



The Canadian Academy of Engineering – L'Académie canadienne du génie

Task Force on the Future of Engineering

A Framework for Discussion

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Engineering, of any description is an art of the possible. It happens at the junction between what is materially possible and what is humanly possible. Its course is shaped by the latest developments in the endless struggle to manipulate obdurate matter, and also by the agendas and priorities and resources and hopes and illusions of a society. Engineering is where science intersects with the way we live.

Francis Spufford - *Backroom Boys: The Secret Return of the British Boffin*

1 INTRODUCTION

The objective for the Task Force on the Future of Engineering was to identify some of the potentially most significant engineering challenges for the next ten to twenty years, and to provide advice on how the Canadian Academy of Engineering (CAE), and the engineering profession generally, can play a meaningful role.

The following three-level model was suggested as a framework for this discussion:

- Level 1 - An examination of the nature and direction of engineering, both as an intellectual and academic discipline, and as a field of practice.
- Level 2 - An examination of selected engineering themes (by economic sector, such as energy, communications, manufacturing and transportation; and in terms of emerging technologies, such as nanotechnology and biotechnology).
- Level 3 - An examination of the interface between engineering and the broader community, in terms of issues such as global competitiveness, technical literacy, the innovation agenda, public policy priorities and directions, etc.

We did not examine Level 1 in depth, beyond a brief review of the literature and a statement on major trends and directions.

We focused most of our attention on Level 2, soliciting brief essays that highlighted significant engineering trends.

We collected the following materials for Level 3:

- John Leggatt (task force member) identified reports of interest that were recently prepared for federal government departments and agencies;
- Dr. Margaret Hill (Director, Research & Analysis for Infrastructure Canada) authored a brief essay on the nation's infrastructure needs and challenges;
- Dr. Alan Winter (task force member) searched for thought leaders with new ideas about the intersection between engineering and biology – an area of profound importance;
- Dr. Peter Frise provided a brief essay on Auto 21; and
- David Forrest (management consultant and publisher of *innovationwatch.com*) reviewed future trends and the innovation culture literature.

This document provides background on the issues we explored and, hopefully, sets the stage for subsequent detailed analyses.

John McLaughlin, FCAE
Chair

2 THE FUTURE CONTEXT

In the next 10 to 15 years, accelerating change in virtually every domain – science, technology, business, the economy, society, global politics, and the environment – will create unprecedented challenges and opportunities for humankind, and new imperatives for the profession of engineering.

We highlight stories in this section that illustrate significant trends. Many of these stories are drawn from the American experience. In subsequent analysis, it will be important to broaden our understanding of what is happening in Canada and other countries.

2.1 Science and Technology Trends

We highlight the following trends in science and technology:

- Design – personal fabrication and the creativity machine
- Materials – nanotechnology and biotechnology
- Information technology – ubiquitous computing and quantum computing
- Robotics – autonomous robots and cybernetic organisms
- Medical technology – neural prostheses

2.1.1 Design

2.1.1.1 Personal Fabrication



“...post-digital literacy now includes 3D machining and microcontroller programming.”

Neil Gershenfeld. “Personal fabrication.”
EDGE. July 24, 2003.

Literacy in the modern sense emerged in the Renaissance as mastery of the liberal arts. This is liberal in the sense of liberation, not politically liberal. The trivium and the quadrivium represented the available means of expression. Since then we've boiled that down to just reading and writing, but the means have changed quite a bit since the Renaissance. In a very real sense post-digital literacy now includes 3D machining and microcontroller programming. I've even been taking my twins, now 6, in to use MIT's workshops; they talk about going to MIT to make things they think of rather than going to a toy store to buy what someone else has designed.

Task Force on the Future of Engineering

In a place like Cambridge (MA or UK) personal fabrication is not urgently needed to solve immediate problems, because routine needs are already met. These students were not inventing for the sake of their survival, or developing products for a company; they were expressing themselves technologically. They were creating the things they desired, rather than needed, to make the kind of world they wanted to live in.

Between this short-term teaching with advanced infrastructure and our long-term laboratory research on personal fabrication, I had an epiphany last summer: for about ten thousand dollars on a desktop you can approximate both. What makes this possible is that space and time have become cheap. For a few thousand dollars a little table-top milling machine can measure its position down to microns, a fraction of the size of a hair, and so you can fabricate the structures of modern technology such as circuit boards for components in advanced packages. And a little 50-cent microcontroller can resolve time down below a microsecond, which is faster than just about anything you might want to measure in the macroscopic world. Together these capabilities can be used to emulate the functionality of what will eventually be integrated into a personal fabricator.

So we started an experiment.

Long before the research was done, we thought that it would be a good idea to learn something about who would care and what it's good for. We started using micromachining and microcontrollers to set up field "fab labs" (either fabulous, or fabrication, as you wish). They weren't meant to be economically self-sustaining; it was just a way of building up experience. We intentionally put them beyond the reach of normal technology in places like rural India and the far north of Norway. Once again we found a desperate response, but here personal fabrication does address what can truly be life-and-death problems.

In one of these labs in rural India they're working on technology for agriculture. Their livelihood depends on diesel engines, but they don't have a way to set the timing. The instrument used in your corner garage to do that costs too much, there is no supply chain to bring it to rural India, and it wouldn't work in the field anyway. So, they're working on a little microcontroller sensor device that can watch the flywheel going by and figure out when fuel is coming in. Another project aimed a \$50 Webcam at a diffraction grating to do chemical spectroscopy in order to figure out when milk's going bad, when it's been diluted, and how the farmers should be fairly paid. Another fab lab is in the northeast of India, where one of the few jobs that women can do is Chikan embroidery. The patterns are limited by the need to stamp them with wooden blocks that are hard to make and modify; they're now using the lab to make 3D scans of old blocks and 3D machine new ones. At the other end of the world, at the top tip of Norway, there's a fab lab that is being used to develop radio "bells" so that nomadic data can follow the Sami's nomadic herds of sheep and reindeer around the mountains.

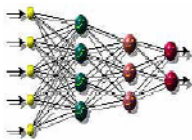
Each of these examples really are matters of survival for these people. Silicon Valley start-ups aren't trying to solve these problems, and even if they were the business models are unlikely to work on this scale. Through fab labs, locally-appropriate solutions can be developed and then produced locally. The design files can also be shared globally, for open-source hardware as well as software problem-solving.

Working on this project has led to some very strange days in Washington DC for me, where I'll go from the World Bank to the National Academies to the Pentagon, and they all want to

talk about the same thing. The possibility of personal fabrication is enormously important for each of these institutions' agendas, but it does not easily fit into their existing organizations.

The World Bank is trying to close the digital divide by bringing IT to the masses. The message coming back for the fab labs is that rather than IT for the masses the real story is IT development for the masses. Rather than the digital divide, the real story is that there's a fabrication and an instrumentation divide. Computing for the rest of the world only secondarily means browsing the Web; it demands rich means of input and output to interface computing to their worlds.

2.1.1.2 The Creativity Machine



"...the technology is the best simulation of what goes on in human brains."

**Tina Hesman. "Stephen Thaler's Creativity Machine."
St. Louis Post-Dispatch. February 5, 2004.**

Technically, Stephen Thaler has written more music than any composer in the world. He also invented the Oral-B CrossAction toothbrush and devices that search the Internet for messages from terrorists. He has discovered substances harder than diamonds, coined 1.5 million new English words, and trained robotic cockroaches. Technically.

Thaler, the president and chief executive of Imagination Engines Inc. in Maryland Heights, Mo., gets credit for all those things, but he's really just "the man behind the curtain," he said. The real inventor is a computer program called a Creativity Machine.

What Thaler has created is essentially "Thomas Edison in a box," said Rusty Miller, a government contractor at General Dynamics and one of Thaler's chief cheerleaders.

"His first patent was for a Device for the Autonomous Generation of Useful Information," the official name of the Creativity Machine, Miller said. "His second patent was for the Self-Training Neural Network Object. Patent Number Two was invented by Patent Number One. Think about that. Patent Number Two was invented by Patent Number One!"

Supporters say the technology is the best simulation of what goes on in human brains, and the first truly thinking machine. ...

A Creativity Machine used two neural networks to study toothbrush design and performance. A brainstorming session between the two produced the idea to cross the bristles of the toothbrush for optimal cleaning. That toothbrush became the Oral-B CrossAction toothbrush.

In one weekend, a Creativity Machine learned a sampling of some of Thaler's favorite Top 10 hits from the past three decades and then wrote 11,000 new songs. Some are good, Thaler said. Miller confesses to being haunted by one of the melodies in a minor key. Other offerings are the musical equivalent of a painting of dogs playing poker, Thaler said.

But computer-composed music doesn't have to be bad. Human mentors with good taste could train a critic network to grade the Creativity Machine's songs, punish it for bad tunes and reward it for harmonious melodies. The feedback would hone the machine's composing skills.

Such a self-training system was the Creativity Machine's first invention, and the subject of Thaler's second patent. ...

The technology is not ready for widespread commercial use yet, say some supporters.

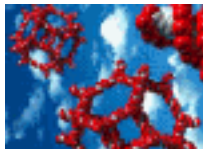
"It's got extraordinary potential. Right now the holdup is packaging the technology as a tool that somebody can actually pull off the shelf and use," said Lloyd Reshard, the Weapons Platform Integration Team Lead at the Air Force Research Laboratory Munitions Directorate at Eglin Air Force Base. With other artificial intelligence technologies, "software is commercially available on the street, but if you want to apply a Creativity Machine to your problem, there's no software package you can go out and buy."

The Air Force is working with Thaler now to solve that problem, Reshard said.

All of the possible applications for Creativity Machines make some people uneasy. The machines could easily supplant people for many mundane jobs, and Thaler predicts that some traditionally human-only jobs, including laboratory scientist, could be up for grabs. Computer chemists could soon design new compounds and figure out how to make them.

2.1.2 Materials

2.1.2.1 Nanotechnology



"...the self-assembly properties of DNA can be used to create quite complicated nano-scale structures and devices."

**Richard Jones. "The future of nanotechnology."
Physics World. August 2004.**

... What we could call "incremental nanotechnology" involves improving the properties of many materials by controlling their nano-scale structure. Plastics, for example, can be reinforced using nano-scale clay particles, making them stronger, stiffer and more chemically resistant. Cosmetics can be formulated such that the oil phase is much more finely dispersed, thereby improving the feel of the product on the skin. These are the sorts of commercially available products that are said to be based on nanotechnology. The science underlying them is sophisticated and the products are often big improvements on what has gone before. However, they do not really represent a decisive break from the past.

In "evolutionary nanotechnology" we move beyond simple materials that have been redesigned at the nano-scale to actual nano-scale devices that do something interesting. Such devices can, for example, sense the environment, process information or convert

energy from one form to another. They include nano-scale sensors, which exploit the huge surface area of carbon nanotubes and other nano-structured materials to detect environmental contaminants or biochemicals. Other products of evolutionary nanotechnology are semiconductor nanostructures - such as quantum dots and quantum wells -- that are being used to build better solid-state lasers. Scientists are also developing ever more sophisticated ways of encapsulating molecules and delivering them on demand for targeted drug delivery.

Taken together, incremental and evolutionary nanotechnology are driving the current excitement in industry and academia for all things nano-scale. The biggest steps are currently being made in evolutionary nanotechnology, more and more products of which should appear on the market over the next five years...

Even if the most extreme visions of the nanotechnology evangelists do not come to pass, nanotechnology -- in the form of machines structured on the nano-scale that do interesting and useful things -- will certainly play a growing part in our lives over the next half-century. How revolutionary the impact of these new technologies will be is difficult to say. Scientists almost always greatly overestimate how much can be done over a 10 year period, but underestimate what can be done in 50 years...

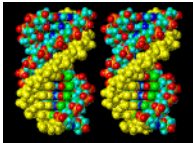
So how could we follow biology's example and work with the "grain" of the nanoworld? The most obvious method is simply to exploit the existing components that nature gives us. One way would be to deliberately remove and isolate from their natural habitats a number of components, such as molecular motors, and then incorporate them into artificial nanostructures. For example, Nadrian Seeman at New York University and others have shown how the self-assembly properties of DNA can be used to create quite complicated nano-scale structures and devices. Another approach would be to start with a whole, living organism - probably a simple bacterium -- and then genetically engineer a stripped-down version that contains only the components that we are interested in.

One can think of this approach - often called "bionanotechnology" - as the *Mad Max* or *Scrap Heap Challenge* approach to nano-engineering. We are stripping down and then partially reassembling a very complex and only partially understood system to obtain something else that works. This approach exploits the fact that evolution -- nature's remarkable optimization tool -- has produced very powerful and efficient nanomachines. We now understand enough about biology to be able to separate out a cell's components and to some extent utilize them outside the context of a living cell -- as illustrated in the work of Carlo Montemagno at the University of California at Los Angeles and Harold Craighead from Cornell University. This approach is quick and the most likely way to achieve radical nanotechnology soon...

