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Canada

SEPTEMBER 2013

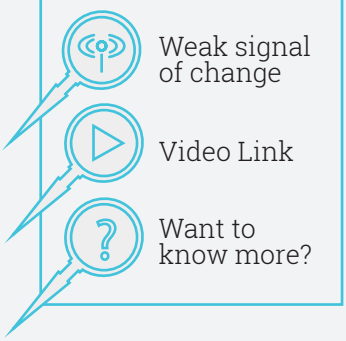
METASCAN 3
Emerging technologies

A FORESIGHT STUDY EXPLORING HOW EMERGING TECHNOLOGIES WILL SHAPE THE ECONOMY AND SOCIETY AND THE CHALLENGES AND OPPORTUNITIES THEY WILL CREATE.

.horizons

INDEX

LEGEND OF INTERACTIVE ICONS



Weak signal of change

Video Link

Want to know more?

DISCLAIMER

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This 2013 foresight study on emerging technologies is a collaborative effort that builds upon the 2012 report: MetaScan 2: Building Resilience in the Transition to a Digital Economy and a Networked Society. More than 90 experts from government, the private sector, civil society and academia were interviewed over the course of this study. We greatly appreciate their expertise and insights in the areas of biotechnology, nanotechnology and neuroscience. The full interviewee list can be found in the Consultations and Interviews section. Special thanks go to Jack Smith and to Karl Schroeder.

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EXECUTIVE SUMMARY

FOCUS ON DISRUPTIVE TECHNOLOGIES. Broadly speaking, there are two types of technological innovation: incremental and disruptive. Incremental changes lead to refinements in processes and products. Disruptive technologies produce radical or abrupt changes that challenge and transform larger social, economic, environmental and/or governance systems. This foresight study examines how four emerging technologies (digital technologies, biotechnologies, nanotechnologies and neuroscience technologies) could drive disruptive social and economic change over the next 10 to 15 years.

MANY DOMAINS ARE AFFECTED. These technologies will impact almost every sector of the economy. One of the most disruptive features of several of the technologies is they increase productivity with fewer workers. Artificial intelligence (like Apple's Siri) combined with data analytics could dramatically change the service sector with fewer workers. In a growing number of sectors, 3D printing could change the economics and location of manufacturing. Synthetic biology could change the economics and flow of raw materials in agriculture, forestry, energy and mining. Governments, business and society will have to work together to ensure there are innovative policies and institutions in place to ride the next wave of technological change. The next 10 to 15 years will be an era of transition. Almost every major piece of infrastructure will likely be under pressure to keep up in areas like skills development, health care, transportation and security. Ignoring or underestimating the rate of change could very well undermine our competitiveness, preparedness and resilience.

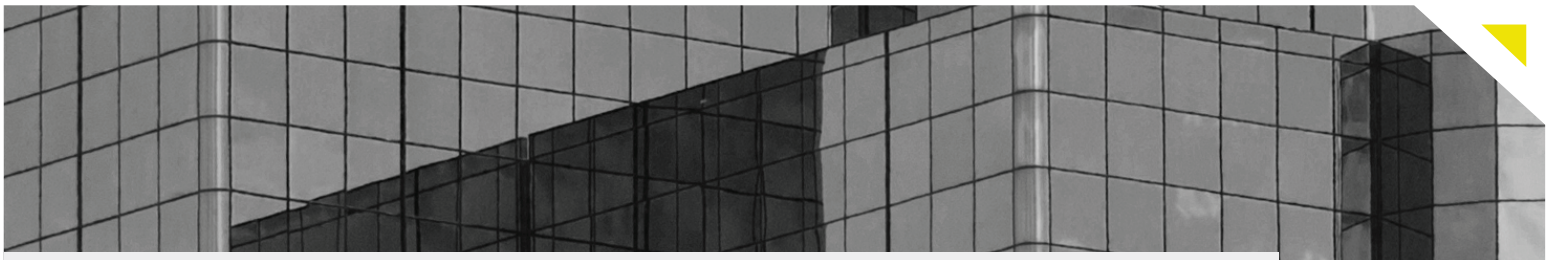
TAKING A LONG TERM VIEW. This study is based on wide research and interviews with more than 90 experts. The technologies in this study are at different stages of maturity and are moving at different speeds. All are expected to have disruptive impacts within 15 years and some much sooner. Some technologies may be rejected by Canada as too risky, but perhaps welcomed by others. The four technologies are laying the foundation for the global economy for the next 50 years. A lead time of 10 to 15 years is needed to take advantage of the opportunities and prepare for the challenges these technologies will present. While Canada has an active Science and Technology Strategy to support technological innovation and training, deeper exploration of the parallel social and economic challenges resulting from these innovations would be useful to help government, business and society prepare.

BUILDING ON METASCAN 2. This study builds on the analysis of digital technologies in MetaScan 2. Digital technologies provide the platform

that enables rapid diffusion and integration of the other three technologies. MetaScan 2 highlighted a number of challenges: The emergence of all-digital supply chains may challenge the tools and notion of a "national economy." The rise of virtual foreign workers who use online tools to work across national boundaries will expand job opportunities for Canadians and possibly change immigration patterns and diversify trade in high- and low-skilled services. The need for just-in-time skills development and reputation systems to track workers' competence will challenge the educational system. Firms will increasingly be virtual, international, project-oriented networks drawing on skilled workers wherever they live. What policies, programs and infrastructure would enable individuals and firms to thrive in this highly competitive environment?

KEY FINDINGS: METASCAN 3 BUILDS ON METASCAN 2 AND ADDS THE FOLLOWING CHALLENGES:

- **The new technologies increase productivity but with fewer workers.** The next decade could be a period of jobless growth.
- **All sectors of the economy will be under pressure to adapt or exploit the new technologies.** The main features of the shift include greater customization, localization and intelligence built into production and delivery. Having people with the right skills will be essential.
- **Shifting competitive advantage.** Synthetic biology is the technology with the greatest potential for surprise. It could make it easier for Canada's customers to grow their own fuel, food and natural resources. It may also make it easier for Canada to grow products like biosteel. The transition will not happen overnight, but Canadians should assess the long-term impact of this technology on key sectors and, if appropriate, develop strategies to move Canada up the value chain.
- **A growing number of jobs will be temporary or non-standard jobs.** For years, temporary work has been one of the fastest-growing employment groups. Interestingly, temporary and freelance jobs are an essential and growing part of the emerging economy. A core opportunity is to help them be more productive. They are outside the current social contract, so freelancers may not get the support they need to develop and prosper.
- **The end of privacy as we know it.** Several of the technologies will combine to make it easier and cheaper to learn about one another. There are huge personal and societal benefits to be gained when personal data is merged in large databases in areas like health care, but traditional notions of privacy may be challenged.
- **New patterns of inequality may emerge.** Technological advance may help generate better opportunities for individuals, but may also create new barriers to access. For example, several technologies offer new ways to assist the injured and the disabled, but the cost of treatment could limit



access and create new inequities.

- **Infrastructure in transition.** The new technologies will likely drive significant change in infrastructure for health, transportation, security and energy systems. The challenge will be determining whether to maintain the old infrastructure or leapfrog to the new, more efficient one.
- **Strengthening risk management and regulatory systems.** All of the four groups of technologies will put increasing pressure on current risk management and regulatory systems in new ways. The global nature of these technologies suggests it will be challenging to respond quickly and in collaboration with other countries.
- **Building a national culture of innovation.** This is an era of considerable opportunity. The four groups of technologies in this study are laying the foundation for the next 50 years of development. With the right information, skills and policies at every level – from the individual to the global – Canada can prosper. Canada needs to see the whole innovation ecosystem and develop policies to support adaptation, experimentation, skills development, regulation and entrepreneurship.

THE OBJECTIVE IS TO EXPLORE ASSUMPTIONS AND CHALLENGES: This report takes the reader through a thought process that will help them examine or build their own mental model about how these technologies could shape the Canadian economy and society. The Horizons foresight method (see Appendix 2) does not predict the future. Rather, it systematically explores a range of futures and identifies plausible surprises and challenges that may emerge over the next 10 to 15 years. The objective of this study is to encourage dialogue and debate on core assumptions and emerging challenges to help develop robust policies and strategies to address them.

USING THIS INTERACTIVE REPORT: The icons – for video links, for where to find additional information and for "weak signals" – are intended to help you "see" signs of change in the present. Reading this report online will allow you to view this information. Pages 4-8 will help you visualize the technologies that will drive change. Pages 9-19 explore how those drivers could shape 10 "domains," including manufacturing, services, resources, health, transportation and security. The domains illustrate the potential for change by providing examples of what our lives could be like in 2025. Pages 20-26 extend the analysis and describe the policy challenges that Canada may confront over the next 10 to 15 years. Pages 27-28 outline new assumptions that may be useful in shaping public policy.

CHANGE DRIVERS

THESE TECHNOLOGIES WILL DRIVE CHANGES THAT WILL SHAPE THE ECONOMY AND SOCIETY OVER THE NEXT 15 YEARS

What are change drivers?
In a world of causes and effects, change drivers are developments that significantly alter the system under study.

How are change drivers used?
Many environmental scans focus on change drivers and their implications. In a foresight study, surprises and challenges emerge as the change drivers interact with each other and the system under study.

