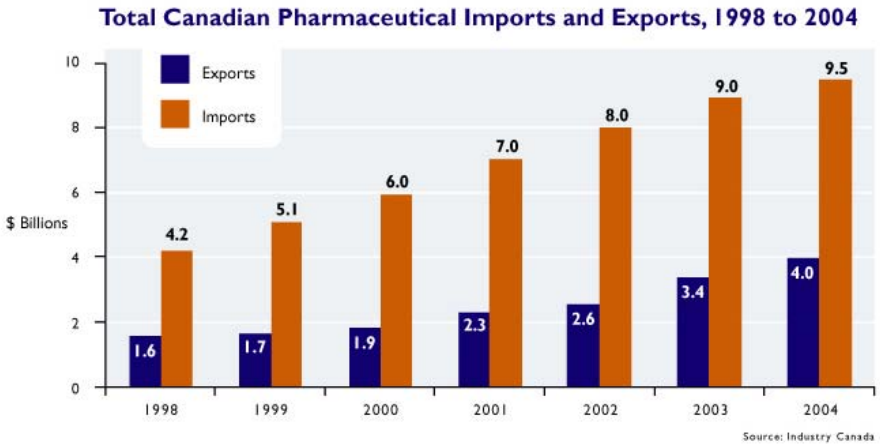
Health-care costs are steadily rising. According to OECD data,[40] the cost in Canada, in U.S. dollars per capita, rose from $289 in 1970 to $2931 in 2002. For the U.S. it was $347 in 1970 and $5267 in 2002. Similarly, in Australia, costs rose from $684 in 1980 to $2504 in 2001. Similar trends were noted in all countries for which data were collected. In addition to health-care costs and impacts on people, health and wellness issues affect productivity and, therefore, the economy.

Canadian Situation

Canada has placed an emphasis on its health challenges, with total R&D funding into pharmaceuticals and disease knowledge (including the basic sciences) increasing from $1.2 billion in 1999 to $2.3 billion in 2004. Our national health R&D infrastructure design is also an indicator of this emphasis, with almost $2 billion of the total health research activity conducted in hospitals and universities.

In 2004, health-care spending reached $130 billion or $4 078 per person. In addition to the overall increasing health-care costs, we will face a shift in health-care requirements from acute chronic care to care for age-related degenerative diseases. If we accept the analysis of the Fraser Institute in its "How Good is Canadian Health-care? 2004 Report", then in 2000/2001 those aged 65 and over (representing 12.5% of the population) consumed 42.7% of the total health-care expenditures.[41]

The most significant drivers of increased costs from 1999 to 2004 in Canadian health-care systems were expenditures on drugs and on salary costs for medical professionals. Canada ranks as the eighth largest pharmaceutical market in the world and we are the second fastest growing market globally after China. However, as demonstrated[42] in the graph from Industry Canada below, Canada is in an increasingly higher trade deficit situation vis-à-vis pharmaceuticals.



[40] http://www.oecd.org/dataoecd/13/53/31963451.xls
[41] *How Good is Canadian Healthcare?* 2004 report, The Fraser Institute, Nadeem Esmail and Michael Walker, http://www.canada.com/national/nationalpost/news/onlineextras/fraserreportonhealthcare/howgood-xsumm.pdf
[42] From Industry Canada Fact sheet on Canadian Pharmaceutical Industry Profile.

Canadians take pride in their health-care system – but without reform, the cost of traditional health-care will continue to rise at an unsustainable rate. There are signs of changes however. Under the 2003 Canada Health Accord, additional investments in diagnostic services were provided, national targets and metrics on waiting times were established and provinces were mandated to provide an annual report outlining their success in achieving these metrics. Recently, the Supreme Court of Canada overturned a Quebec law preventing people from buying private health insurance to pay for medical services available through the publicly funded system, opening the door to further expansion of private health-care.

Some S&T Applications to Address Health and Wellness Challenges

S&T applications that are considered relevant to the health and wellness challenges of the future are:

- Advancing our understanding of challenges related to the aging population, including chronic diseases, Alzheimer's, cancer, heart disease and diabetes;
- Innovations in early diagnosis (including imaging and non-imaging diagnostic equipment); predictive tests, maintaining wellness, and health-care delivery;
- Genomics, proteomics, metabolomics, and other "omics" that have the potential to advance our ability to treat many medical challenges;
- In the area of pharmaceuticals and biopharmaceuticals we can expect the development of more targeted drugs with higher efficacy, new drugs and vaccines (including technologies to expedite their development) to address infectious diseases, nano or molecular drug delivery structures, etc.;
- To reduce costs of drug development, we will see "in silico" drug development (systems biology) as the basis for a new paradigm for drug discovery and development, new bioprocesses for the production and purification of biopharmaceuticals, and advances in novel drug production technologies using transgenic animals and plants;
- In the area of health services, we can expect advances in telehealth, remote surgery, devices and infrastructure that support the development of care services (e.g. home care); and
- We can expect greater use of ICT in terms of electronic health records, registries and databases, communications infrastructure, bioinformatics and high-performance computing, decision support software and interoperable measurement systems.

PART 3 – GROWING GLOBAL ECONOMIC COMPETITION

The Changing Global Market System

Today, money, technology and raw materials move evermore swiftly across national borders. World trade has grown from about US$580 billion in 1980 to a projected US$6.3 **trillion** in 2004, an 11-fold increase.[43] Trade is expected to continue growing impressively, increasing 80% by 2020 over 2000 levels.[44] We are in the midst of major changes in the shape, structure and dynamics of the global economy. The period 2005-2020 will be characterized by changing and migrating demographics, by significant shifts in the markets for goods and services, and by products'/services' accelerated life cycles. To excel in these emerging market realities, organizations must demonstrate agility and adaptability, competently manage their intellectual property and embrace globally-distributed operations. The free flow of innovation and capital will determine the success/failure of industries and nations.