As we learn more about how bionanotechnology works, it should be possible to use some of the design methods of biology and apply them to synthetic materials. Like bionanotechnology, such "biomimetic nanotechnology" would work with the grain of the special physics of the nanoworld. Of course, the task of copying even life's simplest mechanisms is formidably hard. Proteins, for example, function so well as enzymes because the particular sequence of amino acids has been selected by evolution from a myriad of possibilities. So when designing synthetic molecules, we need to take note of how evolution achieved this.

But despite the difficulties, biomimetic nanotechnology will let us do some useful -- if crude -- things. For example, ALZA, a subsidiary of Johnson and Johnson, has already been able to wrap a drug molecule in a nanoscopic container -- in this case a spherical shell made from double layers of phospholipid molecules -- and transport it to where it is required in the body. The container can then be made to open and release its bounty.

2.1.2.2 Biotechnology



“The goal... is nothing less than to ‘reimplement life in a manner of our choosing.’ ”

Oliver Morton. “Life, reinvented.”
***Wired*. January 2005.**

... [Drew] Endy is the newest recruit to a cabal of MIT engineers gathered around one of the university's computer science gurus, Tom Knight. Their aim is to create a field of engineering that will do for biological molecules what electronics has done for electrons. They call it synthetic biology.

"I think this will likely be the most important thing I've done," says Knight, whose track record already includes designing some of the earliest network interfaces, bitmapped displays, and workstations. "We're at the cusp of some dramatic changes."

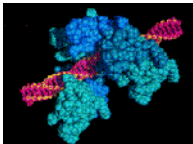
If the notion of hacking DNA sounds like genetic engineering, think again. Genetic engineering generally involves moving a preexisting gene from one organism to another, an activity Endy calls DNA bashing. For all its impressive and profitable results, DNA bashing is hardly creative. Proper engineering, by contrast, means designing what you want to make, analyzing the design to be sure it will work, and then building it from the ground up. And that's what synthetic biology is about: specifying every bit of DNA that goes into an organism to determine its form and function in a controlled, predictable way, like etching a microprocessor or building a bridge. The goal, as Endy puts it, is nothing less than to "reimplement life in a manner of our choosing."

And what might the practitioners of this emerging science do with such godlike capability? Within a decade, some hope to create bacteria able to mass-produce drugs that currently have to be painstakingly harvested from rare plants. Others talk about making viruses encased in protein sheaths that can be used to produce fabric with molecular circuitry woven into its warp and weft. In the more distant future, synthetic biologists envision building more complex organisms, like supercoral that sucks carbon out of the biosphere and puts it into building materials, or an acorn programmed to grow into an oak tree -- complete with a nifty tree house. And there's the opportunity to add new chromosomes to the human genome, ushering in a panoply of human augmentations and enhancements.

Synthetic biology has a long way to go before such wonders become possible, but each year's IAP course brings them closer as the MIT team learns by trial and error. As the

course enters its third year, Endy and his students are closing in on an approach that will let them design systems considerably more elaborate than the simple projects they've attempted so far. And if getting there doesn't go smoothly, that's OK. "Engineers work best by flailing about," Endy says, "and we've been doing as much of that as anybody."

Imagine typing all the three-letter words of a bacterial genome in a text editor and changing all uses of the four less common words for arginine to the two most common. This would preserve the meaning of every gene while giving you four spare words. Presumably you could reassign them to new amino acids - amino acids that living creatures have never used before. This may sound far out, but it has already been done. Scientists at the Scripps Research Institute in La Jolla, California, have modified a bacterium to read a word that normally means "stop making protein" as "add a weird amino acid here."



"...engineers could build life-forms out of entirely different building blocks."

**Oliver Morton. "Rewriting the genetic code."
Wired. January 2005.**

Extending the genetic code in this way opens a wide range of possibilities that are obvious to chemists but that nature has never tried, because it simply didn't have enough words to work with. You could enhance proteins with fluorescent amino acids, making them easier to track as they wander around cells. You could give proteins chemical hooks that would make it easier for them to link to certain sugars, which would be especially useful for proteins in drugs.

New proteins are just the beginning. Rejiggering the genetic code could also eliminate some worries about biotechnology. Synthetic creatures based on a code that looked like nonsense to natural systems couldn't exchange genes with familiar flora and fauna, and thus couldn't escape into the wild. More ambitiously, engineers could build life-forms out of entirely different building blocks. For example, some molecules come in two mirror-image forms, like a pair of hands. Nature uses left-handed amino acids and right-handed sugars. If synthetic organisms worked the other way around, they would be incapable of making use of natural foodstuffs, thus ruling out most of the ways they could disrupt natural ecosystems.

2.1.3 Information Technology

2.1.3.1 Ubiquitous Computing



“We are working towards the point where computers are acting in advance and anticipating our needs.”

Michael Kanellos. “Future life of pervasive computing.”
***ZDNet Australia*. August 28, 2001.**

Computers are on desktops now, but in the future they will be located on tectonic plates, inside of socks and in the middle of forest fires, according to the director of Intel's research and development.

The chip giant will increasingly focus its research on "proactive computing," or the creation of embedded mini-computers that obtain sensory data from the physical world and shuttle it across networks, David Tennenhouse, vice president and director of Intel Research, said during a speech Monday at the Intel Developer Forum.

The heart of these networks will be microelectromechanical systems (MEMS), which are tiny computers with self-aware networking and, in many cases, independent storage. MEMS already exist in antilock brakes and air bags. In the future, however, MEMS will be attached to people to monitor skin lesions or inserted in clothing to track people in case they get lost. Sensors dropped on a forest fire will be able to form an ad-hoc network and provide data about where the fire is burning the most fiercely.

"We are working toward the point where computers are acting in advance and anticipating our needs," he said.

The project also won't be an in-house effort. The company has also kicked off a project to create branches of Intel Research, the company's R&D unit, at engineering universities. Earlier this summer, the company opened a research lab in conjunction with the University of Washington to study so-called ubiquitous computing.

A branch for studying "extremely" networked systems, or networks containing numerous nodes that stretch over small and large geographic areas, has just started at the University of California at Berkeley. In September, another branch of the lab will be set up at Carnegie Mellon University in Pittsburgh to study widely distributed storage, according to sources at the company.

Another five to eight satellite labs will be set up next year, sources said. Intel spends about US\$50 million a year on university research but had not previously set up satellite labs of this sort.

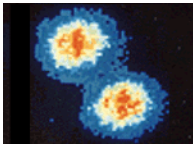
The driving force behind MEMS lies in information overload, said Tennenhouse. Simply put, the amount of data is far outstripping people's ability to manage it.

"Not only are we the input/output devices for these things (computers and handhelds), we are the chauffeurs," he said, adding that machines "either work for us or we work for them."

Micromachines will rein in the data flood by being able to directly gather information from the physical world and deliver it in real time when the data is wanted. Humans won't be needed for data input.

Conceivably, the micromachines can be placed in any environment.

2.1.3.2 Quantum Computing



"These supercomputers... theoretically could... solve in hours problems that might require centuries if run on state-of-the-art silicon."

**Aaron Ricadela. "Quantum's next leap."
Information Week. May 10, 2004.**

At a late-January meeting in a Marriott off the Washington beltway in Falls Church, Va., the Defense Department's main technology-research arm floated a proposal as nearly 100 scientists listened. They'd come from Boeing, IBM, Lockheed Martin, and other companies; from the Army, the Navy, and NASA; and from leading universities to hear a proposal for accelerating efforts to build a computer that theoretically could exist inside a coffee cup.

Within the next several months, the Defense Advanced Research Projects Agency, which will spend more than \$2.8 billion this year on research and development for the Pentagon, is expected to launch a multimillion-dollar program to kick-start U.S. research in quantum computing, an esoteric area of inquiry under way at government labs, universities, and companies such as AT&T, Hewlett-Packard, IBM, and Microsoft. These supercomputers -- built according to the strange laws of quantum physics, often operating at temperatures nearing absolute zero, and occupying spaces that can resemble a vial of liquid more than an electronic box -- theoretically could perform within seconds calculations that take today's machines hours and solve in hours problems that might require centuries if run on state-of-the-art silicon.

If the research pans out, and there's no guarantee it will, quantum computers could revolutionize a computer industry whose main engine of economic growth -- the doubling of computing power each year and a half predicted by Moore's Law -- is in danger of losing steam. ...

Darpa's proposed program, called Focused Quantum Systems, or Foqus, aims to build a quantum computer capable of factoring a 128-bit number -- a common method of online encryption -- in 30 seconds, with 99.99% accuracy. "Darpa has decided to put a huge chunk of money out for researchers to build a quantum computer," says Nabil Amer, the manager and strategist of the physics of information for IBM Research. "This will be a highly coordinated effort with the serious goal of bringing us to a go/no-go point: Will we be able to build this computer or not? Darpa all of a sudden got an epiphany."

2.1.4 Robotics

2.1.4.1 Autonomous Robots



“The long-term goal... is for... small, inexpensive robots to take on some of the duties now performed by large, expensive farm equipment.”

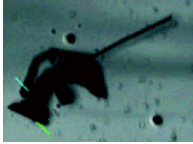
Red Nova. “The future role for autonomous robots.” July 11, 2004.

Farm equipment in the future might very well resemble the robot R2D2 of Star Wars fame. But instead of careening through a galaxy far, far away, these ag robots might be wobbling down a corn row, scouting for insects, blasting weeds and taking soil tests.

University of Illinois agricultural engineers have developed several ag robots, one of which actually resembles R2D2, except that it's square instead of round. The robots are completely autonomous, directing themselves down corn rows, turning at the end and then moving down the next row, said Tony Grift, an agricultural engineer at the University of Illinois at Urbana-Champaign.

The long-term goal, he said, is for these small, inexpensive robots to take on some of the duties now performed by large, expensive farm equipment. As Grift asked, "Who needs 500 horsepower to go through the field when you might as well put a few robots out there that communicate with each other like an army of ants, working the entire field and collecting data?"...

Cybernetic Organisms



“Muscle-powered microelectromechanical systems represent an attractive alternative to micromotors. They could operate inside the human body by feeding on glucose in the blood.”

Will Knight. “Micromachine grows its own muscles.”
New Scientist, January 17, 2005.

A micromachine that walks using muscles that it grew for itself has been developed in a US laboratory.

The remarkable device could eventually lead to muscle-based nerve stimulators that let paralysed patients breathe without a ventilator, or to nanobots that clear away plaque from inside the walls of a human coronary artery.

Scientists at the University of California in Los Angeles grew a length of muscle about 100 microns long on the underside of a silicon frame measuring 200 microns. The cells were taken from a rat's heart and grown in a culture that mimics natural biological conditions. The muscle contracts and relaxes by feeding on glucose in a solution, the contractions causing the tiny structure to shuffle along.

Previously the team had to manually attach developed muscle tissue to a micromachine -- a complex procedure which invariably causes damage to the tissue.

They built the new micromachine by etching the silicon structure using photolithography before coating the frame with a polymer and selectively depositing gold and chromium. The polymer acts as a mould for the muscle to grow along and the gold provides points to which the growing muscle cells can attach.

While the muscles are growing, the structure is physically held in place by a restraining rod. But, once this rod is removed, it immediately begins crawling along.

Muscle-powered microelectromechanical systems (MEMS) represent an attractive alternative to micromotors. They could operate inside the human body by feeding on glucose in the blood. "It could be used for micro-surgery," says Jeff Xi, one of the team. "Perhaps this could be used to push away plaque in an artery."

But integrating biological and man-made materials could have a variety of potential applications. The technique could, for example, enable paralysed patients to breathe without the aid of a ventilator by stimulating the phrenic nerve -- which controls the movement of the diaphragm -- with a small electrical pulse.

And more fantastic ideas have been proposed by NASA, which has provided funding for the project. The US space agency hopes that swarms of muscle-powered microbots could one day repair damage to remote spacecraft automatically.

"It is important to be able to couple a living system with inorganic material," says Joachim Spatz at the University of Heidelberg in Germany.

Spatz says computer sensors could be attached to damaged muscles within a couple of years, to provide useful data on rehabilitation. But he admits the possibility of muscle-powered microbots "is still very far away".

2.1.5 Medical Technology

2.1.5.1 Neural Prostheses



"Unlike devices like cochlear implants, which merely stimulate brain activity, this silicon implant will perform the same processes as the damaged part of the brain it is replacing."

**Duncan Graham-Rowe. "World's first brain prosthesis revealed."
New Scientist. March 12, 2003.**

The world's first brain prosthesis -- an artificial hippocampus -- is about to be tested in California. Unlike devices like cochlear implants, which merely stimulate brain activity, this silicon chip implant will perform the same processes as the damaged part of the brain it is replacing.

The prosthesis will first be tested on tissue from rats' brains, and then on live animals. If all goes well, it will then be tested as a way to help people who have suffered brain damage due to stroke, epilepsy or Alzheimer's disease.

Any device that mimics the brain clearly raises ethical issues. The brain not only affects memory, but your mood, awareness and consciousness - parts of your fundamental identity, says ethicist Joel Anderson at Washington University in St Louis, Missouri.

The researchers developing the brain prosthesis see it as a test case. "If you can't do it with the hippocampus you can't do it with anything," says team leader Theodore Berger of the University of Southern California in Los Angeles. The hippocampus is the most ordered and structured part of the brain, and one of the most studied. Importantly, it is also relatively easy to test its function. ...