EMERGING BIOTECHNOLOGIES

Our understanding of biology is growing and the impact is potentially enormous. Dr. Freeman Dyson, perhaps one of the most influential voices of the science landscape in the recent past, has stated, "the domestication of biotechnology will dominate our lives during the next fifty years at least as much as the domestication of computers has dominated our lives during the previous fifty years." This section examines several of the emerging biotechnologies that will drive social and economic change.

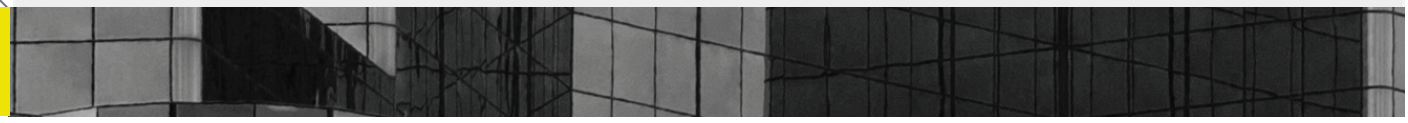
SYNTHETIC BIOLOGY

Synthetic biology may be the least known and most "disruptive" of the technologies in this study. In essence, it is the application of engineering principles to biology. It draws on a number of existing technologies to design and construct new biological systems that produce useful products or serve useful purposes. Current software helps bio-engineers use a growing online library of "biobricks" to design new genetic functions. Biobricks can be assembled by robots, or digital DNA files can be sent to a DNA printer; in either case, the new DNA is inserted into a living cell. The technology is proving to be very efficient. For example, when genetic engineering (which modifies only a few genes at a time) was used to develop a yeast to produce precursors to the antimalarial drug, artemisinin, it took 150 person-years of work and $25 million. Using biobricks, however, a lab of 12 people produced 12 biological systems of comparable complexity in 3 months. Working in this field is becoming easier for researchers at all levels. In 2013, the International Genetically Engineered Machines competition (iGEM) hosted over 200 university and 30 high

Synthetic Biology: Pathway to Innovation in Fuels and Chemicals

Building with Synthetic Biology

Debate Over Glow-In-The-Dark Plants



school teams in using the new technologies to design and build new biological systems. There are clearly risks and opportunities. There are concerns about the safety of creating new life – particularly in the absence of a well-tested regulatory framework. On the opportunity side, life replicates itself for free, input costs are low, and manufacturing more biological devices involves only using more feedstock. Progress in synthetic biology could mean the beginning of a different world that moderates today's concerns over issues like resource depletion and energy supply.

BIOINFORMATICS

Bioinformatics involves storing, analyzing, modeling and sharing large amounts of biological data. Current applications of bioinformatics include DNA barcoding, new bioproducts (such as Millennium Asparagus and biodiesel), modeling disease outbreaks and personal genomics. Our capacity to analyze large amounts of data and our ability to affect traits in plants, animals and humans will increase dramatically. Consider the potential of a widespread medical device costing under $1,000 that sequences your genome, connects to online databases, profiles your genetic history and future, highlights your risk profile, and identifies opportunities to mitigate risks. Bioinformatics holds the promise of tailoring medical and drug treatments to the individual through preventative medicine, using biomarkers to model adverse drug reactions, and helping to understand the complex interplay between genetics and environment. Bioinformatics will fundamentally change the way we think of health care systems.

My Future My Science

TISSUE ENGINEERING

Tissue engineering uses synthetic or naturally grown biomaterials to replace damaged or defective tissues, such as bone, skin and even entire organs. Today, organs that can be regrown include skin, windpipes and bladders; in a decade, this list may expand to kidneys, livers and hearts. Stem cells may also be used to repair damaged or failing organs in place. The most immediate application for tissue engineering is in the area of human health for purposes of healing, replacement and augmentation. This technology will reduce the need for organ donation and eliminate transplant rejection as body parts are regrown or printed using the patient's own cells. In the longer term, advances in skin, bone and muscle synthesis may even allow individuals to change their appearance and augment physical abilities.

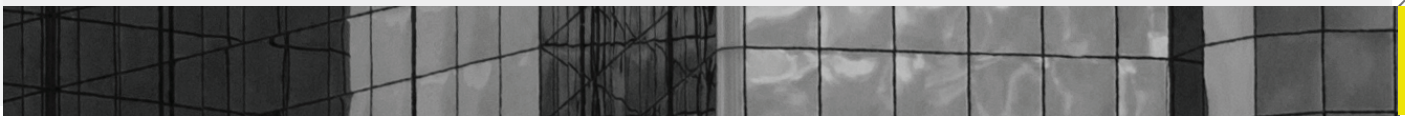
Engineering Organs from Scratch

EMERGING NANOTECHNOLOGIES

Even as our understanding of life grows, new opportunities are emerging at an even smaller scale. Nano is derived from the Greek word "nanos," which means "dwarf," and it refers to the fact that nanoscience operates at an atomic scale. At this scale, substances sometimes behave in novel ways. This field is less advanced than biotechnologies, although much of current nanotechnology has a large biotechnology component. Some say that nanotechnology will be "technology on steroids" as it will improve or speed up developments across many technologies.

NANOMATERIALS

Nano-scale systems often exhibit properties that improve upon or are much different from their human-scale varieties; for example, silver exhibits anti-bacterial properties at the nano-scale that are absent at the



macro-scale. As scientists work with materials close to the molecular level, they can produce new and useful materials, such as nanocellulose and nanocarbon. Both have impressive performance characteristics, being respectively 10 and 50 times stronger than steel for their weight. Nanocoatings provide new ways to make structures self-cleaning, more durable and perhaps even able to receive, store and respond to stimuli. Other nanomaterials are excellent catalysts for making chemistry greener and cheaper. Over the next 15 years, nanomaterials will change the types of things we build and how we build them.

Power of Nanotechnology

Nanotechnology Overview

NANODEVICES AND NANOSENSORS

Nanodevices are machines made of a number of molecular parts that do useful work (such as moving or changing electrically, chemically or optically) in response to specific inputs. Examples include nanoelectromechanical systems (NEMS), nanosensors, nanocomputers and nanorobots. They have surprising energy-efficiency, power density, sensitivity and optical efficiency. Their small size also reduces production costs and increases the number of devices running in parallel, increasing speed. They are likely to be of most use in medical devices, although their small size may lead them to be treated as "smart" drugs. They are also likely to be components of human-scale devices to increase the performance or provide new abilities.

Nanosensors, in particular, are set to have a huge impact. They may open the door to the development of inexpensive, portable devices that can rapidly detect, identify and quantify biological and chemical substances. These may take the form of specific sensing devices, or may simply be features integrated into the next few generations of mobile phones. As such, nanosensors are expected to lead to revolutionary applications, including early disease detection, real-time health monitoring, the early and accurate detection of environmental pollutants and contaminants, and even biological or chemical weapons.

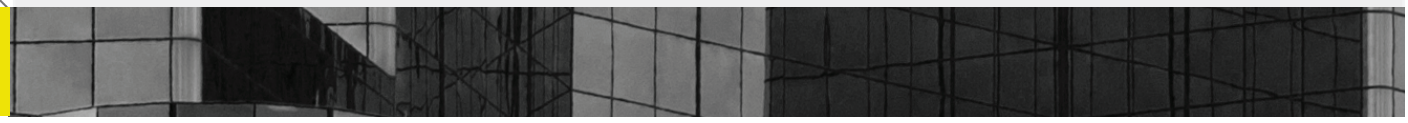
Nanosensors

NANOTECHNOLOGY FOR ENERGY

Nanotechnology may improve energy systems in two key areas over the next 15 years. First, solar cells, cheaper now than they have ever been, are poised for significant improvement due largely to nanotechnology. High-efficiency multi-junction solar cells, infrared energy capture and wavelength-splitting designs may increase high-efficiency solar cell performance by 200-300%. Roll-to-roll printing of solar cells on plastic using photosynthetic inks will allow solar panels to be manufactured at significantly lower costs than even today's low prices.

Secondly, batteries will improve through the use of enhanced nanomaterials and economies of scale. We expect higher capacities, much faster recharging, and greater longevity and significantly lower prices. Better and cheaper batteries could be the cornerstone technology to displace the internal combustion engine for passenger vehicles and support the transition to renewables in homes and businesses by addressing the intermittency of renewable energy sources like wind and solar. Using these technologies, buildings may become energy independent and solar-powered fueling stations could support the growing electric vehicle market.

Roll-to-roll Production of Organic Tandem Solar Cells



EMERGING NEUROSCIENCE TECHNOLOGIES

Neuroscience is the study of the structure and function of the nervous system and brain. Advances in neuro- and cognitive science have improved our understanding of perception, memory, reasoning and emotion. This field is a little less advanced than the previous two but, given recent massive investments in the U.S. and E.U., there is significant potential for surprise in the next 15 years.

NEUROSTIMULATION

Neurostimulation covers those technologies that stimulate, or block, certain parts of the nervous system, particularly within the brain. The technology is used to treat various severe neurological disorders, such as Parkinson's disease, depression and insomnia. Neurostimulation can also be used to augment human cognitive function. Neurostimulation has historically been performed through both invasive (surgery) and non-invasive means (taking pills, electrical stimulation). Wearable headsets are now being marketed that work by adding a slight voltage to neurons, letting them fire more easily. These devices use transcranial direct current stimulation (tDCS), which has the potential to enhance language, learning, attention, problem solving, coordination and memory functions; help combat insomnia, anxiety, and depression; and manage pain. The future use of both "smart drugs" and tDCS could allow some people to gain a competitive advantage over others.