The expansion of economies in India and China presents a fundamental challenge to the continued economic viability of so-called "middle power" countries such as Canada. By 2020, given present trends, China will have an economy that rivals that of the United States in size. India will achieve this mark sometime in the 2040s and Russia may again emerge as a major player. Some predict a trade war between China and U.S.; that world trade will become more vulnerable to the political situation in China and India, and to the relationship between China, India, the U.S. and the European Union (EU); and that more countries will "offshore" basic production and move to more value-added production over time. The traditional strong trading nations, such as the UK and France, will weaken. However, this resetting of the balance of power and an overall "larger global pie" represent interesting opportunities for Canada because of our exceptional natural resource endowments – water, energy, minerals, and arable land.

A country's place in this new world is highly dependent on its social and economic well-being. Currently, about two thirds of the world's population lives in countries connected to the global economy. Countries not so connected will continue to suffer, e.g. Sub-Saharan Africa, which currently has the largest share of people living on less than $1 per day. Even by 2020, the benefits of globalization won't be global. Gaps will widen between the benefiting countries (economically, technologically and socially) and underdeveloped nations. The greatest benefits are expected to accrue to countries that access and adopt new technologies. Increasingly, there is a stronger recognition that S&T is required to survive in the global world and, fortunately, also an acknowledgement that the stronger economies must use their capacities (e.g. S&T) to assist less-fortunate nations – to combat the many "divides" in the world.

While globalization provides new sources of competition and market opportunities, liberalizing the trade process is difficult and slow. The World Trade Organization (WTO), with 140 members and a large range of issues under its purview, is becoming increasingly bureaucratic and slow. We can expect an escalation in trade disputes and challenges to the WTO / General Agreement on Tariffs and Trade (GATT) regime throughout the period 2005-2020 (60 major disputes in 2005). Some believe that non-governmental organizations (NGOs), such as the WTO, the World Bank, and the IMF are going to become less important in the future, as globalization is going to be increasingly driven by "the individuals who understand the flat world, adapt themselves quickly to its processes and technologies, and start to march forward – without any

[43] *Long Term Global Challenges for Europe*, released March 2005, http://www.hm-treasury.gov.uk/documents/international_issues/int_global_index.cfm
[44] *Mapping the Global Future*, Report of the National Intelligence Council's 2020 Project, http://www.foia.cia.gov/2020/2020.pdf

treaties or advice from the International Monetary Fund (IMF). They will be every color of the rainbow and from every corner of the world."[45]

Canadian Situation

Fundamental to our identity and place in the world, Canada is a trading nation – highly dependent on the way the world works, and on the priorities and actions in other countries. One of the more fundamental global dynamics is the emergence of the knowledge economy, accompanied by the expansion of China, India, Brazil and Mexico. The shifting economic power structure presents a fundamental challenge to the continued economic viability of "middle power" countries such as Canada.

The liberalization of international markets presents both an opportunity and a challenge for Canada. We are currently the fifth largest global exporter and importer of goods and services. The percentage of our GDP dependent on trade is higher than any other OECD nation. The US is the recipient of over 80% of our exports. The Canadian economy will continue to be dominated by the North American market for the foreseeable future. However, the US reliance on foreign borrowing has created a global imbalance which some are suggesting may be addressed by a more protectionist stance by the US. This could have significant repercussions to our economy.

By gaining access to global export markets, Canada also makes itself vulnerable to increased international competition for capital, labour and market share. We face the confluence of challenges that arise from our existing reliance on manufacturing activity, a significant growth in China's manufacturing base, expanding free trade agreements, the emerging knowledge economy in India, and the desire on the part of both of these countries to generate novel intellectual property (IP) and to move up the value capture chain (in industries ranging from telecommunications to pharmaceuticals).

An overreliance on U.S. markets when the major global markets will have shifted significantly would be a dangerous economic strategy for Canadian enterprises. Canada will need to adjust to these shifts and explore new export markets such as China, India, Brazil and Mexico. Canada will also need to be adaptive to sudden disruptions in the pattern of trade in light of the potential for trade disputes or sudden changes in political conditions in emerging large markets. Canada faces the real potential to be reduced to insignificance or even irrelevance in the global marketplace. By 2050 Canada will be providing less than 1% of the world's GDP, while China, India and the US will between them generate 63.5%. We will have to work hard to secure our status in the world. [46]

Industrial Challenges

Economic Benefits from S&T

As the global economy transitions from being resource-based to being knowledge-based, and as manufacturing jobs increasingly migrate from developed countries to developing countries, developed countries must maximize the benefit from their knowledge-creation potential. Accordingly, there will be an increasing demand for economic benefits from S&T and innovation that is more than the mere development of new technologies, or even their application in new products and services, but which goes through to the sustainable diffusion of those new

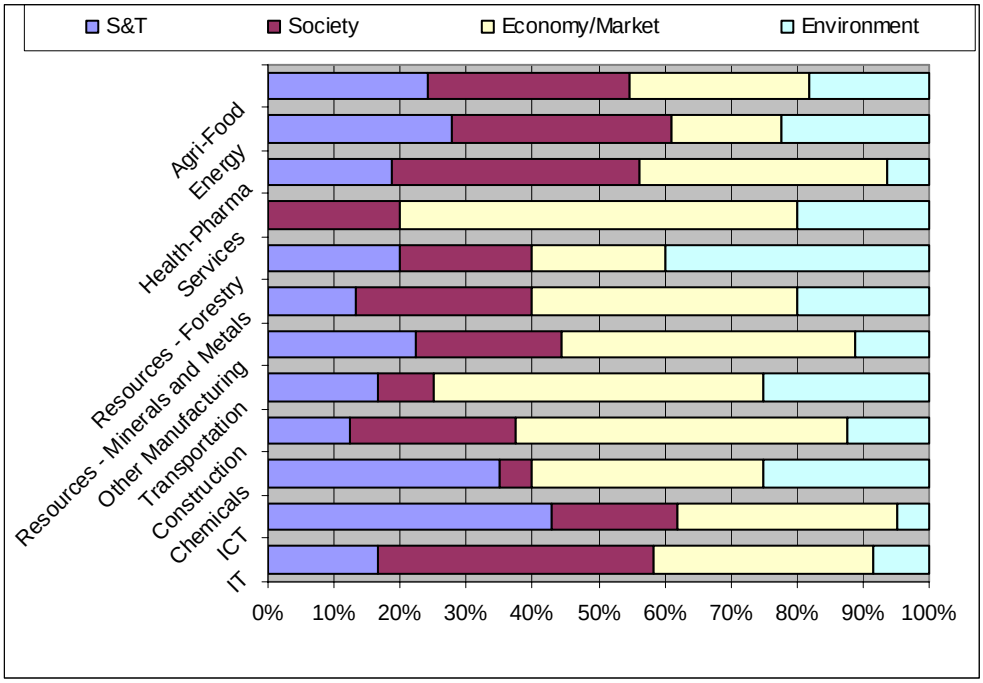
[45] *The World is Flat*, Thomas Friedman, 2005.
[46] Estimates from Goldman Sachs. See Crane, D. (2005), Canada in a Shifting World. Department of Foreign Affairs and International Trade Canada.

