ON THE HORIZON

Several Perspectives on Canada's Technology Future · 2030-35

Report of the Working Group on Horizon Scanning, April 2021

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EXECUTIVE SUMMARY

Eventually the COVID-19 pandemic will be resolved, economies will recover, and Canada's attention will refocus on the future. Certain contours of that future are already clear. Canada will be committed to do its part in the global effort to finally confront climate change and environmental degradation. Our economy will have to discover innovative ways to sustain its competitiveness as data and information become the key factors of production and as the superpower rivalry between the U.S. and China creates new challenges and opportunities for Canada's traditional trade and investment relationships. Health care will need to embrace an expanding array of innovative treatments and technologies while coping with a chronic fiscal challenge in the face of an aging population. These developments will be occurring in a social and political context that has finally begun to acknowledge and address long-standing inequities in the distribution of opportunities and burdens among groups in Canadian society, notably Indigenous peoples and racial minorities.

Each of the foregoing issues is *systemic* in scale and scope. Each will therefore require innovative responses that integrate across disciplines and competencies and that situate technological solutions, more than ever, in their social and cultural context. To that end, the National Research Council of Canada (NRC) invited an informal working group of some 40 thought-leaders to identify potential developments over the next 10 to 15 years that would be significant for Canada. It is emphasized that this report is advisory to the NRC and represents the perspectives of the Working Group alone and not of the NRC or of the Government of Canada.

This report is a collaborative product of that Working Group. It is a *horizon scan* focused on the 2030-35 time period that seeks to frame strategic thinking at a relatively high level but with enough detail to convey a sense of realism. The horizon scan was structured under six broad subject areas:

1. Climate Change
2. Resource Futures
3. Big Data and Artificial Intelligence
4. Cybersecurity and Privacy
5. Health-care Futures
6. New Models of Innovation

For each subject area, the view of the "horizon" in 2030-35 is described under two or three over-arching "Statements" created to organize and summarize the input and discussions of the Working Group. Each Statement is illustrated with two or three specific examples drawn from ideas submitted by Working Group members.

The Statements are not intended as hard and fast predictions. Neither do they purport to encompass all relevant aspects of the six subject areas. The Statements are informed views of the principal contours of what might be called the "space of challenge and opportunity" facing Canada in approximately 10 to 15 years. The emphasis is on the science & technology aspects but complemented with the relevant social and economic context.

Five common themes, summarized in the final chapter of the report, cut across the broad subject areas:

- Competitiveness
- Data as a strategic resource
- Sustainability and resilience
- Community engagement
- Equity, diversity, and inclusion

The Working Group's perspectives on 2030-35 paint a portrait of a successful society in which technology is developed in the service of human goals with the benefits equitably shared. The viewpoint is justifiably optimistic in view of Canada's extraordinary gifts and capabilities but also acknowledges that significant challenges will need to be overcome. Technology will play a vital role, enabling Canadians to meet the challenges and embrace the opportunities, guided by human purpose.

Compilation of Statements

The Statements should be read as reflecting the imagined situation in 2030-35, i.e., from a future perspective. Neither the Statements nor the illustrative examples are listed in any intended order of priority.

1. CLIMATE CHANGE

1.1 Canada makes progress towards carbon-neutral energy production, but important technological, economic, and political challenges remain.

Illustrative examples

1.1(a). Clean, renewable energy and broad application of carbon capture, utilization, and storage are cornerstones of Canada's climate strategy.

1.1(b). Improved efficiency in energy storage facilitates greater adoption of wind and solar.

1.2 Canada embraces electrification of road transportation on the path to eliminating approximately 150 Mt of GHG emissions before 2050.

Illustrative examples

1.2(a). Parked electric vehicles store energy in their batteries and deliver it back to the "smart grid" as needed while the owner is paid by the utility.

1.2(b). Battery and hydrogen fuel-cell technologies enable electrification of the various modes of road transportation.

1.3 Decisions in Canada on climate change mitigation and adaptation earn social trust through alignment and co-development with affected communities.

Illustrative examples

1.3(a). Robust Indigenous authority over infrastructure project decisions, together with (non-Indigenous) local community engagement expectations, transform business models, government decision making, and the timing and nature of responses to climate change.

1.3(b). Unstable citizen trust in institutions and intense political polarization challenge effective climate policy development and implementation.

2. RESOURCE FUTURES

2.1 Advances in technologies to decarbonize production and use of oil and gas enable Canada to achieve substantial emissions reductions while continuing to produce these resources for domestic and export markets.

Illustrative examples

2.1(a). Natural gas combined cycle with carbon capture and storage helps assure Canada's electricity supply while reducing GHG emissions.

2.1(b). Canada is a global leader in "blue" hydrogen supply and use coupled with carbon capture and storage.

2.2 Canada employs innovative technology to augment its natural advantages in agri-food production.

Illustrative examples

2.2(a). "Smart" farms boost production, reduce potentially harmful agri-food inputs, enhance soil health, and bolster Canada's reputation as the world's trusted source of safe and sustainable agricultural exports.

2.2(b). Autonomous and year-round indoor fruit and vegetable production improves Canada's food security by reducing its dependency on imports.

2.2(c). Consumers increasingly choose safe, nutritious, and economically efficient protein sources that are good for animal welfare and have a minimal environmental footprint.

2.3 Canada's forest and mineral resources meet growing global demand through innovative ways to extract greater value with reduced environmental impact.

Illustrative examples

2.3(a). Bioproduct platforms generate consumer materials with new properties while also promoting decarbonization.

2.3(b). The growing global commitment to environmental protection and human safety challenges Canada to be a world leader in the safe and efficient management of mining waste.

2.3(c). Canada is challenged to go beyond "action plans" to sustain its position as a key global supplier of many strategic minerals.

3. BIG DATA AND ARTIFICIAL INTELLIGENCE

3.1 Sustained heavy investment by government and industry in fundamental AI research and niche applications enables Canada to retain its competitive edge and reputation as a world leader in the field.

Illustrative examples

3.1(a). Natural language processing systems are indistinguishable from human communication in both intelligence and empathy.

3.1(b). Brain-computer interfaces and haptic ("touch") simulation are common ways to interact with computers.

3.1(c). Big Data and AI provide lessons for the future by expanding and reshaping understanding of Canada's past.

3.2 Growing cost pressures drive greater efficiency in the provision of health care in Canada, finally overcoming the reluctance of the fragmented system to share data and accelerating the adoption of AI in clinical and administrative practice.

Illustrative examples

3.2(a). Wearable sensors coupled with AI-enabled interfaces help manage chronic health conditions.

3.2(b). Robots complement human caregivers to allow more vulnerable older Canadians to live at home independently.

4. CYBERSECURITY AND PRIVACY

4.1 Canadian governments and businesses "harden" their expanding digital infrastructure by making its resilience the top priority.

Illustrative examples

- 4.1(a). National security and intelligence agencies use lawful, advanced tools to successfully identify and mitigate the threats posed by malicious actors.
- 4.1(b). Computer-aided secure development reinforces the integrity of our solutions.
- 4.1(c). Canada's critical infrastructure is vulnerable to quantum attacks.

4.2 Canada maximizes the benefits of the information economy and society by combining technological innovation for data security with policies to build trust by safeguarding privacy.

Illustrative examples

- 4.2(a). Individuals fully control their personal data.
- 4.2(b). Canada has a nationwide identity system in place for all citizens.

4.3 Thanks to its reputation as a trusted and technologically advanced jurisdiction, Canada becomes a leading global hub for international data flows.

Illustrative examples

- 4.3(a). Canada is a trusted global transfer hub for international data storage.
- 4.3(b). "Confidential computing" technology guarantees data privacy and security in global cloud infrastructures.

5. HEALTH-CARE FUTURES

5.1 Canada integrates genomics, artificial intelligence, and digital tools to create a 21st century health-care system centred on the individual and focused on prevention and early detection of disease.

Illustrative examples

- 5.1(a). Inclusive innovation in telehealth, based on AI and machine learning, increases health-care equity, accessibility, and efficiency.
- 5.1(b). Genomics and related technologies, combined with AI, enable major advances in early diagnosis of diseases and personalized health care.
- 5.1(c). Genome sequencing data is incorporated into electronic health records.

5.2 Canada focuses resources in areas of demonstrated strength to be among the global leaders in research and clinical and commercial application related to stem cell therapies and rapid, point-of-care diagnostic testing.

Illustrative examples

- 5.2(a). Point-of-care diagnostic technologies disrupt and decentralize medical care.
- 5.2(b). Stem cell therapies replace transplants for heart disease and diabetes.

5.3 **Canada pioneers a new model of wellness by integrating the traditional disease-focused approach with interventions that incorporate the social and cultural determinants of lifelong health.**

Illustrative examples

5.3(a). The achievement of more equitable health outcomes in Canada is hindered by the lack of participation of Indigenous peoples in the development and implementation of innovations in health and health care.

5.3(b). Early intervention strategies prevent "deaths of despair" and reverse the trend of widening socioeconomic disparities in health and life expectancy in Canada.

5.3(c). A universal single-payer, portable health-care system in Canada enables implementation of innovative health care, public health surveillance, and applied research.

6. NEW MODELS OF INNOVATION

6.1 ***Data* is recognized as the universal raw material supporting innovation in virtually every domain.**

Illustrative examples

6.1(a). Access to huge volumes of real-time data—from which behaviour can be predicted and manipulated—is a more important source of power and success than technology itself.

6.1(b). Innovative data trusts, combined with collaborative networks and open innovation, catalyze solutions to complex social, health, and environmental problems and enable economic opportunities.

6.2 **The "innovation" in Canada's innovation policy emphasizes a systemic approach that unites academia, business, government, and civil society to improve competitiveness in broad areas of strategic opportunity.**

Illustrative examples

6.2(a). Canada leads global innovation platforms that generate local value and provide international market access.

6.2(b). Canada's "deep tech" ventures are a significant driver of GDP growth and a positive force for solving the world's most important problems.

6.2(c). A vibrant quantum technology sector emerges from Canada's application of a new innovation ecosystem model that capitalizes on early advantages in quantum science & technology.

6.3 **As technology makes many jobs precarious, Canada is among the global leaders in exploring innovative models that promote and enable the creativity of individuals and their communities.**

Illustrative examples

6.3(a). Canadian digital platform co-ops increase and flourish in sectors beyond traditional "sharing economy" businesses.

6.3(b). Interdisciplinary creative hubs in neighbourhoods across Canada foster a new sense of purpose and creative entrepreneurialism among citizens.

INTRODUCTION

Eventually the COVID-19 pandemic will be resolved, economies will recover, and Canada's attention will refocus on the future. Certain contours of that future are already clear. Canada will be committed to do its part in the global effort to finally confront climate change and environmental degradation. Our economy will have to discover innovative ways to sustain its competitiveness as data and information become the key factors of production and as the superpower rivalry between the U.S. and China creates new challenges and opportunities for Canada's traditional trade and investment relationships. Health care will need to embrace an expanding array of innovative treatments and technologies while coping with a chronic fiscal challenge in the face of an aging population. These developments will be occurring in a social and political context that has finally begun to acknowledge and address long-standing inequities in the distribution of opportunities and burdens among groups in Canadian society, notably Indigenous peoples and racial minorities.

Each of the foregoing issues is *systemic* in scale and scope. Each will therefore require innovative responses that integrate across disciplines and competencies and that situate technological solutions, more than ever, in their social and cultural context. Achieving this broader perspective will be a challenge for every organization, public and private. To that end, the National Research Council of Canada (NRC) invited an informal working group of some 40 thought-leaders to identify potential developments over the next 10 to 15 years that would be significant for Canada.

This document is the report of that Working Group.[1] It is a *horizon scan* focused on the 2030-35 time period that seeks to frame strategic thinking at a relatively high level but with enough detail to convey a sense of realism. The Working Group did not engage in scenario creation or technology forecasting but rather sought to provide informed views of what might be called the "space of challenge and opportunity" facing Canada in approximately 10 to 15 years.

The horizon scan described here completes the first phase of a two-phase initiative. It will inform a second phase of focused consultations organized by the NRC and intended to help identify the science, technologies, skills, and other capabilities that will enable Canada to succeed and prosper in the mid-term.

It is emphasized that this report represents the perspectives of the members of the Working Group alone and not of the NRC or of the Government of Canada.

The horizon scan was structured under six broad subject areas:

1. Climate Change
2. Resource Futures
3. Big Data and Artificial Intelligence
4. Cybersecurity and Privacy
5. Health-care Futures
6. New Models of Innovation

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[1] Members of the Working Group were identified in June-August 2020 based on recommendations by external communities and organizations, requirements for subject matter coverage, diversity, and geographical location. Members served voluntarily without compensation and in their personal capacities. All meetings of the group were virtual. See Annex I for a list of members.

Horizon Scanning Methodology

The methodology employed is a variation of a horizon scanning approach developed by Professor William Sutherland at the University of Cambridge (U.K.). In the present version, the Working Group was divided into six Subgroups consisting of six to seven members and corresponding to the foregoing subjects (see Annex I).

Each Subgroup member was asked to develop two to three statements, together with a brief (100-200 word) rationale, that describe developments of potential significance for Canada that might plausibly be realized over the next 10-15 years but were unlikely to be already very familiar outside the relevant expert communities. The developments were not restricted to specific aspects of science and technology (S&T) but could also refer to the social and economic context in which prospective S&T developments would be embedded.

Within a Subgroup, each individual member submitted statements to the NRC secretariat for the project.[2] The full set of anonymized statements (typically numbering about 15) was then circulated to all Subgroup members who scored the statements with respect to potential importance for Canada as well as likelihood within the 2030-35 timeframe.[3]

During October and November 2020, each Subgroup met once virtually for a half-day discussion of the set of statements and ranking results. Those conversations ranged broadly over specific technologies identified in the statements, but they tended to focus primarily on contextual issues—for example, competitiveness, inclusiveness, resilience, the prominence of data, and related matters of trust.

Following the discussions, the secretariat prepared short papers for each of the six Subgroup subject areas. These papers—which ultimately became the following chapters of this report—were based on the statements originally prepared by Subgroup members, interpreted and amended as necessary in light of the Subgroup discussions, bolstered with further supporting evidence, and structured under a small number of over-arching statements together with illustrative examples. The draft chapters were reviewed offline by the relevant Subgroups, amended, and compiled into a single document that was shared with the full Working Group prior to a plenary meeting on March 5, 2021. That meeting provided an opportunity for all members to comment on the output of other Subgroups and to identify a number of cross-cutting themes that are summarized in the concluding chapter of this report. A complete draft was shared with the Working Group for any final comments.

Disclaimer: This report is a collaborative product of the Working Group prepared with the assistance of the secretariat. It is *not* intended to be a formal consensus document although it has benefitted from, and reflects, the input and critique of all Working Group members. Nevertheless, not every member of the Working Group would necessarily agree with every statement or with the choice of emphasis. A spectrum of views regarding the future is both inevitable and proper.

[2] Members of the *ad hoc* secretariat are listed in Annex II.

[3] While there was little discussion of the statement ranking during the Subgroup meetings, it was a useful means of focusing the Subgroup's attention in preparation for the collective discussion.

Note on Interpretation

Each of the following six chapters begins with a presentation of the broad context. The view of the “horizon” in 2030-35 is then described under two or three over-arching “Statements” created to organize and summarize the input of the Subgroup and full Working Group. For example, the first Statement under Climate Change is:

- Canada makes progress towards carbon-neutral energy production, but important technological, economic, and political challenges remain.

The Statements should be read as reflecting the imagined situation in 2030-35, i.e., from a future perspective. Each of the over-arching Statements is illustrated with two or three specific examples drawn from the ideas that were originally submitted by Working Group members. For example, the foregoing Statement in the Climate Change chapter is illustrated with two examples:

a) Clean, renewable energy and broad application of carbon capture, utilization, and storage are cornerstones of Canada’s climate strategy.

b) Improved efficiency in energy storage facilitates greater adoption of wind and solar.

All told, the report contains 17 over-arching Statements and 41 illustrative examples elaborated with supporting text and evidence.[4] The following considerations need to be born in mind when interpreting the Statements and examples.

- The Statements should not be read as hard and fast predictions. They are informed views of the principal contours of what might be called the “space of challenge and opportunity” facing Canada in approximately 10 to 15 years. The emphasis is on the S&T aspects but complemented with the relevant social and economic context. The objective was not to write the last word but rather to stimulate thinking about a future that is necessarily uncertain.
- The Statements are to some extent aspirational although the Working Group believes they are achievable by 2030-35 with sufficient commitment from the public and private sectors and from individuals. While new public policies may be required to achieve aspects of the envisioned future, this document should *not* be read as specific policy advocacy.
- Given the great breadth of each of the six subject areas, it was not possible for the Working Group to cover all relevant aspects. The over-arching Statements attempt to capture what were thought likely to be the most salient features. But gaps will inevitably remain.
- The examples are intended to *illustrate* the over-arching Statements through specific S&T or social and economic developments. Obviously these are not the only possible illustrations. They are drawn from the ideas submitted originally by Working Group members and have been constrained by that process.
- Neither the Statements nor the illustrative examples are listed in any intended order of priority.

Following the next six chapters, the report concludes with observations on themes that were common across several of the subject areas.

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[4] Most references are provided via links to websites and embedded directly in the text.

1. CLIMATE CHANGE

The Context

The UN forecasts that, without action to dramatically cut greenhouse gas (GHG) emissions, the world is on course to warm 3.5°C above pre-industrial levels by 2100, well beyond the Paris Agreement target of between 1.5 and 2.0°C. Without action, average Canadian temperatures are projected to increase by between 1.8 and 6.3°C by the end of the century, with much higher levels in the far north. The global effects of climate change are already being felt in the oceans and on every continent—extreme weather events, sea level rise, permafrost thawing, inland flooding, desertification, wildfires, infestations of invasive species, and a host of other more subtle factors, many of which we have likely not yet identified.

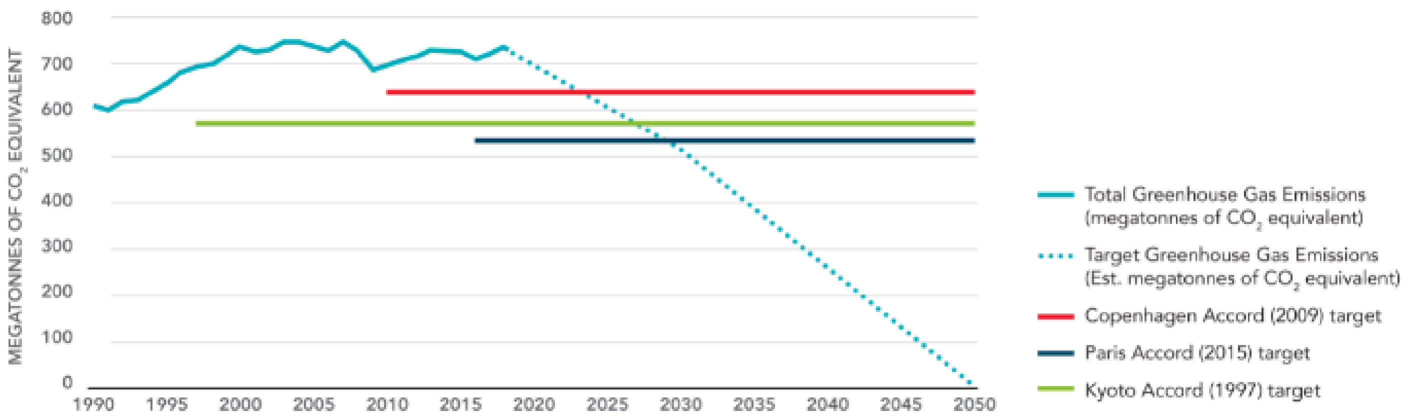
The largest impacts are impossible to accurately quantify—for example, mass migration of displaced people as a result of extensive reduction of habitable land, particularly in Africa and Asia and low-lying coastal areas everywhere. While sea level rose by about 19 cm in the 20th century, it is expected to rise by at least twice that much in the 21st. A billion people around the world now live no more than 10 metres above sea level and are thus greatly at risk from inundating storm surges as the sea level rises and storms intensify. Some forecasts predict more than a billion "climate refugees" by 2050. Such migration would test the limits of national and global governance as well as international cooperation.

Over the next 15 years, significant investment worldwide will be required to adapt to damage resulting from climate change. Even though a certain amount of temperature increase is now inevitable due to the global failure so far to mitigate GHG emissions, we must act immediately to keep the situation from getting even worse. That's why the global campaign to reduce, and then eliminate, *net* GHG emissions is essential.

Canada will have to do its part. This country produces only about 1.6% of global GHGs but, along with Australia and the U.S., is among the top three per *capita* emitters among OECD countries. Canada's emissions in 2018 were 729 megatons (Mt), essentially the same as in 2005 and more than three times the global per capita average. More positively, Canada's per capita emissions have declined by more than 13% since 2005 and, per dollar of (real) GDP, emissions have fallen by more than 21%. Although the GHG intensity of the economy has continued to improve, absolute emissions—which are what really determine global warming—have remained stubbornly high and failed to come close to the reduction targets set over the past 24 years since the Kyoto Accord (Figure 1.1).

To address this problem, Canada—and the world—must radically transform the energy system. However, the world is still dependent on fossil fuels for more than 80% of primary energy. Canada, with its vast resources of oil and gas, will almost inevitably continue to use and export fossil fuels over at least the next 15 years (Table 1.1). Different technological approaches to achieving deep emissions reduction are being taken around the world. What is common is that countries are attempting to take carbon out of the energy mix—through use of non-carbon sources like wind and solar or by capturing carbon before it enters the atmosphere—while greatly increasing the role of electricity in domestic energy supply systems. This requires vast new investments of money and effort to meet the technological, financial, regulatory, political, and behavioural challenges that arise during such a massive transition.

