NRC·CNRC

gameCHANGING
technologies initiative

Summary of On-line Dialogue with Stakeholders

February 9 to 27 2015

National Research Council Canada
Conseil national de recherches Canada

Canada

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Introduction

The world is changing rapidly and Canada's quality of life and prosperity, over the long term, increasingly depend on our ability to understand, develop and deploy game changing technologies. Global issues and challenges will shape the world and Canada over the next 20-30 years, and these technologies will offer potential solutions in a number of areas.

To maintain a forward-looking perspective on these potential game changers, the National Research Council (NRC) launched a foresight exercise to identify areas critical to Canada's future in which technology game changers have the potential to bring revolutionary impacts on Canadian well-being and economic growth.

Over the last year, NRC has worked closely with internal and external stakeholders to identify key opportunities and challenges facing Canada over the next two decades. In order to refine its understanding of these challenges and opportunities, NRC used a web-based approach to seek insights from a diverse range of thought-leaders from across Canada during the period of February 9 to February 27, 2015. The results of this external input are summarized in this report.

The outcomes of the Game Changing Technologies initiative will help to shape NRC's investment strategy in emerging technologies and influence future NRC programs. NRC will establish national R&D partnerships to further accelerate the development and application of these technologies, helping to deliver long-term economic and social benefits to Canada.

What are the global socio-economic challenges that will shape the world and Canada over the next 20-30 years?

What are the potential game-changers that represent opportunities or risks to the quality of life and prosperity of Canadians?

Overview of the Online Dialogue

Approximately 3000 invitations were sent out by NRC and collaborating organizations, including industry associations and other governmental organizations, to participate in a web-based, interactive dialogue. Participants were also welcomed to forward the invitation to members of their organization and their networks. In this early stage of NRC's Game-Changing Technologies Initiative, emphasis was placed on selecting a diverse range of participants to ensure a wide breath of ideas and exchange. Once a few technology opportunities have been narrowed down by NRC, targeted consultation will take place for in-depth exploration.

Overall, 705 people registered on the web-based platform, with 261 active respondents (23% from industry; 22% from academia; 35% from government that included 26% from the Government of Canada; and 20% from the other category that included non-governmental organizations, interest groups, etc.). Sectors represented by the active participants included education, agriculture, management consulting, healthcare, research technology organizations, information and communications technologies, manufacturing, biotechnology, computer and electronics, aerospace, construction, finance, pharma and medicine, and public administration. Figure 1 outlines the distribution of active participants across Canada.

Once registered, participants were invited to review and provide input on up to seven opportunity areas:

- The cities of the future
- Prosperous and sustainable rural and remote communities
- Maintaining quality of life for an aging population
- Protecting Canadian security and privacy
- Transforming the classroom for continuous and adaptive learning
- Next generation health care systems
- A safe, sustainable and profitable food industry

Each opportunity area contained a short description of the major challenges being faced and the future that Canada could have with the implementation of certain game changing technologies. Participants were then asked three questions: Is this future plausible? What are the major socio-economic barriers that need to be overcome to attain this future? What are the game changing technologies that are critical for this future?

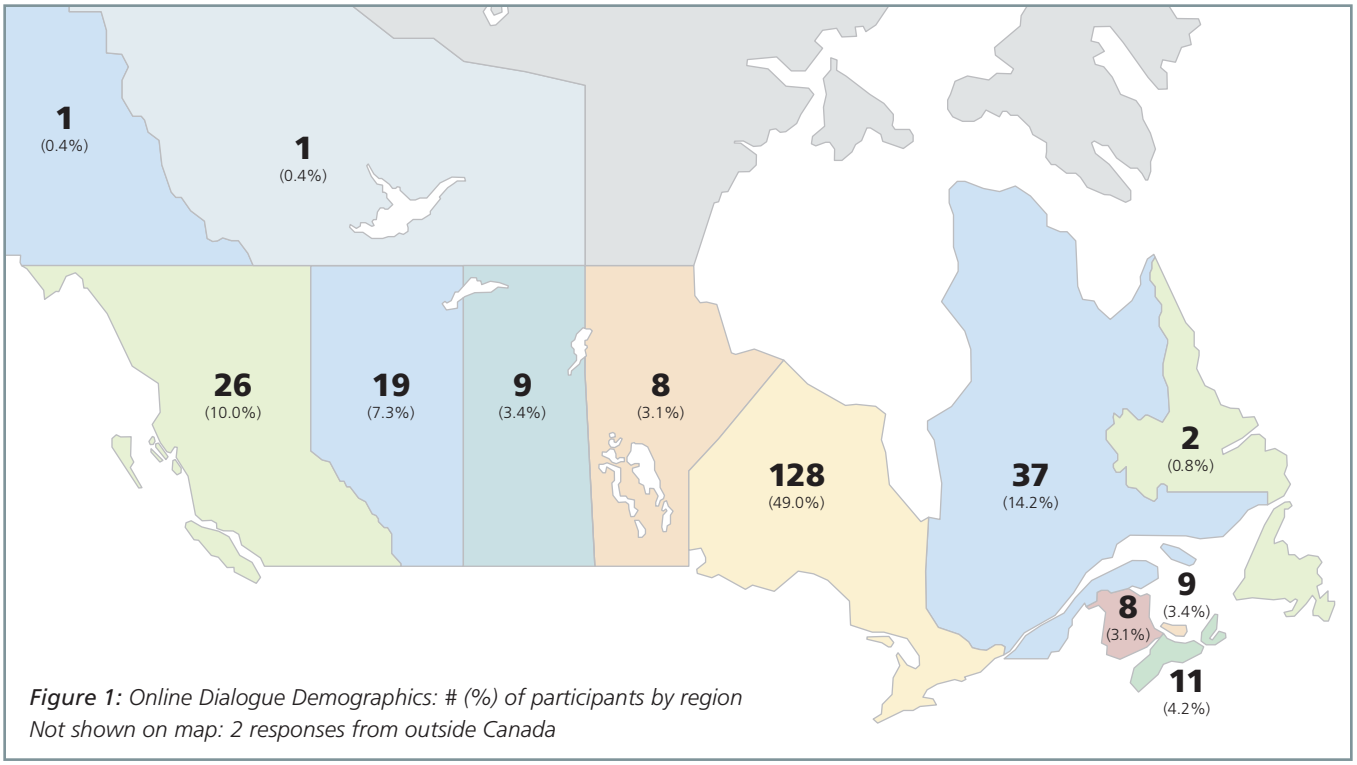


Figure 1: *Online Dialogue Demographics: # (%) of participants by region*
Not shown on map: 2 responses from outside Canada

Overview of the Online Dialogue

The on-line exercise also allowed participants to interact with other participants by commenting on other's responses, starting new discussion topics, or reacting to the daily highlights of participant comments posted by moderators.