Foc.us: a Biohacking Headset to Improve Your Game

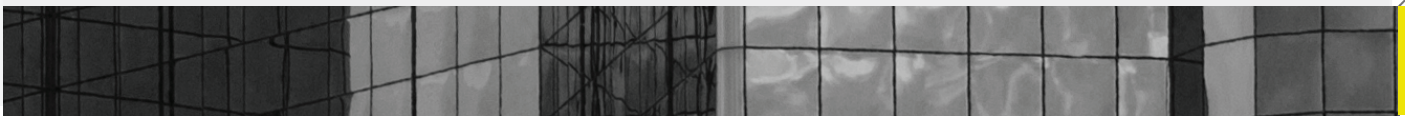
BRAIN-COMPUTER INTERFACE

A brain-computer interface (BCI) is a direct communication pathway that connects nerve signals in the brain to an external computer. BCIs can be invasive (implanted within or just above the brain), or non-invasive (on the scalp surface). BCIs are used therapeutically to assist, augment or repair human cognitive, sensory or motor functions. Today, it requires training and practice to make BCIs useful and reliable. Research, artificial intelligence and more data, however, will improve this significantly. Potential near-term applications include the use of BCIs to detect lapses in attention among occupations requiring vigilance, and as a communication tool for those who have lost motor skills but retained cognition. In the future, this technology could be used to improve cognitive functions, to better understand human preferences, and to augment human capabilities such as coordination and response times. It may even be used to develop senses new to humans, such as the ability to sense magnetic fields, infrared light or radio waves.

Mindster Brain-Computer Interface – Imperial College London

Harvard Study Uses Brain to Brain Interface to Move a Rat's Tail

Sensory Substitution: Welcome to Your Future Brain



EMERGING DIGITAL TECHNOLOGIES

The digital revolution is the most mature of the four technology groups in this study (see MetaScan 2 for a description of digital futures). Digital technologies and infrastructure provide a foundation that will integrate, network and accelerate the three groups of technologies described above.

ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) involves giving machines such traits as reasoning, planning, learning, communication and perception, and the ability to move and manipulate objects. AI is in wide use today: in Apple's Siri for voice recognition, Google's text and image search functions, Facebook's facial recognition capability, NASA's rovers, and algorithmic stock trading. Currently, however, AI is task-specific. The next step is for researchers and computer scientists to advance AI so that computers can learn general knowledge that can be used to enable them to work in new situations, or respond better to the user's contexts and mood. AI innovations are software-based, and are being incorporated into personal tools (e.g., smart phones, Google glasses) as new features, often at near-zero incremental cost. AI will make it possible to automate many tasks, greatly improving personal efficiency and productivity.

Artificial Intelligence Arrives

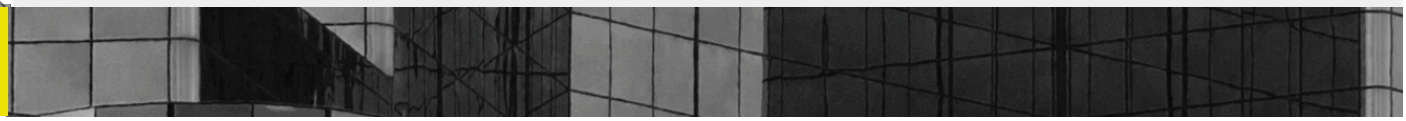
ROBOTICS

Robotics is the branch of technology that deals with the design, construction, operation and application of robots and related computer and control systems. Robots help with or take the place of humans in dangerous environments or manufacturing processes, and/or resemble humans in appearance, behaviour or cognition. Increasingly, robots are designed to act in roles complementary to humans. Today, experimental robots can inventory stock, move loads, pick berries, do housework, perform elder care, sense remotely and create a virtual presence. As their AI improves, they will get smarter and more capable. Robot hardware is improving quickly; the challenge is the software – the intelligence behind the machine that allows it to function in a specific manner. Task-specific robots could do tasks as diverse as surgery, cooking and driving. Businesses will continue to be early adopters of robot technology, with home use following as prices decline and features become more competitive.

NAO Next Gen: Aldebaran Robotics' New Robot

China bought or made 32,800 robots in 2012, more than any other country

The Robot Report



DOMAINS: Potential Impacts

This section illustrates the potential impacts the new technologies could have on ten "domains" within society. It explores four traditional economic domains – manufacturing, services, natural resources and agriculture – then four key infrastructure domains – health, energy, transportation and security – and finally two cross-cutting perspectives on what work and home could look like. It is not a prediction of the future, but rather is intended to help readers get a sense of what is possible if these technologies develop in ways that many experts think are plausible. There are opportunities and risks with each technology that will influence its development.

1. THE POTENTIAL IMPACT ON MANUFACTURING

MANUFACTURING MAY BE MORE LOCAL AND EFFICIENT. When it comes to light manufacturing, synthetic biology and 3D printing have similar characteristics: they both support the local production of a "product" from a digital file using simple low-cost equipment; they enable very low-cost replication of a small or large quantity; and they allow the user to easily experiment and customize the product. Currently, 3D printing uses close to 30 different materials with growing complexity (e.g., Boeing prints 22 000 different airline parts). Soon this will include clothes, many consumer goods and electronic gadgets, to name a few. Synthetic biology will likely produce liquids, solids and industrial chemicals for pharmaceuticals, medicine, paper and building supplies and other goods yet to be imagined, in small or large quantities, and may produce raw materials on-site for local manufacturing plants.

LOW-COST ROBOTS MAY LEVEL THE PLAYING FIELD. Sensors, artificial intelligence and robots will reshape heavy manufacturing and are likely to have a leveling impact across both developed and developing economies. While developing countries may lose their low-cost labour advantage as advanced economies deploy an affordable AI-enabled robotic workforce, both economies will be able to deploy AI and increase the productivity of their low-skilled workers.

NEW MATERIALS WITH NEW PROPERTIES MAY STIMULATE INNOVATION. New bio and nanomaterials are likely to launch a new era of product and process innovation. Their new properties are changing the size, at both ends of the scale, at which designers, engineers and architects can dream. Nanocomposites and other new materials – some as strong as steel and others soft and supple – will improve the performance of manufactured products and support a wider range of 3D printed objects. Embedded sensors and digital tags within materials will enable tracking along the supply chain, offering improved transparency and monitoring of product life cycles.

INDUSTRIAL PROCESSES BECOME MORE ENVIRONMENTAL. Growing pressure on renewable and non-renewable resources, as well as public concern about the safety of new nano and biomaterials, will put greater emphasis on building "closed-loop systems." In these systems, waste from one

industry becomes the feedstock for another. Products may be designed to be safe and fully recyclable. Synthetic biology will enable industrial processes to mimic nature (e.g., enzymes can accelerate the decomposition of industrial waste into safe by-products and have commercial value), and nanotechnology will produce new goods with new properties at a smaller scale that may use far less resources. (For example, soon, a smart phone will contain 20 or 30 tiny nanosensors that collect biometric data.)

The 3D Printing Revolution

Superfast, Cheap DNA Printer

POTENTIAL POLICY CHALLENGE:

- What are the risks for human health and the environment in using biotechnology and nanotechnology to produce goods? Are we able to mitigate these risks?

2. THE POTENTIAL IMPACT ON SERVICES

NEW KINDS OF SERVICES. The Canadian economy is dominated by the services sector, employing 78% of Canada's workforce in 2012. Emerging technologies are likely to increase productivity, but may displace labour in both high- and low-skilled service jobs. Whole new employment and service opportunities are likely to emerge in areas such as professional and business-to-business services; care for aging populations; health care; culture and recreation; intangible products (concepts, designs, information, advice); and international trade-in-services.

SERVICES INCREASINGLY CUSTOMIZED TO THE INDIVIDUAL. Sensors and artificial intelligence (AI) in print media, signs, and devices will mean that services can be increasingly tailored to the users' interests by sensing their demographic information and recalling prior choices. Public spaces will be more interactive and able to offer pertinent information without the user navigating tedious menus. Repeat business is ensured by remembering past preferences. AI could remind a hairstylist how a person likes their hair cut, or what toppings they prefer at the burger joint. Means of gathering instant feedback around new experiences will also be useful; at the dentist, a brain-computer interface could verify the patient's level of comfort. AI tutors could offer students personal attention and "gamify" learning goals (apply game techniques) to encourage progress.

VIRTUAL, AUGMENTED AND REMOTE SERVICES WILL CHANGE THE GEOGRAPHY OF SERVICES. It is likely that services typically conducted face-to-face will be increasingly performed online. Visits to a doctor or lawyer will likely start with a virtual pre-screening interview; the visit itself may also be virtual. In schools, each student may be equipped with a personal AI teacher who monitors their progress and advancement through content modules, with human teachers playing an oversight role. Augmented reality devices may enable travelers and tourists to explore, relax or do business without leaving home. "Telepresencing" (the sense of being in multiple locations at once) will allow users to choose the best service provider for their needs from anywhere in the world rather than the best one in their area.

Google Glasses

Seattle company allows for virtual doctor visits

Virtual doctor's office visits via telemedicine to be the norm

POTENTIAL POLICY CHALLENGES:

- Will new technologies reduce or increase the job-creating potential of the service sector?
- Will there be a global consolidation as large, well-funded companies automate local and national services?
- How do we encourage the right entrepreneurial and technical skills among Canadians to create the next generation of service businesses?