Figure 1.1. Canada's Total Greenhouse Gas Emissions, 1990-2050 (as projected)



Source: Canada's Official Greenhouse Gas Inventory. 2018 is the latest year for which data is available.

Government policies, financial incentives, and targeted procurement can influence the behaviour and economics associated with carbon emissions. The Canadian government is committed to more than a 30% reduction in GHGs by 2030 on the path to net-zero in 2050. To that end, in December 2020 the government released a Climate Plan built around a carbon tax increase from $50/tonne of CO_2 in 2022 to $170/tonne by 2030, along with regulations for the Clean Fuel Standard and $15 billion in incentives for energy efficiency and new technologies. This was followed by a Hydrogen Strategy, featuring a $1.5 billion investment in a Low-carbon and Zero-emissions Fuels Fund, and a Small Modular Reactor Action Plan (the latter without a specified investment commitment).

Table 1.1. Canada's Production of Primary Energy

ENERGY SOURCE	TOTAL ENERGY AMOUNT, 2012 (%)	TOTAL ENERGY AMOUNT, 2018 (%)
Crude oil	42.9	48.7
Natural gas	34.9	33.3
Primary electricity	9.9	8.5
Coal	8.6	5.4
Gas plant natural gas liquids	3.6	4.0
Total energy (petajoules)*	17,335	21,603

* 1 petajoule equals roughly the amount of energy required to operate the Montréal subway system for one year.

Sources: The Daily - Energy Supply and Demand, 2018; The Daily - Energy Supply and Demand, 2012. 2018 is the most recent year for which data is available.

For the objectives of the new Climate Plan to be achieved, significant investments will need to be put in place in a short period of time relative to the scale of the transformation required. Canada has done a good job on non-emitting electricity thanks to hydro power and nuclear capacity combined with a program to phase out coal. However, Table 1.1 shows that Canada's primary energy supply is still very heavily weighted to oil and gas: 82% of the total in 2018, an increase from 78% in 2012. Some can be replaced by further hydro development, nuclear, and bioenergy, but massive non-carbon electrification will require a variety of technologies including increased use of wind and solar, natural gas with carbon capture and storage (CCS),[5] geothermal, and possibly others.

Because of the intermittent supply of wind and solar, there is a need both for enormous energy storage capacity and for flexible means of electrical generation to smooth and complement variable supplies. Given Canada's rich resources of natural gas and the need to minimize GHGs emitted during extraction of oil for as long as it continues to be produced, the deployment of carbon capture, utilization, and storage (CCUS) technologies will be essential.

Looking forward, advances in information technology will have an impact on smart grid development. And, more speculatively, quantum computing may eventually enable innovative ways to reduce GHG emissions through design of new catalysts useful in carbon capture, energy production and storage, fertilizers, and cement and other materials whose production currently emits significant GHGs.

[5] The use of CCS with natural gas-fired generation of electricity is discussed in the Resource Futures chapter. The economics of CCS can be improved by utilization of the captured carbon, for example in certain materials like concrete and carbon fibre as well as its traditional use in enhanced oil recovery. The abbreviation "CCUS" is often used to emphasize these possibilities.

Perspectives on the Future

Drawing on the foregoing context, the ideas developed and discussed by the Subgroup can be encapsulated in the following three Statements that identify key features of Canada's response to climate change from the perspective of 2030-35:

1.1 Canada makes progress towards carbon-neutral energy production, but important technological, economic, and political challenges remain.

1.2 Canada embraces electrification of road transportation on the path to eliminating approximately 150 Mt of GHG emissions before 2050.

1.3 Decisions in Canada on climate change mitigation and adaptation earn social trust through alignment and co-development with affected communities.

Several of the specific ideas originally submitted by Subgroup members are featured under each of the foregoing Statements to provide concrete *illustrations* of the broader theme. These Statements and illustrative examples are not intended to be hard and fast predictions or to present a comprehensive picture of Canada's climate change future. Rather, they comprise a number of informed perspectives on potential developments that Subgroup members believe will be important for Canada. Moreover, the Statements are to some extent aspirational, although the Subgroup believes they are achievable with sufficient commitment from the public and private sectors and from individuals.

1.1 Canada makes progress towards carbon-neutral energy production, but important technological, economic, and political challenges remain.

Over the next 10-15 years, Canada will need to make significant progress towards substantially reducing energy sources that generate carbon dioxide, either by substituting carbon-free forms or by capturing CO_2 from, or before it enters, the atmosphere. The scale of the challenge is illustrated by the fact that the production of oil and gas and the dominant use of petroleum products in transportation generated more than half of Canada's GHG emissions in 2018 (Table 1.2), and thus were the focus of the Subgroup's submissions. But other significant GHG-emitting sectors, such as buildings, heavy industry, and agriculture—which together comprise a third of Canada's emissions—all require situation-specific technologies and approaches if Canada's net-zero objective is to be achieved. The economic transformation required will generate tremendous opportunities over the next decades for new green industries and innovative clean tech companies.

Table 1.2. Canada's GHG Emissions by Sector

SECTOR	MEGATONNES OF CARBON DIOXIDE EQUIVALENT (2005)	MEGATONNES OF CARBON DIOXIDE EQUIVALENT (2018)	% CHANGE 2005-18
Oil and gas	157.6	193.2	+ 23%
Transportation	160.7	185.9	+ 16%
Buildings	86.2	92.5	+ 7%
Electricity	119.3	64.3	- 46%
Heavy industry	87.4	78.3	- 10%
Agriculture	72.1	73.1	+ 1%
Waste & others	46.3	42.2	- 9%
Total	729.6	729.5	

Source: Canada's Official Greenhouse Gas Inventory. 2018 is the most recent year for which data is available.

Meeting the country's ambitious reduction targets in a relatively short time means that R&D alone cannot be relied on to do the heavy lifting.[6] Instead, the challenge is to improve and further deploy those technologies that are already relatively mature—the "safe bets" that we know will be employed on the path to net-zero. A very significant increase of solar and wind can be expected in Canada's energy mix by 2035. But this will need to be complemented with other clean sources, both to meet rapidly growing electricity demand and to smooth the intermittency of wind and solar. Several technologies will play a role depending on how they develop economically and in specific circumstances, e.g., new sources of hydro, nuclear (particularly the new design of small modular reactors or SMRs), and hydrogen.

How to interpret the illustrative examples: The specific developments that appear throughout this document to illustrate the broader Statements are based on examples provided by members of the various Subgroups. It is important to bear in mind that the technologies and approaches described in these illustrations will usually also be applicable in other situations that may not be described in depth or explicitly mentioned.

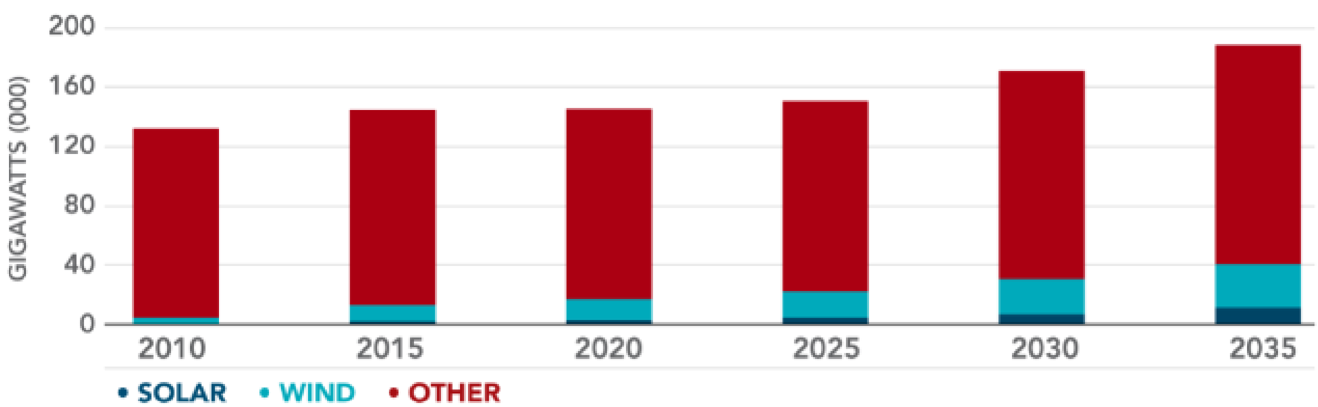
[6] Continued and intensified R&D is of course essential to develop the technologies and other means to achieve net-zero. This must be a global collective priority in which Canada can play a meaningful part.

Illustrative examples

1.1(a). Clean, renewable energy and broad application of carbon capture, utilization, and storage are cornerstones of Canada's climate strategy.

Looking forward to 2035, wind and solar are expected to be the primary component of electrical energy supply *growth* in Canada while advances in storage during times of surplus generation would contribute to enhanced reliability (see 1.1(b) below). Baseload capacity would still need to be provided by some combination of hydro, natural gas, and nuclear. According to the "Evolving Scenario" in Canada's Energy Futures 2020, Canada's overall electricity generating capacity is estimated to grow by 28% between 2018 and 2035, with wind and solar accounting for 62% of that increase (Figure 1.2). However, despite this rapid growth, by 2035 wind and solar would only constitute 22% of *total* capacity (according to the scenario) because these clean renewables are starting from today's very low base. The remaining 78% of generating capacity in 2035 would be contributed by hydro (48% of the total), nuclear (6%), biofuels (2%), and fossil fuels (22%). In this scenario, coal and oil generation would decrease sharply over the next 15 years while natural gas would increase as a proportion of generating capacity from 15% in 2018 to more than 21% by 2035. This scenario is not a forecast, but it is an informed view from Canada's Energy Regulator and highlights the importance of encouraging even greater development of wind and solar while implementing CCUS technologies to sharply mitigate emissions from natural gas generation of electricity (see chapter on Resource Futures).

Figure 1.2 Canada's Electricity Generating Capacity, 2010-35



Source: Canada Energy Regulator.

Despite progress in decarbonizing the electricity grid in Canada, some sectors, including transportation and oil and gas production (particularly from the oil sands), have proven difficult to decarbonize. Because reliance on fossil fuels can only be reduced relatively gradually, capture of carbon emissions from these sources will be needed to meet Canada's 2030 and 2050 climate targets. And the economic necessity of doing so will increase as the imposed "cost of carbon" continues to rise to $170/tonne by 2030. CCUS is the only group of technologies that helps both to lower emissions in these sectors directly and to remove CO_2 from the air to balance those emissions that are extremely difficult to avoid.

1.1(b). Improved efficiency in energy storage facilitates greater adoption of wind and solar.

The cost of electricity generation from wind, and particularly solar, has declined steadily to the point where these clean renewable sources are often the least cost for *new* generation capacity. However, increasing their share of Canada's energy mix requires better management of intermittent supply along with further improvements in the performance of large-scale power storage technologies.

Battery storage is the most common large-scale option today, mostly due to the ubiquity of lithium-ion (Li-ion) batteries and their increasing energy density (i.e., the amount of energy that can be stored per unit of weight). Over the past 10 years, Li-ion energy densities have almost tripled, paving the way for longer-range electric vehicles coming to market. Quebec is already a leader in energy storage, with Hydro-Québec poised to launch EVLO, a new business unit that will design, sell, and operate battery-based energy storage equipment, with a focus on Li-ion technology. Due to the technology's mature state, abundant supplies of lithium, and current deployment at scale both in Canada and globally, continued improvement and expanded use of these batteries would be Canada's best bet for very large-scale storage over the next 10-15 years.

Despite the dominance of Li-ion batteries, other technologies will be superior in some specific situations. Storage options include mechanical systems such as compressed air and flywheel energy storage systems; pumped storage systems; and passive energy storage where energy is stored in the same form (e.g., passive heating, cooling) as it will be used. Hydrogen may eventually be an economic storage medium in many circumstances—whether generated on site via electrolysis from carbon-free electricity (hydropower, wind, solar or nuclear), or via natural gas (with CCS) and stored for peaking needs or to fill gaps when renewables are down.[7] Hydrogen has the further important advantage that it can be transported, most readily in liquid form to minimize volume. As with many energy system challenges, successfully integrating a number of solutions may generate the biggest payoffs.

1.2. Canada embraces electrification of road transportation on the path to eliminating approximately 150 Mt of GHG emissions before 2050.

The road transportation sector is a key target in Canada's new Climate Plan. It accounted in 2018 for 154 Mt of GHG emissions or 21% of Canada's total, up from 18% in 2005. The growth in emissions from half-ton trucks and SUVs over the last 15 years has nullified the progress made in reducing the emissions of cars.

The electrification of road transport—other than heavy freight hauling—is now an established global trend. In 2019, 2.6% of new vehicle sales globally were electric, a 40% year-on-year increase. Norway's fleet of plug-in electric vehicles (EVs) is the highest per capita; more than 40% of all cars sold in 2019 were electric. Canada is not yet among the leaders. In 2019, only 133,840 EVs were sold, constituting 2.7% of new vehicle sales, about

[7] Hydrogen generated via electrolysis with electricity from non-emitting sources is called "green hydrogen" whereas hydrogen generated from natural gas with CCS is termed "blue hydrogen."

equal to the global average. Canada's target is for EVs to reach 30% of new passenger vehicle sales by 2030 and 100% by 2040. Quebec has set a more ambitious target of 100% by 2035, similar to California.

Meeting these targets is of course much easier said than done. Fortunately most of the world's major vehicle manufacturers have committed to substantial, or total, electrification of new models in the 2030-40 timeframe, albeit with slightly hedged bets. Their marketing strategies should be effective in bringing the public along, although this will require complementary public policies to encourage gas to electric switching; clean electricity generation; ubiquitous charging infrastructure; and power grid upgrades. Co-ordination may be the much bigger challenge than technology, *per se*.

Illustrative examples

1.2(a). Parked electric vehicles store energy in their batteries and deliver it back to the "smart grid" as needed while the owner is paid by the utility.

Electric utilities are moving to massive Li-ion battery installations for energy storage to deliver energy from intermittent sources, such as wind and solar, as needed. A huge number of Li-ion batteries in EVs, which are parked, on average, for more than 80% of the day, should also be used for energy storage. The "smart grid" and vehicle-to-grid (V2G) communication, which are at various stages of development and implementation around the world, could enable seamless use of vehicles for storing energy. Vehicle owners would provide a "schedule" of when their vehicles are tethered to the grid and the minimum amount of energy to be left in the battery to support the next drive. All this could be accomplished using software. In addition, modern Li-ion cells could support 10,000 charge-discharge cycles, which is much more than any vehicle would need for driving alone.

Lion Electric in Quebec is planning to install V2G technology in all its electric school buses. Its projects in California and New York have already demonstrated the feasibility of V2G for school districts and utilities. However, scaling up these efforts within the next 15 years depends on achieving a critical mass of EVs on the road; customer buy-in; and investment by utilities that may nevertheless be reluctant in the face of cost challenges. Several factors suggest that EV sales in Canada will grow very rapidly: as noted above, all of the major car makers have made EV production the core of their future; cost and performance (particularly range) will continue to improve; and the rising carbon price will be a further incentive, as will federal and provincial regulations and subsidies.

1.2(b). Battery and hydrogen fuel-cell technologies enable electrification of the various modes of road transportation.

The appropriate technology for vehicle electrification depends on the purpose. While Li-ion batteries are well-suited for cars and light trucks, their weight makes them less suitable to provide the power required for heavy freight haulage. Hydrogen fuel cells could be a zero-emissions alternative. Urban buses are an intermediate case where both battery and fuel-cell electrification are viable.

***Note on other applications*:** Although this example specifically addresses electric buses, the technologies are also relevant to the electrification of other modes of transportation, particularly cars and certain types of trucks where the potential for emissions reduction is larger.

Globally, battery electric buses and hydrogen fuel-cell electric buses are gaining momentum due to their ability to reduce GHG emissions and improve air quality. More than 425,000 electric buses are on the road worldwide, with the majority in China. By 2040 two-thirds of all buses are expected to be powered by batteries although fuel cells could also become a significant part of the mix.

Canada could benefit more from transit electrification than many other countries given its relatively low-carbon provincial electricity grids: about 80% of electricity generation in Canada is non-emitting. Nevertheless, despite Canada's manufacturing capacity in electric buses—represented by GreenPower Motor Company, The Lion Electric Company, New Flyer Industries, and Nova Bus—and Ballard's world-class capability in vehicle fuel-cell engineering, very few Canadian-made electric buses are on the roads today. Toronto, with 60 electric buses, has North America's largest fleet and plans to be fully electrified by 2040. Many other Canadian municipalities have announced short- to mid-term electrification plans, and several transit agencies are adopting electric buses. A recent EKOS poll indicated that 80% of Canadians support a $1.5 billion federal investment to help municipalities put 5,000 electric school and transit buses on Canadian roads by 2025.

Electric buses provide an opportunity for fulfilling a jobs-rich manufacturing mandate while addressing climate change. The biggest challenge is cost: a battery-powered bus currently costs roughly double a diesel bus. Bloomberg, however, expects that e-buses will achieve approximate price parity by 2030, mainly due to the decreasing cost of batteries. Once purchased, electric buses are cheaper to run and require fewer repairs, but governments and transit agencies first need to invest in charging stations. Fortunately, the limited range of a battery vehicle is not a significant concern for urban electric buses since routes are relatively short and re-charging can be centralized in a small number of locations. The recent $1.5 billion investment in electric buses announced in the Canada Infrastructure Bank Growth Plan also includes charging infrastructure. And the Canadian Urban Transit Research and Innovation Consortium (CUTRIC)[8] is investing almost $1 million in the development of a cheaper electric bus charging system. CUTRIC is also developing North America's first centralized and cyber-secured data trust, which enables real-time sharing of data on e-bus performance, charging patterns, energy and electricity loads, and energy intensity.

1.3. Decisions in Canada on climate change mitigation and adaptation earn social trust through alignment and co-development with affected communities.

Policy tools such as carbon pricing, regulation, and financial incentives are necessary to make Canadian behaviour more climate friendly, but they are not sufficient. Traditionally marginalized communities and groups such as remote and Indigenous communities, and those whose livelihoods are "carbon-intensive", will be understandably skeptical that their welfare will be a front and centre consideration when policy decisions are being made. Governments must therefore build *trust* to earn the necessary public support for the far-reaching changes that are needed. There is no guarantee that this will be forthcoming.

Illustrative examples

1.3(a). Robust Indigenous authority over infrastructure project decisions, together with (non-Indigenous) local community engagement expectations, transform business models, government decision making, and the timing and nature of responses to climate change.

Indigenous governments and communities in Canada are pivotal decision-makers for infrastructure projects shaping both climate mitigation (e.g., electricity generation and transmission, hydrocarbon production and transport) and adaptation (e.g., building resilient infrastructure). Some say that the future of the oil and gas industry depends on its relations with Indigenous peoples and governments. Moody's recently identified the failure to achieve social licence from Indigenous communities for natural resource projects as a factor that may downgrade the credit ratings of the implicated corporations.

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[8] Disclosure: The President and CEO of CUTRIC, Josipa Petrunic, is a member of this Subgroup.

Indigenous ownership, equity partnerships, and Indigenous-led impact assessments are becoming the norm for projects on Indigenous territory. Many communities are clarifying the respective governance roles and responsibilities of hereditary and elected chiefs, thus potentially facilitating community involvement in projects. Federal/provincial policy authorities, regulators, and investors are starting to work in lockstep with Indigenous authorities in decision making.

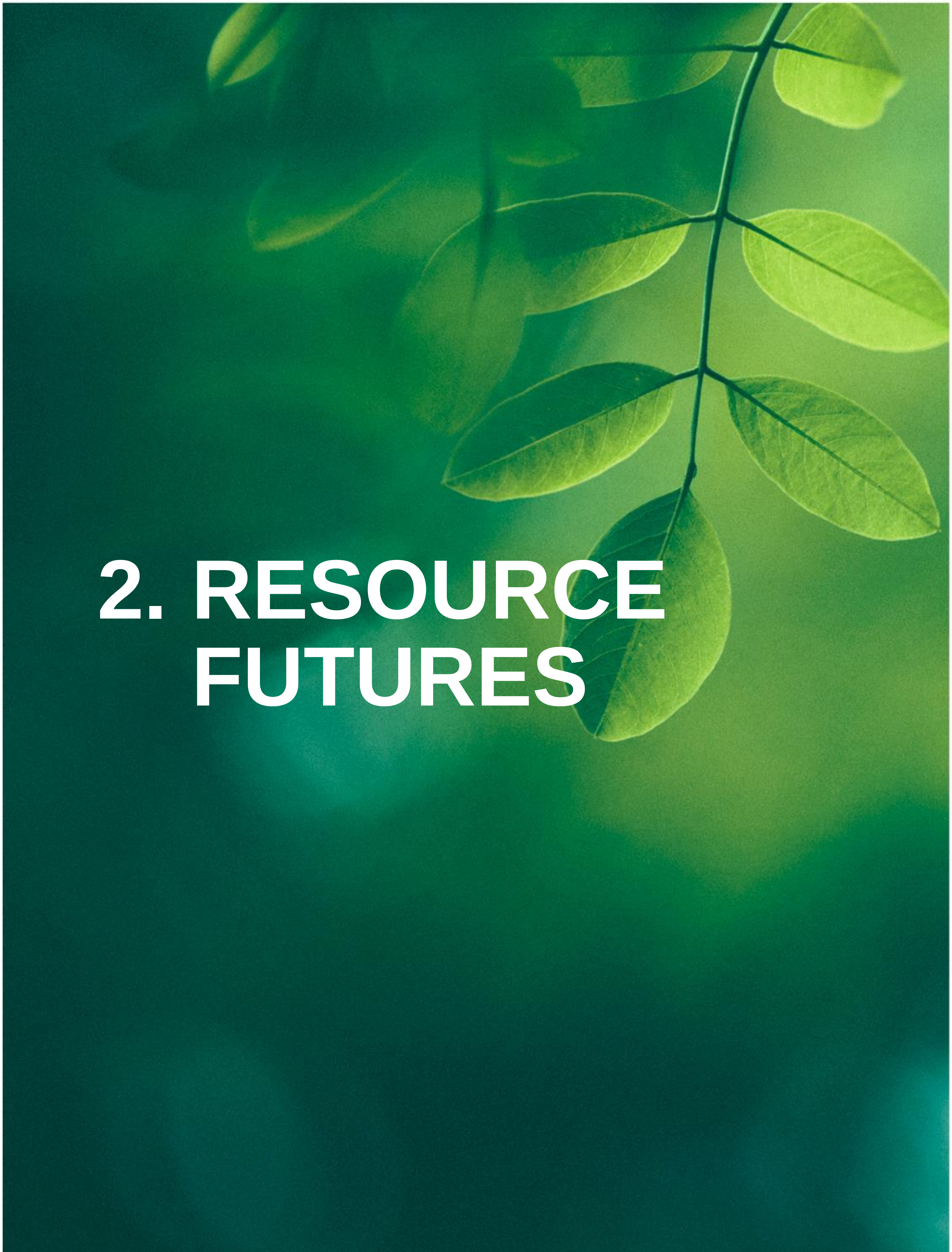
In fact, local communities everywhere today expect and demand meaningful engagement in infrastructure project decisions that affect them. The world of elite centralized decision making is becoming a thing of the past. Indigenous and non-Indigenous community concerns for factors other than climate mitigation—such as local economic benefits, environmental impacts, climate adaptation, fairness, and transparency in decision-making—are often the key determinants of community support or opposition to individual projects and technologies. Successful climate mitigation and adaptation initiatives are those co-developed with communities to align with local interests, expectations, values, and world views.