Participant Response

The highest rate of agreement was seen in the Cities of the Future opportunity and the highest rate of disagreement was seen in the Security and Privacy opportunity (see Figure 2).

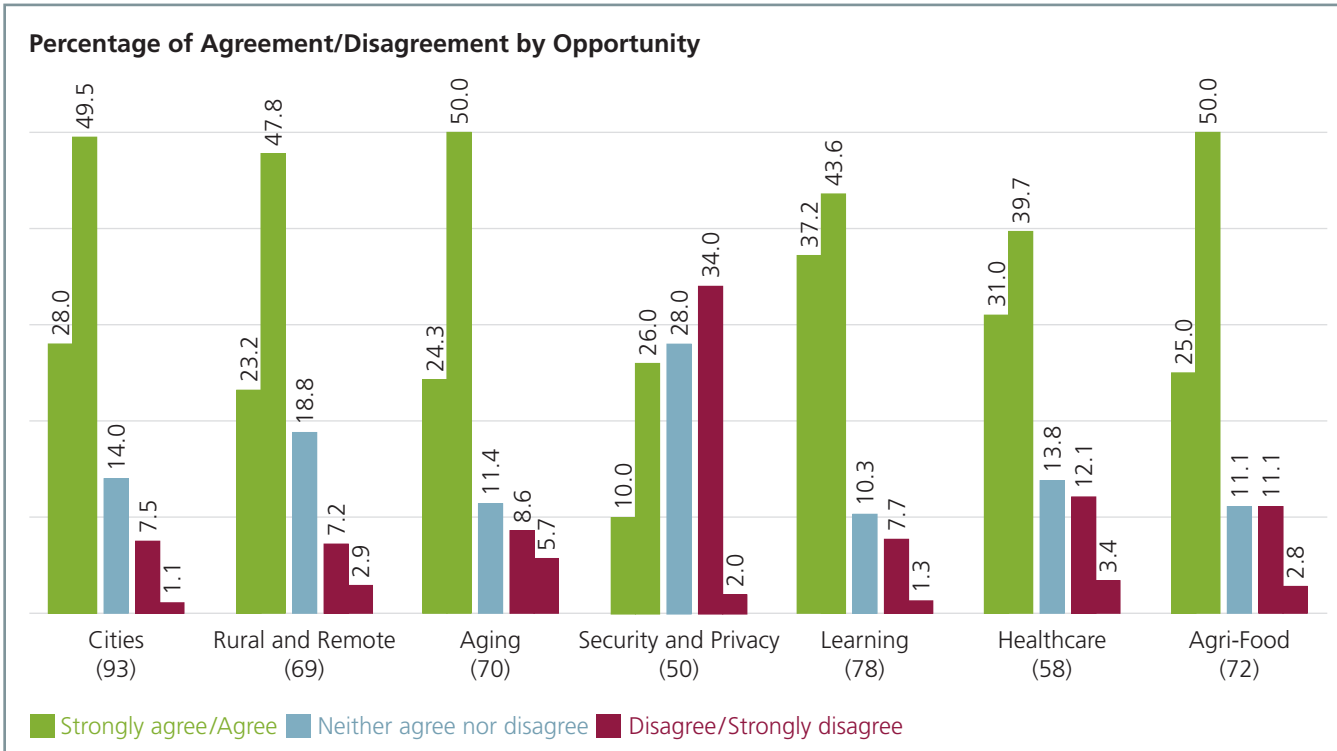


Figure 2: Rate of agreement/disagreement with the plausibility of the future as described for each opportunity area as a % of total # of responses

Those participants that disagreed with the described futures did so for a variety of reasons:

Protecting Canadian security and privacy: Participants commented that the scope and spectrum of cyber-security is continuously expanding and as digital integration continues to increase, security and privacy breaches cannot be prevented. Rather, Canada's goal should be to stay one step ahead.

Prosperous and sustainable rural and remote communities: Disagreement was not about the described future state or the technologies, but centred more on the current cultural, political and market barriers that constrain prosperous and sustainable communities.

Next generation health care systems: Many participants stated that most of the described technologies are already being advanced. Disagreement revolved around issues of accessibility, the need to move towards greater emphasis on preventive medicine and health promotion, and privacy and security concerns around data collection with these new technologies.

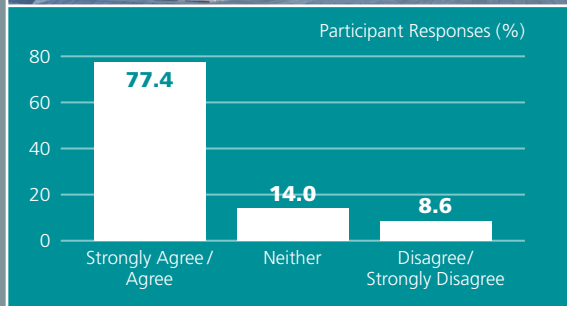
In addition to the above seven opportunities, participants had the option to suggest new opportunities that were not adequately covered in these categories. Participants put forward over 40 new ideas, ranging from technology-specific ideas such as graphene and advanced manufacturing, to broad opportunities and challenges such as renewable energy and dealing with climate change.

The following report provides an overview of inputs in each of the seven opportunity areas and a synthesis of the new opportunities submitted by participants.

The Cities of the Future

The Opportunity: Urban areas are struggling to manage traffic congestion, provision of basic utilities, waste disposal, air quality and more. These issues will grow as more and more people migrate to large cities. Future technologies – such as connected vehicles, delivery drones, waste-to-energy systems, and self-repairing materials – could enable sustainable, urban growth for Canada and the world.

Participant Response: Many participants pointed out that most of the technologies described in the opportunity area already exist/are under development. What is needed is pricing and performance improvements to increase scalability and market penetration. Participants that neither agreed nor disagreed stated that replacing aging infrastructure and high costs would be major stumbling blocks. It was suggested that the focus should be on a shift to smaller, interconnected satellite communities capable of scalable energy production and distribution, local food production, waste management, and recreational space.