3. THE POTENTIAL IMPACT ON NATURAL RESOURCES

SUSTAINABLE RESOURCE MANAGEMENT AND HARVESTING. The new technologies – particularly sensors, data analytics, AI, drones, robots and synthetic biology – could usher in a new era for the sustainable management and harvesting of forest and fish resources. Together, these tools could allow resource managers and government overseers to monitor ecosystem and resource health, to develop more ecological planting and harvesting strategies, and to quickly identify and implement targeted interventions. Being able to see the whole system would improve planning, investment and public accountability.

ROBOTS FOR TRADITIONAL AND UNDERSEA RESOURCE ACQUISITION. Drones and robots will play a growing role in prospecting and extracting in both traditional and undersea mining, particularly in situations that are remote, difficult or dangerous. The operators of these robots may live in urban locations with their families and never set foot on-site. Operators could live in different time zones around the world, enabling round-the-clock production without major disruptions to their personal and family lives.

Robots drive mining trucks

BIOPRODUCTION OF RAW MATERIALS. Synthetic biology uses genetically engineered organisms to manufacture a growing range of materials such as bioplastics, biofuels, biorubber, biosteel, spider silk and industrial chemicals. Industries that may be disrupted include pulp and paper, building materials, chemical manufacturing, pharmaceuticals, agriculture and fossil fuel extraction. Secondary-processing companies could bypass the primary producers and develop self-sufficient factories that grow raw materials to their exact specifications using bioreactors and locally available feedstock. As this field develops, it may be hard for traditional producers to remain competitive.

Bioreactor growing biofuel

POTENTIAL POLICY CHALLENGE:

- What impact could synthetic biology have on the global market for Canada's resources in the next 15 years?

4. THE POTENTIAL IMPACT ON AGRICULTURE

AGRICULTURAL BIOFACTORIES. In 2028, synthetic biology will have the potential to produce different kinds of food, including meat and drinks at lower costs than today. By manipulating genes, brand-new foods can be created with new properties or flavours. The bioproduction industry is expected to reach $100 billion by 2020 alone. This technology, which uses glass or plastic vats (bioreactors), and needs only sun or sugar, algae and nutrients, can be located anywhere.

Synthetic beef hamburger tastes 'close to meat'

MORE ROBUST, GENETICALLY MODIFIED CROPS. Synthetic biology can also be used to develop new crops with desirable traits such as salt-tolerance, drought-tolerance, and pest-resistance. This technology may help address issues raised by climate change or relieve pressure on arable land, particularly that used to grow feed for animals and some food crops (e.g., sugar, corn for fuel).

ROBOTS ON THE FARM. Farming has the potential to become far more resource-efficient and environmentally friendly on existing farmland, given the prospects for greater automation using AI, robotics and sensors. Flying drones could monitor large fields more quickly and precisely. With information from these drones, as well as that provided by satellites and sensors, automated tractors and sprayers could apply water, seeds, pesticides and nutrients in more targeted and timely ways. This precision could further be enhanced through nanomaterial-based, slow-release pesticides and insecticides. Robotic pickers will continue to emerge and, in time, be able to harvest more types of crops. Automated agriculture could make indoor agriculture more viable in regions where the impact of climate change is degrading arable land, food supply and reliability.

Japanese robot picks the ripest strawberries

TRACING FOOD FROM SEED TO MOUTH. Food-related information for monitoring regulations and markets could be enhanced through implanted chips, sensors and bioinformatics. We may be able to trace food production as well as the path of food-borne diseases to a much higher degree. Markets, consumers and governments could have much more detailed knowledge of where food comes from, who produced it, how, and with what by-products.

POTENTIAL POLICY CHALLENGES:

- Public support for genetically modified foods remains uncertain. What risks are involved with synthetic biology?
- Automated smart farms may have a reduced need for traditional labour, but may require farmers with new skills who can take advantage of the new technologies.
- Could these technologies help unlock new potential in remote areas in Canada?

5. THE POTENTIAL IMPACT ON ENERGY

SOLAR AND WIND MAY BECOME COST-EFFECTIVE. Recently, there have been significant improvements in both solar and wind technologies, including cheap printing processes for solar panels. Many science sources suggest that solar and wind energy may become the most cost-effective choice for new electricity generation in many locations within 15 years. As solar and wind have become more affordable, massive research and venture capital has been going into battery storage for homes, buildings and vehicles. Effective and economical battery storage is on the horizon. It is the key enabling technology to ensure that buildings using renewable energy are powered during cloudy and windless days.

The Future of Oil:
Why Demand for Oil Will Start to Fall

New material could
make solar power dirt cheap

DECENTRALIZED ENERGY SYSTEMS. The combination of cost-effective solar, wind and battery technologies are the key building blocks for decentralized energy systems. Buildings could plug into the grid or operate independently. Electric cars could be plugged into buildings where they could act as a supplementary power source.

Emerging energy storage solutions

MORE ELECTRIC AND HYBRID VEHICLES. Electric engines will grow in the auto sector as advanced batteries take off. Initial costs of electric vehicles are foreseen to decline to parity with conventional vehicles as battery production rises twentyfold. The cost of ownership of electric vehicles is a quarter of the cost of those with internal combustion engines, which will further promote the adoption of electric vehicles as parity approaches. Advanced hybrid engines using biofuels may create a new market segment.

BIOENERGY GROWS. Bioreactors using algae modified through synthetic biology will likely allow firms to produce cheap fuels that use only sunlight and waste CO_2 and water as inputs. Production costs for diesel and ethanol through this "green chemistry" could reach $0.30/L in sunny geographies. Since CO_2 could become a valuable commodity as an input for bioreactors, carbon-emitting facilities might diversify into green manufacturing plants. Greener ways to process the oil sands are possible.

POTENTIAL POLICY CHALLENGES:

- Are we transitioning from centralized to decentralized energy systems? What is the right balance? What does it mean for investment and research?
- Could countries, regions or companies that embrace decentralized energy systems have a long-term competitive advantage? Lower costs? More resilience?

6. THE POTENTIAL IMPACT ON TRANSPORTATION

THE ARRIVAL OF AUTONOMOUS AND SEMI-AUTONOMOUS VEHICLES. The transportation system is in transition. As old vehicles are replaced, the new ones will be more autonomous, smarter and more efficient. Autonomous wheelchairs and delivery vehicles, for example, may become available in hospitals, factories, warehouses and resorts. Although not yet fully autonomous, vehicles with "driver assist" are the new standard for public and personal transportation. Diagnostic tools that use AI will enable vehicles to service themselves by seeking oil changes, brake servicing – even cleaning. As vehicles become even more autonomous, their interiors could transform, allowing passengers to comfortably work or play while they move from place to place. And cars will sync with other devices (e.g., phone, computer, refrigerator) to simplify life even more. Accidents could still occur but identifying who is to blame (the manufacturer, the car's AI designer or the owner) will become a challenge. All of these factors will contribute to new notions of vehicle ownership and liability.

What It's Like to Ride in a Self-Driving Car

Nissan plans for several models of autonomous cars by 2020

THE INTERNET OF "MOVING" THINGS. It's not just vehicles; the transportation system itself may also transform. AI in cars and trucks will benefit from highway – and eventually city – roads that include sensors, reflectors, information transmitters and other tools that support autonomous vehicles. Although not all vehicles will be fully autonomous, the majority will at least be "linked" with each other and with traffic control systems to facilitate coordination and communication. This will greatly improve the efficiency of the system, allowing vehicles to move more quickly and, in some areas, travel in a highly coordinated manner that minimizes gridlock. But privacy could be an emerging issue, since all vehicles may now be monitored, mapped – and possibly even controlled – remotely. Trucking and rail transportation methods will continue to compete. Lighter rail cars and the availability of biodiesel means rail may compete more strongly with trucking; however, automated caravans of trucks equipped with sensors will increase the efficiency of the trucking system and reduce costs.

MOVING FROM GASOLINE ENGINES TO HYBRIDS AND ELECTRIC. The power behind transportation is changing. Both electric and hybrid engines will become more common. Energy exchanges between homes and cars using smart grids and "smart homes" technologies will become possible. Fossil fuels may be supplemented with diesel or bioethanol produced locally in bioreactors. The use of light, strong nanomaterials, including nanocarbon, in conjunction with more efficient and longer-range engines and batteries, means vehicles will be safer, weigh less and go farther. The availability of stronger and more heat-tolerant nanomaterials may allow higher running temperatures and more energy-efficient engines. Regardless of mode (airplane, rail, ship or personal car), vehicle range will likely increase, operating costs will drop and environmental impacts will decrease.

ENHANCED DELIVERY SYSTEMS. The transportation portion of industrial value chains will be dramatically more efficient, timely and automated. AI and robotic loading equipment will coordinate

the movement of goods between transportation modes and systems, a factor that may foster a more competitive domestic manufacturing sector and keeps costs low. Lean and efficient business models characterized by "just-in-time" systems means responsive production and delivery of goods. For smaller deliveries, some vehicles may be displaced by programmable flying drones that can carry small packages between local destinations. These changes will have an impact on employment and on the sector's overall contribution to gross domestic product.

POTENTIAL POLICY CHALLENGES:

- Are governments ready to accommodate new forms of vehicle ownership and liability?
- As the availability of new technologies creates new demands, how will governments manage costs for upgrading or replacing infrastructure?
- The emerging transportation system is built on an extensive data-sharing network. What could this mean for privacy?