In the specific case of Indigenous communities, developing robust processes for consensus building, both within those communities and between communities and governments, is essential. Strong political leadership must bring divergent interests together, resolving differences and building trust over the next 15 years. The challenge should not be underestimated. It will play out in the context of the implementation in Canada of the UN Declaration on the Rights of Indigenous Peoples and evolving judicial and political interpretations of "free, prior and informed consent" of Indigenous rights holders. While the Supreme Court has not interpreted the Crown's duty to consult and accommodate as conferring a veto over energy or other major projects, it can be expected that Indigenous views and institutions will have greater legal and political weight in the future.

1.3(b). Unstable citizen trust in institutions and intense political polarization challenge effective climate policy development and implementation.

Annual Edelman Trust Barometer results in 2017 suggest that "trust is in crisis around the world". In 2020 the trust gap between the "informed" and "mass" publics has grown to an all-time high, with distrust "driven by a growing sense of inequity and unfairness in the system". At the same time, group identity and extreme partisanship are driving political polarization. In this context, when people form their opinions on climate risk and risk mitigation (including technology options), they are apt to reason in a motivated fashion, selecting evidence that aligns with their world views, identities, and group affiliations. Evidence-based policy making suffers. These political and social dynamics challenge consensus building and the coherence and stability of climate change policy. In Canada, these factors are exacerbated by the significant regional differences in the impact of GHG reductions.

Leadership from government, industry, community leaders, NGOs, and academics is necessary, but likely not sufficient. Providing more information about the need for climate action is also necessary, but not sufficient. There is a need to transform communication and engagement strategies to focus on building the trust and consensus needed to effectively address climate change in the long term. Inclusive, collaborative approaches that respond to peoples' needs and values will be required to achieve the durable behavioural changes necessary to avert the effects of climate change. The research field of climate change communication (e.g., Yale Program on Climate Change Communication, Alberta Narratives Project) is still in its infancy but offers relevant advice. There is also a role for K-12 education to improve the scientific literacy of Canadian children and teach them how to analyze and judge information delivered by news and social media sources. Although the effects of basic education are felt only in the longer term, climate change is a long-term challenge that nevertheless must be confronted from this day forward.



2. RESOURCE FUTURES

The Context

Vast geography has endowed Canada with an abundant supply of fresh water, arable land, forests, marine life, and energy and mineral resources. These continue to shape the country's economic, social, and political development. In 2019, the natural resource industries (minerals and metals, energy, and forest products) contributed, directly and indirectly, almost 17% of GDP, 10% of employment, and 45% of goods exports. In addition, the agri-food industry generates more than 3% of GDP, employs more than 550,000 people, and contributes about 10% of goods exports.

While Canada's economy relies on a great deal more than raw natural resources, and is among the world's most sophisticated, resources can continue to be as much a part of the country's future as of its past. This potential derives not only from natural endowment but also from a deep base of skills and growing global demand as affluence spreads across the world. But success is not guaranteed. The traditional wealth generation model of Canada's resource-based industries is challenged by a warming world that must eliminate GHG emissions and by a more environmentally sensitive world that demands responsible resource extraction. Canada can only meet these challenges through innovation in products and processes and through respect for the rights of Indigenous peoples as partners in responsible resource development.

The most significant structural factors that will affect Canada's resource industries over the next 15 years are global demand, climate change (the focus of the previous chapter), the impact of digitalization, and economic competitiveness.

Global demand—Growing affluence in emerging economies ensures that demand for Canada's agri-food products, metals and minerals, and forest products will continue to increase. At the same time, the prospect of long-term falling demand for oil and gas, due to measures to eliminate GHG emissions and to electrify transport, leaves significant parts of the Canadian economy vulnerable. The forestry sector, which historically has relied on pulp and paper and lumber production, has already been hard hit by the transformation towards a paperless society and must now focus on new ways to add greater value to this unmatched renewable resource while also protecting biodiversity.

Climate change—Canada's resource extraction industries, particularly fossil energy, contribute to GHG emissions and will be significantly affected by measures to mitigate climate change. The International Energy Agency (IEA) forecasts that meeting the Paris target will require a reduction by 2040 in world oil demand of about one-third; a reduction in natural gas demand of approximately 12%; and a reduction in coal demand of two-thirds. The impacts are not limited to oil and gas production. Biological resources such as forests, crops, and wildlife are highly sensitive to climate, which threatens people's livelihoods in resource-dependent communities. For example, climate change is affecting tree growth and vulnerability to new insects.
While climate change is exposing agriculture to greater extremes, longer frost-free growing seasons are creating potential benefits. Mining operations can also be disrupted by climate change. New opportunities, however, are arising from growing demand from low-carbon technologies that will require massive supplies of specific minerals for solar cells, batteries, and windmills. In sum—(i) all of Canada's resource sectors will face significant adaptation requirements that can be mitigated, however, by management measures to increase resilience; (ii) the shift towards a "circular economy" will require resource industries to design out the concept of waste by rethinking the potential value of materials *before* they become waste; and (iii) the forest and agriculture sectors can play a large role in reducing atmospheric CO_2 by sequestering carbon and adopting innovative practices that minimize emissions.

Digitalization[9]— Larger Canadian resource companies are generally at or near the leading edge in applying digital technology although much of the forestry and agricultural sectors is behind the adoption curve. A rapid increase in uptake by small and medium-sized enterprises is urgently needed. In many cases, this depends on the availability of high-speed internet throughout rural Canada. The federal government has set a target to make speeds of 50/100 Mbps available to all Canadian households by 2030. Currently, the target speed is available to virtually all urban households, but to only slightly more than 40% in rural areas and 30% on First Nations reserves; so there is urgent work to do. Remote operations and inspection (via the Internet of Things) could expand once data connectivity issues are resolved and technologies improve operations in environments that lack GPS service. As low-orbit satellite systems become available and provide ubiquitous high-bandwidth connection, robots "in the wild" may be possible. Robotics will also help alleviate the chronic labour shortage in many resource industries that otherwise have had to rely on temporary foreign workers. As resource industries become progressively more digital, issues of cybersecurity and data governance will need to be addressed in many novel contexts.[10]

Competitiveness—The foregoing structural factors will combine to challenge the competitiveness of Canada's resource industries on whose export earnings Canada depends heavily. Most sectors have relied for generations on the sheer scale of the nation's endowment and on a business strategy that involved relatively little upgrading ("rip and ship"). In many sectors—certainly oil and gas and forestry—that model is already losing viability and in virtually every case there are unexploited opportunities to add greater value to Canada's natural resources and expand markets more aggressively, while adopting practices that are more sustainable. Needed is a much greater commitment to innovation and technology investment.

To compete and thrive in the context of changing global demand, climate change, and rapid digitalization, the development of Canada's resource sectors will need to embody the following four characteristics, which also emerged as over-arching considerations in the discussions of other Subgroups.

- *Resilience*: Building resilience is needed to cope with the varieties of stress due to climate change. Local resilience is essential in remote communities whose economies depend on resources and are also challenged by the consequences of accelerating climate change, which include exacerbated food insecurity. Since increased resilience will often require some sacrifice of short-run economic efficiency and profitability, ways need to be found to increase the incentives that encourage resilient practices and investment.
- *Trust*: The inherent volatility of resource industries, now exacerbated by climate change, has heightened anxiety in communities that depend on resources, potentially leading to fragile trust. Trust is also an issue in Indigenous communities where land rights remain unresolved or where there is a legacy of unfulfilled promises. Trust and credibility gaps must be bridged if Canada's resource economy is to achieve its potential.
- *Governance*: Robust, innovative governance and legal structures can help build resilience and trust. Outdated frameworks risk perpetuating what now may be perceived as an inequitable sharing of the benefits and costs of resource development. Modern governance structures need to accommodate increased engagement of citizens as well as the established decision-making rights of Indigenous communities.
- *Innovation*: Canada's resource industries—facing the challenges of climate change but also the opportunities of digitalization and growing global demand—must become more innovative in product and practice. Innovation is a creative process, and it typically disrupts entrenched habits and vested

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[9] Refer also to the chapter on Big Data and AI.

[10] Many of the generic issues are addressed in the chapter on Cybersecurity and Privacy.

interests. It therefore often emerges in *contested spaces* where contending objectives at first appear incompatible, e.g., between resource companies and affected Indigenous communities. The tension motivates the very creativity from which, ideally, all parties can benefit.

Perspectives on the Future

Drawing on the foregoing context, the ideas developed and discussed by the Subgroup can be encapsulated in the following three Statements that identify key features of Canada's resource future from the perspective of 2030-35:

2.1 Advances in technologies to decarbonize production and use of oil and gas enable Canada to achieve substantial emissions reductions while continuing to produce these resources for domestic and export markets.

2.2 Canada employs innovative technology to augment its natural advantages in agri-food production.

2.3 Canada's forest and mineral resources meet growing global demand through innovative ways to extract greater value with reduced environmental impact.

Several of the specific ideas originally submitted by Subgroup members are featured under each Statement to provide concrete *illustrations*. These Statements and illustrative examples are not intended to be hard and fast predictions or to present a comprehensive picture of Canada's resource future. Rather, they comprise a number of informed perspectives on potential developments that Subgroup members believe will be important for Canada. Moreover, the Statements are to some extent aspirational, although the Subgroup believes they are achievable with sufficient commitment from the public and private sectors and from individuals.

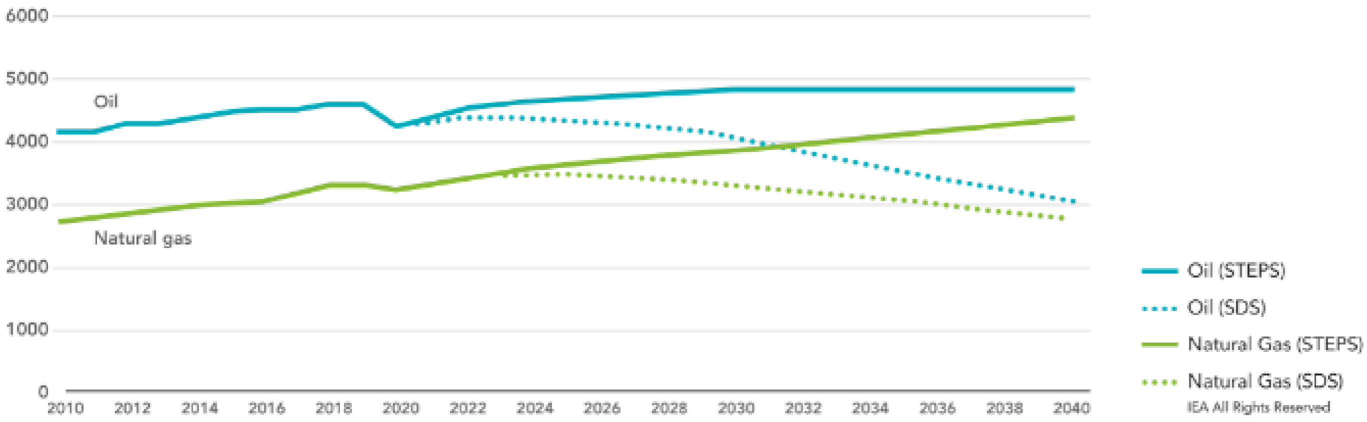
2.1 Advances in technologies to decarbonize production and use of oil and gas enable Canada to achieve substantial emissions reductions while continuing to produce these resources for domestic and export markets.

The energy sector as a whole accounted in 2019 for more than 10% of Canada's GDP and 23% of goods exports, with exports of oil and gas alone totalling more than $122 billion. Governments and the oil & gas sector have until recently assumed that the prosperity generated by hydrocarbons would continue. Forecasts of declining demand were often questioned. While there is still considerable uncertainty about the time path of future demand for oil and gas, the "Evolving Scenario" in Canada's Energy Futures 2020 shows domestic consumption of fossil fuels to be 12% lower in 2030 than the 2019 peak, and 35% lower by 2050. Meanwhile, the 2020 IEA Outlook foresees, in its "Sustainable Development Scenario", a decline in global demand between 2019 and 2040 of about 35% for oil and 15% for natural gas (Figure 2.1). (The IEA's "Stated Policies Scenario"—essentially the status quo—sees global oil demand increasing slightly, then flattening by the mid-2020s, whereas demand for natural gas would increase by about 30% between 2019 and 2040.)

As a relatively high-cost oil producer, Canada is at risk of losing market share in the face of falling global demand and average price reductions in a future where GHG emissions eventually decline towards zero. The outlook for Canadian natural gas is more optimistic in view of its lower emissions and continuing use in (dispatchable) electricity generation to complement the intermittency of wind and solar, as well as growing export opportunities for liquefied natural gas.

Nevertheless, in light of Canada's commitment to net-zero emissions by 2050, policies need to shift from facilitating the *growth* of oil production to transitioning to a non-carbon-intensive energy system. The ongoing importance of the energy sector in Canada creates a large incentive for innovation to reduce emissions associated with hydrocarbon extraction; to enable very low-emission combustion (e.g., carbon capture, utilization, and storage: CCUS); and to develop clean renewables (wind, solar, bioenergy, geothermal) adapted to Canadian conditions.

Figure 2.1 Global Fuel Supply by Scenario, 2010-40[11]



Note: STEPS = Stated Policies Scenario. SDS = Sustainable Development Scenario.

All credible energy decarbonization scenarios foresee a role for carbon capture and storage (CCS) due to the significant lock-in associated with current fossil energy infrastructure and the difficulty in decarbonizing some industrial sectors, notably cement production, steel, and petrochemicals. Canada is already a global leader in CCS, particularly due to the Shell Quest facility in Alberta, plus many other "made-in-Canada" innovations.[12] For example, Carbon Engineering's breakthrough technology uses a chemical scrubbing process to remove CO_2 directly from the air while Mangrove Water Technologies' electrochemical reactor is equipped with ion-selective membranes that desalinate wastewater and convert the CO_2 emitted from oil and gas operations into carbonate salts and acids for on-site use. CarbonCure and Solidia have developed technologies that use captured carbon in concrete production where it remains trapped indefinitely.[13] Policy to support continued investment combined with public procurement would catalyze the growth and maturity of these emerging technologies and products, consolidating their role as cornerstones of Canada's low-carbon future and creating jobs and export opportunities.

Achieving Canada's ambitious emissions reduction targets, on the path to net-zero in 2050, requires significant increases in electricity generation and use. By 2050 electricity could provide more than 27% of Canada's final energy use according to a recent scenario as compared with 16% currently. This increase would include, in addition to a transition to electric vehicles, electrification of many high-temperature industrial processes that are

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[11] Based on IEA data from the IEA (2020) Energy Outlook, www.iea.org/statistics. All rights reserved; as modified by the Government of Canada.

[12] Quest, which opened in 2015, was designed to capture about 1 million tonnes of CO_2 each year from oil sands upgrading and then safely store it more than 2 km underground in a sandstone rock reservoir. To date, Quest has captured and stored 5 million tonnes of CO2.

[13] Disclosure: The President of CarbonCure, Jennifer Wagner, is a member of the Working Group.

currently reliant on fossil fuels. Dramatic reduction in GHG emissions from electricity generation is therefore needed, while maintaining the reliability of large grid electricity supply.

Illustrative examples

2.1(a). Natural gas combined cycle with carbon capture and storage helps assure Canada's electricity supply while reducing GHG emissions.

Ongoing technology advances and supportive government policies could enable natural gas "combined cycle with CCS" to realize CO_2 capture efficiencies of 90% or more and be cost competitive with other low-emission generating sources for major grid supply. This could capitalize on Canada's abundant natural gas supply and carbon storage capacity, develop a technology and skills base for export, and create value through use of captured CO2. The International CCS Knowledge Centre at University of Regina is doing leading work on this technology.

Currently, the commercial viability of CCS is mitigated by significant capital costs and the cost of the energy needed to extract carbon from combustion processes. Continued innovation will encourage broad deployment, resulting in scale economies. At present, CCS adds typically three or four cents per kilowatt-hour to the cost of electricity produced with natural gas. Creating value from the captured carbon will continue to improve the economics of the process. Captured CO_2 could be used to manufacture a diverse range of products, including concrete, fuels, chemicals, and plastics, with some produced at market-competitive rates.

Unlocking the full benefits of energy innovation in resources is challenged by the technical and organizational complexity of integrating multiple solutions, e.g., storage, generation, grid integration, and, where feasible, use of the captured carbon in other products where it can be securely sequestered for very long periods.

2.1(b). Canada is a global leader in "blue" hydrogen supply and use coupled with carbon capture and storage.

In December 2020, the federal government released a document describing a hydrogen strategy for Canada, outlining the role of this potentially important fuel choice for net-zero energy systems of the future. It is in Canada's interests to pursue both "green" hydrogen (produced from electrolysis of water using carbon-free electricity) *and* "blue" hydrogen (produced from natural gas and coupled with CCS). Canada has a competitive advantage in blue hydrogen production, which may be a game-changer for energy use, not only as an industrial feedstock but also as an end-use fuel supporting transportation, heating buildings, and generating electricity. Hydrogen production (including in the compact liquid state) could provide another market channel for Canada's abundant natural gas supply and, when applied to oil sands upgrading and refining, could materially reduce lifecycle GHG emissions intensity.

A supportive policy environment, continuing advances in technology, and collaborative partnerships to develop the necessary production and distribution infrastructure would be required for Canada to establish a leadership position in blue hydrogen. Currently, only two facilities produce blue hydrogen from natural gas with CCS: Shell's Quest plant in Alberta and Air Products' plant at the Valero Port Arthur Refinery in Texas. Equinor has recently announced its plan to build Europe's first large-scale blue hydrogen facility in northeast England by 2026. Among many uncertainties associated with blue hydrogen, cost will be a factor in the context of alternatives and objectives for emissions reduction. The volume of demand for hydrogen, despite its promise in principle, remains uncertain as does Canada's relative competitiveness as a supplier to domestic and export markets. Nevertheless, the urgency of the global challenge posed by climate change means that Canada will have to place some bets on technologies despite significant uncertainties.

2.2 Canada employs innovative technology to augment its natural advantages in agri-food production.

Agri-food production is an area of tremendous opportunity for Canada, employing more than half a million people and generating about $60 billion of export sales, making Canada the world's fifth largest food exporter. With ample land and water resources, and a global reputation for food safety, Canada has the potential to produce, process, distribute as well as export far more than our relatively small population consumes although there is also potential to more effectively supply our own market. The growth opportunity is illustrated by the fact that Canada's agri-food exports to China—a market with huge future potential—almost quadrupled between 2009 and 2018.

Complementary to increased agri-food production and export growth, Canada must ensure that the agri-food industry innovates so as to mitigate and adapt to climate change, enhance health outcomes, prevent or reduce land degradation, and improve food security and resilience. The scale of the challenge and opportunity is illustrated by the fact, for example, that approximately a quarter of GHGs come from the food and agriculture sector and, without mitigation, emissions are expected to increase by another 30% by 2050. Meanwhile, chronic diseases in Canada related to poor eating cost the public purse an estimated $26 billion per year despite the recent promotion of healthy diets. The agri-food industry—through its product development and marketing strategies—bears some share of the responsibility to promote healthier choices and to complement the poverty-reduction measures needed to overcome food insecurity.

Illustrative examples

2.2(a). "Smart" farms boost production, reduce potentially harmful agri-food inputs, enhance soil health, and bolster Canada's reputation as the world's trusted source of safe and sustainable agricultural exports.