Participants identified the following game changers as integral to sustainable urban growth in Canada and the world:

What is Needed?	Contributing Technologies
Better Infrastructure and Infrastructure Management	
Greater ability to monitor and maintain infrastructure (buildings, roads, bridges, and vehicles) more cost effectively and efficiently.	Ubiquitous, cheap sensors (e.g. 'smart-dust' sprinkled to create smart meshes); Nanotechnology; Microelectronics; Computer-assisted decision making/ computational modelling; Internet of Things; Data integration; Analytic tools.
Smart / functional materials to increase durability of infrastructure or to sense environmental changes; using basic structural features (windows, walls, floors and doors) as energy exchange/storage devices, communications interfaces, and/or as filters for air and water.	Self-repairing concrete, coupled with sensors for maintenance; Microelectronics; Industrially available graphene and composites; Nano-structural materials such as nanocrystalline cellulose, Nano-structured metallic thin films.
Efficient Transportation	
Efficient movement of people and goods through autonomous systems and intelligent controls with detection avoidance systems; use of mass transit corridors where possible to reduce need for personal transportation.	Analytic tools; Contextual imaging technology; Connected vehicles; Machine learning; Interoperability; Drones; autonomous unmanned ground or air vehicle (UAVs/UAGs); Big data/ analytics; Cognitive computing; Virtual reality and simulation; Apps for scheduling and movement; Real-time monitoring system/ communication; Geomatics, navigation, and GPS with accuracy down to the millimetre level.

What is Needed?	Contributing Technologies
Localized Production	
Ability to 'replicate' any object anywhere, for more localized production to reduce transport of goods.	Cheap, scalable and improved 3D printing.
Urban agriculture to limit/ reduce footprint.	See notes under Safe, Sustainable and Profitable Food Industry.
Renewable Energy	
Renewable energy generation, storage, distribution and efficient use in residential and commercial buildings; energy conversion / thermodynamic efficiency and the ability to convert readily available point-source energy into useful forms.	Solar panels; Nuclear fusion; Synthetic hydrocarbons made from atmospheric CO_2 and water vapor (artificial photosynthesis); Biorefineries; Smart grids; photochromic/ electrochromic windows; Intelligent controls and nanotech; Thermal technologies (gasification, thermal depolymerization, plasma arc gasification) and Non-thermal technologies (anaerobic digestion, fermentation, and mechanical biological treatment); Scalable reflow batteries (iron, chromium, vanadium etc.).
New energy solutions for power hungry devices (cell phones, tablets, all electronics) that have hard to dispose/recycle batteries.	Organic or bio-batteries supporting storage of Adenosine Triphosphate (ATP), glucose, etc.
Better Resource and Waste Management	
Improved water and waste management to deal with increasing population; closed loop systems are needed so new products are designed for disassembly at the end of their life.	Technologies to remove non-particulate contaminants such as *E. coli*; Bacteria to improve recycling/ obtain usable by-products; Mining technologies to recover metals from electronics; Waste recuperators, regenerators, heat pipe exchangers, and thermal wheels; New bio-products through fermentation and digestion.

The following socio-economic issues were raised as critical barriers / enablers impacting sustainable urban growth in Canada:

To change behaviours, **education and awareness** are critical to get individuals and communities more committed and involved in improving simple, yet essential, lifestyle changes. Collective societal action will be needed to move focus away from technologies based on personal convenience alone.

Equitable access to certain technologies that offer lifestyle improvements will be important to gain momentum and enough magnitude to impact sustainability. Suggestions centred on modifying subsidies and/or replacing with incentives that are aligned with performance targets (e.g. specific building should use X% energy).

Regulatory and public policy development will need to accelerate in multiple areas to manage rapid and structured implementation of game changing technologies, such as: a national strategy to develop, implement, and legislate drones; zoning of smart infrastructure; reducing packaging on products; de-regulating and harmonizing various tiers of transportation and infrastructure laws and standards, with a performance-based approach. Cohesive action at multiple levels of government will be needed to combine investments for public good that promise longer-term return on investments. Finally, it was suggested that municipalities combine efforts to facilitate the adoption of key technologies.

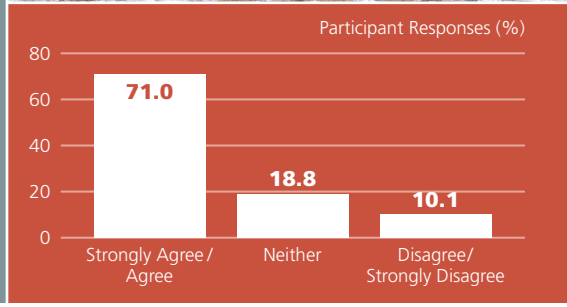
Security and privacy concerns will only increase if ubiquitous sensors and smart everything is collecting massive amounts of data and everything is automated. Ethical implications will become more complex. For example, will sensors in wastewater management become capable of monitoring illegal chemicals (terrorist activities)?

Societal change will mean economic change. As certain technologies are implemented, Canada may see the creation of a distributed network of mini-industries and mini-communities. Changes in services and jobs will become more prevalent as robotics and artificial intelligence becomes more sophisticated and incorporated within the economy. Job losses in one sector (e.g. trucking and delivery) may also mean new jobs in other areas (e.g. robotic repair and maintenance).

Prosperous and Sustainable Rural and Remote Communities

The Opportunity: These communities continue to decline as migration to urban centres increases. Future technologies – such as new materials, locally produced food, and virtual services – could assure the strength and stability of rural and remote Canada in the decades ahead.

Participant Response: Political focus, investment and market forces were cited often as barriers to thriving rural and remote communities. The local mindset and culture were also pointed out as non-technical barriers. Overall, the anticipated cost of implementing technologies to enable prosperity and sustainability was considered too high to attract public or private investments. Some participants indicated that if basic infrastructure was in place (e.g. broadband), some of the barriers would be removed. One participant indicated that the description insufficiently covered opportunities for agriculture in rural Canada, such as commercialization of bio-based chemistry. It was also suggested that the challenge of transportation was underestimated.



Participants identified the following game changers as integral to assure the strength and stability of rural and remote communities in the future:

What is Needed?	Contributing Technologies
Renewable, Localized Energy	
Solutions for cost-efficient and production-effective local, clean energy; solutions to create energy from waste, heat water with waste etc.	Heat pumps; harnessing geothermal energy; solar; wind energy; and micro-cogens; biomass transformation.
Development of bio-based products and chemicals (polymers, fuel) from waste, sugar, lignin, forestry etc.	Bio-refineries; cellulose nanocrystals, process technologies; novel bio-based materials.
Localized Production and Services	
Ability to 'replicate' any object anywhere, for more localized production to reduce transport of goods.	Cheap, scalable and improved 3D printing
Modified plants for local agriculture production; productive crops that can withstand harsh weather conditions. Local agriculture/aquaculture to meet local needs and drive a biomass industry.	Synthetic biology; genomics; permaculture, biodiversity, and indoor farming. See additional notes under Safe, Sustainable and Profitable Food Industry.
Equal access to health care through e-health solutions, on-site diagnostic tools and remote consultations.	Hand-held diagnostics; wearable sensors, search and rescue sets; automated solutions; remote-surgery. See additional notes under Health Care System.