applications into the marketplace. Only then can new technologies address the challenges of the day – and bring economic and social returns to their creators.

Factors Affecting Industry Performance

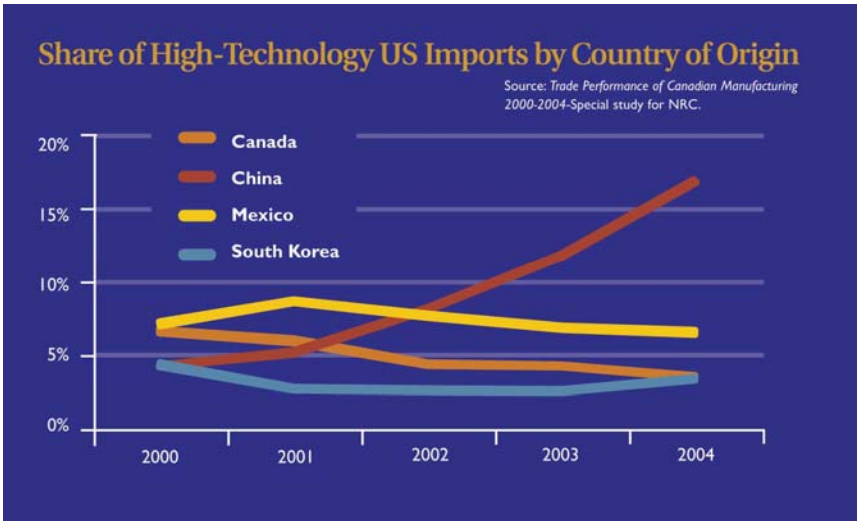
The review of factors affecting the performance of Canadian industry indicates the high influence of economic factors on business. These factors include competition from low cost supplier countries such as China, the impact of rising input costs and changes in competition patterns in industry. However, there is a growing importance of environmental considerations in sector performance, including concerns about hazardous emissions, environmental stewardship, reduction in GHG emissions and more general moves toward sustainable production. A number of important society factors also emerged, including the influence of an aging society on buying habits, the increase in security following 9/11, and changes that pervasive information and communications are creating. The figure below illustrates the relative importance of these factors on several industry sectors. It should be noted that S&T was not identified as a major driver for the services sector. This large sector undertakes little formal R&D and has an innovation process driven by technology adaptation and organizational change.

Relative Influence of External Factors



Shifting Trade Patterns

An analysis was conducted to determine how shares of the North American market have changed over recent years and particularly, if lower labour cost countries – China, Mexico and South Korea – have benefited. Results of the analysis indicate that China has gained significant market share in North America and every other country has lost. An analysis in 2004 by Industry Canada indicated that penetration by Chinese exports was occurring in sectors where there was limited Canadian production and vice versa. In the high-technology sector China's share rose by 11% while Canada lost 3% and Korea and Mexico each lost 1%.



R&D Investment and Receptor Capacity

A ratio of 70:30 of private/public investment in R&D is considered a good benchmark within OECD countries. Against this benchmark, Canadian private R&D is much lower (53%) and is declining, as are the number of companies making such investments, despite one of the most generous R&D tax regimes. In 2001, Canada had only 228 "R&D leader" companies accounting for almost 80% of Canada's private sector R&D. This trend will continue through 2020, straining publicly-funded R&D facilities. Furthermore, as fewer people are active in the workforce, the rate of savings will decline. McKinsey & Co, amongst others, predict a significant decline in available venture capital starting in 2010 and falling sharply thereafter.[47] However, fighting the 'tsunami' that is globalization will only result in defeat. Instead, we need to react, adapt, be agile with our context and find the best ways ahead. Fortunately, human beings are resilient and resourceful.

Canada's private sector is dominated by SMEs, 98 percent of which have fewer than 100 employees. Although SMEs can be nimble, receptive and adaptable, they generally have limited receptor capacity to absorb R&D advantages along with a limited capacity to adjust to rapid liberalization of the economy. This SME reality of Canada's economic composition must influence how we consider the innovation system and technology commercialization.

Global Supply Chains

No longer do individual firms simply compete against each other. Competitiveness is now one supply chain against another. Global supply chains are the dominant force in business today, and participation within a chain is critical for businesses. However, there are some sectors, such as food and commodities, where supply chains may function as an oligopoly (a market shared by a small number of large players), forcing difficult business terms on smaller suppliers. For SME businesses, whether they are in the agri-food, aircraft or automotive sector, participation in such chains brings benefits. However, SMEs must deal with a host of issues as well: certification requirements, protection of IP, meeting the IT interoperability requirements of the chain, threats of a major supply chain reducing the number of suppliers, and the internationalization of supply chains which often requires that local production be established wherever the major firm establishes major production (e.g. automotive sector). In addition, large

[47] Farrell, D., Ghai, S. and Shavers, T. (2005) *The Demographic Deficit – How Aging Will Reduce Global Wealth*. McKinsey Quarterly, April 8, 2005.

customers are demanding risk sharing of product development, downloading more and more functions on SMEs that may lack R&D or product development capabilities.