7. THE POTENTIAL IMPACT ON MEDICINE

SEQUENCING PATIENT DNA MAY LEAD TO PERSONALIZED MEDICINE. DNA data will help medical professionals better identify drug treatments that are effective and safe for a particular patient, and at dosages suitable for their metabolism. Personalized drug testing on stem cells cloned from the patient could reduce the need for more general animal and human drug trials and possibly identify a wider range of possible treatments. As the genetic markers of disease become increasingly known, DNA will grow more useful in diagnosis, as well as pre-diagnosis – offering risk profiles of conditions well before the onset of symptoms. Some chronic diseases may be prevented or even eradicated through prenatal interventions, early-life treatments, or possibly gene therapy.

GENOMICS, NANOTECHNOLOGY AND SYNTHETIC BIOLOGY COULD ALL CREATE PREVENTION

Technology convergence and the future of medicine

SOLUTIONS. Beyond the predictive benefits of personalized medicine, nano-driven sensors are offering earlier detection (e.g., needing fewer cells to spot cancer). These sensors will be paired with therapeutics to support early intervention, such as theranostics. Nanotechnology and synthetic biology may alleviate concerns about growing antibiotic resistance through solutions to reduce the spread of bacteria or, more effectively, destroy it. Viral outbreaks are already being successfully contained by analyzing an individual's DNA to detect pathogens. In the future, sensors and electronic records will facilitate this tracking, while synthetic biology may have a role in formulating just-in-time vaccines.

HEALTH MONITORING WILL MOVE BEYOND THE CLINICAL SETTING, CLOSER TO YOU. Health sensors will appear more frequently in everyday items such as mobile phones or toilets, wearables (e.g., clothing, jewelry – even skin); in a multifunctional "tricorder" (hand-held diagnostic device); or as part of a "lab-on-a-chip" that people may soon keep in their medicine cabinets. The process

for self-monitoring of health indicators, as well as monitoring of healthy or unhealthy behaviours, will be simpler and more routine. When diagnostic data is networked, AI-augmented and relayed to clinicians, round-the-clock remote care becomes possible. As brain-computer interface (BCI) tools bring greater awareness of mental states, the brain-body connection underlying addictions, illness and treatment will present new options (e.g., neurostimulation, neuro-enhancing drugs, or simply behaviour change).

REGENERATION OF LOST OR DISEASED TISSUE. Organ donor wait-lists and black market organ trading may be things of the past for all but the most complicated organs, such as the heart. Growing or 3D printing of organs from a patient's own cells will allow for faster recovery without rejection. Even nerve damage may become surmountable with the assistance of BCI and robotics. As a consequence, we should anticipate that the line between natural versus enhanced human capability will blur.

POTENTIAL POLICY CHALLENGES:

- Can we use these new technologies to design systems that reduce public health care costs?
- What changes in institutions, roles and responsibilities are needed to ensure oversight, safety, equity, effectiveness and accountability?
- As some diseases become preventable and new means of extending life and ability are adopted, the views of Canadians around costs, access and rights are likely to be very controversial.

8. THE POTENTIAL IMPACT ON SECURITY

SLOW SHIFT IN THE TYPES OF RESOURCES THAT ARE SCARCE, AND THE AREAS THAT ARE AT RISK. Resource scarcity is a potential source of conflict. Advances in synthetic biology could reduce pressure on some scarce natural resources by increasing the security of energy, material and food sources. In parallel, new and different minerals may become scarce. For example, lithium reserves may come under pressure as the demand for batteries grows. The Intergovernmental Panel on Climate Change anticipates that food and water scarcity driven by climate change will be a growing issue and a potential source of conflict and population displacement. Cheaper solar energy would lower the cost of desalination, which could increase food production and reduce the number of refugees forced to leave some drought-prone food-growing areas. This could be bolstered by the development of hardier crops and more adaptive farming methods using new technologies.

OPEN-SOURCE WARFARE GROWS. "Do-it-yourself" surveillance and weapon systems will likely become more common, enabling new kinds of crimes and conflict. For example, the Switchblade Drone is lethal at short distances and fits in a small backpack. New developments in sensors, robotics and nanotechnology could lead to the more widespread use of remote sensors in surveillance, intelligence and warfare. Miniature unmanned aerial, surface and aquatic vehicles and devices – controlled either remotely or autonomously – are expected to become more prevalent. These will be smaller, cheaper and more widely available than today. Open-source knowledge may lead to widely distributed cyber-warfare capabilities. In addition, do-it-yourself enthusiasts may use synthetic biology to produce and release harmful substances into the environment – either accidentally or on

purpose. In all these cases, technology originally created to enhance security may become the threat. In response, pre-programmed nanodevices and robots will likely create security networks and sensing surfaces that could identify threats such as nano-enabled weapons, viruses and poisons.

US Air Force on Micro Air Vehicles

THE END OF PUBLIC ANONYMITY. Constant monitoring and surveillance will become increasingly prevalent through the use of nano and biosensors, brain-computer interfaces, and artificial intelligence (AI). Smart devices will routinely know a person's movements and location to within 10 centimetres, which will make it possible to infer a person's activity, behaviour, interactions and relationships. This will make it increasingly difficult for individuals to go unnoticed, as AI can identify people from face and gait, and even determine the behaviour patterns of those without smart devices by looking at those who do. These devices will increasingly be used to identify, authenticate and track the movement of food, goods and materials in value chains. Constant monitoring and surveillance could also enhance public health and environmental and personal security. For example, in emergency situations, sensors, AI and machine-to-machine communication could make it easier to locate people and identify their needs. As privacy becomes a major issue, there may be a need to rethink the balance between public and private interests and liberties.

POTENTIAL POLICY CHALLENGES:

- How can we prepare for the spread of cheap – but lethal – do-it-yourself weapon systems?
- As environmental sensors and security-monitoring systems grow, what new rules, roles and responsibilities will arise between the various government, business and non-government watchdogs to share information in the face of a bio-crisis or terrorist attack?

9. THE POTENTIAL IMPACT ON THE HOME

HOME IS WHERE THE "BRAIN" IS. The "internet of things" will have considerable impact on homes, but at its core will be the need to make sense of all the information being generated. Homes will be able to combine, interpret and relay the information coming in from a variety of new sensors in appliances, fixtures and fittings, information that ranges from specific needs and monitoring of occupants, to basic system diagnostics. Artificial intelligence (AI) and the "internet of things" will move us from the age of the home computer to the age of the "computer home."

INTERACTION WILL CHANGE. New technologies will allow traditional in-home activities to also happen virtually. The seamless management of data and systems, enabled by AI and new materials, will change how homes look. It is likely that new interactive surfaces will appear throughout the home that will allow occupants to monitor and manage household systems and communicate with others. Over time, as technology evolves, traditional building materials and fittings will be displaced by new ones that will integrate with a home's AI and sensors. These sensors will share information remotely with smart phones and smart vehicles, allowing people to administer their house remotely.

WHERE DOES PRIVATE END AND PUBLIC BEGIN? By allowing coordination with systems outside

the home, the line between home and work and between public and private will continue to blur. Home systems that sync with external systems (such those at work or school) will allow occupants to work, learn and relax in one locale. But such systems could also sync with neighbourhoods, regions, municipalities, utilities and more to support decision-making about land-use planning, infrastructure, health outcomes and development.

THE CONSTRUCTION OF 3D-PRINTED HOMES. Innovations in robotics, AI and building materials may change both the look and the construction of new homes. The advent of large-scale 3D printing means that homes could be built more rapidly and with nano-enhanced materials, making them even stronger and more energy-efficient than they are now. It could also mean lower costs and greater flexibility in home and urban design.

The World's First 3D Printed House

Why 3D Printed Houses Matter

THE AUTONOMOUS HOME. The trend toward decentralization of energy and other infrastructure will make homes more autonomous, but will make the need for coordination among systems even more crucial. Distributed energy systems will result in homes that can both contribute to and draw from the grid, but such innovations will be dependent on advances in energy production and storage. Unconstrained by traditional urban services, new homes could proliferate in areas well beyond urban planning control.

POTENTIAL POLICY CHALLENGES:

- Will there be equity issues among those who are in a position to "keep up" and those who can't?
- How will the information gathered by the internet of things be used? Who should have access?
- Who will ensure interoperability among systems? How will infrastructure need to change?

10. THE POTENTIAL IMPACT ON WORK

FEWER, BUT MORE PRODUCTIVE, WORKERS. Artificial intelligence (AI), sensors, data analytics and robots will drive significant change in many workplaces in Canada and around the world. These technologies will transform many jobs where a routine physical or mental task is repeated; AI will increasingly handle the routine, while workers will be free to focus on the exceptions that AI cannot handle. AI and data analytics will also increase productivity and the demand for non-routine and professional skills by reframing the way we design, coordinate, manage, deliver and assess products and services. Sensors will provide workers with a much broader picture of the processes they manage, improving efficiency and client satisfaction. Cheaper, mass-produced robots and autonomous delivery vehicles will change the flow, timing and flexibility of work. Working conditions and on-the-job safety will greatly improve for dangerous professions, largely through the use of

sensors, drones and robots in fields such as mining, policing and rescue missions.