Farm management decisions are increasingly being made by algorithms operating on huge amounts of data on soil, genomic, market, and climate/weather conditions. These tools can help boost production and reduce the environmental footprint of farming, allowing Canada to produce food more intensively but with greater ecological sensitivity. Today's "smart" farms require investments in a range of robotics and AI-related fields. Canadian farms are already using robots, e.g., hands-free tractors, drones, and a variety of specialized harvesting devices. Becoming a global leader in *precision agriculture* also requires Canada to invest in rural broadband, data management and governance, and cybersecurity. Stronger environmental policy could create financial incentives to reduce pollution and promote ecosystem services. It is expected that the government's commitment to a steadily rising carbon price will significantly sharpen the incentives to adopt technologies that result in more efficiently used agricultural inputs.

2.2(b). Autonomous and year-round indoor fruit and vegetable production improves Canada's food security by reducing its dependency on imports.

Technological advances, combined with new land-use and environmental policies, have the potential to make Canada a horticultural powerhouse in the near future. The year-round production of clean and nutritious food could be a cornerstone of our post-pandemic green recovery platform by scaling up existing indoor food production expertise to increase yield and produce more varieties of fruits and vegetables. Current initiatives include year-round tropical fruit in British Columbia, strawberries in Ontario, and greenhouses in northern communities during the long daylight in summertime.

Continued research on rapidly maturing, affordable, and appropriate technologies including, but not limited to, robotics, LED lighting, plant microbiomes, genomic-led assisted diagnostics and crossbreeding, and a cybersecurity data infrastructure could put Canada among the global leaders, joining countries like the

Netherlands and Israel at the leading edge of ag-tech, and more self-sufficient in fruits and vegetables. It would also create new export opportunities in foodstuffs and ag-tech services. Moving fruit and vegetable production indoors, and linking this with land-use planning, could enable transformation of currently farmed land into refuges for biodiversity and other ecosystem services. The cost of energy inputs is the key challenge, but indoor production sites co-located with industry would provide an opportunity to use waste heat.

2.2(c). Consumers increasingly choose safe, nutritious, and economically efficient protein sources that are good for animal welfare and have a minimal environmental footprint.

Broad advances in cellular agriculture—the production of animal proteins in laboratories—and plant-based protein sources portend a major disruption in the traditional protein sector over the next 10 years and beyond. Already, major livestock companies such as Tyson and Maple Leaf have made large investments in alternative protein supplies, including those that are plant-based. Advances in cellular agriculture have lowered the cost of lab-based animal proteins such that they are almost cost competitive with traditional livestock protein. And since “alt-protein” feedstock is yeast-based, it can use waste products from other industries, such as wood processors that are looking for new markets for their residue to offset the decline in pulp and paper. In addition to creating an entirely new sector of the economy, alt-protein must overcome resistance from the well-entrenched traditional producers and the cautions from a health point of view to avoid excessive consumption of highly and ultra-highly processed foods.

For Canada to become a global leader in this emerging field, investments in the fundamental science of cellular agriculture are required as well as policies to assist the transition of the livestock sector to a variety of new paradigms. Canada is currently lagging in this research with most investment focused on maximizing production under the prevailing model. In addition, there are legal and regulatory issues involving food labelling that effectively protects traditional sources, e.g., which products have the right to be labelled as “dairy” and how existing policies could apply to entirely new products that are substitutes for those currently supply-managed.

2.3 Canada’s forest and mineral resources meet growing global demand through innovative ways to extract greater value with reduced environmental impact.

In 2019, Canada’s mining, oil and gas, and forest industries (including pulp and paper) accounted for almost 10% of GDP, or $200 billion of real (2012 $) value added. About two-thirds consisted of oil and gas and almost 20% of other unprocessed minerals. On the positive side of the ledger, these industries continue to be of vital importance, supporting hundreds of thousands of jobs and hundreds of communities, and providing billions of export earnings. On the negative side, their environmental impact is much less tolerated today than formerly. Progress has been made, but standards keep tightening. Perhaps most significantly, the oil and gas sector generates about a quarter of Canada’s GHG emissions (including petroleum refining and fugitive emissions from production), a proportion that has been increasing with oil sands output. The mining and pulp and paper industries, on the other hand, together generate only about 1.5% of Canada’s GHG total, and this proportion has been declining.

The future for these primary resource industries is challenging. They need to stop pollution, drastically cut emissions, restore land, minimize waste, and add greater value to the raw materials. And they need to do all this while being profitable. That in a nutshell is the competitiveness challenge. Fortunately, the world needs more Canadian resources to support the rapidly growing demands of huge, more affluent populations, particularly in Asia. But the intense competition for these growing markets means that Canadian resource industries must become more innovative, particularly in the use and disposal of waste materials, and more outward looking beyond traditional U.S. markets, notably in developing capabilities along the global value chain for strategic minerals.

Illustrative examples

2.3(a). Bioproduct platforms generate consumer materials with new properties while also promoting decarbonization.

To meet Canada's target of net-zero GHG emissions by 2050, the economy requires both an industrial shift and a consumer shift away from petroleum-based products towards greater use of products based on current biological materials that are recyclable/compostable (i.e., part of the "circular economy"). Lumber production, for example, generates significant wastes that are normally redirected to wood panels or pulp and paper production. With reduced paper demand, a large supply is now available to feed a developing bioeconomy. The use of fibres from biomaterial depends on their ability to provide differentiating functions, while respecting manufacturing specifications. The technology to functionalize fibres/molecules with new properties uses the same chemistry as petroleum, but with a sustainable source of materials. Recent work demonstrates the potential of using regenerated fibres from chemically modified pulp, dissolved in an aqueous solution, to produce designer fibres from cellulose. The novel high-quality fibres could be used in applications that require high absorbency, such as diapers and other hygienic products, as well as for wound care. They could eventually be used in construction and electronic materials, and for more speculative uses such as engineered human tissue.

2.3(b). The growing global commitment to environmental protection and human safety challenges Canada to be a world leader in the safe and efficient management of mining waste.

Safety is the top issue facing the global mineral extraction industry (including mining and oil and gas production). The concern encompasses both environmental protection/restoration and the safety of workers and adjacent communities. Storage facilities are failing more frequently and with more severe outcomes, e.g., the tailings dam failure at Vale's Córrego do Feijão mine. An international group of 142 scientists, community groups, and NGOs from 24 countries recently published 16 guidelines for the safer storage of mine waste, asserting that the ultimate goal of tailings management must be *zero* harm to people and the environment. Technology is key in helping miners comply with the Global Industry Standard on Tailings Management, guidelines released in August 2020 and aimed at strengthening current practices.

As a leading mining jurisdiction, Canada should be, and in many respects is, a world leader in setting and meeting standards for reducing the environmental impact of mineral extraction, both above and below ground, while allowing greater resource recovery. For example, minimizing the environmental footprint of oil sands production and cleaning up abandoned oil and gas wells (which can emit GHGs and potentially pollute water supplies) are high-profile opportunities to demonstrate commitment and best practices and development of new technology and expertise that can generate new businesses that can export their expertise to other jurisdictions. However, if other jurisdictions do not impose standardized regulations requiring safe waste disposal, those that do are placed at a competitive disadvantage. Canada therefore has a strong incentive to promote high international standards with meaningful penalties for violation. The challenge is more than technological and economic. Trust in the mining and oil and gas industries has, in many cases, been eroded because the concerns of directly affected communities—often Indigenous and remote—were not sufficiently respected. While there are a great many examples of positive and constructive industry-community relationships, this has not always been the case, leaving a credibility gap that requires creative social and political engagement to overcome.

2.3(c). Canada is challenged to go beyond "action plans" to sustain its position as a key global supplier of many strategic minerals.

Canada is an important supplier of 13 of the 35 minerals that the U.S. has identified as critical to economic and national security: it is the largest supplier of potash, indium, aluminum, and tellurium; the second largest supplier of niobium, tungsten, and magnesium; and supplies roughly one-quarter of U.S. uranium needs. China is one of the top suppliers of 20 of these minerals and, of those, the top supplier of 10. Canada could potentially become a reliable source of other critical minerals, particularly rare earth elements, that are essential inputs to the low-carbon and digitalized world economy. But, to maximize this potential, Canada needs to develop capabilities along the value chain beyond mining where our activity is currently concentrated.

The Canada–U.S. Joint Action Plan on Critical Minerals Collaboration, finalized in January 2020 but with many details still to be negotiated, signifies the intention to advance a mutual interest in securing supply chains for the minerals needed for important manufacturing sectors, including communication technology, aerospace and defence, and clean technology. Implementing the Action Plan, and overcoming the technical and capital challenges faced by many Canadian producers of strategic minerals, requires significant industry support and resources that go beyond guided cooperation and promotion of joint initiatives. The federal government has an important role to play in ensuring the future of this strategic industry and achieving mineral security by encouraging wider domestic production and use of value-added mineral products, particularly through government procurement (e.g., by the Department of Defence). Failure to take action would result in Canada being left behind as other countries, notably China, continue to drive prices down, pursue nationalist protective agendas, and further secure dominant positions in strategic global supply chains.

3. BIG DATA AND ARTIFICIAL INTELLIGENCE

The Context

The globally interconnected network of microchips, and the software that endows them with capability, constitutes a "cyber-nervous system" for the planet. This system is both generating and consuming exponentially growing volumes of data—hence "Big Data"—on the basis of which its subsystems are learning and becoming progressively more artificially intelligent. This has given rise to the ubiquitous prefix "smart", associated first with phones, and now attached to just about anything that seeks to represent the future. Even with the rapid evolution of Big Data and artificial intelligence (AI), their revolutionary impact on the economy, society, and culture appears to be still only in its early stages.

Data Generated by the Internet in a Single Day

In 2019, a single day in the life of the Internet involved:

- 95 million photos and videos shared on Instagram;
- 350 million photos uploaded to Facebook;
- 500 million tweets sent via Twitter;
- 3.5 billion Google web searches (around 70% of all web searches);
- 65 billion messages sent over WhatsApp; and
- 294 billion emails sent, most of them spam.

AI, like all disruptive technologies, is a double-edged sword: benefits come bundled with risks and downsides. This means we need to think deeply about the vulnerabilities and potential unintended consequences that AI creates, so as to proactively mitigate the risks that can be reasonably foreseen: disruption of current jobs, industries, politics, and relationships; and new vulnerabilities as AI comes to play a greater role in critical systems like health-care delivery, finance, power generation and distribution, along with government, societal, and business processes of all kinds.

Canada has played an outsized role in AI development where we rank among the world's leaders thanks to some farsighted investments in talent and research, and government policy that has helped foster a thriving domestic AI ecosystem. Canada's leadership is mostly due to its machine-learning expertise, with initial research supported by CIFAR and later by the federal government's Pan-Canadian Artificial Intelligence Strategy (see recent impact assessment). Since 2010, this expertise, along with Canada's unique combination of AI-related public and private investment, has generated more than 50,000 jobs and nearly $3 billion in investment, including from global technology giants like Google, Microsoft, and Facebook. The impacts of Canadian AI developments have been felt far beyond our borders and illustrate the double-edged nature of the technology. For example, while machine learning has helped catch animal poachers in Africa and loggers illegally cutting the Amazon rainforest, it is also being used to produce "deepfake" images and videos that harass and degrade women or promote child abuse and human trafficking. In fact, the use of AI algorithms to alter virtually any digital object—an image, a video, a voice recording—in ways that are undetectable has the frightening potential to further undermine trust and social agreement regarding what is "true".

Canada's status among the leaders in AI is far from assured as the public and private sectors in the U.S., China, the EU, India, and others establish AI as a national priority. For example, China's AI strategy underpins its aim to become the world leader by 2030. Similarly, the 2021 National AI Initiative Act constitutes the U.S. plan for ensuring leadership in AI R&D. Since AI must be "trained" on very large volumes of data, smaller countries like Canada are at a disadvantage. This makes it doubly important that we overcome challenges such as the huge amount of data that cannot be used because it is not integrated into a homogenous format, the fragmented administration of data, and individuals' mistrust in sharing their data. Canada's labyrinthine federal and provincial data privacy laws are confounding, disconnected, and often conflicting. One consequence is that this privacy quagmire forces health-care researchers to create siloed data repositories that hinder development of domestic AI health-care applications. In response, some researchers have relocated to the U.S. In applications that must be sensitive to local conditions, it is important that the AI algorithms be trained on local data (e.g., reflecting prevalent health conditions or particular speech patterns). In these cases, Canada should not have to rely on tools developed elsewhere. To be given access by Canadians to their personal data, however, trust must be earned. Partly that is a matter of explaining the benefits. But it also requires credible and transparent safeguards of security and privacy.[14]

The development and training of AI systems must reflect the diversity of the affected populations. For example, algorithmic bias can arise due to a lack of diversity in the data on which these systems are trained. This has perpetuated biases in machine-learning systems used in law enforcement, health care, and human resources, among others. Canadian organizations (e.g., Montréal AI Ethics Institute) are prominent in work that seeks to correct such biases, but clearly more needs to be done. Because AI will increasingly affect the lives of all Canadians, it is essential to minimize the unconscious bias that can easily creep into many applications. This means that the developers of the systems should include a diversity that approximately reflects the make-up of the population. In this regard, the under-representation of women in developer communities has been recognized as a major problem.

Perspectives on the Future

Drawing on the foregoing context, the ideas developed and discussed by the Subgroup can be encapsulated in the following two Statements that identify key developments in Big Data and AI from the perspective of 2030-35:

3.1 Sustained heavy investment by government and industry in fundamental AI research and niche applications enables Canada to retain its competitive edge and reputation as a world leader in the field.

3.2 Growing cost pressures drive greater efficiency in the provision of health care in Canada, finally overcoming the reluctance of the fragmented system to share data and accelerating the adoption of AI in clinical and administrative practice.

Several of the specific ideas originally submitted by Subgroup members are featured under each Statement to provide concrete *illustrations*. These Statements and illustrative examples are not intended to be hard and fast predictions or to present a comprehensive picture of Canada's future. Rather, they comprise a number of informed perspectives on potential developments in Big Data and AI—a general purpose technology that could eventually affect almost everything—that Subgroup members believe will be important for Canada. Moreover, the Statements are to some extent aspirational, although the Subgroup believes they are achievable with sufficient commitment from the public and private sectors and from individuals.

3.1. Sustained heavy investment by government and industry in fundamental AI research and niche applications enables Canada to retain its competitive edge and reputation as a world leader in the field.

Current machine-learning methods are based primarily on detecting correlations in data, e.g., if A occurs often, then B occurs often as well. Deep learning (a technique for implementing machine learning) is engineered to find complex correlational patterns in data and has advanced to the point of outperforming humans in

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[14] See the chapter on Cybersecurity and Privacy.

specialized tasks that can be precisely defined and bounded, e.g., deciphering hand-written text or spoken words, diagnosing skin cancer in medical images. Impressive as these types of performance are, such brittle "idiot savant" systems are limited in generalizing from past (training) data to handle new situations. For example, a machine-learning system could tell photos of huskies and wolves apart only because snow appeared in the husky images, but not the wolf images. An image of a wolf in snow (i.e., a new situation) would be identified (incorrectly) as a husky. To resolve a wider array of situations, the AI would need exposure to larger, consistently annotated training data (images, video, audio, text, and structured data) that featured those situations—clearly a potentially open-ended requirement.

Current approaches to addressing this limitation focus on reducing training data requirements via few shot or one shot learning, or generalizing learned patterns to related situations via transfer learning. A more revolutionary approach involves the reorientation of AI R&D towards building models based on a causal "understanding" of relationships between real-world variables, rather than simply finding more elaborate pattern recognition methods. For example, curriculum learning is based on how very young children learn, and reinforcement learning on an iterative simulation with rewards and penalties tied to a desired outcome. Related research is aiming to teach AI systems different types of "common sense" that could be used to build a model of the world from text or video, including physical common sense (i.e., knowledge of objects and real-world physics) and social common sense (i.e., knowledge of what people do, why they do it, and its emotional impact). AIs that incorporate such a knowledge system could learn the answer to questions like: "Which of the following household items is the best to roll dough: a) a plate, b) a bottle, or c) a spoon?" It is usually the case that tasks that are trivial (or unconscious) for humans are very difficult to render as AI, whereas tasks that are very tough for humans (like complex math calculations and logic puzzles) are child's play for a properly engineered AI.

As well as work to improve AI understanding of causality, the development of explainable AI is needed so that users can trust the output, which otherwise could remain completely unintuitive and inscrutable. For example, more explainable AI would help address rising concern about the potential for algorithmic bias influencing automated decision making. Interest in explainable AI is increasing as various jurisdictions (e.g., New York City, EU, Canada) consider adding a "right to an explanation" within legislation and guidelines on automated decision making, particularly for life-altering decisions like prison sentencing or mortgage approvals. Such initiatives would establish a degree of fairness, accountability, and transparency between an AI system and those who are affected by its recommendations and decisions.

By understanding causal relationship and improving the ability to explain recommendations or decisions, the next generation of AI systems would be more robust in new or unexpected circumstances, more data- and energy-efficient to train, and easier to trust since humans easily understand explanatory causal models. But developing these systems would require interdisciplinary teams of data scientists, software engineers, ethicists, designers, and user experience practitioners—all seeking to bridge the gap between humans and the AI systems working on their behalf. This would open the door to building AI tools that work alongside humans on tackling complex problems such as climate change or finding the biomarkers of disease progression.

Illustrative examples

3.1(a). Natural language processing systems are indistinguishable from human communication in both intelligence and empathy.

Rapid advances in natural language processing (NLP) systems, which aim to teach machines how to interpret the nuances of human language, have the potential to improve human productivity and manifest ingenuity in unparalleled ways. Recent developments such as Google's BERT and OpenAI's GPT-3, language models that use deep learning to generate human-like text, are demonstrating the capabilities and potential applications of advanced NLP models, particularly in education and the workplace. However, building these applications carries risks related to the scale and nature of data needed to train models as well as ethical considerations such as the potential for bias, racial insensitivity, and false information. Ignoring the risk of factually incorrect and socially inappropriate models has resulted in NLP-based chatbots that spew hate speech or AI systems that misunderstand simple situations.

Although most NLP models are currently developed elsewhere, Canada has the research capability and trained talent pool to position the country for building the next generation of models. Canada's development of many of the deep-learning methods used for NLP models has attracted AI talent, much of which has stayed and launched AI startups.

Canada's low energy costs and availability of renewable energy create an attractive training location for AI (which is very energy intensive) and technology companies. A 2019 study found that CO_2 equivalent emissions from training a model using a server in Quebec, where virtually all electricity is hydro-generated, was around 20 g, versus 736 g (less than 3%) from an Iowa-based server.

3.1(b). Brain-computer interfaces and haptic ("touch") simulation are common ways to interact with computers.

The ubiquitous keyboard predates every other component of modern personal computers by a century. However, this interface device is likely to be at least partially replaced in the next five to seven years with interfaces that enable human-computer communications via simulated touch (haptics) or even thought (brain-computer interfaces).

Due to their inherent sensitivity, hand or finger-based haptic interfaces create the possibility of interacting with a computer via touch (e.g., patting, poking, squeezing), with life-like simulations of materials or even skin. Such interfaces are used in gaming controllers, mobile phones, and some automobile dashboards. Promising future directions exist for telemedicine (e.g., tele-robotic surgery) and prosthetics (e.g., U.S. DARPA's HAPTIX program). Brain-computer interfaces (BCI) read, interpret, and convert brain signals (i.e., electroencephalogram, EEG) to provide input to a computer. While entirely thought-driven BCIs (e.g., Neuralink) likely remain far off, more speaker- and vocabulary-specific BCI solutions (e.g., thought-based dictation) may be closer. For example, Facebook is working on a non-invasive headset that decodes brain activity to transcribe thoughts into computer-readable text.

Haptic and BCI systems require a computer to correctly interpret the user's movements or brain patterns. These are extremely difficult problems for which current methods are scarcely adequate. For example, although EEG technology is low-cost and user-friendly, its spatio-temporal resolution has so far limited its utility for BCIs. That may be about to change. A recent paper by researchers working on Facebook's headset showed how neural networks (a machine-learning technique) could be used to interpret and decode EEG activity related to a given sentence. Such research could leverage existing deep-learning methods to produce an NLP-like model for interpreting EEG data. Social-oriented and ethical research is also needed to investigate issues such as using someone's BCI data for thought-based sales or advertising or predicting their decisions for commercial or political gain—another example of the double-edged sword nature of AI.

Canada could combine its existing expertise in deep learning with its research and commercial expertise in haptic interfaces and BCIs to be among the leaders in new interaction technologies. Canadian companies are already involved in commercializing haptic interfaces, which could be combined with augmented reality to replace cumbersome hand- and head-held devices with lightweight data gloves (or even data fingertips) connected to "smart glasses".

3.1(c). Big Data and AI provide lessons for the future by expanding and reshaping understanding of Canada's past.

Preserving Canada's cultural heritage helps us better understand our history, supports the economy through tourism, and fosters future cultural growth. Memory institutions (e.g., museums, libraries, archives) are increasingly using digital technologies to capture, manage, and share large collections of cultural artifacts. For example, the Venice Time Machine project (part of the larger European Time Machine) captures and converts physical historical documents into digital, searchable text using semi-automated digital scanners, page-turning robotic arms, and machine-learning-powered handwriting recognition algorithms. Canada's National Heritage Digitization Strategy includes similar initiatives, such as digitizing last copy/at-risk material.

These initiatives, however, merely scratch the surface in terms of cultural applications of AI and Big Data, as they involve existing, well-developed technologies such as optical character recognition. While such digitization efforts provide data sets that help investigate historical questions, there is an opportunity for Canada to apply its growing AI expertise to digital enrichment of cultural heritage, potentially enabling deeper understanding and wider access. For example, deep-learning methods applied to digitized historical documents could simulate the "rebirth" of historical figures, answering questions in natural language through conversational interfaces (e.g., chatbot, Alexa or Siri). AI-enabled recommender systems could suggest other avatars for commentary or alternative views on historical events.