Clusters

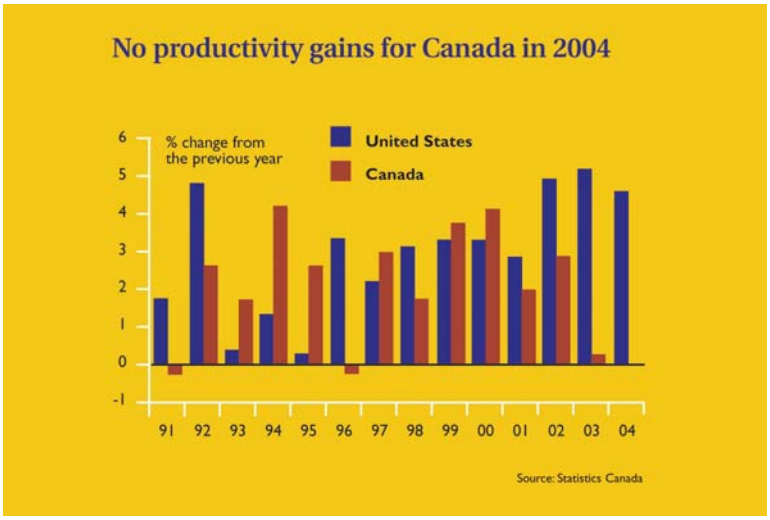
One of the realities of an SME economy is that the ecosystem necessary for them to thrive requires a strong regional or cluster focus – SMEs do not often have geographically distributed operations. In the period between 2005 and 2020, we will see the ebb and flow of clusters. Some will grow and others will decline. It will be difficult to pick "winners and losers". What is known, however, is that clusters attract both HQP and capital and become effective as a means of sustaining an industry sector over time.[48] For example, there is a strong automotive cluster in Southern Ontario that provides a pool of labour and effective access to markets and capital. Although not all firms will be "cluster connected", there will be a growing concentration of industries in clusters.

What will change between 2005 and 2020 is the regional nature of these clusters. Currently, competitive advantage is seen to be linked to regional factors – local access to focused R&D, HQP and related infrastructure. As more manufacturing takes place in India, China, Mexico (so called "offshoring") and other countries and knowledge moves faster globally through ubiquitous and semantic technologies, clusters will become more global – a network or "constellation" of global centres of competence.

Productivity

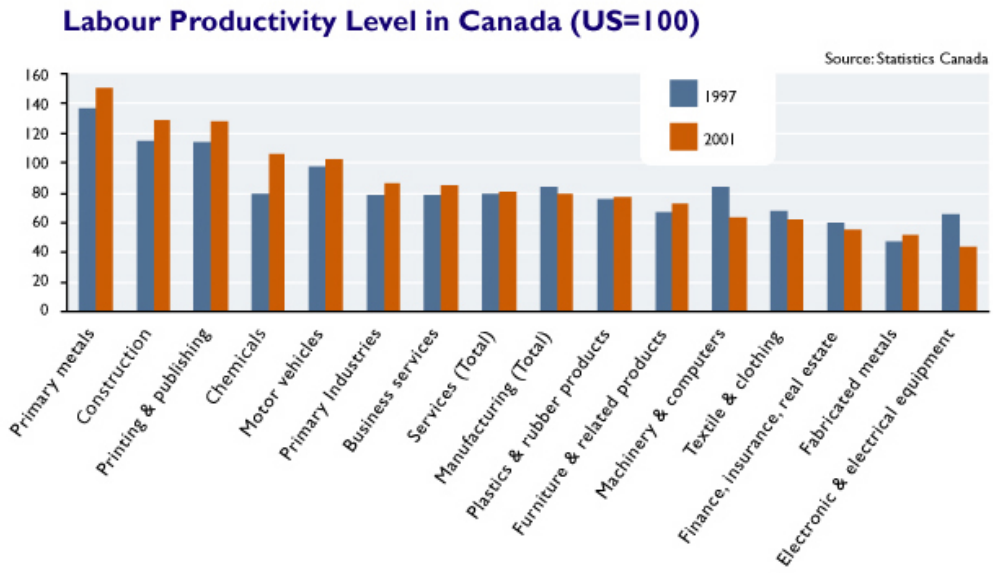
Productivity will shape the competitive position of nations and low productivity will lead to lower standards of living faster than has heretofore been the case. Canada's productivity is declining and is currently ranked 13th in the world (a fall from second place) in the OECD (2004 data) - going from an average of 4% growth per year in the period 1946-1973 to 1.4% in the period 1973-2003.

According to Statistics Canada, in 2004, Canadian businesses recorded their worst performance in labour productivity growth in eight years. The graph below (from Statistics Canada) provides a comparison of productivity growth rates between the US and Canada over the period 1991 to 2004. While the U.S. is increasing its productivity, Canada is falling further behind.



[48] Solvell, O., Lindqvist, G. and Ketels, C. (2003), *The Cluster Initiative Greenbook*, (mimeo)

In terms of particular industry sectors, the graph[49] below compares labour productivity[50] gains and losses for the years 1997 and 2001. It is worth noting that those sectors with poor productivity are the ones in which there are a larger portion of smaller firms that, on average, probably spend roughly one-third what comparable US firms do on R&D.



Productivity – Manufacturing Sector

Labour productivity growth in the Canadian manufacturing sector, the battleground of fierce international competition, has been considerably lower than that of the U.S. since 1995, hovering around 75% of that found in the U.S.[51]. Recent estimates from the Conference Board of Canada place the productivity gap between Canada and the US at US$6,000 per Canadian due to lower labour productivity and lower investments in R&D and capital equipment than the US. The recent large appreciation of the Canadian dollar vis-à-vis the U.S. currency has significantly eroded the cost position of Canadian exporters, in general, and manufacturers, in particular.

The U.S. manufacturing sector is also concerned about its place in this global economy, given the unprecedented global competition for capital and markets. Because manufactured goods make up the bulk of international trade, the competition is especially strong. Taken together, the effects of technology and globalization accelerate the competitive pressures to lower costs and increase productivity. Innovation in products, processes, and services has become a determinant for success. [52]

[49] Statistics Canada.
[50] Labour productivity is defined by Statistics Canada as output, measured as real GDP per hour worked.
[51] See Andrew Sharpe, *The Canada-U.S. Manufacturing Productivity Gap – An Overview*, Centre for the Study of Living Standards (mimeo).
[52] *Manufacturing in America: A comprehensive Strategy to Address the Challenges to U.S. Manufacturers*, U.S. Department of Commerce, January 2004.