MORE CONTRACT AND PART-TIME WORKERS. As noted in MetaScan 2, more and more workers will likely be part-time, self-employed contactors in the emerging "project economy." For the duration of a project, they may work in an office, in their home or from a creative hub or public space. Smart surfaces will enable workers to create or share a workspace anywhere, with capacity for virtual face-to-face and group-to-group collaboration. Both high- and low-skilled workers will do tasks or jobs of varying duration for multiple employers, brokered through social media and "microtasking" apps.

GROWING NUMBER OF INTERNATIONAL "VIRTUAL WORKERS." The same tools that allow Canadians to work from a coffee shop will also support them in becoming "virtual workers" for employers in other countries. If they develop the right skills, they could compete globally for short tasks or part-time or full-time work. The system will also allow foreigners to bid for tasks and jobs in Canada. The workforce will become increasingly global. Worksites are emerging that facilitate finding virtual work (e.g., freelancer.ca or eLance.com). Reputation systems (e.g., eBay's ratings system) will track individual performance, competence and specific skills to allow virtual employers to quickly find competent and trustworthy workers.

NEW ORGANIZATIONAL STRUCTURES. The new technologies, new work arrangements and other global change drivers are likely to generate new kinds of organizations. For instance, one can imagine a service corporation where all of the services are provided by AI with fewer human employees. A growing number of modern corporations will have a small management team that contracts out all functions through the entire product life cycle. It is possible that unorganized skilled workers will find people with complementary skills and create informal, temporary teams to take advantage of an opportunity to work together virtually to deliver a good or service.

The Future of Work

Microsoft View of 2019

POTENTIAL POLICY CHALLENGES:

- What are the emerging social and equity issues if there are fewer traditional jobs?
- Are there infrastructure, institutional or policy changes that will give virtual workers a competitive advantage?
- What is the role of national governments in the regulation and oversight of virtual work and temporary virtual organizations?

POLICY CHALLENGES

THE EMERGING TECHNOLOGIES COULD CREATE SIGNIFICANT NEW POLICY CHALLENGES OVER THE NEXT 15 YEARS

What is a policy challenge?
A policy challenge is an issue that current policies or institutions may not be ready or able to address. Identifying, analyzing, debating and clarifying a challenge helps us to develop a more robust strategy and the policy to handle it. Foresight helps identify emerging policy challenges.

TEMPORARY JOBS BECOME THE NORM

In 2012, the number of Canadians with temporary jobs – often low-paying and with few benefits – was estimated to be 13.6% of the labour force and growing three times faster than traditional jobs. As these technologies evolve, we expect they will increase productivity but may result in more part-time work, short-term contracts, micro-jobs and more foreign "virtual workers" (as described in MetaScan 2). Many have described these jobs as precarious as they lack security in terms of employment, income, skill and career development. As corporations try to reduce costs to increase competitiveness, the number of temporary jobs is growing. Should we look for ways to make these workers more productive? It is interesting to note that the high-income creative class and lower-income temporary workers face similar challenges and have similar needs.

Canada's shift to a nation of temporary workers

- **A new social contract?** The social contract of the last century was that government, business and employed workers would contribute to social welfare programs. A growing number of short-term contract workers and freelancers are outside the current agreement. Given that freelancing is one of the fastest-growing segments in the labour market, it may be timely to explore new ways to bring freelancers into a new social contract.
- **The revival of co-operativism.** One strategy to renew the social contract would be to support "mutualism." The Freelancers Union is the fastest-growing union in the U.S. Members band together to set up social-purpose institutions to serve their mutual needs. Among other things, the union provides low-cost services, including health insurance, to its members. The emergence of freelancing is an echo of the co-operative movement in Canada, the guiding principles of which are mutual benefit and democratic governance. In a time of fiscal constraint, major new government programs are less likely. Are there policies and self-organizing institutions that could help freelancers deal with income variability?
- **New public policy instruments.** Over the last several decades, there have been a variety of proposals and experiments to try to address the challenge of ensuring that people's basic needs are met. These

include: basic income (an unconditional income grant to cover basic needs); guaranteed minimum income (a supplemental grant covering the difference between actual income and a guaranteed level), negative income tax; the guaranteed job; and others. The debate goes on. The "flexicurity" model in Denmark which "combines flexible hiring and firing with a general social safety net" as well as other employment policies may be worth further study. An ongoing sub-issue of the debate is: how do we meet the basic needs of people caught in an economic transition, while avoiding freeloaders? AI and data analytics for a new, customizable transfer payment could help differentiate freeloaders from virtual workers and people learning new skills. It could also reduce the size of the bureaucracy, red tape and costs across three levels of government and possibly reduce other indirect costs (e.g., child poverty, stress-related health issues and failure to learn new skills).

Flexicurity model

- **Fewer jobs, fewer taxpayers.** As new technologies replace workers, one challenge for government is fewer jobs may mean fewer taxpayers and less capacity to redistribute wealth through traditional transfer payments.

NEW PATTERNS OF INEQUALITY

New technologies may disrupt the consensus on what constitutes equal and fair treatment for citizens. The technologies may level the playing field for some, while creating new barriers for others. The public policy questions include timing, efficacy and affordability.

- **Income inequality.** Globalization and advances in technology have given rise to "plutocrats" such as superstar tech titans, bankers, chefs and writers, while diminishing opportunities for the middle class, according to Chrystia Freeland (2013). New technologies may affect income distribution. Economists are debating whether the shape of the income distribution is an hourglass or pyramid. In either case, the gap between rich and poor is likely to grow, and the low-skilled are likely to be worse off.

The age of global plutocracy

- **Unequal access.** The technologies we adopt may serve to narrow or widen the equity gap, especially in the area of health care. Some injured and disabled will benefit from advances in areas like tissue engineering; however, high development and treatment costs could limit access. As we come to understand the human genome, determining what constitutes necessary and elective enhancement will become increasingly complex. Will genetic information lead to new forms of discrimination? In a world of customized medicine, what will constitute guaranteed health services?
- **Increasing social stratification.** Some of the new technologies might promote social stratification. Emerging neurostimulation technologies and genetic selection will give enhanced cognitive powers to those able to afford them. Access to powerful AI and supercomputers will provide overwhelming advantage in financial markets, and advanced sensors may provide new means to safeguard privilege once it is achieved. Such developments may lead to a further stratification of individuals and groups not only in terms of wealth, but also in terms of what it means to be human.

THE END OF PRIVACY

Sensors and the artificial intelligence to use and interpret the information gathered by them will become cheaper, better and faster over the next 15 years. Advances in location sensing gives an indication of the trend. Recently, Google announced the goal to have smart phones in 2015 with positional accuracy within 10 centimetres, with sufficient resolution to notice you sitting up from your desk, taking a call or snuggling up to a partner. By 2028, a package that performs like today's smart phones could cost as little as $2 to produce. At that price, sensing will be nearly ubiquitous. Most people will carry one or several tools that measure ambient audio, location and air quality. Service providers and developers will be watching and listening to understand what's going on, what's around us and where we are, all to feed the helper applications that will support us in our daily lives. One's identity will be increasingly knowable as well. Today, digital chips track our identity and purchasing histories; in the future, face recognition, and gait and gesture recognition will help identify those not digitally broadcasting their presence to the world. Will our current rules and norms about privacy hold up in the face of improved sensing? Is privacy the right to be left alone, or is it the right to prevent others from knowing anything about you?

- **Are we ready for two-way surveillance?** In *The Transparent Society*, David Brin argues that in addition to surveillance (the few watching the many), technological progress may foster a peer-to-peer model dubbed *sousveillance* (the many watching the few). A likely consequence is that preserving secret or private spaces, activities and actions will become both harder and more expensive. Are we prepared for an onslaught of openness?
- **Individual privacy versus public good.** Along with the negative consequences of changes in privacy come great potential benefits. Suppose that one's health status, biometrics and protein levels were anonymously shared during each visit to a doctor's office. By combining these data with patients' genetic information, researchers could gain an enormous and fine-grained set of data that could be studied to understand patterns of viral and bacterial disease, chronic disease progressions, genetic susceptibilities and the effectiveness of specific interventions. The resulting benefits for the health care system would be incalculable. Similar benefits are possible in other fields. How can we structure the balance between privacy and the public good in the coming era of personal Big Data?

INFRASTRUCTURE IN TRANSITION

Infrastructure comes in many forms: transportation, buildings, services and communications technology, among others. There is a high probability that infrastructure of every kind will be influenced by the technologies explored in this foresight study.

- **The fork in the road.** Perhaps the most significant challenge will be deciding whether to maintain or update existing infrastructure, or to leapfrog and invest in entirely new infrastructure based on new technologies. As our current infrastructure continues to age, requiring significant investment simply to maintain the status quo, leapfrogging could reduce costs, greatly improve service and build competitive advantage.
- **Who owns, who pays?** In a world where everything is moving from centralized to networked, issues such as longevity, financing and return on investment will be more challenging. In the past, public utilities and governments provided infrastructure services as part of their commitment to creating public value, and citizens offset costs with their taxes and by paying utility bills. In a future that sees far greater decentralization (of energy, for example), what policies will need to be put in place to support the evolution of new models of infrastructure management?