The inventors of the prosthesis had to overcome three major hurdles. They had to devise a mathematical model of how the hippocampus performs under all possible conditions, build that model into a silicon chip, and then interface the chip with the brain.

No one understands how the hippocampus encodes information. So the team simply copied its behaviour. Slices of rat hippocampus were stimulated with electrical signals, millions of times over, until they could be sure which electrical input produces a corresponding output. Putting the information from various slices together gave the team a mathematical model of the entire hippocampus.

They then programmed the model onto a chip, which in a human patient would sit on the skull rather than inside the brain. It communicates with the brain through two arrays of electrodes, placed on either side of the damaged area. One records the electrical activity coming in from the rest of the brain, while the other sends appropriate electrical instructions back out to the brain.

The hippocampus can be thought of as a series of similar neural circuits that work in parallel, says Berger, so it should be possible to bypass the damaged region entirely.

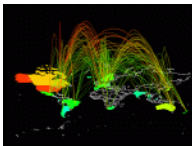
2.2 Business and Economic Trends

We highlight the following trends in business and the economy:

- Globalization – flattening the world and globalization of the value chain

2.2.1 Globalization

2.2.1.1 Flattening the World



“Globalization 3.0 makes it possible for so many more people to plug and play, and you are going to see every color of the human rainbow take part.”

Thomas L. Friedman. *The World is Flat: A Brief History of the Twenty-First Century*. New York: Farrar, Straus and Giroux. 2005.

...[T]here have been three great eras of globalization. The first lasted from 1492 – when Columbus set sail, opening trade between the Old World and the New World – until around 1800. I would call this era Globalization 1.0. It shrank the world from a size large to a size medium. ... [I]n Globalization 1.0 the key agent of change, the dynamic force driving the process of global integration was how much brawn – how much muscle, how much horsepower, wind power, or, later, steam power – your country had and how creatively you could deploy it. In this era, countries and governments (often inspired by religion or imperialism or a combination of both) led the way in breaking down walls and knitting the world together, driving global integration. ...

The second great era, Globalization 2.0, lasted roughly from 1800 to 2000, interrupted by the Great Depression and World Wars I and II. This era shrank the world from a size medium to a size small. In Globalization 2.0, the key agent of change, the dynamic force driving global integration, was multinational companies. These multinationals went global for markets and labor, spearheaded first by the expansion of the Dutch and English joint-stock companies and the Industrial Revolution. In the first half of this era, global integration was powered by falling transportation costs, thanks to the steam engine and the railroad, and in the second half by falling telecommunication costs – thanks to the diffusion of the telegraph, telephones, the PC, satellites, fiber-optic cable, and the early version of the World Wide

Web. It was during this era that we really saw the birth and maturation of a global economy, in the sense that there was enough movement of goods and information from continent to continent for there to be a global market, with global arbitrage in products and labor. The dynamic forces behind this era of globalization were breakthroughs in hardware – from steamships and railroads in the beginning to telephones and mainframe computers toward the end. ...

[A]round the year 2000 we entered a whole new era: Globalization 3.0. Globalization 3.0 is shrinking the world from a size small to a size tiny and flattening the playing field at the same time. And while the dynamic force in Globalization 1.0 was countries globalizing, and the dynamic force in Globalization 2.0 was companies globalizing, the dynamic force in Globalization 3.0 – the thing that gives it its unique character – is the newfound power for *individuals* to collaborate and compete globally. And the lever that is enabling individuals and groups to go global so easily and so seamlessly is not horsepower, and not hardware, but software – all sorts of new applications – in conjunction with the creation of a global fiber-optic network that has made us all next-door neighbors. ...

But Globalization 3.0 not only differs from the previous eras in how it is shrinking and flattening the world and in how it is empowering individuals. It is different in that Globalization 1.0 and 2.0 were driven primarily by European and American individuals and businesses. Even though China actually had the biggest economy in the world in the eighteenth century, it was Western countries, companies, and explorers who were doing most of the globalizing and shaping of the system. But going forward, this will be less and less true. Because it is flattening and shrinking the world, Globalization 3.0 is going to be more driven not only by individuals but also by a much more diverse – non-Western, non-white – group of individuals. Individuals from every corner of the flat world are being empowered. Globalization 3.0 makes it possible for so many more people to plug and play, and you are going to see every color of the human rainbow take part.

2.2.1.2 Globalization of the Value Chain



“...the cost of automotive design in Europe ranges as high as \$800 per hour, and even higher in the US while costs are as low as \$60 per hour in India...”

Geeta Nair. “Design outsourcing set to hit Indian shores.”
***Express India*, December 28, 2004.**

India’s manufacturing exports of \$40 billion (2003) may not be close to China’s figure of \$300 billion but that does not rule out India’s potential to be the next big manufacturing exports story.

“The second and much bigger wave of manufacturing offshoring is yet to come. The first wave amounted to around \$460 billion and consisted mostly of labour-intensive items. The second wave, just beginning, could reach \$1.6 trillion annually and will consist of skill-

intensive manufacturing. This will work to India's advantage," said Ved Narayan, vice-president, Asia-Pacific operations, SolidWorks Corporation.

Mr Narayan, who handles the Asia-Pacific region for SolidWorks which develops and markets software for mechanical design, analysis and product data management, said that India also had the potential to become a design-outsourcing hub and can replicate its software services success in this space as well.

US companies, which have development centres in India, are increasingly outsourcing industrial and engineering tasks to India. "The last few years have definitely seen increased activity in the Indian CAD/CAM/CAE space with MNC product vendors realising the importance of India as a cost-effective destination for outsourcing CAD/CAM/CAE work," said Mr Narayan.

India has the expertise in 3D modeling and plant engineering in sectors like aerospace, automotive and industrial machinery. In the automotive sector, according to industry sources, 15 global car makers, including GM, Ford, Daimler Chrysler, Mercedes-Benz, Audi, Isuzu and Nissan, have set up outsourcing offices in the country, with a combined budget of approximately \$1.5 billion. Component makers Delphi, Visteon and Caterpillar too have found India their best bet.

Mr Narayan pointed out that the cost of automotive design in Europe ranges as high as \$800 per hour, and even higher in the US while costs are as low as \$60 per hour in India for equivalent quality. So, global auto makers are increasingly turning to India for sourcing a wide range of needs that even include designing models meant only for global markets," added Mr Narayan.

2.3 Social Trends

We highlight the following social trends:

- Demographics – the retirement gap
- Education – declining performance and the changing curriculum
- Security – the surveillance society

2.3.1 Demographics

2.3.1.1 The Retirement Gap



"Canada's baby boomers will be leaving some large shoes to fill when they start to retire in the next five years, and filling their old jobs may be a problem."

CBC News. "Skilled new Canadians needed to fill boomer retirement gap." March 26, 2002.

There's a large untapped pool of skilled workers who are new Canadians and using them will be critical as Canada's baby boomers begin to retire...

Kim Peters is president of Workopolis – an Internet recruitment company that posts jobs for job seekers. She says there are about 31,000 job postings available per day on her web site, but the workers aren't always there.

"There are tremendous skill shortages in a variety of different sectors," says Peters. "For example, the Canadian Nurses Association has predicted they're going to be short 60,000 nurses by 2011. And that represents 25 per cent of the current nursing labour force. A really astonishing statistic is from the Association of University and Colleges of Canada – they predict they'll be short 10,000 professors in Ontario alone."

The Conference Board of Canada is hosting a conference today in Toronto to address ways to bridge the looming demographic gap. Canada's baby boomers will be leaving some large shoes to fill when they start to retire in the next five years, and filling their old jobs may be a problem. This makes new Canadians even more critical to the Canadian economy.

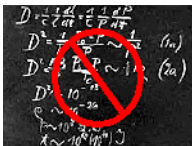
The Conference Board's David Brown says skilled workers are scarce in today's economic climate. "We already realized when we talked to CEOs and people who run major organizations their number one problem today is recruiting and retaining and keeping people with skills to do the job. And that's before we hit the demographic problem."

Brown says there are many new immigrants who have training in jobs that Canadian companies are having trouble filling. "But for various reasons to do with accreditation or cultural gap or just an inability to line up the supply and demand, a lot of those people are underemployed; they end up waiting tables or driving taxis or things like that for years."

Brown says conference delegates will be discussing how to create a workplace that welcomes new Canadians, in order to keep and attract the skilled workers they will need in the years to come.

2.3.2 Education

2.3.2.1 The Changing Curriculum



No science please...

***The Scotsman*. "Top university axes pure physics." December 3, 2004.**

Newcastle University was criticized... for its "short-sighted" decision to axe all its pure physics degrees. The university, one the leading Russell Group of institutions, said it was

concentrating on other subjects because they were more popular with students. The news follows Exeter University's decision to close its chemistry department, which sparked bitter protests from students and world-famous scientists.

2.3.3 Security

2.3.3.1 The Surveillance Society



"...analysts will use custom data-mining techniques to sift through the mass of information... in order to 'preempt and defeat terrorist acts'..."

**Dan Farmer and Charles C. Mann. "Surveillance Nation."
Technology Review, April 2003.**

In 1974 Francis Ford Coppola wrote and directed *The Conversation*, which starred Gene Hackman as Harry Caul, a socially maladroit surveillance expert. In this remarkably prescient movie, a mysterious organization hires Caul to record a quiet discussion that will take place in the middle of a crowd in San Francisco's Union Square. Caul deploys three microphones: one in a bag carried by a confederate and two directional mikes installed on buildings overlooking the area. Afterward Caul discovers that each of the three recordings is plagued by background noise and distortions, but by combining the different sources, he is able to piece together the conversation. Or, rather, he thinks he has pieced it together. Later, to his horror, Caul learns that he misinterpreted a crucial line, a discovery that leads directly to the movie's chilling denouement.

The Conversation illustrates a central dilemma for tomorrow's surveillance society. Although much of the explosive growth in monitoring is being driven by consumer demand, that growth has not yet been accompanied by solutions to the classic difficulties computer systems have integrating disparate sources of information and arriving at valid conclusions. Data quality problems that cause little inconvenience on a local scale -- when Wal-Mart's smart shelves misread a razor's radio frequency identification tag -- have much larger consequences when organizations assemble big databases from many sources and attempt to draw conclusions about, say, someone's capacity for criminal action. Such problems, in the long run, will play a large role in determining both the technical and social impact of surveillance.

The experimental and controversial Total Information Awareness program of the Defense Advanced Research Projects Agency exemplifies these issues. By merging records from corporate, medical, retail, educational, travel, telephone, and even veterinary sources, as well as such "biometric" data as fingerprints, iris and retina scans, DNA tests, and facial-characteristic measurements, the program is intended to create an unprecedented repository of information about both U.S. citizens and foreigners with U.S. contacts. Program director John M. Poindexter has explained that analysts will use custom data-mining techniques to sift through the mass of information, attempting to "detect, classify, and

identify foreign terrorists” in order to “preempt and defeat terrorist acts” -- a virtual Eye of Sauron, in critics’ view, constructed from telephone bills and shopping preference cards.

In February Congress required the Pentagon to obtain its specific approval before implementing Total Information Awareness in the United States (though certain actions are allowed on foreign soil). But President George W. Bush had already announced that he was creating an apparently similar effort, the Terrorist Threat Integration Center, to be led by the Central Intelligence Agency. Regardless of the fate of these two programs, other equally sweeping attempts to pool monitoring data are proceeding apace. Among these initiatives is Regulatory DataCorp, a for-profit consortium of 19 top financial institutions worldwide. The consortium, which was formed last July, combines members’ customer data in an effort to combat “money laundering, fraud, terrorist financing, organized crime, and corruption.” By constantly poring through more than 20,000 sources of public information about potential wrongdoings -- from newspaper articles and Interpol warrants to disciplinary actions by the U.S. Securities and Exchange Commission -- the consortium’s Global Regulatory Information Database will, according to its owner, help clients “know their customers.”

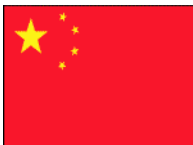
2.4 Geopolitical Trends

We highlight the following geopolitical trends:

- New powers – the emergence of China and the rise of the BRICs
- Global security – the threat of terrorism

2.4.1 New Powers

2.4.1.1 The Emergence of China



“China’s rise is no longer a matter of the future. It is already the fourth largest economy in the world, and is growing at three or four times the rate of the first three.”

**Fareed Zakaria. "What Bush and Kerry Missed."
Newsweek, October 25, 2004.**

There have been two great shifts in the international balance of power over the past five hundred years. The first was the rise of Western Europe, which by the late 17th century had become the richest, most dynamic and expansionist part of the globe. The second was the rise of the US, which between the end of the Civil War and World War I became the single most important country in the world. Right now a trend of equal magnitude is taking place -- the rise of Asia, led by China, which will fundamentally reshape the international landscape in the next few decades. Recognizing and adapting to this new world order is key.

China's rise is no longer a matter of the future. It is already the fourth largest economy in the world, and is growing at three to four times the rate of the first three. It is now the world's largest importer and exporter of many commodities, manufactured goods and agricultural products. It will soon be the largest exporter of capital, buying companies across the globe.