"Productivity" did not resonate high as a challenge within the Canadian industry. Rather, the industry sectors reviewed, with the exception of steel or process industries, tended to see issues such as cost competitiveness, rising input costs and competition as more critical concerns.[53] It is important to recognize, however, that this view of productivity is for all Canadian industry and that some industries are effective competitors and productive. For example, motor vehicle, primary metal, wood and paper industries are all high performers, whereas computer, instruments and textile mills are very weak.

The Centre for the Study of Living Standards has suggested six policies to improve productivity in Canada, namely:

1. pursuit of a macroeconomic environment that gives high priority to full employment;
2. promotion of the diffusion of new technologies;
3. fostering competitive markets, particularly in the product market area;
4. movement of the workforce from low to high productivity activities;
5. investment in post-secondary education; and
6. reduction of working time.

Canada's Innovation Ecosystem

There is good evidence that Canada's science and technology expertise is world-class and productive.[54] We also have effective and generous tax-credit regimes that support innovation. Canada's R&D community is busy, complex but unfocused as we do not have a clear, explicit strategy for science and technology. In addition, Canada does not have innovation practices that enable increased private sector R&D investment, and support the flow of venture capital. Therefore, Canada's S&T strongly favours public and social outcomes of innovation investments. This situation may not be appropriate, given the long-term outlook of the Canadian economy and Canada's declining competitiveness.

Canada has poor coordination among the players in innovation policy, both provincially and federally. There is a lack of focus in innovation policy, strategy and execution – too many players working with different and sometimes opposing plans and policies. In the fast-growing innovation economies (e.g. Finland, Japan), integration, convergence and focus are keywords representing action. They need to be made real in Canada, and some limited progress is now slowly being made.

The Canadian innovation system is also challenged by shortages of highly qualified people in all stages of the innovation process, affecting economic progress. Canada ranks 14th in OECD countries in management (company operations and strategy geared toward improving entrepreneurship and productivity), has fewer S&T workers than many other advanced economies and lacks experienced venture capital fund managers. Other difficulties include securing angel funding, costs of securing access to markets, intellectual property, the business climate and culture, and regulation.

The aging workforce, expected high retirement rates, and the fact that Canada continues to lag behind leading OECD countries in science and engineering degrees and in graduation rates at the PhD level (less than 1% of university graduates received a doctoral degree in 2000)[55]

[53] *2020: Building our Vision for the Future*, Canadian Manufacturers and Exporters, 2004.
[54] Based on OECD evaluations of research productivity.
[55] *Developing Highly Skilled Workers: Review of Canada*, OECD Report, 2004.

means that Canada will become increasingly dependent on immigration to fill needs for specialized skills and sustain labour force growth in the long term.[56]

Consequently, attracting and retaining scientific, engineering and technical workers will be especially challenging as labour market alternatives for graduates in science and engineering are neither extensive nor varied, largely due to the low level of research and innovative capacity in the Canadian private sector.[57] Canada will need to rely on foreign talent likely to come from China, India, Pakistan, the Philippines and other transitional economies (India and China are currently producing a fifth of the world's supply of PhD graduates in science and engineering). Although foreign talent can bridge supply gaps in OECD countries, including Canada, it may not be a permanent and acceptable replacement for national investment in the science and technology workforce.

In summary, we can say that unless significant and systemic changes are made in innovation practices of Canada, the pace and substance of economic innovation in Canada will be problematic. In particular, we will need to respond to a 2020 innovation culture that has these features:

- Challenging trade and economic conditions, with significant tensions between emerging major trade nations and traditional major trade nations;
- New product innovations that substantially change major industries and utilities that require adaptive and nimble organizations with strong and effective leadership and management skills;
- Limited venture capital resources, constrained by the demands of key social systems – health care, environmental sustainability and transport;
- An ongoing and tough war for talent that will change the nature of work and retirement practices, which will lead to a heavy reliance on immigration;
- New kinds of innovative clusters, which make use of global networks and ubiquitous technology to achieve competitive advantage and manage effective global supply chains;
- Slow and "catching up" regulatory regimes; and
- A cultural concern about the balance of social and economic innovation linked to growing issues of climate, environmental sustainability and economic vulnerability. This will result in political pressure to increase social funding for innovation while at the same time pressure for economic performance will increase.

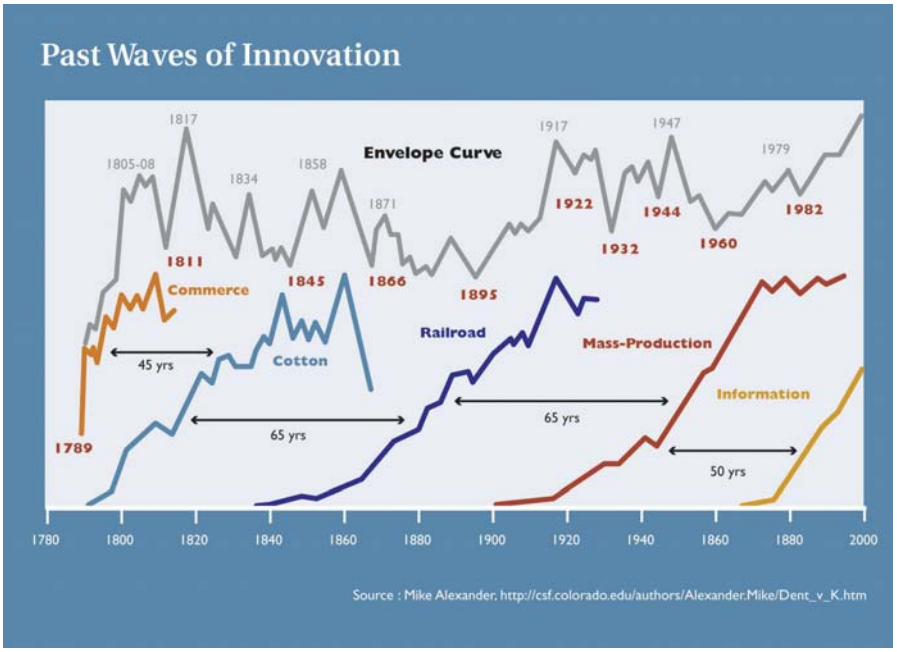
[56] Ibid.
[57] Ibid.