Automated Translation of Canada's Indigenous Languages

The use of machine learning has greatly improved the accuracy and utility of automated language translation. However, tools provided by Google, Facebook, Microsoft, DeepL, and others do not include less-spoken languages, including Indigenous languages. To help address this gap, the NRC is collaborating on developing speech- and text-based technologies to help Indigenous peoples stabilize, revitalize, and reclaim their languages. For example:

- Developing predictive text software for SENĆOŦEN language use on mobile devices;
- Indexing audio recordings for Cree and Inuktitut languages to support automated translation;
- Creating Indigenous language spelling & grammar applications, such as a verb conjugator for Kanyen'kéha (the Mohawk language), with other Mohawk dialects and Iroquoian languages (e.g., Wendat) planned; and
- Developing a common digital infrastructure for Algonquian languages, including dictionaries and a linguistic atlas.

AI expertise built through translating and interpreting historical documents could be applied elsewhere, such as in the translation and interpretation of legal documents (e.g., court depositions, parliamentary proceedings). Using AI-based tools trained on historical legal documents for such tasks could speed up the process of legal translations. These tools could potentially improve access to the Canadian legal system for those whose first language is not English or French.

3.2. Growing cost pressures drive greater efficiency in the provision of health care in Canada, finally overcoming the reluctance of the fragmented system to share data and accelerating the adoption of AI in clinical and administrative practice.

Machine-learning methods that analyze health-care-related data and various determinants of health are already yielding interpretations comparable with those of experienced clinicians, allowing distribution of clinical expertise at very low incremental cost. Specialized clinical research that combines large-scale population health data, genomics, and AI is also accelerating the discovery and development of new diagnostic tools & treatments. While these AI tools can reduce costs and improve clinical outcomes, they require vast amounts of homogenous health data to work effectively and reliably. This would require those in the health-care system to share data, and Canadians to agree to the sharing of potentially sensitive personal data, which even if anonymized, could still create challenges related to trust.

The problem today is that Canada's fragmented health-care system—medical professionals, facilities, regulatory bodies, and multiple government departments and agencies—all maintain their own data silos. They often operate under different privacy rules and with little or no ability to connect or share data sets, even if permissions were provided. At the heart of the issue is whether health system leaders have the will to work together across jurisdictional boundaries and across private- and public-sector domains. While Canadians have largely embraced telehealth services, they remain wary of sharing personal health information. Greater transparency in health data management is needed to build trust. For example, an independent data trust could manage personal health data and allow researchers to create multipurpose or pan-Canadian data repositories. Other trust-building measures could require inclusion of explainable AI in AI-enabled health-care solutions to allay fears that these systems are little more than black boxes.

These issues are dealt with in more detail in the chapter on Health-care Futures. What follows is a glimpse of some of the kinds of innovative health-care services that AI and data make possible.

Illustrative examples

3.2(a). Wearable sensors coupled with AI-enabled interfaces help manage chronic health conditions.

Chronic health disorders such as hypertension and diabetes are increasingly common in Canada: in 2019, 44% of adults aged 20 years and older and 73% of those aged 65 years and older had at least 1 of 10 common chronic conditions. Chronic disease treatment accounts for 67% of all direct health-care costs, a proportion expected to rise as the population ages.

This implies a growing benefit from wearable sensors that allow patients and caregivers to monitor conditions in real time. Apple Watch, for example, has an optical sensor to measure heart rate & rhythm, an electrical sensor to record electrocardiogram (ECG) data, and accelerometers/gyroscopes to detect falls. Other wearable sensor-enabled devices in development include biosensing contact lenses to detect glucose levels, "smart" fabrics/e-Fabrics for monitoring blood pressure, and tattoo sensors that can collect biosignal data such as ECG, EEG, and skin temperature/hydration.

The integration of sensors with interface devices (e.g., watches, clothing) and machine learning allows data to be presented as visualizations that empower people to monitor and assess their own conditions. AI-enabled monitoring of historical sensor data could potentially identify abnormalities that signal the need for medical intervention. This capability could reduce hospital visits, thus saving money and capacity without impairing outcomes.

Canada has expertise in wearable sensor systems in biomedical engineering schools and startups like Hexoskin whose machine-washable "smart shirt" measures heart rate, breathing volume, and physical activity.

However, the fragmented regulatory system is a barrier to commercializing this technology: for example, wearable health-care sensor devices may need to go through separate approval processes for radio spectrum use (ISED), telecommunications network access (CRTC), and medical device licensing (Health Canada), among others. In contrast, the U.S. FDA Center for Digital Health centralizes all regulatory approvals for wireless sensor devices under one roof and coordinates with other government organizations. Adoption may also be hindered by lack of trust in organizations suspected of using, for commercial purposes, data collected from wireless sensors (e.g., daily steps, calories burned, heart rate).

3.2(b). Robots complement human caregivers to allow more vulnerable older Canadians to live at home independently.

A lasting impact of the world's experience with COVID-19 is likely an acceleration of the automation of tasks previously done by humans. Seniors and vulnerable persons requiring personal care could benefit from this trend. Along with the loss of personal autonomy, these Canadians are more vulnerable to physical and psychological abuse from care providers, the incidence of which has increased during the pandemic.

Home care delivered in part by AI-enabled robots is already established in Japan where the number of seniors is projected to equal about 80% of the working-age population by 2050 (i.e., four seniors for every five workers). In response, in 2012 the Japanese government identified priorities for nursing care robotics (e.g., lifting, bathing & mobility aids, smart toilets), followed by investment. The result has been development of robotic devices that boost the autonomy of seniors with mobility issues, such as transforming bed-wheelchairs and walking aids that detect when someone is walking up a hill and engage an electric motor to aid them. In China, during the pandemic, service robots perform basic jobs such as food and drug delivery in hospitals and businesses.

Developing similar robots in Canada—or upgrading the "skills" of robots produced elsewhere—could help Canadian seniors preserve cognitive function through stimulation of speech, alleviating the effects of memory loss through targeted reminders, or even detecting and appropriately responding to emotions. For example, semi-humanoid robots, Pepper and Stevie, are already interacting with seniors in the U.S., Japan, and Finland. They can recognize faces, play games, do exercise routines, and conduct basic conversations. The robots' functionality can be upgraded with new AI-based skills (e.g., prescription reminders) that Canada's AI workforce is well-placed to develop. Moreover, senior-oriented AI skills developed in Canada could be sold internationally for robot upgrade, creating a new export market.

As Canada's population ages, amid rising expectations for standards of care, it will be essential to automate more routine tasks to assist over-worked staff in care facilities at a cost that health-care budgets can sustain. Initially, many will recoil at the thought of entrusting the care of vulnerable loved ones to a robot! But, as the experience in Japan has shown, the AI-robotic technology—always complementary to human care—is safe and effective, and can only continue to improve.

4. CYBERSECURITY AND PRIVACY

The Context

The emergence of the global internet has flooded humanity with data, creating in effect a “cyber atmosphere” that now envelops us all. The benefits have been transformative in cultural and economic terms and herald a new Industrial Revolution. But, as with every transformative technology, the upsides come with downsides.

Prominent among these are new security vulnerabilities together with threats, seen and unseen, to individual privacy.[15] As we come to rely increasingly on cyber technology for society’s essential functions—finance, energy delivery, military and police operations, supply chains, businesses of all kinds—cybersecurity becomes a vital matter for national security and personal security. The threats to individual privacy are equally pervasive because our “data” is valuable to so many others: to advertisers eager to better discern our tastes and desires; to police and security agencies tasked with stopping crime or insurrection; and, unfortunately, to malicious actors seeking to steal our identity for any number of nefarious purposes. Ensuring cybersecurity and privacy will therefore be among the defining challenges of the 21st century.

The same cyber technologies that deliver benefit can equally enable threat. Policies to promote benefit while mitigating threat must contend with unrelenting technological change that is opaque to all but the most expert. Moreover, the global nature of the phenomenon often reaches beyond the control of state jurisdictions into spaces where regulations are lacking, leading to unregulated competition driven by national ambition. Yet the benefits of cyber technology are so enticing that we are tempted to downplay the threats, putting off for another day strengthening a password or investing in a better firewall.

Mostly we get away with it, so vulnerability is building. There is a telling analogy with pandemic disease. For a century after the great influenza of 1918, we became accustomed to the annual flu season; we sometimes got a shot and were occasionally alarmed by reports of a virulent strain detected in some ducks in China. Indeed, some years were worse than others, but the Big One never materialized. Gradually, vigilance eroded, expert warnings went unheeded, and investment in preparedness was displaced by other priorities. And we got away with it—until we didn’t.

Perspectives on the Future

Drawing on the foregoing context, the ideas developed and discussed by the Subgroup can be encapsulated in the following three Statements that identify key developments in cybersecurity and privacy from the perspective of 2030-35:

4.1 Canadian governments and businesses “harden” their expanding digital infrastructure by making its resilience the top priority.

4.2 Canada maximizes the benefits of the information economy and society by combining technological innovation for data security with policies to build trust by safeguarding privacy.

4.3 Thanks to its reputation as a trusted and technologically advanced jurisdiction, Canada becomes a leading global hub for international data flows.

Several of the specific ideas originally submitted by Subgroup members are featured under each Statement to provide concrete *illustrations*. These Statements and illustrative examples are not intended to be hard and fast predictions or to present a comprehensive picture of Canada’s future. Rather, they comprise a number of

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[15] In the context of data, *privacy* might be thought of more broadly as *personal information management* because the concept involves more than just confidentiality. However, this report uses the term “privacy” throughout in view of its common usage.

informed perspectives on potential developments related to cybersecurity and privacy that Subgroup members believe will be important for Canada. Moreover, the Statements are to some extent aspirational, although the Subgroup believes they are achievable with sufficient commitment from the public and private sectors and from individuals.

4.1. Canadian governments and businesses "harden" their expanding digital infrastructure by making its resilience the top priority.

Canadians continue to enthusiastically embrace digital technologies and applications but without sufficient understanding of the security and privacy implications and risks. This reflects human nature. We have biases that work against proactively dealing with uncertain, long-term threats. So, we muddle along until the consequences cannot be ignored, as our unpreparedness for COVID-19 has shown. Cybersecurity is no different. Successful cyberattacks and data breaches occur so often that most individuals, and even many organizations, have become inured and complacent. For example, although Yahoo's data breaches affected 500 million users, its final settlement was valued at US$358 million—less than US$1 per affected user. It could be seen as simply the cost of doing business.

Emerging technologies enabling mass deception, misinformation, and disinformation present new, more insidious threats. AI-enabled deepfakes can generate disconcertingly realistic video and audio content that, for example, criminals can leverage to impersonate CEOs, or unscrupulous politicians can use to discredit an opponent. Sophisticated automated text generation systems (e.g., GPT-3) use natural language processing to write at a human-equivalent level, making it more difficult to detect potential subterfuge from "phishing attack" emails. These technologies, combined with social-engineering techniques, could trick users into complicity in a cyberattack.

But as digital and cyber-physical systems become more integrated into essential functions like finance, electricity distribution, national security, and business operations, the resilience of such systems becomes mission critical. Canada's cyber-resilience can be improved by creating incentives—carrots and sticks—that raise the priority for up-front investments and system designs to countervail threats that may be of low probability but enormous cost, just as the COVID pandemic has proven to be. This means, for example, providing Canadian security and intelligence agencies with appropriate tools to mitigate threats and better protect digital infrastructure by "hardening" the supply chains involved in building it. The objective is to "bake in" cyber-resilience from the outset.

Illustrative examples

4.1(a). National security and intelligence agencies use lawful, advanced tools to successfully identify and mitigate the threats posed by malicious actors.

The scope of the mandates of national security agencies often include acting as arbiters in verifying individuals' identities and assessing the risks associated with emerging technologies. Activities include gathering and analyzing intelligence/evidence, assessing risks, and deploying mitigation measures. To perform these activities, agencies monitor emerging technologies and technical information in the public and private domains.

The digitization of personal data has created many new opportunities for exploitation by criminal organizations or nation-states. Sophisticated disinformation campaigns, deepfakes, and people with multiple user profiles increasingly undermine the positive benefits of linking an individual to their digital identity. To protect the benefits, national security agencies must be equipped with the best available technology to positively verify the identity of individuals who enter and leave the country, apply for legal documents (e.g., passports, driver's licenses), or are the subject of criminal and security investigations. Making a mistake (e.g., as was the case with Mahar Arar) can have dire consequences.

National security and intelligence agencies also assess the novel security and privacy risks associated with emerging technologies (e.g., AI, 3D printing, advanced robotics, blockchain, autonomous vehicles, quantum computing, 5G/6G, Internet of Things). The rapid pace of technology development always threatens to outstrip the ability of governments to anticipate and manage threats. Canadian security agencies therefore need reliable analytical tools that balance national security obligations against a respect for privacy. Such tools must counter disinformation and foreign influence in democratic processes; address use of the dark web or blockchain technologies by criminal organizations or as a tool for recruitment, propaganda, and financing by terrorists; and provide next-generation digital forensics and interception techniques to enhance evidence collection.

Securing public trust for the use of these tools and techniques is inherently challenging because the need for confidentiality and examples of misuse—particularly affecting certain groups—have produced an aura of suspicion. The government's COVID Alert smartphone application illustrates the difficulty of setting socially acceptable norms for individual privacy versus national (health) security. By January 2021, nearly six million Canadians had downloaded the app, but only 2% of those who tested positive had activated the feature to alert others of potential exposure. This hesitancy, along with an overall reluctance to install the app in the first place, is partly due to mistrust in how security and intelligence agencies and big tech companies may use this information even though, in this case, everything is under the user's control. The lesson is that technical safeguards, while necessary, are not in themselves sufficient to gain public trust. There is also a need for transparent processes that demystify the technology and that assure accountability in the event of misuse.

The Internet of Things

The Internet of Things (IoT) refers to an interconnected network of physical objects (i.e., "things") that collect and then transmit sensor-based data to the internet via wireless networks. Recent research suggests IoT devices will become increasingly ubiquitous, with billions of IoT-connected devices expected to be deployed worldwide over the next 5-10 years. This rise will support and reinforce emerging consumer, industrial, and infrastructure IoT applications, such as "smart" home thermostats, supply chains, logistic networks, and power grids. But security and privacy concerns may temper this growth. The weak security of consumer IoT devices (e.g., wireless cameras) has made them vulnerable to cyberattacks and the focus of privacy-infringing surveillance networks. For example, many U.S. police departments can request video and data for all Amazon Ring "smart doorbells" within a neighbourhood without obtaining consent from device owners or others inadvertently recorded.

4.1(b). Computer-aided secure development reinforces the integrity of our solutions.

Product engineering involves the design and reuse of a multitude of elements from different commercial manufacturers and teams developing open-source software solutions. However, a single design defect or vulnerability in one of the components used in these applications can make the resulting product potentially vulnerable to cyberattacks. Examples of supply-chain attacks include the recent "Solar Winds" hack on U.S. government networks. Therefore, processes must be put in place to ensure the constant evaluation of the security and integrity of Canada's digital infrastructure. Such processes would span the secure development lifecycle of each infrastructure component, from design through delivery to retirement of the final product. This requires integration of *automated* methods for software analysis into development tools for digital infrastructure. The toolbox could include:

- AI techniques to automatically scan and identify potential security vulnerabilities in code;
- Ensuring the robustness of solutions under development by continuously fuzzing and simulating cyberattacks based on threat models;

- Digital Twin copies of critical infrastructures and network assets to perform modelling and simulation as well as cybersecurity optimization.
- Blockchain/distributed ledgers that keep track of manufacturers or open-source software projects that have contributed to a product to help ensure supply-chain integrity; and
- Expanding the DevSecOp model, where development, cybersecurity, and operations staff share the goal of enhancing the security for a software application.

Canada has some competitive advantages in developing and implementing this toolbox, including AI and blockchain ecosystems that could develop home-grown security-based solutions.

4.1(c). Canada's critical infrastructure is vulnerable to quantum attacks.

Cyberattacks and data breaches continue to increase, with the scale rising rapidly: the first half of 2019 saw the exposure of four billion records worldwide. Quantum computing technology could enormously magnify the threat. The key difference between present computers and their quantum cousins is how they process information. Quantum computers exploit certain aspects of the behaviour of matter and energy at the atomic scale (superposition and entanglement) to perform calculations that, for certain classes of problems, including decryption, can provide a significant advantage over conventional computers. Despite formidable engineering challenges, quantum computers are developing at a rapid pace. Cloud-based access to early models is already available from Amazon, Google, Microsoft, IBM, and Canada's D-Wave. Current encryption standards, such as the commonly used RSA public-key system, are essentially immune to cracking by conventional computers but not by quantum computers. Most experts estimate a significant likelihood of practical quantum codebreaking in 10-15 years. Consequently, farsighted malicious actors may already be instigating breaches to harvest and store enormous volumes of encrypted data related to individuals, businesses, and governments in anticipation of future decryption by quantum computers.

Before that day arrives, Canadian businesses and governments should be exploring how to protect themselves against both the possibility of quantum computer-based cyberattacks and decryption of encrypted data harvested earlier. Some work has already been done in this area such as Canadian Security Establishment's (CSE) development of quantum-safe algorithms. Canada's advantages include its established quantum ecosystem with quantum computers located on Canadian soil (those of D-Wave and Xanadu, available as a cloud service); world-class research depth (e.g., University of Waterloo's Institute for Quantum Computing, University of Sherbrooke's Quantum Institute); support for quantum education and startups (e.g., Creative Destruction Lab's Quantum Stream); policy development and advocacy groups (e.g., Quantum Safe Canada); and a quantum-aware government (e.g., CSE, Canadian Centre for Cyber Security, NRC, Canadian Forum for Digital Infrastructure Resilience).

Still missing is a detailed, sector-specific analysis to protect organizations and governments against quantum-based cyber threats, although CSE (and other organizations) is already working on quantum-safe algorithms, as noted above. The work needed to counter these threats must be scheduled in the context of other IT projects. Because these typically have timeframes of 5 to 10 years, projects that address future quantum computing threats risk being postponed in favour of more immediate needs, such as maintaining legacy systems.

4.2. Canada maximizes the benefits of the information economy and society by combining technological innovation for data security with policies to build trust by safeguarding privacy.

We have entered an age where the most significant economic and cultural activities involve the creation, distribution, and manipulation of data via digital intermediaries. The business models of "big tech" companies such as Google, Apple, Facebook, Amazon, Microsoft, Baidu, and Tencent are all based on the collection and use of personal data, generated by individuals either directly (as in a Facebook post) or passively (as in location data generated by the post). The imperative of the business model—dubbed as "surveillance capitalism"—means that the legal terms and conditions they use have effectively nullified user consent, which traditionally has been a foundational principle of privacy law. (Who reads the legal boilerplate before clicking "Agree"?) The federal government's announcement of the *Digital Charter Implementation Act* (DCIA) is a first step towards establishing new privacy laws to address this new circumstance.

Digital Charter Implementation Act

The introduction of the DCIA as Bill C-11 in November 2020 responds to long-standing complaints about the *Personal Information Protection and Electronic Documents Act* (PIPEDA). An omnibus data protection bill, the DCIA proposes major reforms that would move Canadian privacy laws closer to Europe's GDPR in the collection, use, and disclosure of personal information.

The DCIA maintains some PIPEDA features, notably using a principles-based, rather than a rights-based approach, staying technology-neutral, and emphasizing transparency, accountability, and consent as central principles of Canada's privacy. The DCIA adds flexibility to consent models by replacing the principle of "meaningful consent" with a requirement for organizations to obtain "express consent" (i.e., opting in based on a plain language explanation of an organization's intentions). The Office of the Privacy Commissioner's new powers include ordering an organization to take action to comply with the law, halting infringing practices, and recommending penalties and fines to a new Data Protection Tribunal. The Act's new transparency requirements for AI systems include a right to explainability and enforcement of algorithmic transparency for automated systems that help/render decisions about individuals. The draft legislation differs from the GDPR (and Quebec's Bill 64) in that it does not include a right to object to or opt out of such automated tools.

The government has not indicated a timeline either for adopting the DCIA or for the transition period for businesses once the Act is passed. The government may seek stakeholder input via consultations and hearings before taking it to Parliament. However, the Bill may have a rough ride through the legislative process. The DCIA essentially institutes a federal consumer protection framework that could result in constitutional challenges, as these laws usually fall under provincial/territorial jurisdiction.

Illustrative examples

4.2(a). Individuals fully control their personal data.

Companies like Facebook, Amazon, Apple, Netflix, and Google (the FAANG) exploit personal data for profit, typically for highly targeted advertising. You are not their actual customer—you are their product. Of course there is a benefit. You enjoy a valuable service that is often "free" and the collection of personal data may result in more relevant targeting of ads.

Nevertheless, as the scope and scale of personal data surveillance grows, there is increasing concern about its potential use, e.g., the Cambridge Analytica scandal fallout, a steady flow of revelations about the questionable collection of personal data (e.g., Google's ongoing collection of location data even when this appears to be turned off). An early example is the January 2020 California law allowing residents to opt out of having their personal data sold, as well as opening the door to "authorized agents" that exercise data rights on individuals' behalf. These automated agents would manage digital-privacy related tasks in the background, such as requesting removal of personal data from digital platforms and indicating to platforms what personal information can be collected.