As well, India is growing with impressive resilience and determination. East Asia has been in a boom for three decades. Asians are also the world's biggest savers and their savings have financed the deficit spending of the US

One of the reasons the US has been able to dominate the global economy has been its dominant lead in science and technology. But even here, Asia is gaining strength. From computer science to biotechnology, one can see the emergence of Asian science. "Physical Review", a top science journal, notes that the number of papers its publishes by Americans has been falling dramatically, from 61 percent in 1983 to 29 percent last year.

With economic growth comes cultural confidence and political assertiveness.

2.4.1.2 The Rise of the BRICs



"The newest megatrend? It's the rise of the BRICs. That's shorthand for four developing nations with large populations – Brazil, Russia, India and China."

**Christopher Farrell. "Four countries you must own."
Business Week. December 27, 2004.**

Once in a great while a trend takes hold that's so powerful, it transforms the entire global economy: the Industrial Revolution of the 18th century, the modern industrial nation in the 19th century, and the emergence of cheap computing and communications in the 20th century.

The newest megatrend? It's the rise of the BRICs. That's shorthand for four dynamic developing nations with large populations -- Brazil, Russia, India, and China. The four now account for less than 15% of the economies of the G6 nations. But collectively they could be larger than the G6 in just four decades, say economists at Goldman, Sachs & Co. That depends, of course, on whether they get the fundamentals right: sound fiscal and monetary policies, free trade with the outside world, and massive investment in education. "It's a story for the future," says Robert Hall, portfolio manager for global emerging markets at Russell Investment Group.

2.4.2 Global Security

2.4.2.1 The Threat of Terrorism



"...we recognize the threats as being all too real but difficult to assess in terms of their imminence and gravity. There are too many unknowns and uncertainties."

**John Newhouse. "The threats America faces."
World Policy Journal, Summer 2002.**

Before September 11, the threats from weapons of mass destruction and terrorism were treated for the most part as ugly abstractions and not likely to materialize, even though they had done so in the recent past. Now we recognize the threats as being all too real but difficult to assess in terms of their imminence and gravity. There are too many unknowns and uncertainties. What does seem clear is that the major source of the threat has changed. State-sponsored terrorism has steadily declined in recent years. However, the incidence of acts by nonstate terrorists has risen.

Both the Clinton and Bush administrations elected to stress a highly implausible threat to the territorial United States from unfriendly regimes, notably North Korea and Iran. Early in 2001, the State Department conveyed the official line in a guidance memorandum to embassies: "The principal threat today is...the use of long-range missiles by rogue states for purposes of terror, coercion, and aggression."

This dubious proposition -- an article of faith within parts of the defense establishment -- obscured existing and far more credible threats from truly frightful weapons, some of which are within the reach of terrorists. They include Russia's shaky control of its nuclear weapons and weapons-usable material; the vulnerability of U.S. coastal cities and military forces stationed abroad to medium-range missile systems, ballistic and cruise; the vulnerabilities of all cities to chemical and biological weapons, along with so-called suitcase weapons and other low-tech delivery expedients. Vehicles that contain potentially destructive amounts of stored energy are a major source of concern, as is one of their most attractive potential targets, a nuclear spent-fuel storage facility.

The example set by youthful Palestinian belt bombers can and very possibly will be emulated by terrorists elsewhere, including the United States. Preventing human bombs is "an incredibly difficult business," says Christopher Langton, an authority on terrorism at the International Institute of Strategic Studies. "It's cheap," he says. "It has the most accurate guidance system available to mankind. It is easily concealed."

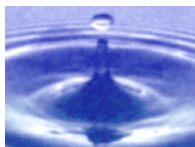
2.5 Environmental Trends

We highlight the following environmental trends:

- Resource depletion – water, food and energy
- Global warming

2.5.1 Resource Depletion

2.5.1.1 Water



“The... World Commission on Water estimated in 2000 that an additional \$100bn a year would be needed to tackle water scarcity worldwide.”

**Alex Kirby. “Water scarcity: A looming crisis?”
BBC. October 19, 2004.**

A third of the world's population lives in water-stressed countries now. By 2025, this is expected to rise to two-thirds. There is more than enough water available, in total, for everyone's basic needs.

The UN recommends that people need a minimum of 50 litres of water a day for drinking, washing, cooking and sanitation. In 1990, over a billion people did not have even that.

Providing universal access to that basic minimum worldwide by 2015 would take less than 1% of the amount of water we use today. But we're a long way from achieving that...

Global water consumption rose sixfold between 1900 and 1995 -- more than double the rate of population growth -- and goes on growing as farming, industry and domestic demand all increase. As important as quantity is quality -- with pollution increasing in some areas, the amount of useable water declines.

More than five million people die from waterborne diseases each year -- 10 times the number killed in wars around the globe. And the wider effects of water shortages are just as chilling as the prospect of having too little to drink.

Seventy percent of the water used worldwide is used for agriculture. Much more will be needed if we are to feed the world's growing population -- predicted to rise from about six billion today to 8.9 billion by 2050.

And consumption will soar further as more people expect Western-style lifestyles and diets - one kilogram of grain-fed beef needs at least 15 cubic metres of water, while a kilo of cereals needs only up to three cubic metres...

The UN-backed World Commission on Water estimated in 2000 that an additional \$100bn a year would be needed to tackle water scarcity worldwide. This dwarfs the \$20bn which will be needed annually by 2007 to tackle HIV and Aids, and, according to the Commission, it is so much it could only be raised from the private sector.

2.5.1.2 Food



“China is the first major grain-producing country where environmental and economic trends have combined to reverse the historical growth in grain production.”

Lester Brown. “China’s shrinking grain harvest.”

***The Globalist*, March 12, 2004.**

Water tables are falling throughout the northern half of China. As aquifers are depleted and irrigation wells go dry, farmers either revert to low-yield dry land farming or -- in the more arid regions -- abandon farming altogether.

In the competition for scarce water, China's cities and industry invariably get first claim, leaving farmers with a shrinking share of a shrinking supply. Losing irrigation water may mean either abandoning land or less double cropping.

China's farmers are also losing land to expanding deserts, such as the Gobi, which is consuming an additional 4,000 square miles each year. Paying farmers in the north and west to plant their grainland to trees to halt these advancing deserts is further reducing the grain area....

Reversing the fall in grain production will not be easy, even with China's newly adopted economic incentives. Each trend that is shrinking the grainland area has a great deal of momentum. Reversing any one of them would take an enormous effort. Reversing all of them seems impossible.

If the new economic incentives should coincide with unusually favorable weather this year, a modest upturn in grain production might result -- but it will likely be only temporary.

China is the first major grain-producing country where environmental and economic trends have combined to reverse the historical growth in grain production. This decline in the grain harvest in a country that is home to more than one-fifth of the world's people will affect all of us.

Barring an economic collapse, China soon will be forced to turn to the world market for massive imports of 30, 40 or 50 million tons per year. This comes at a time when world grain stocks are at their lowest level in 30 years -- and when U.S. farmers are losing irrigation water to aquifer depletion and to cities. Among other things, this means that the surplus world grain production capacity and cheap food of the last half-century may soon be history.

Higher food prices could become a permanent part of the economic landscape. Adjusting to these higher food prices could become a dominant preoccupation of governments in the years ahead.

When China turns to the world market, it will necessarily turn to the United States -- which controls nearly half of world grain exports. This presents an unprecedented geopolitical situation: 1.3 billion Chinese consumers who have a \$120 billion trade surplus with the United States -- enough to buy the entire U.S. grain harvest twice over -- will compete with Americans for U.S. food. This will likely drive up food prices for the United States -- and the world.

2.5.1.3 Energy



“We are heading into a new energy world. Energy is the core of virtually every problem facing humanity. We cannot afford to make mistakes.”

**Rudolf Rechsteiner. “Ten steps to a sustainable energy future.”
Energy Bulletin, July 5, 2004.**

Compare modern society and its growing scarcity of cheap oil with the functional system of a rain forest. In a rain forest you have extreme mineral scarcity and a huge diversity of specialized organisms find their way of living in recycling and managing materials with solar energy, recycling materials and heat. Our own society must turn away from non-sustainable nuclear or chemical fuels like coal, oil or gas and satisfy its energy demand primarily from sustainable “physical sources” like electricity derived from solar, wind, water, ocean waves or geothermal heat, supplemented by biomass from natural growth and organic waste.

We have both an immediate and a long-term source problem. However, in recent years we have developed and matured a variety of commercially available technologies to relieve it. Wind, solar, geothermal and biomass truly are energy sources with a positive Energy Return on Energy Investment (EROEI)...

Renewables require an energy investment before they generate a usable fuel. These up-front costs may be quite high, but on a life-cycle basis they are more and more affordable, for there are no fuel costs. Thus, with renewables one attains a high degree of cost stability in an environment that is increasingly volatile. The ongoing flow of primary energy is essentially free -- save for maintenance on and for amortization of the equipment costs...

As we leave oil behind as our dominant energy technology we will more and more convert our energy system from a chemical to an electrical base. Electric power will be the reference energy against which all other forms of energy will be compared. The cost of synthetic hydrogen will be compared against the cost of electricity needed to obtain this hydrogen. It is clear that this hydrogen is more expensive than the electricity “burned” in producing it.

Applying the principles of this simple comparison may well lead to new technologies focused on energy use more than on energy production and distribution. Engineers will make choices that are quite different from those made a generation or two ago. Electrical systems with their proven high efficiencies will gradually displace chemical energy conversion systems saddled with inferior efficiencies.

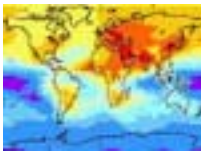
Efficient electric systems will replace inefficient chemical energy converters like thermal power plants, IC engines or fuel cells. This is not a vision or personal view, but it is directly related to the physics of the future energy supply and the necessity for rational use of the energy mankind is able to harvest from renewable sources.

Energy production will become more regional. Wind energy and biomass conversion offers a certain measure of choice on where and when to produce electricity. Wind farms are located on the basis of decisions that take account of where suitable wind conditions and land are available and of where customers are. By contrast, there is no choice possible on where to locate an oil field -- it must be where the oil deposits are, and that may be half a world from where most customers are.

The enormous infrastructure for transporting oil and gas will take on diminished utility in competition with super-efficient HVDC systems for bringing electric energy to industrial and personal consumers. By 2050 we might not be transporting energy as chemical commodity at all. Instead we will transport energy as pure energy itself.

We are heading into a new energy world. Energy is the core of virtually every problem facing humanity. We cannot afford to make mistakes. We should not assume that the existing energy industry will be able to provide solutions on its own. Somehow we must find a basis for energy prosperity for ourselves and for worldwide peace. Energy needs to be available, affordable and secure for all. To do this we need to improve or adapt the existing technology. We also need new policies for a sustainable solution.

2.5.2 Global Warming



“The area... is the world's largest frozen peat bog and scientists fear that as it thaws, it will release billions of tonnes of methane... into the atmosphere.”

**Ian Sample. “Warming hits ‘tipping point.’”
The Guardian. August 11, 2005.**

A vast expanse of western Siberia is undergoing an unprecedented thaw that could dramatically increase the rate of global warming, climate scientists warn today.

Researchers who have recently returned from the region found that an area of permafrost spanning a million square kilometres – the size of France and Germany combined – has

started to melt for the first time since it formed 11,000 years ago at the end of the last ice age.

The area, which covers the entire sub-Arctic region of western Siberia, is the world's largest frozen peat bog and scientists fear that as it thaws, it will release billions of tonnes of methane, a greenhouse gas 20 times more potent than carbon dioxide, into the atmosphere.

It is a scenario climate scientists have feared since first identifying "tipping points" -- delicate thresholds where a slight rise in the Earth's temperature can cause a dramatic change in the environment that itself triggers a far greater increase in global temperatures. ...

Western Siberia is heating up faster than anywhere else in the world, having experienced a rise of some 3C in the past 40 years. Scientists are particularly concerned about the permafrost, because as it thaws, it reveals bare ground which warms up more quickly than ice and snow, and so accelerates the rate at which the permafrost thaws.

Siberia's peat bogs have been producing methane since they formed at the end of the last ice age, but most of the gas had been trapped in the permafrost. According to Larry Smith, a hydrologist at the University of California, Los Angeles, the west Siberian peat bog could hold some 70bn tonnes of methane, a quarter of all of the methane stored in the ground around the world.

The permafrost is likely to take many decades at least to thaw, so the methane locked within it will not be released into the atmosphere in one burst, said Stephen Sitch, a climate scientist at the Met Office's Hadley Centre in Exeter.

But calculations by Dr Sitch and his colleagues show that even if methane seeped from the permafrost over the next 100 years, it would add around 700m tonnes of carbon into the atmosphere each year, roughly the same amount that is released annually from the world's wetlands and agriculture.

It would effectively double atmospheric levels of the gas, leading to a 10% to 25% increase in global warming, he said. ...

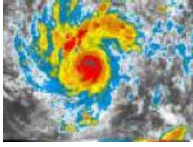
In May this year, another group of researchers reported signs that global warming was damaging the permafrost. Katey Walter of the University of Alaska, Fairbanks, told a meeting of the Arctic Research Consortium of the US that her team had found methane hotspots in eastern Siberia. At the hotspots, methane was bubbling to the surface of the permafrost so quickly that it was preventing the surface from freezing over.