PART 4 – EVOLVING ROLE OF S&T

Part 2 of this report outlined the demands that the three global challenges of energy, the environment and health and wellness will place on developing S&T. This section outlines the role of S&T in shaping our world, how science itself is evolving and how critical S&T will be to successfully compete in the global economy.

Innovation Waves: A Lesson from History

Throughout history, "waves" of innovation, many of them based on developments in S&T, have been diffusing through, and significantly impacting on our lives and behaviour as well as on the global economy. These waves are becoming more disruptive – the Internet (Amazon, eBay, Cisco), informatics (genomic research), and wireless technologies (cell phones). They never act in isolation – as one wave is waning, the subsequent wave is forming. In recent years, they are growing closer together and in the future will most likely have more cross-influence and therefore require more interdisciplinary collaboration than ever before.



The current wave, *information and communication technologies,* will continue to have considerable transformative influence to 2020, particularly with the application of automated processes and tasks, computational sciences, predictive simulation, software engineering, and standardized operating systems and transport infrastructure. The next wave, expected to be biotechnology, will on its own have considerable impact in the areas of gene function, and molecular, cell and system biology. It will, as well, converge with information technology, thus increasing the potential for more significant impact.

Energy and environmental technologies see likely to form the basis of the seventh innovation wave. Already, products, industrial processes, and systems and supply chains are changing in ways to enable the energy and environmental technologies to flourish on a global basis.

Rapid emergence of S&T can shape the foundations of our collective abilities to address global challenges (climate change, resources and energy, health), the competitiveness of countries (quality of life, economic productivity, increased recognition of the importance of a knowledge economy) and the structure of competition in whole industries.

Primary Transformative Technologies

As mentioned above, the primary transformative technologies to 2020 are expected to comprise information and communication technologies, biotechnologies, and energy and environmental technologies.

The nature of the economic transformations changes as the S&T development diffuses through the marketplace. For instance, the initial transformation generally affects the foundations of the economy, or its infrastructure. As those infrastructure technologies become ubiquitous, they establish the environment for new applications to take hold. In the final stages, new services that use the new applications emerge. For example, while we have already seen very significant changes caused by ICTs disruptive influence (e.g. the Internet, wireless technologies, fibre optic transport), they have all primarily been related to information and communications infrastructure. We can expect to see equally disruptive influences in the next phase from the new applications that are enabled with the new infrastructure.

Information and Communication Technologies

The transformative power expected of information and communication technologies is already under way and is expected to be even more profound. By 2020, we will have computing power that is ubiquitous, and part of the fabric of daily living. The information and communication networks and applications will be seamlessly converged. The amount of data from commonplace physical objects, which will be equipped with sensor nodes and network connected, will be generated every minute of every day. There will be advances in mobile communications devices, the addition of video content to the growing transport stream, and a host of other S&T advances. The challenges to be overcome by Information and communication technologies to 2020 are still significant; they include software agents, cognitive technologies, semantic Web, computational sciences/predictive simulation, software engineering, standardized operating systems and standardized transport infrastructure.

Biotechnologies

It is believed that the transformative nature of biotechnology eventually will impact most sectors of the global economy. Biotechnologies are often regarded as the most significant S&T of the current century, with impacts exceeding those of information and communication technologies. Biotechnologies allow us to access the breadth of nature's diversity to develop new S&T and products that combine functions and traits, are environmentally benign and treat global challenges (drought resistance, "third world diseases"). On the other hand, biotechnologies raise many ethical and environmental concerns about many issues, such as cloning, embryonic stem cell sources and containment of transgenics, to name a few.

To date, biotechnologies have been primarily applied to human health products (e.g. biopharmaceuticals, biodiagnostics), a reflection of the market value that can be attributed to those products. The global biotechnology industry is largely comprised of firms in human health. In Canada, the human health sector represents about 80%[58] of our biotechnology companies. By 2020, however, biotechnology will play an increasingly prominent role in agriculture and food

[58] Canadian Biotechnology Industry Report, P. Winter.

processing, forestry, fisheries, the chemical and textile industries, environmental management and animal health.

Beginning with a focus on the basic sciences of genomics, proteomics, metabolomics, and other "omics", the core biotechnologies will move up the "complexity" hierarchy to include molecular biology, cell biology and system biology.

Energy and Environmental Technologies

The development and diffusion of energy and environmental S&T are fast gaining prominence globally and are both driven by these same global trends: environmental health (e.g. climate change, global warming) and energy consumption (e.g. alternative energy, renewable energy). Early signs suggest that this innovation wave has already begun to take hold and will have a growing impact over the years to 2020. Some of these technologies include advances in nuclear energy, mobile power generation, hydrogen technologies, energy storage, energy monitoring, control and management systems and environmental management technologies (environmental remediation/treatment, sensors, freshwater supply and treatment).

As we look further ahead to 2020, it is likely that advanced clean energy and environmental S&T, such as fuel cells, will become widely available and adopted by mainstream users. Other technical innovations that will impact energy efficiency in this period will include high temperature superconductivity and smart materials. Within this period, it is not impossible that some new energy source (e.g. biologically-generated solar energy conversion) will be commercialized, although it is likely to take a decade or more to gain a major market share.

Primary Enabling Sciences and Technologies

In today's reality, most advances are only made possible by complementary advances in other enabling sciences and technologies. All science and technology advances rely on excellence in and developments made in the basic sciences, especially those of physics, chemistry, and biology. Therefore, excellence in the basic sciences must be maintained to support S&T advances in all disciplines and to support the development of applications.