Prosperous and Sustainable Rural and Remote Communities

What is Needed?	Contributing Technologies
Improved Virtual Access (ICT infrastructure)	
Better ICT infrastructure and high-bandwidth internet, along with broad, reliable access is greatly needed to improve accessibility for all Canadians.	Mobile access/ wireless technologies; Internet of Things; microelectronics; security and privacy technologies, such as encryption; miniature power supply; big data and database integration; data management and server management; cheaper sources of energy to power the cloud.
Efficient Transportation	
More efficient, clean transportation and automated solutions for goods delivery, and assembly/ disassembly.	Electric cars, mass transit, light rail, search and rescue sets; robotics, aeronautics, heavy-lift airships, drones, sensors, driverless cars.
Better Resource and Waste Management	
Increased availability and sustainability of local water resources, including water recycling and resource monitoring.	Technologies to remove non-particulate contaminants such as *E. coli*; bacteria to improve recycling/ obtain usable by-products; sensors.

The following socio-economic issues were raised as critical barriers/enablers impacting the strength and stability of rural and remote Canada in the decades ahead:

A balance will need to be found between technological advances and cultural sensitivities. **Personal preference and unique cultures** are strong driving forces in these communities. Rural or remote lifestyles are sometimes a conscious choice that allows for more space, time and clean air (and perhaps less influence of technology). Technology solutions developed for urban lifestyles may not be readily transferable and direct human contact will continue to be an important aspect of these societies.

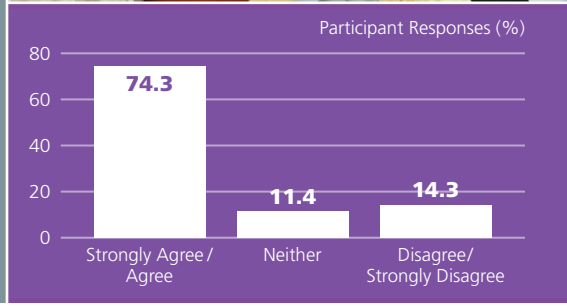
A shift needs to take place in public policies. Regulations do little to discourage the current situation where urban living, large scale farming, etc., is facilitated. Environmental and sustainable practises should be prioritised and valued accordingly. Issues such as equitable access to fundamental resources (does that include internet?); oversight of investments and development, and regulation of remote health care should all be considered.

Long-term sustainability will be highly dependent on **local job creation** and access to virtual jobs across Canada.

Maintaining Quality of Life for an Aging Population

The Opportunity: By 2035, a quarter of Canada's population will be over 65. By 2045, 10 per cent will be over 80. The future could see technologies – such as virtual health care, smart homes, and automation – enabling better physical, financial and social well-being for seniors.

Participant Response: Given the "aging tsunami", many participants agreed with this scenario. Those who disagreed, saw this future as plausible but not desirable (e.g. constant /remote monitoring and heavy reliance on technology). These respondents held that the challenges were more likely to be addressed through social policies and cohesive family units. Social isolation was also seen as a risk in a future too reliant on virtual technological fixes. Another commented that although diagnostic/ sensor technology is desirable and useful, a basic shift to prevention would do more to improve quality of life. Others disagreed with the projected timelines, or remarked that the envisaged future was not likely to happen in certain remote, less economically developed regions of the country.



Participants identified the following game changers as integral to maintain the quality of life for seniors:

What is Needed?	Contributing Technologies
Better Diagnostics and Therapeutics	
Treatments and diagnostics for the conditions of old age, such as dementia, arthritis and decreased mobility, diabetes, cancers, etc.	Precision medicine based on genomics; advanced materials for drug delivery (e.g., nanocapsules and safe/implantable medical devices) and improved assays/kits for (early) diagnostics; 3D printed prostheses and devices, exoshells to enable strength and mobility; big data and analytics for drug discovery and epigenomics; improved electronic health records and privacy/ security solutions to protect personal data.
Assisted Living and Improved Home Environments	
Automated food preparation and medication dispensing, assistive robotics to help with household chores, industrial robotics to perform tasks formerly undertaken by workers now retired, unmanned vehicles to assist users no longer willing/able to drive, robotically assisted medical procedures such as surgeries.	Robotics and autonomous technologies guided by smart algorithms and designed to be "sociable" and easy to use; Wireless connectivity; and Self-driving cars.

Maintaining Quality of Life for an Aging Population

What is Needed?	Contributing Technologies
Assisted Living and Improved Home Environments	
Home-based monitoring (e.g., of vital signs, glucose levels, mobility issues such as falls) of seniors and remote medical visits.	Sensing, wearables; mobile devices and connectivity; biosensors; easy to use mobile devices and apps, broadband and wireless connectivity, cloud computing and storage, improved user interfaces; virtual reality; analytics and artificial intelligence (AI) applied to real-time data and images, advanced imaging technologies; integrative platforms to tie together streaming of data; alert systems, etc.
Improved and sustainable residential housing suited to a senior population, along with accessible transportation.	Through retrofits or new construction, technology to enable accessibility, comfort, and affordability (e.g., using smart, energy efficient materials, movable walls, replacements to stairs); transportation accessible to those with reduced mobility; self-driving cars.
Increase Connectedness and Community Access	
Greater social connection should be a priority to support a policy shift to wellness and prevention, to engage seniors and profit from their knowledge, to keep minds and bodies active.	Social media and apps, fitness equipment and apps, games, improved interfaces and usability suited to the purpose and the population, open online courses for lifelong learning, high tech community centres.

The following socio-economic issues were raised as critical barriers/enablers impacting the physical, social and financial well-being of Canada's aging population:

In addition to the clear challenge of dealing with the rapidly increasing number of seniors, **affordability and adoption** of technologies, for both governments and individuals, is a key concern. There is the generalisation that seniors are not 'tech savvy', which would present a significant barrier to improving lifestyles and health. Any technology solution would also need to focus on reducing costs and implementing user-friendly designs.

Seniors are not a single-dimension demographic. For example, the needs of someone who is 65 versus 90 are very different. There is ample scope here for a wide variety of supportive and life-enhancing technologies, and demographic projections suggest that this will be a ready market in need of innovative solutions for at least the next thirty years.

Certain technologies in this domain, such as biosensors/ wearables or precision medicine, already exist or are experiencing rapid advances. Focus should be on technologies that promote **independence, wellness, and social integration** – solutions that are both high-touch and high-tech, and which are designed specifically for the needs of Canada's senior population.

A wide variety of challenges face this area including: a **lack of supportive public policies and social attitudes** (ageism, disintegration of the family unit), a **dearth of medical staff** and others trained in the care of the aged, tackling ethical issues (should we aim at prolonging life or simply better quality of life?), jurisdictional conflicts between **various levels of government and regulations**, and risks in the area of data breaches and **protection of privacy**.