2.6 Wild Cards

We highlight a number of possible wild cards:

- Natural disaster
- Infectious disease

2.6.1 Natural Disaster



"...the tally of natural disasters reported each year has been steadily increasing in recent decades..."

**Ker Than. "Humans add to natural disaster risk."
MSNBC. October 17, 2005.**

Along with the Office of U.S. Foreign Disaster Assistance, CRED [Center for Research on Epidemiology of Disasters] maintains an emergency disaster database called EM-DAT. An event is categorized as a natural disaster if it kills 10 or more people or leaves at least 100 people injured, homeless, displaced or evacuated. An event is also included in the database if a country declares it a natural disaster or if the event requires the country to make a call for international assistance.

According to the EM-DAT, the tally of natural disasters reported each year has been steadily increasing in recent decades, from 78 in 1970 to 348 in 2004.

[Debarati Guha-Sapir, director of CRED] said that a portion of that increase is artificial, due in part to better media reports and advances in communications. Another reason is that beginning in the 1980s, agencies like CRED and the U.S. Agency for International Development began actively looking for natural disasters.

"Like in medicine, if you go out into a village and look for cases you find much more than if you just sit back and let people come to you when they're sick," Guha-Sapir said.

However, about two-thirds of the increase is real and the result of rises in so-called hydro-meteorological disasters, Guha-Sapir said. These disasters include droughts, tsunamis, hurricanes, typhoons and floods, and they have been increasing over the past 25 years. In 1980, there were only about 100 such disasters reported per year, but that number has risen to more than 300 a year since 2000.

In contrast, natural geologic disasters, such as volcanic eruptions, earthquakes, landslides and avalanches, have remained steady in recent decades.

Scientists believe the increase in hydro-meteorological disasters is due to a combination of natural and human-caused factors. Global warming is increasing the temperatures of Earth's oceans and atmosphere, leading to more intense storms of all types, including hurricanes.

Natural decadal variations in the frequency and intensity of hurricanes are also believed to be a contributing factor, as are large-scale temperature fluctuations in the tropical waters of the Eastern Pacific Ocean, known as El Niño and La Niña.

People are also tempting nature with rapid and unplanned urbanization in flood-prone regions, increasing the likelihood that their towns and villages will be affected by flash floods and coastal floods.

2.6.2 Infectious Disease



“...the trend is up. Annual infectious disease-related death rates in the United States have nearly doubled... after reaching an historic low in 1980.”

National Intelligence Council. *The Global Infectious Disease Threat and Its Implications for the United States*. January 2000.

Although the infectious disease threat in the United States remains relatively modest as compared to that of noninfectious diseases, the trend is up. Annual infectious disease-related death rates in the United States have nearly doubled to some 170,000 annually after reaching an historic low in 1980. Many infectious diseases --- most recently, the West Nile virus -- originate outside US borders and are introduced by international travelers, immigrants, returning US military personnel, or imported animals and foodstuffs. In the opinion of the US Institute of Medicine, the next major infectious disease threat to the United States may be, like HIV, a previously unrecognized pathogen. Barring that, the most dangerous known infectious diseases likely to threaten the United States over the next two decades will be HIV/AIDS, hepatitis C, TB, and new, more lethal variants of influenza. Hospital-acquired infections and foodborne illnesses also will pose a threat.

- Although multidrug therapies have cut *HIV/AIDS* deaths by two-thirds to 17,000 annually since 1995, emerging microbial resistance to such drugs and continued new infections will sustain the threat.
- Some 4 million Americans are chronic carriers of the *hepatitis C* virus, a significant cause of liver cancer and cirrhosis. The US death toll from the virus may surpass that of HIV/AIDS in the next five years.
- *TB*, exacerbated by multidrug resistant strains and HIV/AIDS co-infection, has made a comeback. Although a massive and costly control effort is achieving considerable success, the threat will be sustained by the spread of HIV and the growing number of new, particularly illegal, immigrants infected with TB.
- *Influenza* now kills some 30,000 Americans annually, and epidemiologists generally agree that it is not a question of whether, but when, the next killer pandemic will occur.
- Highly virulent and increasingly *antimicrobial resistant pathogens*, such as *Staphylococcus aureus*, are major sources of hospital-acquired infections that kill some 14,000 patients annually.
- The doubling of US food imports over the last five years is one of the factors contributing to tens of millions of *foodborne illnesses* and 9,000 deaths that occur annually, and the trend is up.

3 THE CHANGING PROFESSION OF ENGINEERING

Engineering practice and the engineering profession has been shaped throughout history by changing circumstance – new need, new challenges, and new opportunities. In this section we look briefly at its past, its evolution, and its emerging future.

It will be critical as this work continues, to identify Canadian contributions to this literature, and new professional paradigms.

3.1 The Engineering Challenge

Sunny Auyang. *An Endless Frontier*. Cambridge, Massachusetts: Harvard University Press. 2004.

Natural scientists discover what was not known. Engineers create what does not exist. Both boldly go where no one has gone before, each original and creative in its own way. Through intensive research efforts in the past fifty years, engineers have developed engineering sciences, bodies of coherent knowledge that are comparable to the natural sciences in their length of vision, breadth of scope, depth of analysis, level of creativity, rigor of research, and criteria of acceptance. In the process they are neither imitating natural scientists nor ignoring them... They have common knowledge, methods, and ways of thinking, which include mathematics and instrumentation, theory formation and controlled experimentation, research and development... Their domains increasingly overlap as swelling knowledge bursts the boundaries of academic departments and society increasingly demands useful results from research... Convergence accelerates and interdisciplinary research centers mushroom as the twenty-first century dawns. (pp. 3-4)

Frederick Clarke. Quoted in Sunny Auyang. *An Endless Frontier*. Cambridge, Massachusetts: Harvard University Press. 2004.

[Engineering] involves the delicate and difficult task of translating scientific abstraction into the practical language of earthly living; and this is perhaps the most completely demanding task in the world. For it requires an understanding of both spheres – the pure ether in which science lives, and also the goals and drives and aspirations of human society in all its complexity. The engineer must be at once philosopher, humanist and hard-headed, hard-handed worker. He must be a philosopher enough to know what to *believe*, humanist enough to know what to *desire*, and a workman enough to know what to *do*. (p. 6)

3.2 Historical Perspectives

3.2.1 The Second Industrial Revolution

Thomas P. Hughes. *Human-Built World: How to Think about Technology and Culture*. Chicago: University of Chicago Press. 2004.

Mechanization

A second industrial revolution brought an era of mechanization to America and Germany after 1880. Independent inventors and then industrial research laboratories carried on

invention, research, development, and innovation. Electricity and the internal combustion engine brought the telephone, electric light and power, wireless radio, the automobile, and the airplane. The age of steam was giving way to an electrical one. New materials included steel, aluminum, plastics, and reinforced concrete. Mass production and scientific management transformed industrial management. Organizational and social changes included the rise of giant industrial corporations, the spread of higher technical and scientific education in universities and colleges, the increased influence of professional experts from engineering, sciences, and social sciences, and rapidly expanding metropolitan centers, especially Berlin and New York. (p. 46)

Perry Miller, Harvard history professor, literary critic, and a doyen of American studies scholars, has written eloquently about American attitudes and ideas among the reflective classes toward technology and nature. ...

In *The Life of the Mind in America: From the Revolution to the Civil War* (1995), he describes the general transformation from the eighteenth to the nineteenth centuries in America, especially New England, of attitudes toward science, technology, and wilderness. In the eighteenth century, those who formulated and articulated attitudes—editorial writers, speakers on public occasions, authors of books and articles for educated general readers, and clergy—celebrated the passive contemplation of divine creativity revealed in nature.

The coming of steam engines, steamboats, canals, and railroads in the early nineteenth century changed the ideological landscape from passive contemplation to active transformation. A nation of immigrants, impoverished in their homelands, now empowered by technology, busies themselves improving their worldly circumstances. ...

Rejecting thought that had turned to dry and barren pursuits, they celebrated a new utilitarian age. They believed that creative minds inventing and controlling machines could transform nature by organizing it for human ends. (pp. 28-29)

Electrification

Thomas Edison inventing like a wizard in his Menlo Park laboratory, electrical engineers bending over their drawing boards in Berlin and Schenectady, New York, and white-coated scientists experimenting in industrial and university laboratories brought the electrification of industry and cities in America and Germany. (p. 47)

Transcending the Organic

Werner Sombart argued that the machine embodies a prevailing trend of modern age, which is to free humans from the limitations of the organic. (p. 61)

He defined technology as systems that are means to fulfill determined ends. He identified production technology as essential for sustaining modern culture, the technology on which many other technologies depended. He argued that science-based technology, rather than an empirical approach, characterized the modern style. Yet he had an ambivalent attitude toward technology and modernity, which technology sustained.

Mechanization of Culture

Rathenau had a more advanced concept of mechanization than most of his German and American engineering and managerial contemporaries. In referring to systems, he used

“net” and “web” metaphors employed by those describing globalization and the Internet today. He anticipated transition of modern technology from mechanization to systematization.

Yet the complex Rathenau reacted ambiguously to the mechanized and systematized world that he helped create. He feared that the shaping of human activities and institutions by mechanization would result in a world devoid of human spirit, or soul. He, like Mumford, whom he influenced, believed that the rationality of mechanization would overwhelm the organic character of life. (p. 67)

American Pragmatism

Unlike Rathenau, Spengler, and Mumford, some leading American social critics reacted positively to the technological transformation of culture.

(Charles) Beard not only influenced other historians, but also the literate public through his enormously successful American history text entitled *The Rise of American Civilization* (1927), coauthored with his wife, Mary. In it they enthusiastically and often eloquently argue that the electrical, internal combustion, and mass-production technology of the second industrial revolution was bringing an era of economic democracy in which all classes would enjoy material abundance. (p. 68)

Beard celebrated the machine, inventors, and Christian virtues, but reserved his lavish praise for engineers. He commended them for forcing nature to conform to human will. (p. 73) Both Beard and Mumford revealed their political naïveté in assuming that scientists and engineers could wrest the direction of public affairs from politicians and industrialists. (p. 74)

Beard, Compton, and Josephson, unlike a post-World War II generation of intellectuals, found technology defining American characteristics that they believed would set an example for, and arouse the envy of, older European nations. . . . Just as Americans living on the frontier had, in the opinion of historian Frederick Jackson Turner, acquired the defining characteristics of nineteenth-century America, inventors, engineering, and scientists inhabiting machine-age America were acquiring the characteristics of a new America – technology’s nation. (p. 75)

3.2.2 Technology as Systems and Controls

Thomas P. Hughes. *Human-Built World: How to Think about Technology and Culture*. Chicago: University of Chicago Press. 2004.

Large-scale complexity characterizes the post-World War II era of technology systems and distinguishes it from the preceding machine era. (p. 77)

The Systems Era

Russell Ackoff . . . The machine age with its mechanical devices could be understood, he explained, through rational analysis associated with problem solving as taught in engineering schools and schools of management. Because the number of variables was severely constrained, problems could be reduced to quantitative dimensions. Problem solvers assumed that they fully understood a machine or a machinelike bureaucratic organization.

Because many complex systems, on the other hand, cannot be fully comprehended, engineering and managers need to be satisfied with a partial, ambiguous understanding. Technological and organizational systems are often so complex, so large, and so heterogeneous that interdisciplinary interactive groups sharing perspectives and information are needed to create and control them. (p. 78)

Spread of the Systems Approach

Despite the attacks upon the military-industrial-university complex, it has had a lasting influence upon the character of American technology and its management. Tens of thousands of engineers, scientists, and managers who took part in building weapons systems in the 1950s acquired from this learning experience a systems approach to projects. They and other professionals influenced by them increasingly conceptualized the world around them in terms of systems. (p. 82)

Urban Systems: Promise and Failure

In 1968 Vice President Hubert Humphrey eloquently expressed the administration's enthusiasm for the systems approach when he predicted that techniques used to manage the creation of large weapons systems and space exploration projects could solve pressing urban problems. (p. 84)

The systems approach also fell into disrepute because managers and engineers designing and deploying large systems, especially urban transportation systems, did not sufficiently take into account the traditional and delicate social fabric of urban communities. (p. 85)

The Failure of Controls

While the anti-technology values of post-World War II intellectuals influenced a limited segment of the public, well-publicized technological catastrophes heightened anxieties about the functioning of the human-build world.

Technological catastrophes raised serious doubts about the capability of engineering and scientists to control technology, a capacity that they claimed to have had during the machine age. (p. 89)

Cybernetics

Aware of the failure of controls and the frequency of "normal accidents," engineering and scientists sought to improve control theory and practice. (p. 90)

[Norbert] Wiener conceived his influential cybernetic theory when designing and analyzing gunfire-control devices during World War II. (p. 91) ...

Years later he [Gregory Bateson] recalled cybernetic ideas as more profound and dramatic than the concepts associated with the double helix model of Francis Crick and James Watson. (p. 95)

3.2.3 The Information Revolution

Thomas P. Hughes. *Human-Built World: How to Think about Technology and Culture*. Chicago: University of Chicago Press. 2004.