There are a number of "subsets" of these sciences (defined herein as Enabling Sciences and Technologies) that are expected to have a greater impact on the Primary Transformative Sciences and Technologies. One of the more important of these historically is the field of Materials Sciences. Think of its contributions to the semiconductor industry and the connection to increasing computing power. Photonics is another science that has already made significant contributions (e.g. fibre optics).

While there are a host of sciences and technologies that are important, those mentioned below are some that are expected to see significant advancement to 2020.

Nanoscience and Nanoengineering

The prospective impact of nanoscience and nanoengineering technologies are expected to be the most profound of all primary enabling technologies. Nanoscience – materials science on the scale of the atom and molecule – will change the very fabric of society in the long term. The knowledge from those efforts will be applied by nanoengineering, the technologies used to control material properties (by controlling the shape and size of molecules and, de facto, their interstitial spacing) at the nano scale and scaling them to "real world" applications – often creating new materials in the process. Within the foresight horizon to 2020, applications based on nanoscience and nanoengineering will certainly be present, but greater transformative

impacts will be yet to come. The Nanotechnology Foundation of Texas has forecasted the potential development time of nanoscience and nanoengineering applications until 2050. In the first stage of market diffusion, the emergence of a new nanomaterials sector can be perceived, which turns into a mature and largely consolidated sector during the second stage. During the third stage, nanomaterials become widespread, leading to commercialization of new and improved products and processes.

Materials Science

Materials science is a multidisciplinary field focusing on functional solids, whether the function served is structural, electronic, thermal, chemical, magnetic, optical or some combination of these. It uses those parts of chemistry and physics that deal with the properties of materials, but also includes a distinctive set of scientific techniques that probe materials' structure. Evaluation of material performance is grounded in the field of engineering, where that material is applied, and applying materials science requires knowledge of the processing sciences and technologies of the material in question.

Better understanding of intermolecular interaction is needed for design and control of structural function, and to enable greater control of super-molecular assemblies. Interfacial reactions between polymer and fibre, and polymers and metals will also be better understood. An understanding of the equations governing structure-property relationships is also important to the development of new materials, including the ability to control molecular structure during free-radical polymerization.

Photonics

Photonics refers to science and technology based on and concerned with the controlled flow of photons, or light particles. As a tool, optics is making its way into virtually every field of science and technology. From data transmission and storage using diode lasers, to ultra-powerful lasers for materials processing, photonics has become indispensable to science and technology-driven everyday life.

Its most recent transformative impact has been in the field of fibre optics, e.g. in such innovations as optoelectronic integrated circuits. Photonic applications include data storage, data transmission, optical computers, optical switches and light modulators.

One of the newer areas applying photonics is the field of biophotonics – referring to the emission, detection, absorption, reflection, modification and creation of photon radiation from living organisms and organic material. Areas of biophotonics applications are in life science, medicine, agriculture and environmental science.

Microfluidics

Microfluidics is perhaps the future of the wet lab. It may be thought of as the miniaturization of the cell culture laboratory, with the ability to control complex combinations of interactions between test molecules and individual sites on individual cells. In simple terms, microfluidics use devices with lots of micro or submicron channels that can manage minute amounts of liquids. These might be used in a range of fluid-management applications from the study of cell biology to water management in micro fuel cells.

Microfluidics is a multidisciplinary field, comprising physics, chemistry, engineering and biotechnology, that studies the behaviour of fluids at the microscale and mesoscale, i.e., fluids at volumes thousands of times smaller than a common droplet. It also concerns the design of systems in which such small volumes of fluids will be used. It is a new science, having emerged

only in the 1990s, so the number of applications for this science or technology is currently small. However, it is potentially significant in a wide range of sciences and technologies. Microfluidics is currently used in the development of DNA microarray science and technology, as well as in microthermal and micropropulsion sciences and technologies.

Quantum Information

Quantum information has the potential to revolutionize many areas of science and technology. It exploits fundamentally new modes of computation and communication because it is based on the physical laws of quantum mechanics instead of classical physics. It holds the promise of immense computing power beyond the capabilities of any classical computer, it guarantees absolutely secure communication, and it is directly linked to emerging quantum sciences and technologies, for example, quantum-based sensors.

In addition to the science itself, recent success in quantum science and engineering has created several extremely valuable optical tools that operate exclusively under the rules of quantum mechanics and offer practical optical measurement and characterization techniques (quantum optical metrology) that have clear advantages over existing technologies.

Converging Technologies

Converging technologies are sciences and technologies that enable each other in the pursuit of a common goal. This definition captures the scientific and technical potential of convergent sciences and technologies and suggests opportunities for research priorities. Increasingly, themes of "convergence" will dominate S&T development. New technologies will often be a blend of two or more disciplines and advances in one field will enable advances in another (e.g. the influence of informatics on genomics research).

As mentioned above, information and communication technologies helped (and continue to) produce a profound transformation of daily life. Biotechnology is transforming many areas such as agriculture and medical diagnosis and treatment. Most recently, the transformation potential of nanotechnology has emerged. Adding to these new developments in cognitive and neuroscience and the rise of the importance of social sciences, it is widely believed that, because of the convergence of these sciences, the early decades of the 21st century will see vast improvements in human abilities, societal outcomes, productivity and our quality of life.

Convergent S&T research will require new models for "product development," peer review processes, ownership of and rights to IP, and a host of other issues. Put simply, many of the existing precepts about the conduct of research will be challenged and likely spawn new approaches. Convergent S&T requires a transparent and open political process. Because of its openly political character, research utilizing convergent S&T builds trust, creates legitimacy, and draws on public debate as a resource and inspiration for convergent S&T agendas.

However, if individual technologies created some controversy and anxiety, their convergence will pose a major challenge to the research community as well as to policy-makers and society at large. It will be imperative that proper attention be given to ethical issues and societal needs.

Factors that may Impact on the Development and Acceptance of S&T

Several factors will impact the timely development and deployment of S&T. Among them will be the convergence of transformative technologies and technology-enabling sciences, the fear of technology, the challenge of coping with the fast pace of S&T developments, and dealing with

discontinuities in both S&T and global issues. Together, these factors pose a major challenge to the research community.