Canada appears to be moving in a similar direction with the introduction of the DCIA. Some relevant aspects would allow users to transfer their data between organizations and request that organizations dispose of their personal information. The rise of such legislation could create an opportunity for software developers to create the means to provide individuals with greater control and fair compensation for willingly selling/sharing personal data. For example, a data trust could manage the privacy aspects of the data of many individuals, ensuring that data is not monopolized by a single company and is used according to the user's wishes, e.g., for environmental or health research, but not for advertising or sales purposes. Of course there is a flip side since such measures would fundamentally undermine the business models of the platform providers and would require explicit payment by users in return for enhanced privacy and data control. The balance of customer preference remains to be tested.

A data trust was proposed by Sidewalk Labs as a solution to the divisive issue of large-scale data collection within its Quayside project in Toronto (cancelled in May 2020). The debate stimulated interest in finding new governance models for personal data. For example, a Toronto Board of Trade report proposed the Toronto Public Library as the administrator of a "data hub" given the latter's data management expertise.

4.2(b). Canada has a nationwide identity system in place for all citizens.

Today, validating the digital identity of a user is most often done by asking for user credentials (i.e., user ID + password). Problems using passwords as the sole means of identification are well-known: people tend to recycle common, easy-to-guess credentials across multiple digital platforms. This aspect of human nature was leveraged in the September 2020 cyberattacks that briefly suspended Canada Revenue Agency's online services. Solutions such as two-factor authentication and open authentication (i.e., logging in with a Facebook/Google account) have reduced the potential for attacks on certain platforms. However, they also enable the potential cross-platform tracking of users in the case of open authentication. It has been suggested that the Canadian government could solve these identity problems by implementing a national identification system based on "smart ID cards" for all citizens. Such a card could replace the variety of Canadian government-issued ID documents currently in circulation. Western democracies already using such systems include all European Economic Area countries, Brazil, South Korea, and Estonia.

Opponents of national identity systems are concerned about the potential threat to privacy, claiming that governments could use this system to track citizens' activities. Over time, a system whose initial uses were strictly circumscribed would tend to expand one case at a time—the slippery slope. They point to China's large-scale, identity-enabled surveillance: for instance, a Chinese resident identity card is needed not only to access government services and conduct business (e.g., open a bank account), but also to access products and services usually considered to be more personal (e.g., buying cell phones, playing video games at internet cafes).

Beyond the technical and scientific challenges of implementing a secure, privacy-protected national ID, much work remains to be done in the realm of policies and education to establish the social acceptability of such a system. The last major study on this issue, a 2007/08 Office of the Privacy Commissioner report, identified challenges such as the co-existence of a new system, at least for a time, alongside other forms of long-standing federal, provincial, or territorial identification that Canadians may be reluctant to give up. The government would also need to convince Canadians of the tangible benefits of a new, all-purpose identity card against the risk that, if the card were lost or hacked, an enormous amount of critical personal information would be suddenly unavailable or compromised. Such a "single point of failure" would be a major concern as cyberattacks on government systems by malicious actors accelerate.

4.3. Thanks to its reputation as a trusted and technologically advanced jurisdiction, Canada becomes a leading global location and transfer point for international data flows.

Cyberattacks and disinformation campaigns are both enabled by "stateless" data that flows freely across the internet, irrespective of geography (with a few exceptions such as China). Such free movement allows data and digital content to be created and transferred between—and potentially stolen from—societies with divergent views on freedom and public responsibility.

Two general policy frameworks have emerged as countries seek to lock in the benefits of the digital society while protecting against data misuse. On the one hand, Europe has adopted a relatively restrictive interpretation of data governance that is made at the multilateral state level, e.g., GDPR, European Strategy for Data, Open Data Directive, proposed Data Governance Act. These frameworks tend to limit cross-border data transfers, require data localization, and mandate strict enforcement and penalties for misuse. By contrast, the U.S. has adopted a more open approach to data governance, relying primarily on self-regulation and antitrust law. Data governance in the U.S. occurs at the level of the individual organization, rather than the state. However, this is beginning to change with the introduction of state legislation on personal data collection. In this approach, the prospect of lawsuits may dictate how organizations approach data governance, rather than explicit state directives or frameworks. While this open approach may have created a disjointed mess, it also helped create big tech and Silicon Valley itself.

Canada has been caught between these divergent approaches. The introduction of the DCIA suggests that the present government would lean closer to the European model. Although the DCIA will likely change before becoming law, data governance and privacy issues could affect existing trade agreements with the EU and U.S. As a result, Canada will face challenges in navigating a compromise position that remains compliant with all international agreements. But if successful, by 2035 Canada could leverage its position as a trusted trading partner together with several competitive advantages to become a global data transfer hub and preferred location for hosting cloud services.

Illustrative examples

4.3(a). Canada is a trusted global transfer hub for international data storage.

Expectations of privacy differ by generation, geography, and government, whereas the internet was built on the assumption that everyone everywhere would be connected through seamless global computer networks. That expectation is changing, with tremendous implications for social networking sites and associated platform technologies. The recent demise of the U.S.-EU privacy shield and the GDPR's growing pains represent a shift towards data localization (storing personal data within geographical borders where local standards of privacy can be enforced). Hubs for huge data storage would particularly be at risk since local storage would require them to be re-architected to compartmentalize data geographically. The engineering complexity involved in compartmentalization forced, for example, Google to shut down an expansion of its cloud services in China although Amazon Cloud services continues to operate two data centres in mainland China.

Canada has several advantages that make it attractive as a global transfer spot for international data storage. It enjoys a broad international reputation for trust bolstered by special trade agreements with the EU and U.S., and with many Asian countries via the CPTPP. Specific technical advantages include a large supply of electricity not generated by fossil fuels, a cool climate that would reduce costs associated with cooling large data centres, as well as plenty of remote locations to enhance physical security. Looking forward, Canada's quantum computing ecosystem includes research expertise related to quantum cryptography and software, which will become important as quantum-based cyberattacks and unauthorized decryption eventually emerge. To become a major global data hub, Canada would have to complement the foregoing advantages with (i) a legal and policy framework strategically tailored for the digital age; and (ii) a robust, globally competitive telecommunications network. At the same time, Canada would need to prepare for becoming an increasingly important cyber target.

4.3(b). "Confidential computing" technology guarantees data privacy and security in global cloud infrastructures.

Software runs increasingly over the internet, metaphorically in the "cloud", rather than locally in a computer. Common software applications like Google Docs and Office 365 may consist of various cloud-based services that are deployed in multiple virtual spaces emulated on physical infrastructure anywhere on the planet. Despite solutions for encrypting data, both stored and in transit, few solutions exist for maintaining the security of data as it is actually being processed in the cloud. Confidential computing, which is gaining traction among technology providers, uses hardware- or software-based techniques to isolate data, specific functions, or even an entire application, from an operating system running on a cloud server. This data is stored in a "trusted execution environment" (TEE) that vets and controls access to the data and automatically denies any alteration or tampering with the application requesting access. A TEE could potentially prevent access, regardless of server location, to real-time calls on videoconferencing software as happened with Zoom in 2020 due to its less secure encryption standard.

Although Canada's presence in cloud computing is not yet substantial, a recent expansion of Microsoft's Azure cloud service in Canada and announcements from IBM and other big tech companies suggest a growing profile in this area. So, if Canada were to become prominent in the development of confidential computing technologies over the next 15 years, it could harness its other advantages noted above and become a global centre for cloud computing servers.

5. HEALTH-CARE FUTURES

The Context

Health care is the world's biggest industry, accounting in Canada for 11.5% of GDP and 35-40% of provincial government spending. These percentages can be expected to grow under the pressure of population aging and of public expectations for the longer, disease-free life that health innovation promises to deliver. The resulting tension between constrained resources and potentially unlimited demand creates a fertile environment for innovation. But innovation in the health field is constrained by the requirement, first and foremost, to deliver better outcomes for the individual as well as equitable access to the benefit. Among the hard lessons of COVID-19 is that despite the miracles of medical technology—such as vaccine development in a tenth of the time previously thought possible—the burden of disease still falls most heavily on poor or marginalized populations, often including those who provide essential services in nursing homes, health-care settings, and food provision. As technology advances, health disparities will only grow if equity in access, particularly for Indigenous peoples, is not a top priority.

The digital revolution has disrupted one industry after another but has been late coming to health and health care. That is now changing fast as monitoring devices and high-bandwidth communications make available unprecedented volumes of data that provide the raw material for potentially transformative advances in individual and population health. The data is being analyzed by increasingly "intelligent" software to estimate risk, support earlier and more accurate diagnosis, and guide treatment and follow-up. This has led some to suggest—probably with excessive or premature enthusiasm—that we are moving from clinical science supported by data to data science supported by clinicians. Nevertheless, the direction is clear. Digital technology, more generally, is also enabling the genomics revolution, new "rational" approaches to drug and vaccine discovery, and more precise treatments and surgical techniques. No aspect of health care will remain untouched. But without assurance of appropriate privacy or anonymity, Canadians will understandably be reluctant to share their health-related data, leaving important benefits unrealized.[16]

The exciting prospects of innovation in health practices and technologies need to be tempered with the recognition that the health system is by nature *conservative,* for the good reason that it deals with people's lives. Regulation and caution are necessarily prominent. Moreover, because the system is so vast and fragmented, there is a great deal of inertia as well as bureaucratic constraint in the face of chronic resource pressures. Unfortunately, these characteristics are inimical to a culture of innovation, and particularly to the culture of innovation in the digital era with its motto to "move fast and break things", which is precisely the obverse of medicine's injunction: "first, do no harm". As the irresistible force meets the immovable object, there is bound to be frustration and failure mixed with success. Nevertheless, the opportunity clearly exceeds the challenge. The time is finally at hand to create a health system that is dedicated to lifelong wellness, individually tailored and equitably delivered.

What follows is necessarily just a glimpse of some aspects of this future, the nature of which has only begun to unfold.

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[16] See the chapter on Cybersecurity and Privacy.

Perspectives on the Future

Drawing on the foregoing context, the ideas developed and discussed by the Subgroup can be encapsulated in the following three Statements that identify key features of Canada's health-care future from the perspective of 2030-35:

5.1 Canada integrates genomics, artificial intelligence, and digital tools to create a 21st century health-care system centred on the individual and focused on prevention and early detection of disease.

5.2 Canada focuses resources in areas of demonstrated strength to be among the global leaders in research and clinical and commercial application related to stem cell therapies and rapid, point-of-care diagnostic testing.

5.3. Canada pioneers a new model of wellness by integrating the traditional disease-focused approach with interventions that incorporate the social and cultural determinants of lifelong health.

Several of the specific ideas originally submitted by Subgroup members are featured under each Statement to provide concrete *illustrations*. These Statements and illustrative examples are not intended to be hard and fast predictions or to present a comprehensive picture of Canada's health-care future. Rather, they comprise a number of informed perspectives on potential developments that Subgroup members believe will be important for Canada. Moreover, the Statements are to some extent aspirational, although the Subgroup believes they are achievable with sufficient commitment from the public and private sectors and from individuals.

5.1. Canada integrates genomics, artificial intelligence, and digital tools to create a 21st century health-care system centred on the individual and focused on prevention and early detection of disease.

There is alluring promise in digital tools that allow for capture of raw data on the state of an individual followed by manipulation in cloud-based AI technologies to improve assessment, diagnosis, treatment, and monitoring.[17] Canadian health-care systems continue to lag the international leaders in applying digital health solutions. For example, while use of electronic medical records (EMRs) by primary care physicians increased markedly from 37% in 2009 to 86% in 2019, Canada still trails the average of peer countries and, more significantly, has not developed an integrated system to facilitate portability or analysis of the incorporated data. In addition, the operation of many AI and machine-learning systems is based on EMRs. Therefore, we cannot create, audit or use such systems until an accessible national electronic health record (EHR) is established.

Bureaucratic barriers, probably more than ethical and privacy concerns, have so far limited the use of digital tools in health care. Nevertheless, systems in which citizens own and share health information are being explored, along with patient-centred (rather than system- or provider-centred) approaches. While digital technologies may promise to reverse inequalities in traditional health-care systems by facilitating a shift towards prevention, wellness, and increased access, most companies in this emerging industry continue to focus on disease management. Participation in the development of national and international ethical and legal frameworks would help Canada protect user data against competing interests.

[17] See the chapter on Big Data and AI.

Illustrative examples

5.1(a). Inclusive innovation in telehealth, based on AI and machine learning, increases health-care equity, accessibility, and efficiency.

Telehealth—the use of digital information and communication technologies to access health-care services remotely and manage an individual's health—provides the building blocks in a world where technology and health care become inseparable. It is already improving immediacy, reducing costs, and creating intimate, one-on-one consultations. The switch from in-person doctor appointments to video, telephone, email, and instant messaging consultations and conversations from patients' homes—accelerated during COVID-19—facilitates safe patient care and allows doctors to pool their resources to relieve strain on the health-care system. In February 2020, fewer than 25% of family doctors in Canada made themselves available by email, with only 4% providing video "visits". But under the pressure of COVID, by June 2020 virtual delivery represented more than 70% of outpatient care in Canada. It remains to be seen whether this shift will reduce or widen disparities in health-care access and to what extent it will persist post-COVID.

Advances in AI and medical robotics have the potential to create much more innovation in telehealth. These systems can be trained to perform an increasing array of tasks with accuracy potentially comparable to the best doctors while never tiring. Once trained with initial data and tasks, AI systems can continue to learn, generalizing to novel conditions and populations (provided the training was performed on a sufficiently diverse population base.) Wearables would routinely monitor multiple aspects of health including unusual heart activity, sleep patterns, oxygen levels, and unusual brain activity. They would all be integrated with telehealth platforms focused on disease prevention and early detection. Continued improvement of such models would free clinical staff to focus on the human essentials of caregiving.

The strictly medical benefits of telehealth are potentially transformative. Equally important is that inclusive innovation in telemedicine could increase health-care equity, accessibility, and efficiency in Canada, making the health-care dollar go farther and fairer. With services provided at multiple locations, telemedicine could overcome physical, social, economic, and geographical barriers, especially for remote and resource-limited populations and for individuals with disabilities. But this readily achievable vision depends on the ability to ensure data safety as well as the near universal availability of high-speed internet connectivity that meets at least the federal government's target of 50 Mbps (download) by 2030.

5.1(b). Genomics and related technologies, combined with AI, enable major advances in early diagnosis of diseases and personalized health care.

The future vision for health-care practice is moving away from a singular focus on the diagnosis and treatment of disease towards prevention, earlier detection, and promotion of well-being. We are now able to interpret and use the information contained in our genetic code in an unprecedented way thanks to a combination of the dramatic decrease in sequencing costs, a significant increase in computer power, and the convergence with new machine-learning technologies. A suite of "omics-based" technologies (genomics, proteomics, metabolomics) can already help mitigate disease through effective early intervention (e.g., screening for rare disease in early life, non-invasive pre-natal diagnosis, and pro-active screening of familial cancer by using whole genome analysis) and by enabling quick response to evolving threats like pandemic disease as the rapid development of mRNA vaccines against COVID-19 has demonstrated. The early promise of genomics may have been over-hyped in the public mind, as is often the case with any radical breakthrough. It must be remembered, however, that the human genome was first fully sequenced only in 2003, so its implications for improved human health are still in the earliest stages.

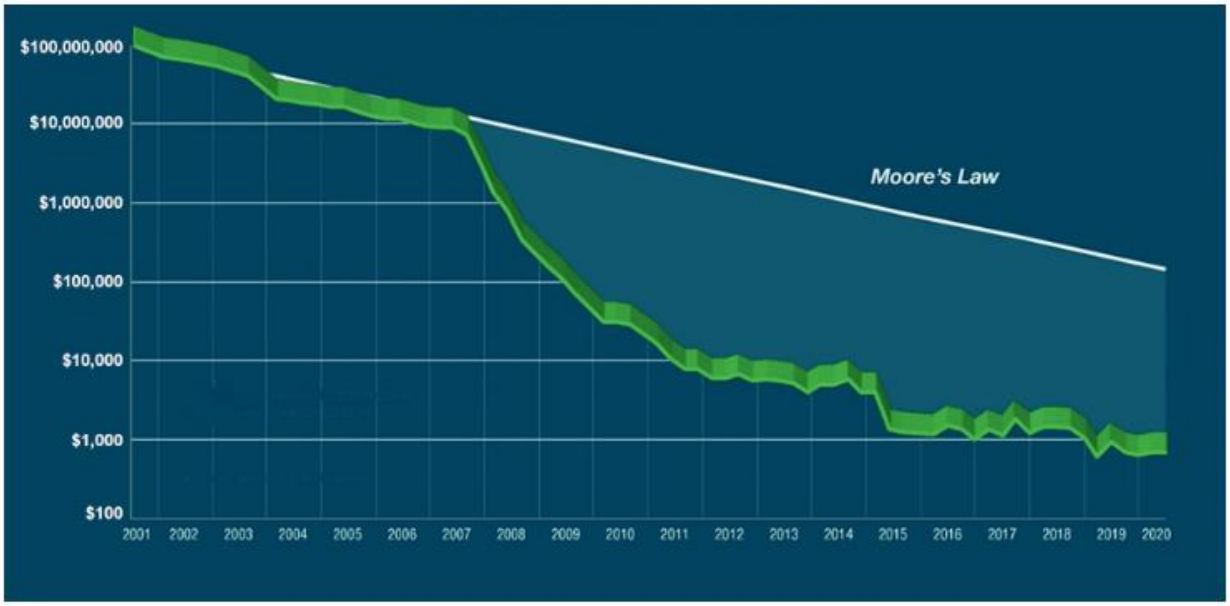
Implementing "omics" technologies in clinical care, together with powerful AI platforms, would foster a learning health-care environment where clinicians and researchers work together to maximize the use of multi-omic data to improve diagnosis and facilitate more precise and personalized drug treatments. Genomic data generated at hospitals and laboratories in Canada would be available for patients through personal apps and securely connected with other individuals with the same disease. Of course, one's genome is not the only risk factor for the vast majority of diseases. Environmental and behavioural factors, including gene-environment interactions, usually play the predominant role. In fact, knowing the three billion or so base pairs in an individual's genome is a very long way from a quantitative estimate of risk for all but a small number of diseases, mostly quite rare. But as millions of genomes are sequenced and associated with the individual's health data, more robust correlations will emerge. In this regard it will be important to sample well beyond the European-origin individuals who, to date, have been over-represented in genetic databases.

5.1(c). Genome sequencing data is incorporated into electronic health records.

Genome sequencing data has not yet become a systematic component of EHRs despite a growing demand for such a resource, evidenced by the increasing number of patients bringing the results of consumer DNA tests to their family doctor for inclusion in their health records. Incorporating an individual's genomic profile in an EHR could enable personal risk stratification; improve a diagnosis; and allow for novel, repurposed (e.g., using existing drugs for another purpose), and targeted treatments. For example, the EHRs of cancer patients could include real-time, AI-generated profiles that are directly applied throughout individual cancer care journeys including diagnosis, treatment, ongoing surveillance, and after-care. Some countries, such as the U.K., U.S. France, and Australia, have begun these types of initiatives in which patients enrolling in a program consent to use of their data. England's 100,000 Genomes Project, for example, is sequencing the genomes of patients with cancer or rare diseases and linking the data to EHRs.

Canada's significant investment in genomics research, headlined by Genome Canada and its regional affiliates, has not been matched by similar investment in clinical applications even though the genomic sequencing technology is certainly available. Implementing a national integration effort would require a systems change, with a focus on the management, integration, and governance of the exponentially growing volume of disparate health-care data—a challenge given that health care is the responsibility of provinces and territories. More AI tools to analyze the data are also required. Cost, relative to perceived benefit, continues to be a barrier, with current whole genome sequencing estimated at around US$1,000 but falling to perhaps US$100 within the next five years or so (Figure 5.1). Other considerations include patient privacy, security, and assurance of access by under-represented groups including Indigenous peoples. By overcoming these barriers, integration of genetic data into EHRs at birth could be implemented for all Canadians, thus positioning future generations for the benefits that innovation in genomics is almost certain to bring.

Figure 5.1 Sequencing Cost per Human Genome (US$)



Source: National Human Genome Research Institute.

5.2. Canada focuses resources in areas of demonstrated strength to be among the leaders in research and clinical and commercial application related to stem cell therapies and rapid, point-of-care diagnostic testing.

No country can lead the world in all areas of research and application. Canada, as a relatively small nation, has to pick its spots to be among the global leaders. In most cases, this means building on existing strengths. Two areas of particular Canadian achievement, and where there is growing global need and market potential, are diagnostic technologies for infectious disease and development of stem cell therapies.

Illustrative examples

5.2(a). Point-of-care diagnostic technologies disrupt and decentralize medical care.

Despite advances in treatments, infectious diseases pose an increasing threat to the global population due to emergence of novel pathogens like SARS-CoV-2, growing resistance to drugs, and increasing international travel. But in the last 15 years, the centralization of diagnostic laboratories has had the unintended effect of delaying disease diagnosis by several hours or even days. Such delays can prove fatal since infectious diseases progress exponentially within the individual and often spread very quickly between individuals. At the same time, slow diagnosis has led to over-prescription of antibiotics.

COVID-19 has demonstrated the urgent need to develop and employ rapid (less than 1 hour), user-friendly, “near-patient” point-of-care (POC) diagnostic technologies. These have the potential to revolutionize and decentralize health care by, in effect, bringing the lab to patients, whether in intensive care units, emergency rooms, pharmacies, emergency sites, or patients’ homes.

Rapid molecular diagnostics (the application of molecular biology to medical testing) could help control treatment of infectious diseases and prevent the overuse of antibiotics. Increased development and use of POC tests require building transdisciplinary team of experts in diverse technologies including microfluidics, nanotechnologies, optics, photonics, sequencing and amplification technologies (PCR, isothermal technologies), and ‘omics (genomics, proteomics, glycomics) for genetic profiling; psycho-socioeconomic sciences; and industry. POC instruments that are easy to operate, flexible, compact, portable, fully automated, stand-alone, and inexpensive could be adapted for the developing world, and also applied to animal health, defence, space travel, agriculture, food safety, among others.