Information theory and metaphors not only pervaded biology, but also increasingly infiltrated scientific, engineering, and managerial discourse about communication and control. (p. 96)

The Revolution's Technical Core

Like the second industrial revolution, the information revolution involves the spread of new pervasive technology and its interaction with existing technological systems. (p. 97)

Initially mistakenly considered peripheral to computer, or hardware, development, software soon became a major component in the evolving information revolution. (p.100)

Reactions to the Information Revolution

The designers of microchips and the other technology of the new age, he (George Gilder) delights in saying, are not Ivy League graduates in gray flannels and button-down blue shirts, but outsiders, nerds, science wonks, and upwardly mobile engineers.

The creators of the new age who generate wealth by creativity are becoming not only the masters of the economy, but also of politics and social life. (p. 104)

In *The Closed World* (1969), media historian Paul Edwards provides an enlightening perspective on Castell's space of flows. Edwards defines the closed world, or cyberspace, as an artificial space inside a computer or a computer network. (p. 106)

3.3 New Sensibilities

Thomas P. Hughes. *Human-Built World: How to Think about Technology and Culture*. Chicago: University of Chicago Press. 2004.

Machine-Era German Architects

Influential German architects believed that machine technology was creating a new modern culture. They aspired to construct architecture expressing modern values. . . . German architect and industrial designer Peter Behrens argued in 1910 that technology should not be an end in itself, but used as a means to establish a culture expressing itself through the language of art. (p. 112)

In 1910 Behrens summarized his design philosophy in a seminal lecture entitled *Art and Technology* (p. 114)

The Nazis, however, shut down the Bauhaus school in 1933, believing it to be un-German. Instead, they cultivated and nourished German romanticism and kitsch. (p. 117)

Machine Art in America

Duchamp . . . referred to himself as an “artist-engineer” and was familiar with the imaginative drawings of engineering artifacts... even declared in 1921 that he was abandoning art and becoming an engineer – neither of which he did. (p. 128)

Bourke-White, Margaret . . . Her reputation increased dramatically, when she signed an exclusive contract in 1936 with Luce's new Magazine, Life, which became a sensational success. Her picture of Fort Peck Dam in Montana appeared on the cover of the first issue, which also included some candid shots of engineers, workers, and women living at the construction site. (p. 132-4)

Raymond Loewy . . . Wanting to be remembered as an engineer by training and an artist by profession, he founded a consulting firm specializing in industrial design in the late 1920s. Loewy developed a style he called “contemporary American” that blended the modern with the traditional. . . . he became most famous for streamlining Pennsylvania Railroad locomotives and Studebaker automobiles.

In designing automobiles, Loewy sought elegance, finesse, and emotional appeal. A lover of fast, sleek automobiles, he and his firm styled a cleanly streamlined, swift, and low-slung 1953 Studebaker, at a time when other American cars were large, overdecorated, and fin-tailed. In 1962 Loewy unveiled the Studebaker Avanti, his most daring auto design. (p. 137-8, 140)

Artists against Systems, Order, and Control

An influential art critic, Clement Greenberg, whose essays nurtured abstract expressionism, observed that these painters withdrew to a domain they believed to be uncontaminated by technology, science, and industry. (p. 141)

Creating an Ecotechnological Environment

Today people in the industrialized nations, especially the United States, do not grasp the large range of possibilities for creative action that technology offers. We are satisfied to see it used mostly for consumer goods and military weaponry, not realizing that we are unconsciously and unthinkingly also using technology to create a human-built physical environment. (p. 153)

Ecotechnological Systems

Dayton, Ohio, found ways to counter the cold whipping winds of winter and the hot, humid air of summer that flowed into the city from the surrounding countryside. Using a six-foot-wide model of the city with building and streets to scale, graduate students in landscape design at Harvard University then studied the three-dimensional model in a wind tunnel. Drawing upon their studies they proposed locating trees, new buildings, and streets to channel the flow of air from the surrounding countryside to remove polluted air, temper cold winds, and stimulate cooling breezes according to the season. (p. 158)

William Cronon, a professor at the University of Wisconsin, in *Changes in the Land: Indians, Colonists, and the Ecology of New England* (New York: Hill and Wang 1983) has described the interactions of flora, fauna, Indians, colonists, and natural forces in a complex and

changing ecological system within which social political, and other events and trends occurred. (p. 179)

A symposium at the National Academy of Engineering published its presentations in *Engineering and Environmental Challenges: A Technical Symposium on Earth Systems Engineering* (Washington, D.C.: National Academy of Engineering, 2003). The theme was the development of a new field, earth systems engineering, that deals with the natural and human-built worlds. (p. 202)

Technological Literacy

In order to participate effectively in project design specifically and technology policy generally, however, the public needs to learn about the engineering, architectural and managerial processes used in creating and nurturing ecotechnological systems. (p. 170)

The National Academy of Engineering, which speaks for leaders in the profession, recently sponsored a committee to study and issue a major report on technological literacy. Entitled *Technically Speaking: Why All Americans Need to Know More about Technology*, it calls for relevant education in schools, colleges, museums, the media, and elsewhere. (p. 172-3)

3.4 Public Perceptions

Francis Spufford. *Backroom Boys: The Secret Return of the British Boffin*. London: Faber and Faber. 2003.

'The backroom boys' is a phrase from the 1940s. It's what industrial-age Britain used to call the ingenious engineers who occupied the draughty buildings at the edge of factory grounds and invented the technologies of the future. Almost always, they were boys, or rather men: for historical reasons, but also because there is perhaps an affinity between the narrow-focused, wordless concentration required for engineering and a particular kind of male mind. Black-and-white war films made them iconic, gave them a public face everybody recognised, as the unworldly innocents who somehow produced a stream of spectacularly lethal gadgets. ... The public learned a set of characteristics that apparently spelled boffin: distracted demeanour, ineptitude at human relationships, perpetual surprise at the use that other people put their ideas to. But the backroom boys didn't only do military technology. They existed in every industry. They worked on the chemistry of paint, they devised new relays for telephone exchanges, they improved the performance of knitting machines. They were the quiet makers, regarded with affectionate incomprehension (and a little condescension) by a nation which found it easier to admire its smooth talkers and nice movers.

Stephen Turner. Notes. Fredericton. University of New Brunswick. December 10, 2004.

Historically the "public prestige" of engineers has varied inversely with that of "scientists," on the one hand, and business people and "entrepreneurs" on the other. In the 1950s and 1960s, engineering was high-profile and prestigious because "technology" in the public view was symbolized by government-funded mega-projects like NASA, the development of the highway and electrical power infrastructure, and the memory of the Manhattan Project.

Beginning in the late 1970s there was a shift of public fascination back toward the mysteries of the market, and corporations and heroic entrepreneurs made a cultural-comeback. That

hurt the public image of engineers. The Silicon Valley start-ups were ballyhooed for their entrepreneurial hutzpah and their huge profits, with little if any attention paid to the fact that the entrepreneur-champion behind each one was an engineer or a team of engineers. (Once an engineer starts making money, it as if he is no longer an engineer!)

Engineers and engineering have not benefited in terms of prestige and cultural profile from the Information Revolution; they are just not associated with it at the visceral popular level at which these kinds of mass perceptions are molded. And the more recent wave of biotechnology innovations and start-ups have also bypassed engineers and engineering.

3.5 The Future of Engineering

3.5.1 Rethinking the Professions

William M. Sullivan. "Markets vs. professions: value added?"
Daedalus, Summer 2005.

The bruising experience of the 1990s boom-and-bust in the financial markets glaringly revealed just how important professional acumen and integrity are to the viability of the marketplace. Professionalism, it turns out, provides a public value essential to modern societies. The real issue is how to promote and ensure the viability of genuine professionalism amid highly challenging conditions.

The academic institutions in which professionals begin their apprenticeships are key. Professional schools are the single institutional context that professionals control, the sole site where the professions' standards of good work set the agenda for learning. Professional schools are not only where advanced practitioners communicate their expert knowledge and judgment to beginners – they are also the place where the professionals put their defining values and exemplars on display, and where future practitioners begin to assume, and critically examine, their future identities. (pp. 19-20)

Today's professions face not only changing domains of knowledge, but also shifting fields of practice within a dynamic and often confusing society. Therefore, the horizons of the professions need to be broad: Practitioners must be able to think critically about their own situation and that of their field in relation to its defining purposes. The institutions of professional education must challenge students to be both experts and citizens. (p. 25)

3.5.2 Global Reach, Many Disciplines

National Academy of Engineering. *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press. 2004.

In this new global economy, high-end services like electronic design, applied research, accounting, aerospace design, technical consulting, and x-ray assessment can be done more economically back to the developed countries. Thus, new semiconductors can be readily designed in China and India and used to manufacture chips anywhere in the world.

Many advanced engineering designs are accomplished using virtual global teams – highly integrated engineering teams comprised of researchers located around the world. These teams often function across multiple time zones, multiple cultures, and sometimes multiple languages. They can also operate asynchronously. (p. 33)

National Academy of Engineering. *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press. 2004.

In the past, steady increases in knowledge have spawned new microdisciplines within engineering (e.g., microelectronics, photonics, biomechanics). However, contemporary challenges – from biomedical devices to complex manufacturing design to large systems of networked devices – increasingly require a *systems* perspective. Systems engineering is based on the principle that structured methodologies can be used to integrate components and technologies. The systems perspective is one that looks to achieve synergy and harmony among diverse components of a larger theme. Hence, there is a need for greater breadth so that broader requirements can be addressed. Many believe this necessitates new ways of *doing* engineering. ...

Because of the increasing complexity and scale of systems-based engineering problems, there is a growing need to pursue collaborations with multidisciplinary teams of experts across multiple fields. Essential attributes for these teams include excellence in communication (with technical and public audiences), an ability to communicate using technology, and an understanding of the complexities associated with a global market and social context. Flexibility, receptiveness to change, and mutual respect are essential as well. For example, it already is found that engineers may come together in teams based on individual areas of expertise and disperse once a challenge has been addressed, only to regroup again differently to respond to a new challenge. (pp. 34-35)

3.5.3 The 21st Century Engineer

National Academy of Engineering. *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press. 2004.

Engineers in 2020, like engineers of yesterday and today, will possess **strong analytical skills**. At its core, engineering employs principles of science, mathematics, and domains of discovery and design to a particular challenge and for a practical purpose. This will not change as we move forward. ...

Engineers in 2020 will exhibit **practical ingenuity**... Yesterday, today, and forever, engineering will be synonymous with ingenuity – skill in planning, combining, and adapting. Using practical; ingenuity, engineers identify problems and find solutions. This will continue to be a mainstay of engineering. But as technology continues to increase in complexity and the world becomes every more dependent on technology, the magnitude, scope, and impact of the challenges society will face in the future are likely to change. ...

Creativity (invention, innovation, thinking outside the box, art) is an indispensable quality for engineering, and given the growing scope of the challenges ahead and the complexity and diversity of the technologies of the 21st century, creativity will grow in importance. ...

As always, good engineering will require good **communication**. Engineering has always engaged multiple stakeholders – government, private industry, and the public. In the new century the parties that engineering ties together will increasingly involve interdisciplinary teams, globally diverse team members, public officials, and a global customer base. ...

In the past those engineers who mastered the principles of **business and management** were rewarded with leadership roles. This will be no different in the future. However, with the growing interdependence between technology and the economic and social foundations of

modern society, there will be an increasing number of opportunities for engineers to exercise their potential as leaders, not only in business but also in the nonprofit and government sectors. ...

In preparation for this opportunity, engineers must understand the principles of **leadership** and be able to practice them in growing proportions as their careers advance. They must also be willing to acknowledge the significance and importance of public service and its place in society, stretching their traditional comfort zone and accepting the challenge of bridging public policy and technology well beyond the roles accepted in the past. ...

Complementary to the necessity for strong leadership ability is the need to also possess a working framework upon which **high ethical standards** and a strong sense of **professionalism** can be developed. These are supported by boldness and courage. Many of the challenges of the new century are complex and interdependent and have significant implications for the technologies intended to address them and the ways in which those technologies affect the planet and the people that live here. ...

Given the uncertain and changing character of the world in which 2020 engineers will work, engineers will need something that cannot be described in a single word. It involves **dynamism, agility, resilience, and flexibility**. Not only will technology change quickly, the social-political-economic world in which engineers work will change continuously. In this context it will not be this or that particular knowledge that engineers will need but rather the ability to learn new things quickly and the ability to apply knowledge to new problems and new contexts.

Encompassed in this theme is the imperative for engineers to be **lifelong learners** (pp. 54-56).

3.5.4 Challenges in Engineering Education

The Royal Academy of Engineering. *The Future of Engineering Research*. London. August 2003.

Accepting that the future of the national wealth creating capability depends substantially on the knowledge and skills of the working population, the dwindling supply of engineering graduates is a cause for extreme concern. In 1991, engineering attracted 10.7% of all accepted domestic higher education applicants processed by the Universities and Colleges Admissions Service [in the UK] – by 2001, this figure had fallen to 5.2%. (p. 19)

Larry J. Shuman, Cynthia J. Atman, Elizabeth A. Eschenbach, et al. “*The Future of Engineering Education*.” Boston: ASEE/IEEE Frontiers in Education Conference. November 6-9, 2002.