- **Longevity isn't so long any more.** In the past, many infrastructure investments were expected to last decades and in some cases, even longer. As technologies evolve, the need to adapt quickly to replace infrastructure that is failing, or to accommodate the public's expectations for performance, efficiency and safety, will require initiatives that support scalable and modular approaches. The constant quest for better infrastructure solutions, in combination with science's push to develop better and safer options, could see the lifespan of certain investments becoming shorter.
- **Innovate, demonstrate, test.** In this period of transition, there will be many opportunities to experiment and test different approaches. Often, existing institutions, policies and regulations – and vested interests – can impede innovation. We need to encourage experimentation to overcome impediments. We can learn lessons from the open source movement about ways to ensure diverse innovations work together as a system.

SHIFTING COMPETITIVE ADVANTAGE

The emerging technologies will make it harder to find and keep competitive advantage in the production of some goods and services. Bioproduction through synthetic biology will likely make it easier and cheaper to make some classes of goods. These technologies have the potential to help countries be more self-sufficient in some foods, fuels and materials. Advanced nanomaterials and nanodevices are likely to require a more educated workforce and more intricate production, resulting in a smaller number of competitors using these technologies.

- **A more level playing field for resources.** Natural resources are a significant export for Canada. Will we need to rethink our strategy over the next decade or two? Some of our customers are going to use synthetic biology to make their own fuels, feedstock and primary goods. There may be an opportunity to move up the value chain and use synthetic biology to preprocess natural resources where we have a competitive advantage.
- **Governance as brand.** In a world where production using synthetic biology or 3D printing can take place in a wider range of places, and where technology races can rapidly shift direction, it could be beneficial to brand the Canadian products that use these new technologies for their safety, design and added value. Government, business, science and non-governmental organizations will have to collaborate in new ways to ensure safe and responsible forms of production that will help Canada maintain a competitive position.

STRENGTHENING THE RISK MANAGEMENT SYSTEM

Risk management is an approach that allows governments to assess, implement and evaluate policy, regulations, processes – and, in some instances, even products and services – to ensure that standards for public safety are met. Current approaches to risk management rarely go beyond the short- and medium-term, focusing on only first- and second-order consequences. The discipline of foresight can assist by systematically considering plausible futures, which can help uncover unexpected risks and buy time in the face of future challenges. As new technologies proliferate, the possibility of unforeseen consequences increases and citizens will look to governments to help them make sense of a potentially shifting terrain. This presents a variety of possible challenges.

- **Institutionalization of risk.** Governments, through legislative and policy instruments (such as assessment and insurance regimes) have traditionally been active in helping understand and manage risk. New technologies are evolving rapidly and existing models of risk assessment and mitigation may

not be able to respond in a timely fashion. What is essential for government to provide in terms of risk management? To what degree will the onus be on producers and consumers to be aware of and manage their own risk? Will the need to "assess" everything drive up costs?

Kickstarter funding from glowing plants crosses $250,000

Kickstarter bans funding for synthetic biology projects

- **Building science and technology literacy.** Past experiences with genetically modified foods and other emergent technologies have shown that adoption of new technologies can have unexpected social, political and emotional dimensions. As new technologies evolve, what will be required to ensure a basic level of technology literacy so decision makers and the public have a good understanding of both risks and benefits?
- **Risk doesn't respect borders.** As we have learned through experience, potential consequences of technology don't always stop at national borders. Global protocols have been required to address some of the more serious transnational effects of ozone-depleting substances and chemical pesticides. There is always the potential for such challenges to emerge as a consequence of new technologies. Will a plethora of uncoordinated national responses to potential risk increase the potential for global consequences? Are current national and international mechanisms adequate to anticipate, assess and manage such risks? Are we moving toward an international body to set standards for all?

REGULATION OF RAPIDLY EVOLVING S&T

The rate of change in science and technology is likely to accelerate, and science and technology are likely to play an increasingly important role in our economy and our lives. Product safety, public trust and competitive advantage will best be served by systems with efficient and timely testing and regulation.

- **Dealing with the exception.** Emerging technologies will create many first-in-class products that may fall between current regulatory categories and practices. For instance, should direct-to-consumer neurostimulation be regulated as a medical device, a substance or a consumer product? Can we develop a safe system that is capable of revising regulations quickly enough to cope with new and unexpected substances and products?
- **Building science capacity.** We need to try to anticipate where science and technology may go, and ensure we have appropriate skills and innovative testing methods. One complex area that may need attention is the rise of the talented amateur in areas like synthetic biology and 3D printing. While innovation should be supported, new ways to monitor or engage amateurs may be needed to capture problems before they leave the home lab.

TRADITIONAL NOTIONS OF IP MAY NO LONGER BE RELEVANT

The institutionalization of intellectual property (IP) regimes by national governments is designed to create economic incentives for research and development that, over time, may improve social welfare. The new technologies could help solve global problems in areas like health care, energy and security. Rigid and globally inconsistent IP regimes could allow IP owners to block innovation, limit the pace of development, exclude the possibility of new entrants and even threaten international relations.

- **Open source versus patent protection.** Open source collaboration appears to be particularly appropriate and effective in the early stages of the development of new technologies. There have been remarkable open source successes over the last decade, such as Linux, Firefox and Android. This model is being adopted in the area of these new technologies as well, such as FabLab's 3D printing prototyping service, and open source biobricks in the field of synthetic biology. Such approaches aim to support open and ethical research to foster cumulative improvement and support results that could benefit people and the planet. They diverge, however, from the traditional business strategy of relying upon patent portfolios to ensure profitability for corporate entities. On one hand, there are uncertainties as to how to generate stable profits from open source technology. On the other hand, strong intellectual property protection is viewed as limiting innovation and raising the price of technology in the high-tech sector. What is the appropriate balance between protecting intellectual property and promoting more rapid progress and collaboration? Who will invest in the research and development of important products that may have no patent protection and may never be commercialized in the traditional sense? What will we need to know to understand incentives for new entrants in an open source environment? What is the role of individual investors, financial markets and governments in an open source IP regime? Are there phases in the development of new technologies or innovation ecosystems that require different IP regimes?
- **Enforcement of IP rights under pressure.** Notwithstanding a clear and strictly enforced IP regime, piracy will continue to be a factor. Emerging technologies will be subject to piracy themselves and will make piracy easier. For example, 3D scanners translate tangible products into data, which can then be 3D printed, or edited and modified. Given the advancements in materials science, this could make it possible to replicate a whole range of goods at home. This may increase patent and copyright infringement and affect manufacturing. How will different industries react to the loss of unilateral control that comes with replicative technologies? What is the role of national governments in protecting IP? Is criminalizing infringement the only approach?

EXPLORING NEW APPROACHES TO PRODUCTIVITY AND INNOVATION

The emerging technologies described in this study point to the importance of innovation as a key driver of the economy. Human capital, government policies, societal actors from all sectors and physical infrastructure are major elements of an innovation system. How can we redesign societal systems to maximize innovation?

- **Productivity measures for a digital economy.** One of the biggest surprises of the digital era has been the dramatic amplifying power of technology on productivity; with anticipated improvements in artificial intelligence and robotics, this multiplication effect will only grow. New measures would help untangle those productivity gains which are due to technology and individual factors, and their interaction. Productivity measures that help us understand the competencies required in an innovative economy will allow us to develop skills accordingly.

- **Individual-level innovation approaches.** Innovation research shows us that broader individual traits such as cognitive ability, personality, behaviour, motivation and emotion interact with knowledge to create innovative individuals. While some of these are not amenable to intervention, many are (text box). Can we improve Canada's innovation potential by systematically intervening to encourage these traits? For instance, we may gain by teaching innovation-oriented skills, such as solving problems by alternating between "generate" and "explore" phases, system mapping, constructive self-evaluation and experience with innovation-enhancing tools.

BEHAVIOURAL TRAITS THAT SUPPORT INNOVATION AND PRODUCTIVITY

- A questioning disposition
- Risk-taking
- Openness to criticism
- Curiosity
- Exploration
- Creativity and play
- Desire to solve problems
- Proactivity
- Personal autonomy and self-starting approach
- Persistence
- Long-term orientation and gratification deferral

Source: Characteristics & Behaviours of Innovative People in Organizations. Patterson et al.

- **Corporate-level innovation approaches.** Environments that systematize creative activities and encourage risk-taking and experimentation foster innovation. A decentralized organizational structure, shared vision and culture and flexible and supportive leaders and managers all support the innovative potential of staff. Training leaders how to foster innovation and co-creative environments would magnify the effects of individual-level contributions. To be innovative, firms should become intrinsically global and pay more attention to attracting and retaining innovative talent. What strategies do we need to support innovation at all levels in society?

Smart Policy: Building an Innovation-Based Economy

Supporting an Innovation Ecosystem to Build Canadian Competitiveness

Characteristics and Behaviours of Innovative People in Organizations

CREDIBLE ASSUMPTIONS

How do we use assumptions?
The Horizons' process looks at two kinds of assumptions. At the start of a process, we try to identify the "current assumptions" that are buried in current policy and dialogue. At the end of the process, we test these assumptions against the findings in the study to identify "credible assumptions" that appear to be robust across a range of futures. The assumptions that survive this testing are useful in shaping forward-looking research, policy and program development and decision-making.