Canada is a leader in *development* of rapid molecular diagnostic tests and POC instruments and technologies, with many Canadian tests used around the world, but it lags in *implementation* of the technology. Comprehensive information on the state of POC testing in Canada is available from the Canadian Agency for Drugs and Technologies in Health (CADTH). Challenges include regulatory hurdles and the absence of home-grown, multinational big pharma in Canada. Nevertheless, Canada has world-class performers in specialized areas, including adMare Bioinnovations, MaRS, and Creative Destruction Lab, among many others. And, in the context of rapid molecular diagnostics, the Quebec City-Laval University innovation ecosystem has been a world-class performer and fertile environment for commercialization and job creation.

5.2(b). Stem cell therapies replace transplants for heart disease and diabetes.

The current last resort treatment for insulin-resistant type-1 diabetes and end-stage heart failure in Canada is a donor transplant: islet cells for diabetes and the entire heart for heart disease. Given organ shortages, these treatments are not widely available and are expensive. Pluripotent stem cells, often known as “master” or “blank slate” cells, can be coaxed to make cells from all three basic body layers (ectoderm, mesoderm, endoderm). Thus they can potentially produce any cell or tissue needed for self-repair. By 2035 the promise of stem cell therapies for regenerative medicine could be fulfilled, replacing donor transplants for many conditions.

The earliest research on stem cells was performed by McCullough and Till at the University of Toronto in the early 1960s. Building on that legacy, Canadian scientists are leaders in developing stem cell therapies, e.g., a team in Edmonton was the first, in 2000, to pioneer transplantation of pancreatic islets. Initial clinical trials got underway in 2020. At present, only a limited number of stem cell therapies have been approved for use in Canada, primarily to treat blood cancers such as leukemia, aggressive multiple sclerosis, and some types of bone, skin, and eye diseases.

5.3. Canada pioneers a new model of wellness by integrating the traditional disease-focused approach with interventions that incorporate the social and cultural determinants of lifelong health.

COVID-19 has accentuated what we have long known: access to primary health care, long-term care, and home care is only part of the equation that determines health status. COVID cases are highest in areas where poverty, job insecurity, food insecurity, and homelessness are also highest with BIPoC groups[18] disproportionately affected. Unfortunately, this is also the case for many other health issues, including chronic diseases, mental health, and workplace accidents. There is currently a push towards integrated health-care systems that seamlessly move people from hospital to home care or other support systems as appropriate. While a good first step, this does not address the underlying socioeconomic determinants of health. A fully integrated system would include social housing and basic income support as part of the overall health and well-being plan for every Canadian. With integrated health and social support systems, we could look forward to a time when postal codes are no longer a major determinant of the health status of Canadians.

[18] Black, Indigenous, and People of Colour.

Illustrative examples

5.3(a). The achievement of more equitable health outcomes in Canada is hindered by the lack of participation of Indigenous peoples in the development and implementation of innovations in health and health care.

When it comes to innovation in medical care, those who stand to benefit the most are often least likely to benefit at all. Innovation and the resources for implementation flood to the southern, metropolitan, academic, and commercial hubs—far from rural, northern, and, in particular, Indigenous communities. The mistakes of the past embedded in marginalization, exclusion, and inequity in health care therefore continue to be propagated. Current life expectancy rates for Indigenous peoples in Canada are significantly lower than for the non-Indigenous population.

This inequity exists not only in the paucity of Indigenous health-care providers and researchers, but also in the planning, implementation, and sustaining of health initiatives—whether related to technologies, resources, or policy. The irony is that the greater the success of innovations in health, the greater the health disparities created. Tackling health-care futures with the overt objective to include the perspectives of Indigenous peoples would help prevent the widening of such disparities. This would include the role of Indigenous data sovereignty and governance; Indigenous holistic world views and concepts of health and wellness; and self-determination in areas of genomics, Big Data and AI, universal pharmacare, and health care and policy. Failure to include Indigenous perspectives and representation would exclude Indigenous communities from the clinical benefits of the technological innovations, public health improvements, and personalized medicine trends featured in this report.

5.3(b). Early intervention strategies prevent "deaths of despair" and reverse the trend of widening socioeconomic disparities in health and life expectancy in Canada.

After decades of decreasing mortality rates in North America, life expectancy rates began to stagnate in 2000 and have actually been declining in the U.S. due to rising rates of drug overdoses, suicide, and alcohol cirrhosis. The term "deaths of despair" was coined to highlight the fact that these conditions disproportionately affect communities that have experienced economic decline, and proposes despair as a common causal mechanism. Suicide rates in North America increased by 15% from 2011 to 2015, with the largest relative increase occurring among adolescents. Suicide is the second leading cause of death both for Canadian youth (aged 10-19) and young adults (20-29).

Reversing this trend requires a dramatic rethink of how we understand and address mental health and addiction, shifting our focus from treatment to *early intervention* strategies that promote resilience in high-risk youth and communities. Research on the origins of addiction and mental health conditions is limited. However, what is clear in the work to date is that (i) the first symptoms of substance use disorders and suicide risk occur during adolescence; (ii) risk for such behaviours can be predicted by genetic, familial, individual psychological, and social contagion processes; and (iii) these risk factors can be moderated through early intervention.

A systemic shift in health-care resources and research towards early intervention and prevention (which currently accounts for only about 1% of spending attributed to substance abuse in Canada) would require a coordinated interdisciplinary effort. Close partnerships among scientists, health providers, and local communities could deepen understanding and address socioeconomic risk as it interacts with biological, developmental, and social influence processes. With appropriate data, it is believed that advances in AI could be used to model the impact of early interventions on social and neural development, substance use, and suicidal behaviours. The result could be fewer "deaths of despair" and more resilient young Canadians.

5.3(c). A universal single-payer, portable health-care system in Canada enables implementation of innovative health care, public health surveillance, and applied research.

The founding principle of Canada's health-care system was access based on need, rather than ability to pay. With decentralized service delivery across provinces and territories, Canadians experience varying levels of service, access, and wait times, particularly for elective care. This results in significant inequities in health outcomes across the country and for vulnerable populations. In addition, not all services are provided free of charge by health-care systems, e.g., dental care, vision, home and long-term care, prescription medicine (outside hospitals).

Canadians spent $34 billion on prescription medicines in 2018, with drugs the second largest expenditure in health care, more than on doctors and trailing only spending on hospitals. On a per capita basis, only the U.S. and Switzerland pay more for prescription drugs. A truly universal health-care system will be increasingly necessary to enable cost control and equitable access. The next step could be to complete Tommy Douglas' vision of national pharmacare. Canada is the only country with universal health care that does not include universal prescription drug coverage. Instead, there is a patchwork of over 100 public prescription drug plans and 100,000 private plans, with 20% of the population having inadequate or no coverage at all.

The Final Report of the Advisory Council on the Implementation of National Pharmacare in June 2019 argues that a national pharmacare program could save billions of dollars by lowering the price of prescription medicines and by eliminating the greater costs associated with complications or a health crisis when someone cannot afford to take prescribed medicine for what should be a manageable condition. For example, removing out-of-pocket costs of medications for diabetes, cardiovascular disease, and chronic respiratory conditions would result annually in around 220,000 fewer emergency room visits and 90,000 fewer hospitalizations—representing potential annual savings to the health-care system of up to $1.2 billion.

Universal public pharmacare would also enable the creation of a secure but accessible national database for patient care and research and evaluation with a national lens for the benefit of patients, health-care quality and efficiency, and industry partnerships. The national pharmacare program could link access, utilization, compliance, side effects, and effectiveness to national-level health data including capacity for real-time knowledge of intended and unintended benefits.

6. NEW MODELS OF INNOVATION

The Context

Innovation is defined most simply as: new or better ways of creating significant value. As such, innovation is not limited to technology and includes social, cultural, and artistic innovations like the welfare state, rock 'n roll, and impressionist painting; process innovations like the factory system; and business model innovations like ad-supported entertainment. The emphasis in this chapter is on technological innovation and on various organizational or institutional models within which such innovation in Canada occurs or is promoted. Examples of these "models of innovation" are given below, following some contextual remarks on the nature and importance of innovation.

An invention, or a new idea, is only the *front end* of innovation. An invention is not an innovation until it becomes embedded in practice and is therefore of value—economically, socially, or culturally. The economic importance of innovation derives from its impact on productivity, which is usually measured as economic output (GDP) per hour worked. Innovation causes productivity to increase in many ways, e.g., via introduction of new kinds of machinery that amplify the amount of goods or services that can be produced by a worker; by new ways to organize production more efficiently (like the assembly line); or by creation of entirely novel forms of value (like the internet) that lead, directly and indirectly, to an increase in the output of the economy. The productivity growth that follows innovation is sometimes resisted in situations where significant job loss is anticipated, e.g., as a result of automation.[19] But innovation causes the economy as a whole to grow. So, the social challenge is to smooth the transition for the communities and individuals that are adversely affected through, for example, retraining or assisted early retirement. Such measures can reduce resistance to technological change and actually enable stronger economic performance.

The ultimate economic and social value of any innovation is related to the extent of its adoption and adaptation, often far from the point of origin. Although being the site of a world-first innovation often generates first-mover advantages, the fact is that most innovation in Canada will involve the adoption, and adaptation to our circumstances, of innovation originating elsewhere. It follows that fostering rapid adoption of innovation must be a priority goal of innovation policy.

Innovation arises in contexts that demand or require creativity—solving problems, exploiting opportunities, or simply giving free rein to the imagination. As anyone involved in team problem solving knows, a diversity of perspectives is a key stimulant of innovation. Even the paradigm-breaking innovators like Thomas Edison, Alexander Graham Bell, Marie Curie, and Elon Musk surrounded themselves with talented teams. After the original spark, most innovation is a team sport. In that regard, Canada's unmatched diversity of culture and geography—bringing together a great variety of perspectives, world views, and ways of knowing from around the world and from our own Indigenous peoples—is arguably this country's greatest comparative advantage as an innovative nation.

[19] The classic example was the often violent resistance of weavers in the late 18th and early 19th centuries to the introduction of automated looms giving rise to the term "Luddite" (after Ned Ludd, an icon of the resistance) for those who resist new technology. More profound has been the reduction of the agricultural workforce, which in Canada declined from almost 50% of employment early in the 20th century to less than 10% within about five decades. Yet this revolution in innovation-driven productivity, which continues, did not raise the unemployment rate overall. Farm jobs were simply replaced by manufacturing and service sector jobs overlain by a slow decline in average hours worked. Meanwhile, average affluence continued to increase.

Indigenous Knowledge Systems

Two-Eyed Seeing/*Etuaptmumk* encourages the realization that beneficial outcomes are much more likely in any given situation if we are willing to bring two or more perspectives into play: ….learn to see from your one eye with the best or the strengths in the Indigenous knowledges and ways of knowing…and learn to see from your other eye with the best or the strengths in the mainstream (Western or Eurocentric) knowledges and ways of knowing….but most importantly, learn to see with both these eyes together, for the benefit of all.

- Two-Eyed Seeing - Elder Albert Marshall's Guiding Principal for Cross-Cultural Collaboration

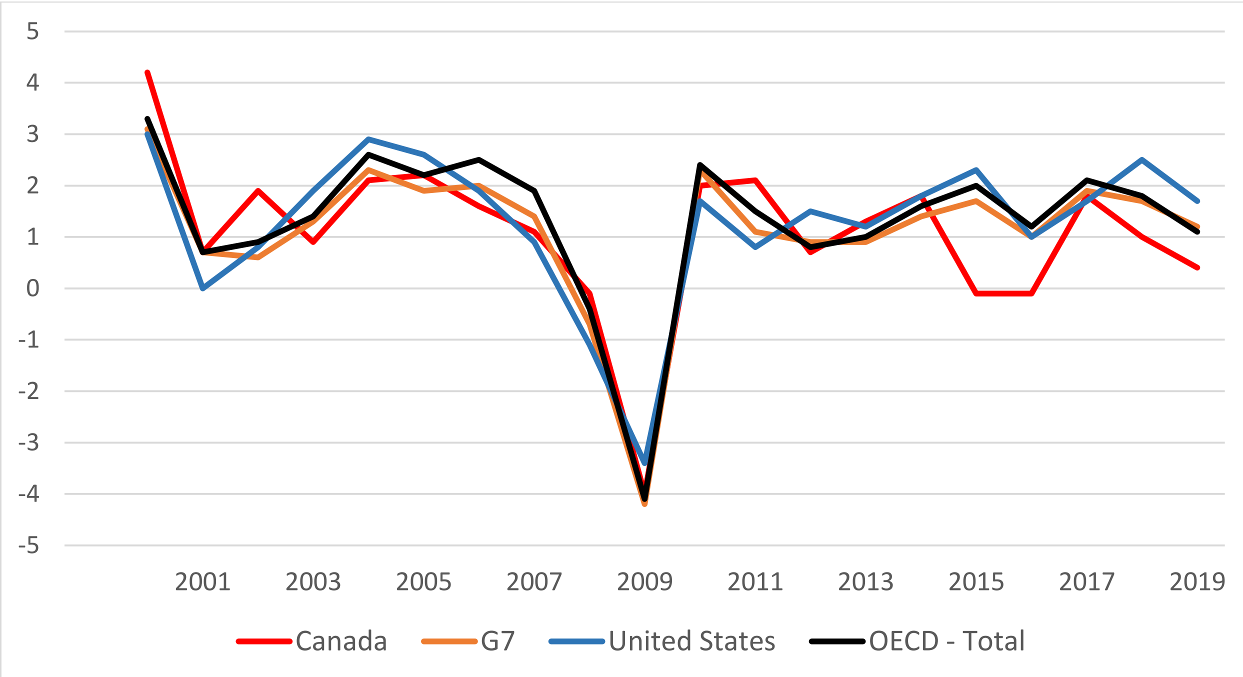
Traditional knowledge recognizes the different strengths of multiple understandings and explicitly incorporates the cultural experience of the observer into interpretation of the natural world. Traditional Ecological Knowledge is highly rational, empirical, and pragmatic, while simultaneously integrating cultural values and moral perspectives. With its worldview of respect, responsibility, and reciprocity with nature, TEK does not compete with science or detract from its power but extends the scope of science into human interactions with the natural world.

- Robin Wall Kimmerer, *Weaving Traditional Ecological Knowledge into Biological Education: A Call to Action*

Canada has been a mediocre performer according to virtually all of the traditional, internationally comparable innovation metrics, e.g., business R&D, patents, exports of technology-intensive products, annual innovation rankings compiled by the World Intellectual Property Office, World Economic Forum, and others. More significantly, Canada's productivity growth—which reflects in large part the economic *outcome* of innovation—has been comparatively stagnant for more than three decades. Nevertheless, the growth rate of Canada's per capita GDP (the most widely cited metric of overall national economic performance) has kept pace, on average and over the long term, with that of the U.S. and other G7 comparators (Figure 6.1). How? The answer is that the extraordinary strength of Canada's job growth, relative to population, was able to offset the impact on per capita GDP of weak productivity. But looking forward, as the population ages, the tailwind of job growth (relative to the size of the total population) is turning into a headwind. The laws of arithmetic show that Canada's economic growth—and the size of the tax base to fund public initiatives—will depend increasingly on productivity growth, and therefore on more vigorous innovation.[20] This, in a nutshell, is *the predominant economic challenge facing Canada*.

[20] GDP per capita is by definition equal to "GDP per worker" multiplied by "number of workers per capita" or in other words: "productivity" times the "employment ratio". The growth *rate* of GDP per capita is thus the growth rate of productivity *plus* the growth rate of the employment ratio. Aging demographics are tending to cause the employment ratio to decline (i.e., more people retiring than coming into the workforce), so the burden of sustaining growth falls squarely on productivity.

Figure 6.1 GDP Per Capital Growth Rates



Source: OECD.

Since the country's founding, we have always stepped up, relying on pragmatism, sound institutions, creative diversity, and on a productive economic integration with the U.S, the lead horse in the global economy for a century. The formula has worked exceedingly well for Canada, and therefore has persisted. But it has relied on extraction from our resource endowment and on a great deal of "branch plant" innovation from the U.S. This largely explains why, for generations, most Canadian business strategies have not emphasized innovation. On the whole, they have been successful without doing so.

But the world has changed. The U.S. is being challenged by Asia for economic leadership and is consequently tempted to be more protectionist. Information technology is now disrupting every business and activity. The sustainability imperative, particularly the elimination of GHG emissions, is arguably both the greatest challenge and the most significant opportunity facing Canada and the world. Finally, Canada can no longer rely on job growth to offset sub-par productivity. Bottom line: this changed world demands a commitment to innovation from Canada, and especially from Canadian businesses.

Over the decades, Canada and other economically advanced countries have evolved a variety of means to foster elements of the innovation process. These might be called "models of innovation", with the following examples familiar in Canada:

a) Fundamental (curiosity-driven) research: the raw material for much technical innovation, but also the training ground for the human skills to support innovation.
b) Government R&D labs: performing pre-competitive R&D in support of public purposes.
c) Mission-directed national projects: e.g., U.S. space program, development of the A-bomb.
d) Business R&D labs: focused largely on turning inventions and ideas into products.
e) Branch plants: use of foreign direct investment to import full-blown innovation. (This has been a prominent model in Canadian manufacturing.)

f) Business-university collaborations: the front end of some types of commercial innovation.
g) Venture capital: mobilization of finance and mentorship for risky projects.
h) Competition and trade policy, tax and regulatory policy, and subsidies and procurement: employment of the levers of government to create incentives and environments conducive to private-sector innovation.

These established models of innovation continue to be relevant and deserve to be supported and improved. But Canadians must also apply “innovation” to models of innovation themselves. These will be needed to adapt to new circumstances. Several were suggested and discussed by the Subgroup.

Perspectives on the Future

Drawing on the foregoing context, the ideas developed and discussed by the Subgroup can be encapsulated in the following three Statements that identify key developments that should give rise to new models of innovation over the next 10 to 15 years:

6.1 *Data* is recognized as the universal raw material supporting innovation in virtually every domain.

6.2 The “innovation” in Canada’s innovation policy emphasizes a systemic approach that unites academia, business, government, and civil society to improve competitiveness in broad areas of strategic opportunity.

6.3 As technology makes many jobs precarious, Canada is among the global leaders in exploring innovative models that promote and enable the creativity of individuals and their communities.

Several of the specific ideas originally submitted by Subgroup members are featured under each Statement to provide concrete *illustrations*. These Statements and illustrative examples are not intended to be hard and fast predictions or to present a comprehensive picture of Canada’s future. Rather, they comprise a number of informed perspectives on potential developments that Subgroup members believe will be important for innovation in Canada. Moreover, the Statements are to some extent aspirational, although the Subgroup believes they are achievable with sufficient commitment from the public and private sectors and from individuals.

6.1. *Data* is recognized as the universal raw material supporting innovation in virtually every domain.

There is growing acknowledgement that information technology is driving much of contemporary innovation, whether social, cultural, or technological. Data is the raw material. For example, self-driving cars would not be possible without access to GPS data for location; weather data for road conditions; and 3D object data for training AI-enabled driver-assistance systems.

The self-driving car poses immense technical challenges but at least the uncertainties it faces can largely be categorized and quantified, and need only exceed human capabilities in this regard. We can be reasonably confident that, with enough data and software, these kinds of “known-unknown” uncertainties can eventually be dealt with. More complex by far are the radical uncertainties characterized by “unknown-unknowns” where statistical models of prediction are inapplicable and we must fall back on human judgment and iterated experience. So as the Age of Data unfolds, it will be essential to explicitly distinguish between those decisions and understandings that more data can potentially resolve from those that it cannot. The more profound innovations will belong to the latter domain. Nevertheless, a great deal of useful innovation remains to be harvested from the exponential torrent of data that information technology will continue to generate, capture, and interpret.

Illustrative examples

6.1(a). Access to huge volumes of real-time data—from which behaviour can be predicted and manipulated—is a more important source of power and success than technology itself.

States, private enterprises, and individuals all potentially have access to the same technology, but not to the same *data*. That is why data will be the real differentiator going forward—more so than technology—and why Canadian decision-makers need to ensure that data is at the forefront of our economic and security agendas. A society and its government without access to real-time actionable data is at risk of yielding this space to trans-national infotech companies such as the so-called FAANGs. These behemoths already know more than governments in Canada about traffic patterns; real-time consumption patterns; even when and where the next pandemic could strike; and countless other metrics that constitute, in effect, the vital signs of society. Real-time actionable data will determine future winners. This trend will accelerate as more organizations use AI-enabled services to optimize operations and build new revenue streams, such as from data generated by the Internet of Things. So, a society without access to its real-time data, or a government too slow to regulate its use, will end up yielding its data to technology companies that collect, analyze, and repackage it, for private rather than for public purposes.

6.1(b). Innovative data trusts, combined with collaborative networks and open innovation, catalyze solutions to complex social, health, and environmental problems and enable economic opportunities.

The collection of ever-increasing amounts of personal data by tech companies and consumer businesses is reducing public trust and confidence in data collection and sharing, and is one more manifestation of a general erosion of public trust that is occurring in many spheres. This threatens to restrict Canada's ability to unlock the power of data to underpin innovation in a variety of social, health, environmental, and economic domains. One innovative solution is the concept of a data trust, which implements a model of citizen-centric innovation policy based on the idea that the data of individuals, subject to their consent, is a public good.