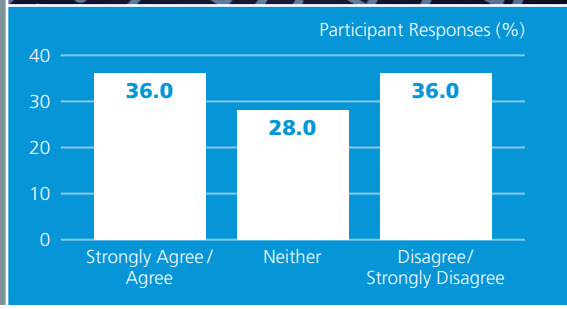
Protecting Canadian Security and Privacy

The Opportunity: As our capacity to collect, analyse and share massive amounts of personal and other data increases, so does the risk of privacy and cyber-breaches. Physical security is also important to our safety and well-being. Future technologies – such as remote and automated sensing, robotics, big data and more – could provide greater protection without creating its own threat to personal, national and economic security.

Participant Response: Participants that agreed cited advances in technology, as well as the strength of Canada's engineering community and their vision. Those who disagreed generally did so on the basis that security is an arms race:

- The rate of digital integration is high and is increasing.
- Systems are only as strong as the weakest link. Finding vulnerabilities is easier than writing perfect code
- Scope and spectrum of cyber-security is continuously expanding from traditional "hacker" to criminal organizations to nation-states. Criminals, terrorists and other adversaries are extremely adept at adapting to the operating environment.
- Corporate spending on cyber-security is insufficient.

One point often echoed was constant innovation and R&D investment is required to contend with growing threats.



Participants identified the following game changers as integral to provide greater protection and privacy:

What is Needed?	Contributing Technologies
Better (Physical) Threat Detection	
Real-time network analysis (automated intrusion and abuse detection) and real-time biometric recognition and translation are needed to allow for more effective threat detection.	Analytics; computational intelligence; biometrics; neuromorphic engineering; intelligent networks, smart grids, advanced distributed computing platforms and cloud computing.
Remote detection of threats that is accurate, real-time, and non-invasive.	Sensing; optical imaging and spectroscopy; and small molecule detection.
Protection of Data, Networks and Privacy	
Securing individual IT systems and protecting personal data, as well as low-cost, high-accuracy proof of identity. Robust networks that don't rely on human safeguards, like passwords that can heal themselves against intrusions.	Cryptography; quantum encryption; homomorphic encryption; biometrics; graphene-based electronics; neuromorphic engineering.

Protecting Canadian Security and Privacy

The following socio-economic issues were raised as critical barriers/enablers impacting the ability to provide greater protection without creating its own threat to Canada's personal, national and economic security:

Privacy concerns in relation to cyber-security were the most commonly cited socio-economic consideration. The clear message is that government and industry must be accountable. Recommendations to achieve this included legislation mandating:

- A framework for transparent data collection that identifies how, by whom, and for whom data is collected.
- Automated / secure logging of data use, providing an audit trail.
- Non-trivial financial penalties for inadequate protection or misuse of personal data.

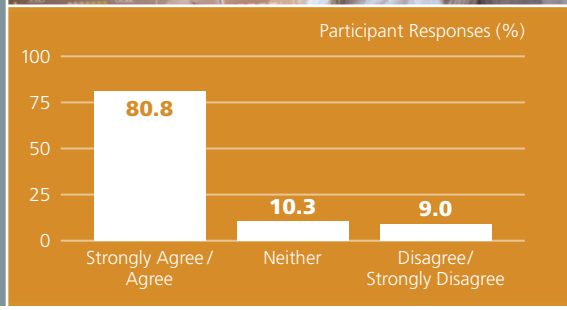
Multiple participants expressed concerns that the public at large does not have **adequate education/skills** in the area of cyber-security (for personal use), and that there is a lack of understanding of the magnitude and frequency threats. Public awareness campaigns and open seminars outlining personal security and implications of cyber-attacks should go hand in hand with technology development.

Canada needs to objectively evaluate the **economic costs of security failure** (terrorism, cyber-intrusions, etc.), and compare them with the costs of investing in new technologies and systems. Without quantifying the threat and opportunity cost, it would be politically challenging to justify massive investment in technology development and infrastructure.

Transforming the Classroom for Continuous and Adaptive Learning

The Opportunity: Education and training are changing at a faster pace than at any time in history – including the way we learn and how knowledge is shared. The future could see technologies – such as virtual reality and simulation, knowledge in the cloud, personalised development and more – contributing to an education system that is accessible, dynamic, and offers and encourages lifelong learning.

Participant Response: The benefits of virtual education and training are undeniable. Many participants felt that the technologies already exist but that we lack the institutional structures or incentives to deploy them, and that the education system and society will not be able to keep pace. However, given human inclinations, there will always be some aspects of education and training that should be hands-on. Furthermore, the credibility and sources of the information for online courses will be difficult to ensure, along with mechanisms for accreditation and remuneration.



Participants identified the following game changers as integral to the future of continuous and adaptive learning:

What is Needed?	Contributing Technologies
Improved Virtual Access	
Better ICT infrastructure and high-bandwidth internet, along with broad, reliable access is greatly needed to improve accessibility for all Canadians.	Mobile access/ wireless technologies; Internet of Things; microelectronics; security and privacy technologies, such as encryption; miniature power supply; big data and database integration; data management and server management; cheaper sources of energy to power the cloud.
Better Human-Computer Interaction	
Enhanced human-machine interaction incorporating senses in the learning experience; advanced collaborative spaces for learning.	Connected wearables; ocular devices, voice recognition; gesture-based technology; massive online interactive courses; interfaces and interactive devices.
Analytics for personalised education on demand.	Universal translators; context-aware applications; language translation; data analytics for monitoring skills requirements; automated content creation from reliable sources. Understanding of linkages to prior learning experience, attitude and attention are necessary conditions.
Virtual reality/ augmented reality, along with simulation for learners to absorb and immediately practice skills (such as surgery).	Robotics; immersive technologies such as object recognition, touch, motor-coordination, speech recognition and spatial reasoning are all important drivers of deep learning.

Transforming the Classroom for Continuous and Adaptive Learning

The following socio-economic issues were raised as critical barriers/enablers affecting the ability to create an education system that is accessible, dynamic and offers and encourages lifelong learning:

Fair and equal access to e-learning resources will be a key challenge. Many Canadians still do not have affordable and reliable high-speed internet access, and the question of who will pay for this is frequently raised. In addition, learning in Canada may need to be accessible in more languages than English and French, particularly if immigration will increase over the next 30 years.