COMMONLY HELD ASSUMPTIONS IN 2013	CREDIBLE ASSUMPTIONS LOOKING FORWARD
Technological change is disruptive. We will figure it out when things stabilize.	**We are in a period of transition. The pace of technologically driven change is going to accelerate as the technologies described in this study interact with each other.** Individuals and institutions underestimate the rate of change, and thus don't prepare adequately for it.
Most of the technological changes are incremental improvements in information technology and communications.	**Manufacturing, services and natural resources will all be affected by new technologies.** The digital revolution (artificial intelligence (AI), sensors, data analytics) is quite mature and is impacting all sectors of the economy now. Biotechnology, nanotechnology and energy are ramping up with big impacts in 5 to 15 years. And neuroscience technologies could present some significant surprises in that period.
When the economic downturn lessens, there will be more full-time jobs with good salaries and pensions.	**The new technologies will increase productivity with fewer workers. Non-standard jobs and project work will likely become more common, but they don't have to be precarious jobs.** Driven by technology, the logic of the market is creating a class of workers doing part-time contract work without benefits. They are essential to the operation of a competitive project economy. Creative thinking is needed to encourage innovation, recognize their contribution and share the risks. Many options exist to create a new social contract.

Canada is an attractive place for skilled workers.	**Attracting, keeping and growing talented workers, especially in "the creative class" will require vision and cooperation at every level of government.** The creative class and project workers are key drivers in the emerging economy and in job groups with growth potential. They have similar needs. Cooperation across governments to support cities becoming innovation "clusters," building state-of-the-art health care, education and infrastructure, and developing supportive policies appears to be one way to attract, enable and keep them.
Billions of dollars are needed to repair and maintain aging infrastructure, and expansion means more of the same.	**The new technologies may present opportunities to leapfrog to the next generation of infrastructure and reduce costs over the long term.** In areas like transportation, energy and health care, systematically and proactively exploring the full potential of the new technologies could help avoid investing in costly, but soon-to-be obsolete infrastructure while improving service at lower cost. Countries that leapfrog from old to next-generation infrastructure may have a competitive advantage.
The national economy matters. A strong policy framework (responsible fiscal and monetary policy, promoting productivity, investment and trade) is a key tool in navigating a turbulent global economy.	**An increasingly networked, integrated and interdependent global economy is emerging. Our policy tool kit and institutions need updating.** International cooperation to manage a globally networked economy, new kinds of safety, infrastructure and regulatory challenges, mobile virtual workers and a reinvention of health care and income support programs are needed. Some traditional national instruments will be ineffective in dealing with the emergent global systems. National policies could hinder growth if they are out of alignment with the major developed and emerging economies. But international cooperation that involves aligning interests and sharing sovereignty is notoriously difficult. Modernizing the policy framework will likely be incremental, experimental and possibly outside the current international institutions.
Current intellectual property (IP) and research and development regimes promote effective development.	**Each stage in the development of a new technology may benefit from an evolving global ecosystem of information sharing, collaborative development, incentives, oversight and IP protection that balances the public good and private interests.** Currently, the corporations battle each other in court and the long-term public interest is assumed to be represented by market behaviour. Today's new technologies are going to play out over decades. Allowing private firms to lock down and shape large parts of that evolution in the very early stages of a new technology for their own benefit may not be in our long-term interest. Giving people what they want at an affordable price is proving to be the best protection against piracy in many fields.

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APPENDIX 1:

SCENARIOS – WHAT MIGHT THE FUTURE LOOK LIKE?

The following scenarios are not attempts to predict the future. Rather, these scenarios provide an opportunity to consider how the future might emerge, allowing decision makers to understand how different planning assumptions may play out over time. They allow us to evaluate existing and proposed policy approaches against a range of plausible futures and to identify possible surprises.

Although any, or none, of the scenarios may play out, they support the development of a more robust understanding of the future. For the purposes of this study, four analytical scenarios have been developed that examine the economic, social and governance landscapes within the context of the rapidly evolving technologies explored in this study.

FOLLOWING THE COAST

Business, government and public cautious about new technology

Back to the Future
HEADLINES FROM 2028

"Canada part of growing global rare earth boom as autonomous robots deployed to Baffin Island mining operation"

"Calgary loses bid to host Tech Giant BioSynth Labs to Indonesia – municipal officials blame other levels of government and community activists for loss of jobs and growth"

Caution is the order of the day in terms of investment, adoption and policy related to new technologies. Some technologies, such as synthetic biology and 3D printing, have begun to transform the manufacturing, agriculture and natural resources sectors. Artificial intelligence is starting to change the services sector. But adoption of technologies by governments, businesses and individuals is slow because of concerns about long-term profitability, an uncertain regulatory environment and their potential impact on everything from environmental risk to privacy. This situation has been further complicated by poor coordination among levels of government to foster technological innovation, build upon global opportunities and update risk management approaches that support effective regulation of products and processes. As a consequence, economic growth is slow in Canada, but not in the new economic superpowers emerging in Asia. In those countries, support for new technologies, investment and science and technology literacy is high and growing. Canadian workers with the right skills are in high demand, but adoption of some of these technologies is displacing lower-skilled workers. But high-skilled workers are also facing considerable pressure as virtual work and global competition drive down wages. These factors are slowing immigration and many high-skilled workers are leaving Canada or working virtually for foreign firms. The policy response has relied heavily upon encouraging individuals to continue to build their skills, but Canadians are increasingly concerned about the growing number of people with precarious work. Canada is maintaining an increasingly dated public infrastructure with static or decreasing public revenues. Consequently, opportunities to leverage newer technologies and infrastructure to improve public outcomes are sometimes missed.

BUFFETED BY THE WINDS

Business leads, government supportive, public concerned

Back to the Future
HEADLINES FROM 2028

"Over 2 000 jobs lost as retail giant replaces truck fleet with autonomous freight-movement systems"

The pace of technological change and adoption is largely set by business in an environment of supportive governance. Although economic growth is stable, personal wealth is not and the number of jobs is static or shrinking. Technological uptake is rapid. Industry is leveraging synthetic biology and robotics to improve efficiency in manufacturing and natural resource extraction and processing, areas where there is high commercial profitability and markets for commodities in emerging markets. Although there is low coordination among levels of government, some cities and provinces are working to find their niche within the growing global technology marketplace. The governance emphasis is on positioning industry to succeed in an increasingly competitive global environment. There is growing underemployment and unemployment among both low- and high-skilled workers, both as a consequence of a growing global market in virtual work and increases in non-standard work. Large urban centres continue to grow as workers move to areas where technology is creating opportunities; however, "ghettoes" are emerging as Canadian virtual workers compete with skilled virtual workers from other countries for low wages. As a consequence, and in light of shrinking public revenues, this period is characterized by policy experimentation. This includes society and governments making creative use of alternative policy models, such as social impact bonds and public-private partnerships, to leverage business capacity to support broader public objectives. Similar approaches are being taken regarding infrastructure, which is in a state of considerable decline. In some areas, such as transportation, those in charge of publicly owned infrastructure are experimenting with new models of shared public and private ownership and management. The degree to which public goods, institutions and infrastructure are modernized is determined by their relevance to business needs.

CHARTING A COURSE

Stakeholders collaborate to design robust strategy

New technologies are having a significant impact on all sectors of the economy. Diverse actors are working together to engineer systems that foster efficient and coordinated processes that minimize risk to society. Industrial processes characterized by closed-loop systems are the ideal. As opportunities are identified and exploited, frequent and rapid changes in direction are required by industry and governments. The policy framework fosters entrepreneurship by remaining adaptable and by supporting an environment where risk is shared among governments, industry and other actors. Concerns about the impact of new technologies remain, but have been reduced by the supportive policy environment, education, and an evolving sensor network that demonstrates that, although not without risk, new technologies are safe and improving quality of life. Work is precarious, particularly for the low-skilled, as a consequence of global competition and the growth of non-standard work. An updated social contract, however, is allowing

workers to take time to upgrade their skills and to compete globally. Government invests in understanding and supporting the importance of innovation and integrates it across all systems (from policy, program design and delivery, to investments and partnerships in both domestic and global research and development). Canadian workers and commodities are in considerable demand both domestically and globally. Transportation, energy and communications infrastructure are being renewed to support the cultural and economic shift towards an innovation economy.

Back to the Future
HEADLINES FROM 2028

"Increases in non-standard work and new global opportunities make choosing a career path more challenging, say new grads"

STRIKING OUT IN NEW DIRECTIONS

Open source innovation in global networks becomes key driver

Back to the Future
HEADLINES FROM 2028

"AI-enhanced Global Health Tracking Network now includes 96 countries and growing – coordinated tracking and responses to disease outbreaks improving health outcomes worldwide"

Innovation is a global phenomenon and the results of technological innovation are largely open source. As a consequence, innovation is occurring more rapidly and benefits are more equitably distributed. The creative commons is borderless and characterized by a community of innovators that builds constructively upon one another's work. The intellectual property system has evolved and innovators are rewarded by micro-payment systems. The Canadian economy is growing slowly in an environment of hyper-competition. Workers at all levels need to be mobile, flexible, adaptable and transdisciplinary. Even low-skilled manufacturing and service jobs are now shaped by rapid technological innovation. In response, the social policy framework provides ongoing support for skills development and "flexicurity." This approach recognizes that technological change is constantly redefining the world of work and that society and individuals require support to adapt. Infrastructure is modular and, increasingly, globally linked. Interoperability is the ideal, but complicated by the rapid pace of innovation. Government services at all levels involve high levels of automation, in particular, artificial intelligence and robotics (in areas from taxation, social programs, and health care through to national defense). The national government is increasingly constrained by the need for increased global coordination.

APPENDIX 2:

HORIZONS' PROCESS