Data trusts create "virtual walls" around data. Data owners, whether individuals or organizations, allow a trust to collect/store their data on the condition that it is managed securely and used according to owners' collective wishes, e.g., location-based data used for medical research and not advertising. Early examples of data trusts have been established in the U.K., Israel, and California. The recently cancelled Sidewalk Toronto provides a cautionary tale about Canadians' high expectations for data governance and privacy.

Establishing a network of data trust platforms in Canada could enable a new era of open innovation, with organizations looking beyond their own resources to drive innovation by collaborating and co-developing solutions to complex social, health, and environmental issues. Approved users of the open innovation platforms could access the suitably anonymized data and use AI, blockchain, federated data, and cybersecurity technologies to develop new solutions in a privacy-protected environment. This approach could balance the individual's right to privacy with the public benefit to be gained by access to individual data, subject to regulations of the type introduced in the recently proposed *Digital Charter Implementation Act*. Canada has an opportunity to be among the world leaders in data trusts, with a trust-based digital ecosystem as a competitive advantage that could spur international adoption of "made-in-Canada" data and AI products and applications.

6.2. The "innovation" in Canada's innovation policy emphasizes a systemic approach that unites academia, business, government, and civil society to improve competitiveness in broad areas of strategic opportunity.

The focus here is on a more *systemic*, collaborative approach to innovation policy going forward, involving academia, industry, government, and members of civil society such as NGOs and community groups. A systemic focus is particularly important in developing truly disruptive technology, as illustrated by the discussion of deep tech below. Future innovation policy must also focus on collaboration. Innovation models, like the Creative Destruction Lab and MIT's The Engine, are successful because they bring together multidisciplinary teams and provide them with a neutral space, allowing them to explore problem spaces and co-create/design solutions. Building on these highly collaborative models, such as through innovation platforms and living labs,[21] will be critical to finding solutions to systemic challenges like sustainable energy, water and food security, and more equitable health.

Illustrative examples

6.2(a). Canada leads global innovation platforms that generate local value and provide international market access.

Scalable "innovation platforms", seen mainly in Europe and the U.K., can take many forms, but typically provide an arena for diverse stakeholders (e.g., government, citizens, academia, private industry, NGOs) to engage in collective co-creation and problem solving around common issues. The innovation platform concept is in many ways analogous to the business-led "innovation marketplaces" recommended by the 2016 Advisory Council on Economic Growth. The Council called for the federal government to help form these marketplaces around sectors and technologies where Canada already has momentum. The objective is to match the demand for innovation from companies and governments with the supply from researchers and entrepreneurs. (The government's $950 million Supercluster initiative appears to have been inspired by the Advisory Council's recommendation.) The idea is that innovation happens when innovators and entrepreneurs work alongside corporate or government customers to generate solutions to real commercial problems and pressing national challenges.

Recent initiatives towards developing Canadian innovation platforms/marketplaces include, in addition to the five Superclusters, the Canadian Agri-food Automation and Intelligence Network (CAAIN) and sector-based recommendations emanating from the federal government's Economic Strategy Tables. To date, the Innovation Superclusters are the most ambitious example of the model, but more time is needed to evaluate performance relative to high expectations for what must still be regarded as a learning opportunity.

6.2(b). Canada's "deep tech" ventures are a significant driver of GDP growth and a positive force for solving the world's most important problems.

Deep tech refers to foundational, general purpose technologies that are not focused on end-user services. They include, for example, AI, robotics, blockchain, advanced material science, photonics and electronics, biotech, and quantum computing. The significance of deep tech lies in the fact that these technologies are fundamental building blocks that radically improve existing, or build entirely new, products, businesses, and industries.

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[21] Westerlund and Leminen define living labs as "physical regions or virtual realities, or interaction spaces, in which stakeholders form public-private-people partnerships (4Ps) of companies, public agencies, universities, users, and other stakeholders, all collaborating for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts".

Deep tech has the potential to successfully tackle some of the world's most significant challenges, from climate change and sustainable food to chronic disease and pandemics. The problem is that deep tech startups require more capital and patience to germinate and scale up than many venture capital firms—attracted by the quick hit of the latest app or software gizmo—are willing to provide. This does not mean that deep tech ventures cannot provide even greater investment returns. It is just that the expected timelines and capital requirements for realizing the returns are *very* different. Consequently, the traditional venture capital commercialization model leaves much of the most promising and impactful research in deep tech on the sidelines instead of translating these ideas into socially transformative innovation through commercialization.

The further problem in Canada is that we do not have a domestic capital market structured to provide long-term patient capital to Canadian deep tech and scale-up firms. This structural problem cannot be overcome quickly, but the objective is nevertheless clear. Canada's innovation policy, which has squandered many opportunities, should prioritize long-term impact over short-term investment returns to support the research and patient capital needed to develop and commercialize deep tech, e.g., as described below in the special case of quantum technologies.

6.2(c). A vibrant quantum technology sector emerges from Canada's application of a new innovation ecosystem model that capitalizes on early advantages in quantum science & technology.

Canada has developed a vibrant quantum technologies ecosystem with a foundation of robust partnerships among government, universities, industry, and investors. These emerging technologies exploit unusual properties of matter and energy at the sub-atomic scale and include quantum computing (hardware, software, cryptography, and applications like material development), quantum sensing, quantum communications, among others. Canada, as one of the pioneers in the field, has a domestic producer of quantum computing hardware in D-Wave, considerable depth in quantum research, support for quantum technology education and startups, and supportive areas within the federal government, including the Department of National Defence and NRC.

However, Canada's early lead in quantum research and technologies faces increasingly stiff international competition. The U.S., EU, and China have all launched major national quantum computing initiatives within the last five years and China already has had some recent success in long-distance quantum communications. Given this scale of activity, there is reduced likelihood that a globally competitive Canadian quantum ecosystem will emerge *organically* from its current state.

To maintain its competitive advantage, Canada will likely need to provide strategic direction to catalyze an innovation ecosystem for quantum computing. The overall goal would be to build a thriving economic sector in the highly specialized hardware and software and related applications such as cryptography, secure communications, materials development, and sensing. One approach could be to set up a Canadian quantum-related "innovation platform" (as described above). Such a platform could build on the existing quantum network of participants and partnerships to more effectively diffuse quantum-related innovation, such as by providing startups with priority access to network resources (e.g., D-Wave's Leap quantum computing cloud). Establishing living labs across the country could facilitate faster learning and user-centred experimentation with quantum technologies, e.g., government departments interested in using quantum computing in operations.

6.3. As technology makes many jobs precarious, Canada is among the global leaders in exploring innovative models that promote and enable the creativity of individuals and their communities.

Many countries, including Canada, are pursuing the idea of a "Startup Nation", where entrepreneurship and innovation are encouraged and supported in equal measure. The general approach is to emulate Silicon Valley by developing innovation ecosystems that accelerate the creation of high-growth, high-tech startups. Canada has achieved some success, evidenced by the healthy tech startup community and growing availability of venture capital funding.

But is creating a "Silicon Valley North" a realistic or desirable goal for Canada? A relevant criticism of the current fashion in innovation ecosystems is that too often they have produced a homogenous culture that tends to crush competition, produce monopolies, and reflect low levels of diversity and inclusion. Moreover, despite an active startup environment, Canada struggles to scale up its technology-based startups into larger firms that can compete internationally. Instead, the later and larger rounds of venture capital are typically dominated by foreign (usually U.S.) investors who may then move most of the job growth and intellectual property out of Canada.

An alternative model of innovation would support creation of new methods, products, and ideas that deliver value at the community level. Entrepreneurs and communities working collectively could provide a more sustainable alternative to the current obsession with exponential growth. This approach is already being explored in Canada through the College and Community Innovation program and Carleton University's Centre for Community Innovation, among others.

As outlined below, *platform co-ops* could address the downsides of "gig work" and *community innovation hubs* could help Canadians transition to a future where automation and AI have disrupted the current model of work and its larger purpose.

Illustrative examples

6.3(a). Canadian digital platform co-ops increase and flourish in sectors beyond traditional "sharing economy" businesses.

The rise of companies like Uber and Airbnb reflects a shift towards a sharing economy where online services and digital technologies enable ad hoc sharing of resources previously used by a single individual or group. While this opens new work opportunities, an unintended consequence is the rise of gig work—a string of short-term, lower-income jobs managed by automated technology platforms that match labour with tasks on a project basis. Such precarious work is becoming the norm in Canada, accounting for more than 8% of the workforce in 2016, and undoubtedly greater since. Gig work is especially prevalent among lower-income Canadians.

AI-enabled platforms for services ranging from rideshares, to ghost kitchens, to long-term care are increasingly being used to maximize profit often at the expense of the gig worker. However, efforts to develop relevant policy is hampered by the difficulty in measuring the Canadian gig economy. This is compounded by the fact that these digital platforms are largely privately owned and based outside Canada. Thus their features may not reflect Canadian values or priorities.

In response, Canada could encourage the development of worker-owned (digital) platform co-operatives, building on, for example, a history of successful agricultural co-ops in the Prairies and financial co-ops in Quebec. Such co-ops would deliver the benefits of the sharing economy, but incorporate co-operative principles and governance models that shift ownership of the underlying technology platform to its workers. Examples include CoopCycle, active in more than 50 cities across eight countries, which helps delivery couriers launch their own co-ops by sharing a technology platform, customer-facing smartphone app, and knowledge about delivery service, business strategy, and pricing; and OCAD University's soon-to-be announced platform co-operative initiative for artists and designers.

One way to encourage creation of platform co-ops would be to establish government-funded digital commons accelerators (or "labs") that provide space, resources, talent, and guidance for them. Existing startup-oriented organizations (e.g., Communitech, District 3, IDEABOOST) could easily fit platform co-ops into their mandate.

With appropriate support and incentives, Canada could become a global champion of platform co-ops by 2030, as Canadian workers unite to create more agency for themselves and better service for their customers.

6.3(b). Interdisciplinary creative hubs in neighbourhoods across Canada foster a new sense of purpose and creative entrepreneurialism among citizens.

The future of work is currently top of mind as AI and automation loom large and policymakers seek to find ways to delay or cope with the negative effects in the workforce. There is renewed urgency as COVID-19 has accelerated trends already underway, e.g., more remote work and automation, increasing use of gig workers, and growing economic inequities. All these trends demonstrate the importance of community resilience. New models proposed in this regard include portable benefits for gig workers and micro-credentials.

Rapid pandemic-driven technological and organizational changes have also re-opened the debate on what a job should represent in the future and where an individual's "purpose" could be found, if no longer in employment. This is all the more relevant given that 80% of employees, globally, feel disengaged from their work. Nevertheless, the millennials entering the workforce expect fulfillment, social engagement, and creativity from their jobs. Many studies on the future of work emphasize "soft skills", such as creativity, leadership, and ethical thinking, along with active learning, and reskilling. But transitioning the Canadian workforce from its current state of "just showing up" to one focused on creativity and leadership is clearly challenging.

Income support tools (e.g., continuing vocational education and training programs that are well integrated into the social security system, along the lines of Denmark's flexicurity system; the potential for universal basic income, UBI) could not only help ease the workforce transition and alleviate poverty, but also incentivize creative work more effectively than traditional pecuniary rewards. In short, innovative income support could help shift Canadians from doing meaningless work for money towards using money for meaningful work.

The introduction of some form of UBI in Canada could unleash a torrent of creative output whose value lies in the creation of an object or experience, such as in gardening, painting, song writing, carpentry, design, or software coding. Such creative work could be facilitated and organized in neighbourhood "creative hubs". These hubs would provide professionals and citizens with a sense of purpose and create innovative new forms of value exchange in local communities.

CONCLUDING OBSERVATIONS ON COMMON THEMES

The foregoing chapters structure the Working Group's perspectives on Canada's mid-term future (2030-35) under six broad subject areas: Climate Change, Resource Futures, Big Data & AI, Cybersecurity & Privacy, Health-care Futures, and New Models of Innovation. These categories were chosen as a way to tap into the Group's domain-specific expertise as represented by the 17 Statements and 41 illustrative examples that constitute the core of this report. But cutting across the specifics were five repeated themes:

- Competitiveness
- Data as a strategic resource
- Sustainability and resilience
- Community engagement
- Equity, diversity, and inclusion

Without attempting to capture the full richness of the Working Group's discussions, following is a sample of the salient observations.

Competitiveness

The continued competitiveness of Canada's economy—essentially its capacity to deliver a rising average standard of living at a rate comparable to or exceeding that of other advanced countries[22]—is a precondition for most of the future portraits described in this report. Competitiveness is necessary to provide fulfilling and well-paying jobs as well as the tax base to support social policy and other collective objectives. But competitiveness alone is not sufficient to ensure the equitable distribution of the benefits of economic growth. That depends on the political choices we make. Nevertheless, national competitiveness (proxied by GDP growth) constrains the total amount that can be distributed.

Competitiveness is closely linked to the innovative capacity of a society, which comprises not only its S&T competencies but also a base of relevant talent, the prevalence of entrepreneurial creativity, willingness to take risks, and receptivity to diverse perspectives—all together with a policy environment that promotes these elements. Canada has actually fared better in these respects than is suggested by the country's mediocre ranking according to most conventional innovation indicators, e.g., business R&D spending, the trade balance in technology-intensive products. The fact is that Canada's economic performance, on average, has been consistently among the leaders. But competitiveness involves a race without a finish line so both the pressure and the opportunity to do better always self-renew.

As a rich resource-oriented economy with a large presence of U.S.-owned branch plants, Canada has prospered despite often being a *taker* rather than a *maker* of technologically advanced products. Partly this is inevitable for a relatively small economy and particularly given Canada's integration with the U.S. colossus. That is why, looking forward, Canada must pick its spots in specific areas of advantage where it can meet the test of international competition as a "maker" while also increasing its capacity to be a quick, smart "taker" of the best ideas and practices from around the world.

[22] A frequently cited measure of *national* competitiveness is the rate of growth of GDP per capita, or sometimes GDP per hour worked (labour productivity). Although GDP has many limitations as an indicator of quality of life, it nevertheless correlates with many social indicators. Competitiveness is more commonly thought of as the ability of a domestic industry or an individual company to thrive in its relevant market, which will often be international. Canada's competitiveness, in whatever way it is measured, is ultimately determined by the competitiveness of many thousands of individual enterprises.

Data as a Strategic Resource

The collection and analysis of data has always been foundational in the natural and social sciences and in applied domains like engineering and medicine. But as data has been exponentially amplified by information technology—sensors, communications linkages, and computers and software—it has become a *prime mover* in virtually every field. In applications ranging, for example, from precision agriculture, forest genomics, climate observations of unprecedented granularity, "training" for AI systems, to wearable sensors that record health status continuously, the acquisition and analysis of data is now at the cutting edge of innovation, not only in S&T but in virtually every aspect of economic, social, and cultural life. As data has thus become a mission critical resource, issues associated with the security and control of data, and with public trust in the sources and uses of data, have become paramount.

It can be expected that "data", in its expanding manifestations, will feature ever more prominently in all the domains covered in this report. It is already taking its place, along with labour, energy, and capital investment, as a primary factor of production in the 21st century economy, and as a principal driver of social and cultural change. In short, data (comprising its collection, analysis, communication, ownership, and use) must now be regarded as a strategic national resource, necessary to build Canada's economic competitiveness, to sustain a leadership role in S&T, and to foster cultural innovation and independence. This will require Canada to create a world-class data infrastructure, develop talent to match, and implement policies that ensure equitable access to the expanding benefits.

Sustainability and Resilience

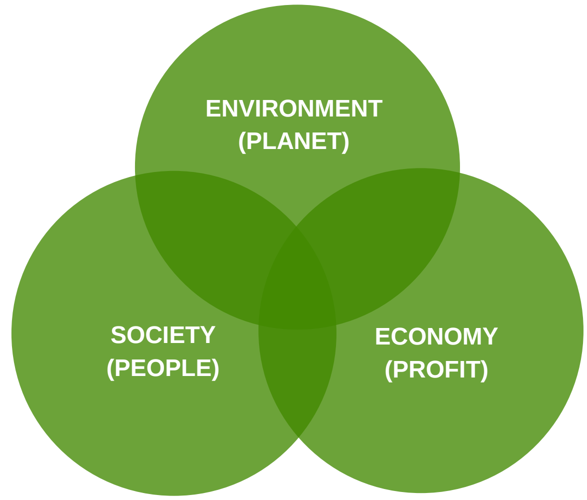
Sustainability is a watchword of the 21st century. It has risen in public consciousness in parallel with the exponentially growing impact of the human species on both animate and inanimate Nature. The concept of sustainability originated in an environmental context but has broadened to encompass economic and socio-cultural aspects—the triple bottom line. The interaction can also be symbolized in the catch phrase, *Planet + People + Profit*, among which a dynamic balance must be struck that "meets the needs of the present without compromising the ability of future generations to meet their own needs."[23]

The sustainability theme is clearly prominent in the climate change and resource futures chapters. In the latter case, the contemporary understanding of sustainability includes not only minimizing environmental impact but also taking fully into account the effects, positive and potentially negative, of resource development on local communities and Indigenous rights holders.

[23] Definition of sustainable development put forward in the UN's Brundtland Commission report.

Sustainability is also linked with *resilience* since the capacity to withstand shocks, whether natural or human-caused, will often be a precondition for sustainability.

For example, developing resilient adaptation to climate change will clearly be of growing importance. The COVID-19 experience has also demonstrated the need to invest to make health-care systems more resilient. (At the same time, technical and operational innovation is required to make health care fiscally *sustainable* as the population ages.) And, as we become progressively more dependent on cyber-systems, increased investment will be needed to ensure their resilience to both natural failure and deliberate attack. More generally, sustainability and resilience should become fundamental design considerations "baked into" models of innovation from the outset because once the need becomes apparent it could be too late.



THE 3 Ps OF SUSTAINABILITY

Community Engagement

There was a time, not that long ago, when science and technology were widely regarded as activities to be admired and appreciated, but best left largely to the experts. Today, as communities and individuals better recognize the transformative influence of S&T, they are less prepared to delegate. Symptomatic of this attitudinal shift was a recurring emphasis, in Working Group sessions, on non-technical aspects of the technologies under discussion: e.g., which societal goals would a particular technology actually serve? what factors could enhance public trust and acceptance? would there be equitable access for Indigenous and disadvantaged groups and individuals? would communities be adequately engaged in the decisions that affected them? Narrowly technical questions tended to receive less attention. This does not appear to have been due to the particular make-up of the Working Group. A similar theme was evident in a recent symposium sponsored by the U.S. National Academies.[24]

Community Engagement in S&T: A View from the U.S. National Academy of Sciences

Interactions between science and the broader society would keep the research enterprise from bulldozing over fundamental questions of identity, belonging, and sense of community. When we put community at the center, it's a different problem that we are trying to solve and then the conversation changes. Such conversations benefit all parties including scientists. They identify questions or approaches not previously considered, provide new reasons for investing in research, and better reveal the value and potential of research. The result is more than just the co-production of knowledge. It changes the culture of institutions. The overall challenge is to ensure that people have more agency in achieving their own priorities through S&T.

[24] The symposium celebrated the 75th anniversary of the publication in 1945 of a seminal monograph by Vanever Bush (an advisor to U.S. President Truman), entitled: *Science, the Endless Frontier*. Participants reflected on changes since that time and prospects for the next 75 years.

The [U.S.] federal government has been very intentional about setting up an infrastructure for research to support commercialization. It has been less intentional about building on models that have been fruitful for engaging more people in innovation and creating opportunity. Engaging the public in science requires building an infrastructure to harness the tools and the processes of answering questions and applying those answers in a way that addresses community priorities, not just the priorities of those inside the system. Building such an infrastructure can be done from the bottom up or the top down in different kinds of institutions. But there are some things that only the federal government can do at scale to incentivize all of us to change practices. For example, one practical step would be to overhaul the public comment process at federal science agencies. Another would be to leverage existing institutions for public engagement, including science museums, after-school programs, and other places where families gather.

Source: *The Endless Frontier—The Next 75 Years in Science*, pp18-19. Lightly edited excerpts.

Equity, Diversity, and Inclusion (EDI)

The application of an EDI lens to a growing spectrum of institutions and activities—S&T very much included—constitutes a paradigm shift in Canadian society that is still in the formative stages of implementation. The EDI movement cuts across all the domains examined in this report and reflects the growing recognition that technology is rarely neutral and cannot be decoupled from its economic, societal, and cultural context. Too often this has been a context in which the interests of Indigenous, racialized, and otherwise marginalized groups and individuals have been ignored or inadequately recognized.

While accommodating diversity is sometimes a challenge since many voices and perspectives can slow the consensus needed to act, diversity is also a distinguishing Canadian strength. Canada's extraordinary diversity of cultural and regional perspectives is clearly a competitive advantage in the context of globalization. At the same time, a diversity of experience and perspective is often a source of innovation as well as providing the variety that contributes to societal resilience.[25]

In Conclusion

The perspectives on 2030-35 contributed by the Working Group and compiled in this report paint a portrait of a successful society in which technology is developed in the service of human goals with the benefits equitably shared. The viewpoint is justifiably optimistic in view of Canada's extraordinary gifts and capabilities but also acknowledges that significant challenges will need to be overcome. Technology will play a vital role, enabling Canadians to meet the challenges and embrace the opportunities, guided by human purpose.

[25] By analogy with rich ecosystems, variety better equips a society to respond to a wide range of opportunities and threats and to avoid the trap of *groupthink*. In short, a wide variety of perspectives tends to make a society more innovative and adaptive, and therefore resilient.

ANNEX I: WORKING GROUP MEMBERS

Disclaimer: This report is a collaborative product of the Working Group. Although it has benefitted from, and reflects, the input and critique of all Working Group members, not every member of the Working Group would necessarily agree with every statement or with the choice of emphasis. A spectrum of views regarding the future is both inevitable and proper.

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