Resistance from the existing primary education system and unions will need to be addressed. Most of the technologies described are already under development, but adoption by educators and the education system in general is not keeping pace. As technology advances, the role of the teacher will significantly change. Unions may not respond well to reductions in the workforce as a result of technology advancements. A balance will need to be found between the use of technology and the use of hands-on and/or face-to-face education.

Higher learning institutions may need significant **restructuring and redefining of their traditional roles and curriculum**. For example, if one institution such as Harvard offers an online program for ethics, and it is considered to be the premier program, why would other universities develop their own program? Would institutions then only focus on areas of excellence, rather than having a more balanced, diverse campus? Large multi-institutional agreements may need to be developed to ensure consistent content delivery.

With accessibility to learning opportunities and breaking down of institutional learning, **accreditation, certification and knowledge recognition** become key issues. 'Reputation metrics' may need to be developed and could affect compensation schemes. The apprenticeship model may become the norm and an integral part of the learning culture.

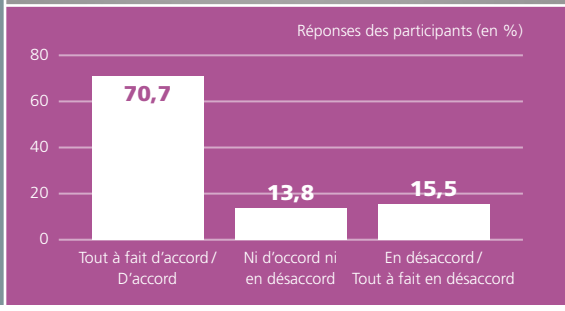
As learning becomes virtual, personalized and targeted at individuals, there will be a need to ensure **security and protection of online privacy**. In addition, mechanisms will be needed to combat plagiarism.

Next Generation Heath Care Systems

The Opportunity: Pressures are mounting on the Canadian health care system, ranging from hospital spending to health care delivery in remote communities. The future could see technologies – such as remote surgeries, virtual practitioners, implantable devices, smart vaccines, and more – assuring the effectiveness and affordability of Canada's universal health care system in the future.

Participant Response: Those that agreed indicated that the described technologies were plausible (with the exception of the self-mutating vaccine, which is neither plausible nor desirable). Indeed, many indicated that most of the technologies were already well under development or even in early use. Disagreements arose when noting that technology alone would not solve all system problems:

- Advanced technologies may raise costs and reinforce the existing disease-focused paradigm.
- Lasting impacts on costs and on overall societal health require a major shift from treatment to health promotion and maintenance; from reactive to preventive medicine.
- Even where technologies are invented and developed, adoption, acceptance and integration into daily practice can take much longer, and may still be decades away for some of the described technologies (e.g. implantable devices or remote surgery).



Participants identified the following game changers as integral to the future of the health care system:

What is Needed?	Contributing Technologies
Improved Virtual Access	
Better ICT infrastructure and high-bandwidth internet, along with broad, reliable access is greatly needed to improve accessibility for all Canadians.	Mobile access/ wireless technologies; Internet of Things; microelectronics; security and privacy technologies, such as encryption; miniature power supply; big data and database integration; data management and server management; cheaper sources of energy to power the cloud.
Better Diagnostics and Therapeutics	
Interpretable data streams from wearables, implants, and monitoring systems that can enable delivery of reliable, real-time diagnosis and early warning signals/alerts.	Analytic tools; machine learning, neural networks; data visualization; modeling, simulation; haptic interface; user-friendly robotic systems; cryptographic and biometric security; bioinformatics.

What is Needed?	Contributing Technologies
Better Diagnostics and Therapeutics	
Observe, record, and report patient/ client movement, activities, vital signs and other physiological processes, in health, disease progression, and therapeutic response. Safely non-invasive whenever possible; minimally invasive otherwise.	Wearables, scanning and monitoring sensors: microelectronics, MEMS, nanotechnology; biochemical assays; genomics/ proteomics/ lipidomics; photonics, cameras and computer vision; accelerometers and GPS; voice and gesture recognition; image and scene recognition.
Miniaturization of healthcare tools, and in some cases the ability to intervene as well as observe (e.g., release dose of drug, or clean plaque from an artery).	Implantable devices and materials; micro- and nano-systems; new materials, biomaterials, bioprinting, additive manufacturing and printable electronics.
Enhanced Prevention and Prediction	
Understanding of the molecular mechanisms underlying health, nutrition, stress, disease, and drug response; inherited and environmentally triggered effects, and their interactions. At both population and individual levels.	Personalized medicine; Genetics, 'omics and bioinformatics; genome sequencing; gene expression arrays, proteomics, lipidomics, and epigenetic markers; ongoing progress in molecular assay technology, Lab-on-Chip, 'Human-on-Chip', bio- and chem- informatics, advanced analytics and machine learning.
Personalised coaching on healthy nutrition and lifestyle; assist humans in patient care and in home-based self-care.	Wearables, scanning and monitoring sensors; microelectronics, etc.

The following socio-economic issues were raised as critical barriers/enablers impacting the effectiveness and affordability of Canada's universal health care system:

As health care system costs continue to rise, questions are raised on the nation's ability to continue to provide **equal access**. Will provincial funding be sufficient for universal access in the future? Will expensive new technologies result in *de facto* 2-tiered or multi-tiered care? Can health issues as a direct result of poverty be addressed?

A great deal of investment goes towards diagnoses and treatment but less focused is placed on technologies for **preventive care and promotion of a healthier lifestyle**. Healthier diets, more exercise, cleaner air and water, pathogen-free food, strong personal relationships and communities, activity and a sense of purpose – all of these contribute to better individual and societal health, and lower spending on the chronic diseases that drive unsustainable medical costs.

As medical data becomes increasingly digitized, there will be risks and trade-offs that will have to be considered with respect to **security and confidentiality**.

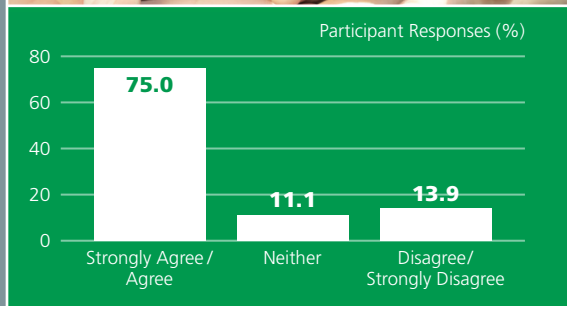
Several participants suggested that the system needs **restructuring, with greater empowerment of patients/citizens, nurses and other caregivers**. Various comments suggested a vision of agile teams – patient, doctor, nurse, nurse-practitioner, nutritionist, family members, and analytics/AI/robotic systems – cooperating in a person's wellness and, when necessary, in disease management, treatment and cure. Better intra- and inter-provincial coordination was also recommended.