In 1999, engineering represented only 7.0% of all US baccalaureate degrees, compared to 18.4% for China, 19.0% for Taiwan, 19.4% for Japan, 22.1% for South Korea, and 29.5% for France. (p. 3)

The Royal Academy of Engineering. *The Future of Engineering Research*. London. August 2003.

A recent survey of UK Deans of Science conducted by Save British Science indicated that on 70% of undergraduate physical science courses, less than 50% of students were considered to possess the required level of mathematics skills. Indeed, the current low

standards of basic mathematics and physical science education in the UK are having direct repercussions on the capacity of undergraduate engineering students to meet the demands of their courses. (p. 19)

The Royal Academy of Engineering. *The Future of Engineering Research*. London. August 2003.

[T]here is a 'demographic time bomb' for engineering caused by growing numbers of academic staff reaching retirement age by 2010 and exacerbated by the lack of UK engineering students wishing to follow academic careers. Staff numbers in university engineering departments are steadily falling and an increase in recruitment rates of between 22% and 36% over the next seven years is required just to maintain the current numbers of staff. In reality, many institutions already have severe difficulty in recruiting and retaining staff in engineering-related subjects.

A yet more pressing concern is that the percentage of younger academics in engineering departments is falling even more rapidly than the other age categories, with the percentage of staff under 30 almost halving between 1995 and 2000. Collectively, these data herald an impending crisis in staffing levels at university engineering departments. (p. 20)

4 CASE STUDIES

Case studies illustrate the nuances of emerging trends. Several stories are outlined below to facilitate discussion:

- The automotive sector – revolutionizing the automobile industry
- The energy sector – creating energy alternatives
- Biology and engineering – turning to biology from inspiration and engineering biological systems

4.1 The Automotive Sector

4.1.1 Revolutionizing the Automobile Industry

The Economist. “Ripe for revolution.” September 2, 2004.

The car business is ripe for revolution. Once it epitomised 20th-century capitalism, but today it looks poorly equipped to thrive in the 21st century, or even to survive in its present form. Many of the world's biggest car firms are destroying wealth rather than creating it. About half of the industry is regularly incapable of earning a decent return on its invested capital. Although it still accounts for about a tenth of economic activity in rich countries, it has been virtually shut out of stockmarkets for the past 20 years, accounting for a mere 1% of total market capitalisation...

All car firms have learned from Toyota how to use just-in-time, lean production to make cars much more efficiently. A continuous flow of parts arrives from the other side of the world (increasingly from China) just when they are needed. But, oddly, the finished cars then sit in parking lots for up to 90 days before they are sold, usually at a discount because they are not the colour or do not have the optional extras that the buyer wants. The whole industry is straining to find ways of making cars to order rather than producing them for inventory....

Some parts suppliers have taken over the role of final assembly of niche models for big car firms, and others are doing more of the development work on new cars. The virtual car company could be in sight: perhaps one day some firms will own only technology, design and a brand, while a contract-manufacturing industry, born of today's suppliers, springs up, a path already taken by the consumer electronics and computer industries.

The industry of the future will look more like other consumer products businesses-crowded, fast-moving and a slave to the whims of customers.

From the main article...

For the past 20 years carmakers round the world have been trying to emulate Japanese companies, success in lean manufacturing, seen as the benchmark for ensuring quality and efficiency, especially as practised by Toyota. Most car factories have now been revamped more or less along Japanese lines, so the gap between Japanese and western producers has become much smaller. Indeed, four of the five most efficient assembly plants in North America belong to GM.

Glenn Mercer, head of automotive services at McKinsey, a consultancy, explains that once all the makers have got the labour content of assembling a car down to 18-20 man-hours, lean production becomes less of an issue. "Manufacturing is not the game now," he says. But differences at the margin still count. GM is ahead of Ford on productivity, giving it lower variable cost and enabling it to offer larger discounts to hold on to market share. The next thing everyone has to do is to make factories more flexible so that they produce what customers want and what is selling well. The idea is to tie product development, marketing and manufacturing more closely together.

In their book, *Time for a Model Change*, Messrs Maxton and Wormald say that this proliferation of models and variations is making the business too complex and too expensive. But others are more sanguine about the larger range of models. David Cole, chairman of the Centre for Automotive Research (CAR) in Ann Arbor, Michigan, thinks the business has become less risky now that engineers are able to use computers to speed up the development of new models and variations.

Bob Lutz at GM reckons it takes about 36 months to get a new vehicle into the showrooms. The first 12 months go on figuring out what sort of vehicle it should be and making the business case for it, and the next 24 months are spent working on the design and engineering.

Given the huge range of models that car companies must offer now, they have found they need factories that are completely flexible, able to switch from making one model to another to inert fluctuating demand. Honda was first to latch on to this, organising its global spread of factories so that any one of them could make any car, with only short delays for rearranging the machinery.

There is a glaring paradox in the way cars are produced. Manufacturers sweat blood, and squeeze their suppliers hard, to operate a just-in-time production system whereby the components for each car arrive at the right place on the assembly line at precise intervals several times a day. Given that the average car is made up of about 10,000 parts, some of them produced thousands of miles away, this is a miracle of logistics.

4.2 The Energy Sector

4.2.1 Creating Energy Alternatives

Robert F. Service. "The Hydrogen Backlash."
Science, Vol. 305, August 13, 2004.

...the United States, the European Union, Japan, and other governments have sunk billions of dollars into hydrogen initiatives aimed at revving up the technology and propelling it to market. Car and energy companies are pumping billions more into building demonstration fleets and hydrogen fueling stations. Many policymakers see the move from oil to hydrogen as manifest destiny, challenging but inevitable. In a recent speech, Spencer Abraham, the U.S. secretary of energy, said such a transformation has "the potential to change our country on a scale of the development of electricity and the internal combustion engine."

The only problem is that the bet on the hydrogen economy is at best a long shot. Recent reports from the U.S. National Academy of Sciences (NAS) and the American Physical Society (APS) conclude that researchers face daunting challenges in finding ways to

produce and store hydrogen, convert it to electricity, supply it to consumers, and overcome vexing safety concerns.

As a result, the transition to a hydrogen economy, if it comes at all, won't happen soon.

In the meantime, some energy researchers complain that, by skewing research toward costly large-scale demonstrations of technology well before it's ready for market, governments risk repeating a pattern that has sunk previous technologies such as synfuels in 1980s. By focusing research on technologies that aren't likely to have a measurable impact until the second half of the century, the current hydrogen push fails to address the growing threat from greenhouse gas emissions from fossil fuels. "There is starting to be some backlash on the hydrogen economy," says Howard Herzog, an MIT chemical engineer. "The hype has been way overblown. It's just not thought through."...

Economic and political difficulties abound, but the most glaring barriers are technical. At the top of the list: finding a simple and cheap way to produce hydrogen. As is often pointed out, hydrogen is not a fuel in itself, as oil and coal are. Rather, like electricity, it's an energy carrier that must be generated using another source of power. ... every time a fuel is converted from one source, such as oil, to another, such as electricity or hydrogen, it costs energy and therefore money...

A handful of automakers are developing internal combustion engines that run on hydrogen, which burns more readily than gasoline and produces almost no pollutants. If manufacturers can get enough of them on the road in the next few years, hydrogen internal combustion engine (or H₂ ICE) vehicles might spur the construction of a larger infrastructure for producing and distributing hydrogen -- the very same infrastructure that fuel cell vehicles will require.

If all goes as hoped, H₂ ICE vehicles could solve the chicken-or-the-egg problem of which comes first, the fuel cell cars or the hydrogen stations to fuel them, says Robert Natkin, a mechanical engineer at Ford Motor Co. in Dearborn, Michigan.

In the long run, most experts agree, the hydrogen fuel cell holds the most promise for powering clean, ultraefficient cars. If they improve as hoped, fuel cells might use fully extract two-thirds of the chemical energy contained in a kilogram of hydrogen. In contrast, even with help from an electric hybrid system, an H₂ ICE probably can extract less than half. (A gasoline engine makes use of about 25% of the energy in its fuel, the rest going primarily to heat.) And whereas an internal combustion engine will always produce some tiny amount of pollution, a fuel cell promises true zero emissions. But H₂ ICE vehicles enjoy one advantage that could bring them to market quickly and help increase the demand for hydrogen filling stations, says James Francfort, who manages the Department of Energy's Advanced Vehicle Testing Activity at the Idaho National Engineering and Environmental Laboratory in Idaho Falls. "The car guys know how to build engines," Francfort says. "This looks like something that could be done now." ...

If technologies for hydrogen fuel take off, one of the biggest winners could be the developing world. Just as cell phones in poor countries have made land lines obsolete before they were installed, hydrogen from renewable sources--in an ideal world--could enable developing countries to leap over the developed world to energy independence. "The opportunity is there for them to become leaders in this area," says Thorsteinn Sigfusson of the University of Iceland, one of the leaders of the International Partnership for a Hydrogen

Economy (IPHE), a cooperative effort of 15 countries, including the United States, Iceland, India, China, and Brazil, founded last year to advance hydrogen research and technology development.

With their growing influence in global manufacturing, their technical expertise, and their low labor costs, Sigfusson says, countries such as China and India could play extremely important roles in developing more efficient solar or biotech sources of hydrogen--as well as vehicles and power systems that use the fuel. "They have the opportunity to take a leap into the hydrogen economy without all the troubles of going through combustion and liquid fuel," he says. The impact would be huge. The IPHE members already encompass 85% of the world's population, he notes.

S. Pacala and R. Socolow. "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies." *Science*, Vol. 305. August 13, 2004.

Humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century. A portfolio of technologies now exists to meet the world's energy needs over the next 50 years and limit atmospheric CO₂ to a trajectory that avoids a doubling of the preindustrial concentration. Every element in this portfolio has passed beyond the laboratory bench and demonstration project; many are already implemented somewhere at full industrial scale. Although no element is a credible candidate for doing the entire job (or even half the job) by itself, the portfolio as a whole is large enough that not every element has to be used.

4.3 Biology and Engineering

4.3.1 Turning to Biology for Inspiration

Bi-Directional Connections

Joel Cuello. "Engineering to Biology and Biology to Engineering: The Bi-Directional Connection Between Engineering and Biology in Biological Engineering Design." Tenth Annual Meeting of the Institute of Biological Engineering. Athens, Georgia. March 4-6, 2005.

Biological Engineering, the engineering discipline that connects engineering and biology, encompasses both "connecting engineering to biology" and "connecting biology to engineering" in its engineering design process. The first directional case of "connecting engineering to biology" pertains to the application of the engineering design process to regulate and manipulate a given biological system for the purpose of achieving a desired end. The second directional case of "connecting biology to engineering" pertains to employing the knowledge of the attributes of biological systems to inform or guide the engineering design of a physical system for the purpose of achieving a desired end. For "connecting engineering to biology," the object of the design process is a biological system and its design factors are limited by physicochemical principles. Contrastively, for "connecting biology to engineering," the object of the design process is a physical system and its design factors are limited by biological attributes. The first case of "connecting engineering to biology" addresses the design of: (1) protocol for biological system; (2) structure for biological system; and (3) model for biological system. The second case of "connecting biology to engineering" addresses the design of: (4) material based on

biological system; (5) machine/device based on biological system; and (6) instrument based on biological system.

Biological Engineering at Duke University

Duke University received a major grant from NSF in 2003 to begin a graduate training program in biologically inspired materials through their Center for Biologically Inspired materials and Material Systems (part of the Pratt School of Engineering).

Biological Engineering at MIT

The molecular and genomic revolutions in biology place it as a new foundational science for engineering, joining the well-established engineering foundations of physics, chemistry and math. Towards forging a new disciplinary connection with biology – “Biological” Engineering -- that has applications ranging from biotechnology to electronic materials (and of course, medicine!). As with other revolutions in basic science, engineering analysis, design, and synthesis are needed to translate breakthrough discoveries into products and create new industries.

Biological applications are integrated into the core curricula of most MIT engineering departments, and are the entire focus of the Biological Engineering Division, created in 1998 foster development of world-leading new degree programs that fuse biology and engineering by bringing engineering and biology faculty together in one academic unit.

4.3.2 Engineering Biological Systems

Lauren J. Clark. Notes on the First International Meeting on Synthetic Biology. Cambridge, Massachusetts. June 10-12, 2004.

Defined by Thomas F. Knight Jr., a senior research scientist in the Computer Science and Artificial Intelligence Laboratory, as "leveraging natural structures as ways of building things on the molecular scale".

Work in synthetic biology has been evolving for more than two decades, although researchers are only at the preliminary stages of being able to engineer biological systems. Synthetic biology has been compared to mechanical engineering in the 1800s, when machine components had yet to be standardized.

In a talk titled "Biological Simplicity," Knight used Legos to demonstrate the usefulness of standardized parts. "You can put them together however you want Can we construct a chromosome from standardized parts?" At the conference Knight explained that he applies to biological systems the same tools he used to control the complexity of a billion-component silicon chip. He pointed out that while biologists celebrate the "wonderful complexity" of biological systems, "engineers cherish the simplicity of systems."