Multidisciplinary Collaboration

In this day of S&T convergence, no technology succeeds on its own, but depends on other enabling technologies. Consequently, interdisciplinary collaboration may represent the most important challenge facing the future of S&T development to 2020. Research teams of the future will be aggregates of experts in engineering, natural, social, and human sciences at regional, national and international levels. The projects will be conducted across different infrastructures, geographies and time zones, thus requiring a whole new level of project management skills. Communication will have to bridge various scientific domains so that "unrelated" fields can integrate their respective needs, capacities and limitations effectively. Peer reviews will have to balance "depth" against "breadth" of knowledge. There will be issues surrounding sole or co-ownership of intellectual property and we could be operating in a world of more and more "open-source" science in which the IP is owned by the collaborating parties or "society". The struggle between those who advocate privatizing IP and the open-source movement may become protracted and bitter.

Coping with the Pace of S&T Developments

The adoption of many new sciences and technologies can be "throttled" by industry's inability to embrace them. Two primary challenges are often a lack of metrics and measurement standards for confirming the efficacy of the new technology (e.g. as a replacement product for an existing use, or as a new use altogether) and a lack of standards and regulatory guidelines for using the new technology.

S&T is changing faster than regulators' ability to "keep up". A case in point, Canada's recent focus on Smart Regulations found that, generally, regulation does not respond in a timely fashion to fast paces of change (i.e. science and technology advances, new business practices, changing consumer needs). A number of regulatory challenges impede the introduction of new technologies. In addition, there are a number of new technologies that have no regulatory framework to guide their adoption (e.g. stem cell technologies), despite a recognized need for one. Some would argue, however, that there is too much regulation of stem cell research, particularly in Canada.

Acceptance

While S&T is advancing rapidly and has the potential to radically change our world, there are counter-trends that may influence the implementation and uptake of such developments, the strongest of which is the public's fear and concern about our future. Some examples include opposition against genetically modified organisms (potential danger to environment and health), cloning and stem cell research (ethical issues) and the adoption of new bioproducts (general reluctance to change). This observation underscores the importance of education and the philosophy of science, as science input is increasingly needed for sound decision-making. We need to have open debates about the direction and meaning of science in Canadian (or global) civil society, without which science may face greater hostility from those who may have been identified as its beneficiaries, but have increasingly come to see S&T as an alien force.

Breakthroughs and "Tipping Points"

History has shown us that many truly transformative sciences and technologies were not foreseen (at least not their importance nor timing); examples include Albert Einstein's Theory of Relativity in 1905, or James Watson's and Francis Crick's discovery of the double helix structure

of deoxyribonucleic acid (DNA) in 1953. These kinds of breakthroughs are not normally foreseen and set out one of the principal reasons for a continuing effort in basic research.

Breakthroughs in applied research can sometimes be more predictable, often in response to a compelling "demand pull." For example, government and military priorities can shape science or technology development efforts. Examples are the Manhattan Projects and the space program. Equally, private sector priorities can have a similar influence. Another key driver to the intensity of technological innovation is when the enabling infrastructure reaches a "tipping point," that dramatic moment when something unique becomes common. Consider the impact of the diffusion of personal computers and the new sciences and technologies that are, and will be, spurred by the growing ubiquity of wireless broadband deployment.

The outcomes to science or technology development as a result of these influences can be profound – and impossible to anticipate. At best, one can only surmise that breakthroughs or tipping points will spawn one or more transformative sciences and technologies to 2020 that are not anticipated today.

The past five years has seen some significant discontinuities that affect society, for example:

- 9/11 and the changing world security climate
- New diseases: SARS, BSE, Avian flu, West Nile Virus
- Increase of over 100% in the price of oil (US$25 a barrel in 2000)
- Ascension of China to WTO.

By definition, these discontinuities are unplanned and have rapid impact. In such a context, S&T organizations must be highly agile and responsive to changing priorities.

CONCLUSION

"It has become increasingly clear that humanity has the resources to address its global challenges; what is less clear is how much wisdom, good will, and intelligence will be focused on these challenges" – State of the Future, 2004

The future will not be a replay of the past and present. Not only are the challenges in each era fundamentally different, our capacities to respond to and to cope with them will harbour the most meaningful changes. Ahead, we see a global population that is more self-aware and demanding – of each other, of our institutions and governments, even of our societies. Perhaps the greatest "micro-change" will be greater expectations of ourselves, of what we each can expect from our world, of what we can contribute to our world, of our ability to migrate toward greater opportunities, of the personal securities we demand and of our personal social responsibilities.

To 2020, the "freedom" to consider the needs and wants of oneself are made possible and reinforced by the many trends we see:

- By the migration of peoples, to show us that we can choose our environment, and to heighten our awareness of other cultures (at the same time, reminding us of our own);
- By the globalization of trade and inter-connected economies that give us choices among the world's products, processes and services, and that allow us to choose the global "customers" we want to serve;
- By S&T developments that increase our abilities to communicate anywhere, anytime; to travel everywhere; to be aware of everything; that bring us personalized networks, personalized medicine, distributed energy; even personalized space travel;
- By the higher independence to encourage us to let flourish our greater social responsibility for our environment, our sustainable future and our fellow humankind.

Though these higher-level trends might be anticipated, their expression cannot. Ours is to be a world where uncertainties and constant change are a reality and promise only to challenge even our basic assumptions. Important changes and discontinuities are part of our lot – and occurring at an increasing pace and with evergreater transformative influence. Canada, a great resourceful country, has an important role to play in this world, but can only do so by developing an agility and adaptability that will allow us to embrace this certain change.

We have seen that these characteristics will be particularly demanded in Canada's innovation system – our ability to bring the application of S&T developments sustainably into the marketplace to yield economic and social benefits. Most enduring and emerging global and Canadian challenges can be met with effective application of science and technologies. Already bridging the basic sciences to commercialization, the NRC is a key actor in the Canadian innovation system and can play a pivotal role in its development and functioning – working with Canada's S&T community to meet the challenges to 2020.