With rapidly advancing technologies and treatments, some question the **ability of provinces to keep pace with cost-effective and cost-efficient assessment and adoption** by health care systems. Suggested improvements include: more risk-sharing and coordination in technology assessment between public and private partners; greater harmonization of standards between provinces and between countries; and greater reliance on international assessment/ testing/ regulatory data in accelerating Canadian regulatory and adoption decisions.

A Safe, Sustainable and Profitable Food Industry

The Opportunity: Input costs continue to rise and threaten affordability for consumers. Environmental impacts, climate change, global trade, and food safety continue to threaten industry success. Future technologies – such as sensors to monitor food safety, nutraceuticals, big data and analytics and more – could enable the food supply chain to balance economic and environmental sustainability, with safety and stable food prices.

Participant Response: Although a large majority of the respondents agreed with the plausibility of the opportunity, there was a split in the commentary regarding the potential of agricultural technology. On one hand, participants commented that "genetically modified organisms are the way of the future." On the other, some participants felt that "bio - [organic] growing would meet all the social, ethical, environmental, etc. requirements and expectations that the population would expect and support."



Participants identified the following game changers as integral to the future success of the food industry:

What is Needed?	Contributing Technologies
Food Safety	
Advancing a variety of analytical and detection options (e.g. spectral) for food identification and contaminant detection would be ideal to empower both producers and consumers.	Ubiquitous, cheap sensors; nanotechnology; microelectronics; computer-assisted decision-making/ computational modelling; internet of things; data integration; analytic tools, Lab-on-Chip, synthetic biology; in-situ monitoring/ imaging devices; smart food packaging; handheld sensors capable of auto-correcting for moisture content; multi-variate spectral analysis for key markers - protein, fat, carbs, sodium, pharmaceuticals, bacteria, and other possible contaminants.
Increased Productivity	
Developing/ adapting semi-tropical crops to Canada's southern areas, as well as disease, heat, drought and pest resistance, to combat the negative effects of climate change and precision breeding tools are all needed to increase production.	Genomics, biotechnology, genetic engineering; soil science such as microbial dynamics, plant-pathogen and plant-plant interaction; nutrigenomics, natural product discovery, analytic chemistry and advanced in big data analytics, and capacity; sequencing, proteomics, marker technology, advanced analytics.

A Safe, Sustainable and Profitable Food Industry

What is Needed?	Contributing Technologies
Increased Productivity	
On-farm production of fertilizers/ fuels from co-product streams, by ready-to-run (turn-key) process plants in a box that can be tuned to optimize yield from each individual farm's co-products.	Automation of farm processes, remote sensing/ monitoring, data analytics, artificial intelligence and pattern recognition, machine learning; Genetic markers, low volume libraries, data management, apps, Lab-on-Chip, Internet Barcode of Life on Chip (iBol-on-Chip); soil science such as microbial dynamics, plant-pathogen and plant-plant interaction; handhelds for simple soil quality testing, pest and pathogen identification in field with immediate results.
Laser-based robotics for weeding, bug-hunting, picking fruit, grain transportation and more. Farm equipment designed on closed loop systems so new products are designed for disassembly at the end of their life, or identify safety and repair requirements.	Analytics, artificial intelligence, robotics; contextual imaging technology; connected vehicles; machine learning; interoperability; drones; autonomous unmanned ground or air vehicles (UAVs/UAGs); big data/ analytics; apps for scheduling and movement; real-time monitoring system/ communication; geomatics, bio-recognition; navigation, with some GPS and remote sensing systems with accuracy down to the millimeter level.
Better Resource and Waste Management	
Improved water management to deal with intensive production, and drought resistant plants; urban agriculture to limit/reduce footprint. Energy efficient vertical farms, and controlled growth facilities (greenhouses/growth chambers) for agriculture N60 to be more and more possible with limited environmental footprint.	Sensor technology; apps for scheduling and movement; real-time monitoring system/ communication; nano-based materials and new materials; energy systems, solar, along with re-claimed/ refuse energy production systems.

The following socio-economic issues were raised as critical barriers/enablers impacting Canada's ability to balance economic and environmental sustainability, with food safety and stable prices:

There is an increasing sentiment of '**thinking locally**'. In addition to the benefit of reducing issues from long-distance transportation, local production would tackle multiple challenges such as food safety (knowing where your food came from), reduction of waste along the food chain, control of contaminants and water use, etc. Technologies that allow for both urban and remote farming are critical.

Food safety is of paramount importance to many participants. Consumers are becoming empowered and want to know more information about what they are eating. New technologies (that impact what is ingested) should be adopted under an 'open approach', where more information is made available.

Several participant comments supported a move towards a '**Blue Revolution**', where most of our protein is derived from aquatic farming. Another supported the notion of '**carniculture**' (growing meat protein in vats similar to hydroponic farms).

Public education on healthy eating, chemicals, and ethical and general public concerns regarding genetically modified organisms should be top of mind, as should reaching out to remote communities to ensure they have **access to healthy food**. This would also address issues raised under the health care system opportunity.

New Opportunities

Participants were invited to suggest opportunity areas they felt were not reflected in the opportunities as presented. Forty-one (41) new opportunities were suggested. In addition, the general discussion section was surveyed to capture other new opportunities suggested there. The table below summarizes the topics suggested. Some of the suggestions were related to broad challenges, while others were very technology-specific.

Suggestions related to climate change, sustainable energy and the environment dominated the discussions of new opportunities; 34% of new submissions discussed these topics, while related issues such as sustainable and efficient natural resource extraction, clean transportation and development of the North were also highlighted.

Overview of New Opportunities Submitted

What is Needed?	Contributing Technologies
Sustainable Natural Resource Extraction	
• Sustainable practices in resource and energy extraction as key to combatting climate change. • Value-added materials should be produced and processed in Canada, rather than exporting raw materials for processing elsewhere. • Environmentally-friendly and efficient exploration, extraction and processing technologies. • Northern Canada's long term resource extraction potential requires new applications of transportation and transmission technology. Current infrastructure planning is on a project by project basis with little long term coordination of multi-user potential for legacy infrastructure – these could be more environmentally sustainable with long-term planning and reuse for different modalities in the future.	• Mineral extraction: process technologies; membrane separation technologies; miniaturization; robotics; automation; sensors; nanotechnology; and bioleaching. • Hydrocarbon extraction: process technologies; conversion technologies (like coal-to-liquids and coal gasification); membrane separation technologies; miniaturization; robotics; automation; sensors; nanotechnology; and microbial conversion. • Transportation of resources: slurry pipelines; autonomous trains; maglev/pneumatic tube transport; superconductivity/ high voltage DC transmission; linear induction and vacuum tube technology; new construction technology to avoid permafrost degradation in a warming North.