For instance, he described his work on rewriting the genome of a microorganism called mesoplasma. One way to do this is to "take stuff out until it breaks. An alternative to understanding complexity is to remove it..... which could lead to "new science and novel engineering."

5 THE POLICY AGENDA

Accelerating change, and its accompanying challenges, will create new questions in public policy. Among other issues, declining productivity, growing international competition, intellectual property issues, the emerging crisis in education, and concerns about the impact of new technologies on public safety will all have to be addressed.

5.1 The Productivity Challenge

Andrew Sharpe. Edited testimony given to the Senate Standing Committee on Banking, Trade and Commerce hearings on productivity. Ottawa, Ontario. May 11, 2005.

What has happened recently is unprecedented in our economic history in terms of productivity developments. In 2003, we had a rate of productivity growth in the business sector of 0.1 per cent. In 2004, we did even worse. It was zero. Thus, in the last two years, there has been virtually no productivity growth in the business sector in Canada. Productivity is here defined on an output per hour basis, which is the most relevant measure of labour productivity.

In stark contrast to recent developments in Canada, productivity growth in the United States has soared. Output per hour in the business sector advanced 4.3 per cent in 2003 and 4.0 per cent in 2004 for a two-year increase of over 8 per cent. This has led to a cumulative difference of about 8 percentage points between labour productivity growth rates in the two countries since 2002, with the result that Canada's level of business sector output per hour, as a proportion of that in the United States, has plummeted from 81 per cent in 2002 to 74 per cent in 2004. This represents a major deterioration in our relative productivity performance vis-à-vis the United States. ...

It appears that the very rapid productivity growth in the United States is due to an acceleration in the pace of technological change. Productivity growth picked up in the second half of the 1990s, a development found due to advances in the information and communications technology (ICT) area. Since 2000, there has been a second productivity growth rate acceleration to over 3 per cent per year, again likely linked to ICT, particularly to its more widespread and effective use.

World Economic Forum. Growth Competitiveness Index in *Global Competitiveness Report 2005-2006*. Geneva, Switzerland. 2005.

Country	GCI 2005 rank	GCI 2005 score	GCI 2004 rank
Finland	1	5.94	1
United States	2	5.81	2
Sweden	3	5.65	3
Denmark	4	5.65	5
Taiwan	5	5.58	4
Singapore	6	5.48	7
Iceland	7	5.48	10
Switzerland	8	5.46	8
Norway	9	5.40	6
Australia	10	5.21	14
Netherlands	11	5.21	12
Japan	12	5.18	9
United Kingdom	13	5.11	11
Canada	14	5.10	15
Germany	15	5.10	13
New Zealand	16	5.09	18
Korea, Rep.	17	5.07	29
United Arab Emirates	18	4.99	16
Qatar	19	4.97	—
Estonia	20	4.95	20

Sunny Auyang. *An Endless Frontier*. Cambridge, Massachusetts: Harvard University Press. 2004.

Technology is a scientific capacity for creative production and an enabler of activities. Like all potentials, it may or may not be realized. A depressed economy with plants idled and engineers and scientists driving taxi cabs is wasting its technological capacity. Workers exercise a society's technological capacity in their technical activities. Activities in engineering, science, and industry produce results, which in turn generate demand pull and supply push for technological progress. (pp. 17-18)

5.2 Innovation and International Competition

Peter Calamai. Centre for Research and Information on Canada. Vol. 6, No. 29-September 30, 2004.

There is also a pressing science, policy issue ready-made for the Canadian Academies to consider how Canada should respond to, the latest message about *The Scientific Wealth of Nations*.

Deliberately crafted to evoke the title of Adam Smith's *The Wealth of Nations*, the initial Scientific Wealth League Table was an annotated study that ranked the scientific clout of 31 countries according to how frequently research by their resident scientists was cited by the world science community. That original bibliographic study covered 1981 to 1994 and was

carried out by Robert May, then Chief Science Advisor to the UK government and now (as Lord May) President of the Royal Society in London.

Lord May's successor as chief science advisor, David King, has now extended this study to cover 1993-2002 and published the results, along with his trenchant analysis, this July in *Nature*, the influential British research journal.

There are potential pitfalls in using highly cited research papers as a surrogate for a nation's scientific impact, but King's approach has avoided or minimized most of the known ones. His findings have important implications for Canada's attempts, largely driven by the federal government and centred on universities, to improve national performance in research and development. The key ones are:

- Canada ranked sixth overall in production of highly cited papers, even while ranking outside the top dozen among Western industrialized nations in research spending per capita:
- Among the G-8 Canada ranked second, after Britain, in the amount of private sector research done in university and government labs.
- Among the G-8, minus the US, Canadian research output ranks near the top in two of seven categories – environment and preclinical medicine/health – but at, or near, the bottom in engineering and the physical sciences. In math, biology and clinical medicine Canada was middle of the pack.

Overall, the new League Table is good news, providing strong evidence that the nation gets an excellent bang for its research buck with many scientists here consistently outperforming their better-funded counterparts in larger countries.

Yet, a deeper look at the League Table strongly suggests the federal government will not only have to look outside to something like the Canadian Academies for new approaches but will also have to further step up its investments in strategic areas of research and development.

... the second-place ranking behind Britain that, at first seems to be a plus actually reflects a structural weakness. A high degree of corporate R&D is contracted to government and universities because so few, companies in Canada maintain large research facilities. Also some that once did their own research in-house, such as the pulp and paper sector, have recently closed labs.

Yet, the biggest challenge comes from Canada's surprisingly low scientific impact (tied with Russia for last place among the G-8) in engineering and the physical sciences, such as geology, physics and chemistry. It would be, difficult to overemphasize the relevance of these two fields to the nation's future economic health.

The emerging discipline that is supposed to launch the next global Industrial Revolution, nanotechnology, is a marriage between engineering and the physical sciences. As well realizing the much-ballyhooed economic payoffs from areas like agricultural biotechnology rests directly on national strengths in engineering and chemistry.

Recently the country has emerged, somewhat, from this backwater. An emphasis on engineering and the physical sciences characterize all three of the country's recent forays

into quasi-Big Science -- the Sudbury Neutrino Observatory, the Canadian Light Source in Saskatoon and the Perimeter Institute for Theoretical Physics in Waterloo.

Yet even these three new projects leave Canada still well behind the Big Science investments of economic rivals such as France or Germany and not even in the same league as the UK or Japan.

**Jim Stanford. "Wood-hewers and gas-pumpers 'R' Us".
G&M. Dec. 6, 2004.**

Canada's economy has achieved a dubious milestone. As of 2004, Canada is once again officially a hewer of wood and drawer of water for the global marketplace. Well over half of our total merchandise exports this year consist of natural resources and bulk industrial commodities (such as nickel and aluminium). Less than half consists of higher-value products, such as machinery and equipment, automotive products, and consumer goods.....In the first eight months of this year, we exported \$144 billion worth of commodities (\$65 billion more than we imported) and imported \$151 billion worth of value-added products (\$17 billion more than we exported).

The effort to develop value-added industry has been a defining feature of Canadian economic policy since Confederation. For decades we made relatively steady progress...1965 Auto Pact helped immensely. By 1999 we reached a watershed: fifty-six per cent of our exports consisted of value-added products -- the highest ever. Since then, it has been downhill. (p. A-13)

5.3 Intellectual Property

**Julian Morris et. al. *Ideal Matter: Globalisation and the Intellectual Property Debate*.
Brussels, Belgium: Centre for a New Europe. June 2002.**

...IP, it is argued, creates incentives to invest in the development of new ideas and thence to acquire capital to develop businesses based on these ideas. Commentators point to evidence that intellectual property rights have been an important spur to innovation and growth over the past century and a half.

In spite of the benefits that IP appears to have conferred on society, there has long been a debate over its real utility. Criticisms of IP come in waves and at the present time we seem to be at the crest of such a wave. Ironically, this criticism has been stimulated in large part by recent technological developments. Users of distributed networks such as Freenet, Gnutella and Napster (until it was successfully sued by the RIAA) acquire copyright material without payment. Pressure groups seeking cheaper medicines co-ordinate their activities through websites and email lists, demanding that patented pharmaceuticals be provided without due payment to the patent holder. Other pressure groups, using similar means, object to the patenting of genes, threatening to undermine billions of dollars invested in the development of new and superior crops and medicines. Even trademarks have come under attack in the new economy, with cybersquatters linking to competitor's web pages or defaming brands.

These attacks have called into question the morality of intellectual property rights. Is it just that individuals and corporations should be granted exclusive rights to ideas and/or their expression? Are the higher prices that are charged by the owners of IP worth paying in

return for the stimulus to invention that results? Are there more morally acceptable ways of promoting invention and creativity? (p. 9)

5.4 The Crisis in Education

**Thomas L. Friedman. "Fly Me to the Moon."
New York Times. December 5, 2004.**

We are facing a mounting crisis in science and engineering education. The generation of scientists, engineers and mathematicians who were spurred to get advanced degrees by the 1957 Soviet launch of Sputnik and the challenge by President John Kennedy to put a man on the moon is slowly retiring.

But because of the steady erosion of science, math and engineering education in U.S. high schools, our cold war generation of American scientists is not being fully replenished. We traditionally filled the gap with Indian, Chinese and other immigrant brainpower. But post-9/11, many of these foreign engineers are not coming here anymore, and, because the world is now flat and wired, many others can stay home and innovate without having to emigrate.

If we don't do something soon and dramatic to reverse this "erosion," Shirley Ann Jackson, the president of Rensselaer Polytechnic and president of the American Association for the Advancement of Science, told me, we are not going to have the scientific foundation to sustain our high standard of living in 15 or 20 years.

Instead of doubling the N.S.F. budget - to support more science education and research at every level - this Congress decided to cut it! Could anything be more idiotic?

If President Bush is looking for a legacy, I have just the one for him -- a national science project that would be our generation's moon shot: a crash science initiative for alternative energy and conservation to make America energy-independent in 10 years. Imagine if every American kid, in every school, were galvanized around such a vision...

5.5 Protecting the Public

**PhysOrg.com. "Computer simulation shows buckyballs deform DNA."
December 6, 2005.**

A new study published in December 2005 in *Biophysical Journal* raises a red flag regarding the safety of buckyballs when dissolved in water. It reports the results of a detailed computer simulation that finds buckyballs bind to the spirals in DNA molecules in an aqueous environment, causing the DNA to deform, potentially interfering with its biological functions and possibly causing long-term negative side effects in people and other living organisms.

The research, conducted at Vanderbilt by chemical engineers Peter T. Cummings and Alberto Striolo (now a faculty member at the University of Oklahoma), along with Oak Ridge National laboratory scientist Xiongce Zhao, employed molecular dynamics simulations to investigate the question of whether buckyballs would bind to DNA and, if so, might inflict any lasting damage. "Safe is a difficult word to define, since few substances that can be ingested into the human body are completely safe," points out Cummings, who is the John R. Hall

Professor of Chemical Engineering and director of the Nanomaterials Theory Institute at Oak Ridge National Laboratory. ...

The findings came as something of a surprise, despite earlier studies that have shown buckyballs to be toxic to cells unless coated and to be able to find their way into the brains of fish. Before these cautionary discoveries, researchers thought that the combination of buckyballs' dislike of water and their affinity for each other would cause them to clump together and sink to the bottom of a pool, lake, stream or other aqueous environment. As a result, researchers thought they should not cause a significant environmental problem.

Cummings' team found that, depending on the form the DNA takes, the 60-carbon-atom (C60) buckyball molecule can lodge in the end of a DNA molecule and break apart important hydrogen bonds within the double helix. They can also stick to the minor grooves on the outside of DNA, causing the DNA molecule to bend significantly to one side. Damage to the DNA molecule is even more pronounced when the molecule is split into two helices, as it does when cells are dividing or when the genes are being accessed to produce proteins needed by the cell.

"The binding energy between DNA and buckyballs is quite strong," Cummings says. "We found that the energies were comparable to the binding energies of a drug to receptors in cells."

It turns out that buckyballs have a stronger affinity for DNA than they do for themselves. "This research shows that if buckyballs can get into the nucleus, they can bind to DNA," Cummings says. "If the DNA is damaged, it can be inhibited from self-repairing."

6 NEXT STEPS

It has been the intention of this report to portray the changing context for engineering in the first decade of the 21st century. We have used vignettes to help describe the future that lies before us – a future that will bear very little resemblance to the past. Unprecedented advances in science, accelerating technological change, security threats, rapid globalization, diminishing resources, and pressing environmental challenges will create new demands for engineering expertise. Our future will depend on it.

This report is only the beginning of the conversation. The case studies included in this document will be developed further on the “engineering futures” website. However, more extensive work remains to be done.

The challenge for the Canadian Academy of Engineering is to encourage a deeper dialogue between the engineering profession and the broad community of stakeholders that will shape our country’s future. The stories in this document show that there is an important opportunity – indeed, a pressing need – for engineers to provide leadership in an increasingly complex, globally competitive, high-risk world.

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