New Opportunities

What is Needed?	Contributing Technologies
Renewable energy, a green environment and combating climate change	
• Fossil fuel use must be curtailed and a path must be planned to reduce greenhouse gas levels to safe levels. • Combat climate change by decreasing reliance on fossil fuel with renewable energy. Improve power infrastructure, transmission and storage (both efficiency and cost), and build decentralized, smart grids. Develop local energy production, distribution and storage. • Reduce environmental impacts. Transform waste (agricultural, municipal, industrial) into products; improve material science; clean transportation technologies; transition to a bio-based economy; water and soil remediation. • New forms of energy distribution and storage are required to harness the potential of photovoltaics and micro-fusion. • Eco-Friendly home appliances. Energy from home appliances such as clothes dryers and refrigerators can be recycled. Sun, wind, cold, snow, and air flow could be directed to be re-used in the home. • High-performance building technologies can deliver significant savings with low barriers to implementation. Technologies already exist or are being developed to build 'net zero homes' within the next 15 years. Regulations and standards will be the biggest barriers, and more training in these technologies is needed. • Zero emission power plants could be achieved, but challenges to address include: integration of renewable energy to the grid; improvements to production processes and consumption; develop and promote carbon capture and storage technologies; social acceptance. • Switching to a renewable-energy economy is the obvious long-term solution to climate change, but the transition will likely take several decades.	• Carbon capture and storage; geothermal energy; advanced biofuels; next generation nuclear power; energy storage devices; integrated transmission lines; solar, wind and hydro power; solar powered appliances; solar cells on roof shingles; cool/green roofs; sub-metering; district energy; air source and ground source heat pumps; improved photovoltaic devices; load-levelling storage; high performance batteries for clean transportation; smart grids; micro-fusion. • Adaptation strategies, such as flood defenses and efficient irrigation systems. • Geospatial and remote sensing information systems; grey-water and rain water recycling systems; biorefineries; bioplastics; crop science to produce sustainable biomass; sensors and monitoring; climate modeling.

New Opportunities

What is Needed?	Contributing Technologies
Sector/Economic Development	
• Advanced manufacturing that is knowledge-based, not resource-based, and is export-oriented. – The challenge is to become world class at introducing the technologies we have funded to domestic and world markets. Organizational change is needed, as well as developing a strong talent pool. – Canada's economy relies on SMEs. We should provide them with the space and hardware needed to develop expertise in using new manufacturing tools (3D printing, bio-engineering, or *manufacturing in a box*). Could we add a manufacturing hub like mini-Shenzhen to the innovation corridor? • R&D efforts should concentrate on exporting knowledge developed and derived from our resource sectors. Canada has strengths in mining, bioremediation, pipeline technology, cold climate engineering, hydropower, and remote sensing – all related to resource extraction. • Our land and water are key resources that give us a huge advantage over other countries. "Food production will become more and more important to the world and yet challenging. Canada's agriculture and aquaculture production could be doubled or tripled, driven by technology, with the required social and political will. The recognition of farming and farmers needs to increase, which is difficult given the urban - rural divide."	• Carbon nanotubes, especially to replace silicon in electronics; 3D printing; Nanocomputing; Quantum computing; Blockchain technology – used by crytocurrencies (e.g. Bitcoin); Integrated energy systems – to collect and use renewable energy; Battery technologies, especially for electric vehicles; Augmented and virtual reality. • Graphene technology. • Neuromorphic engineering; Nanoelectronics. • Organic and printed electronics; Connecting objects through next generation information systems; Big data analytics.
Data Management	
• The need to address capacity and the fast processing of massive amounts of data generated on the Internet, including the Internet of Things. • Technology development projects require data to test, and verify. Having "open data" would help reduce the effort to generate new data, making research money go farther. • To capitalize and promote the use of open data requires more than passive archiving of data, communities that use the data should be nurtured, and effective interfaces to the data need to be designed. • The provinces have moved to electronic health records – could this long term data sets on public health in the world be mined, while still maintaining patient privacy?	• Computational methods to integrate devices, data sources, models and intelligent computing; human-computer interaction through neuroscience; security, privacy and resilience of networks • Parallel and integrated systems; High-bandwidth connectivity on the ground and from space; High throughput data routers capable of 5000 Terabits/second; Virtual reality; augmented reality; Haptic interfaces; AI agents; Quantum computing

New Opportunities

What is Needed?	Contributing Technologies
Enhancing Humans	
• Better protective gear. • Smart textiles that harvest energy. • Wearable and implantable devices enhancing ability to learn or perform tasks. • A "universal translator, which combines advanced translation software with cochlear implants to allow for real-time wearable/implantable translation devices." This is a particular advantage to a multi-lingual country like Canada and, "as our economy diversifies its export markets to non-English speaking emerging markets the benefits of these universal translators will only increase."	• Advanced materials • Analytics • Exoskeletons • Cognitive enhancements • Machine translation
Autonomous Systems	
• Autonomous systems with applications in home comfort, transportation, medicine, security, internet, and entertainment. • Autonomous space technologies and exploration	• Mechatronics; IT (hardware & software); Sensors; Artificial intelligence, Machine learning; Design (CAD, CAM, bio-mimetic); robotics • 3D printed devices with embedded artificial intelligence can be cheaply launched into space to self-assemble or morph into the correct configuration for use.

Other issues raised by participants:

Culture and Community

- Cultural shifts required to encourage Canadians to adopt new technologies
- Technologies and policies to improve living conditions of Aboriginal peoples. This includes improving infrastructure, education and employment rates.
- A world without conventional work – we have moved from localized, job or industrial based economies to more networked and distributed social organization. Enabling future tech for this job-free world: cheap/abundant (alternative) energy, artificial intelligence, omics technologies
- Cultural implications of technology advancements. For example, consider the impact of bringing high speed internet into a remote community where this service has not been used before. We must consider how the social and cultural fabric may change, for good or bad, with the introduction of innovations.
- Current economic systems have created massive economic inequality locally, nationally and globally, so there is a need for technologies that deliver opportunities to otherwise disadvantaged people to share ideas, resources, and skills development, with a view to community economic development and a focus on diversity, equity and inclusion.

Achieving greenhouse gas reductions

- Advances needed in both technologies and policy.
- Alternative energy need to become a cheaper alternative to fossil fuels.
- How can we make electric cars more affordable?
- Introduce carbon tax, and funnel that revenue to R&D on alternative energy.
- The world will not move toward alternative energy sources until the price of oil becomes prohibitive.
- Improvements to solar and wind energy are needed to address cost and performance, compared to energy from oil.
- The government should provide seed capital for alternative energy development.
- We should conserve energy waste and use other waste streams as a source for raw materials.