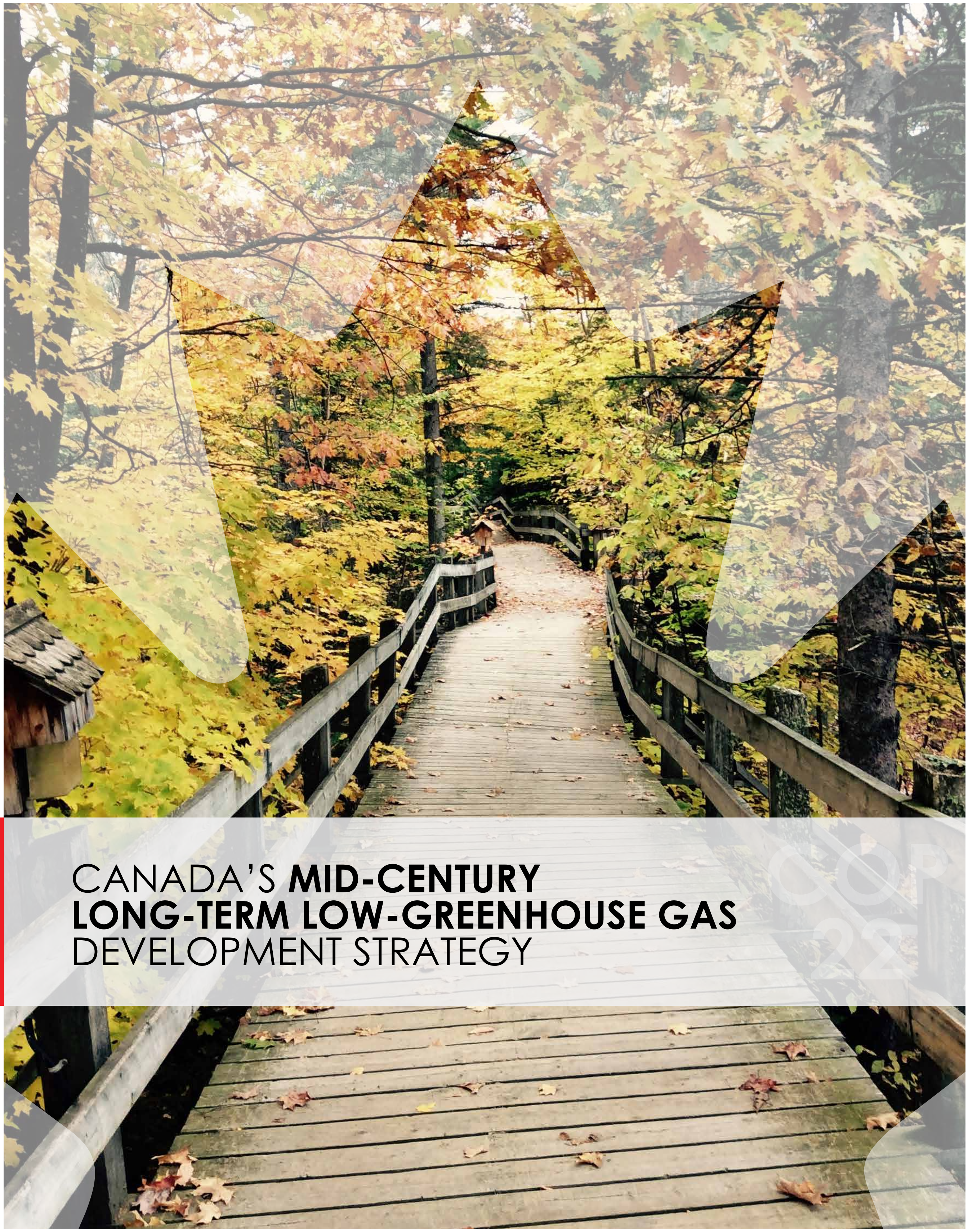
Government of Canada Gouvernement du Canada



CANADA'S **MID-CENTURY LONG-TERM LOW-GREENHOUSE GAS** DEVELOPMENT STRATEGY

Canada

Cat. N°.: 978-0-660-06577-9
ISBN: En4-291/2016E-PDF

Environment and Climate Change Canada
Public Inquiries Centre
7th Floor, Fontaine Building
200 Sacré-Coeur Boulevard
Gatineau QC K1A 0H3
Telephone: 819-997-2800
Toll Free: 1-800-668-6767 (in Canada only)
Email: ec.enviroinfo.ec@canada.ca

Aussi disponible en français

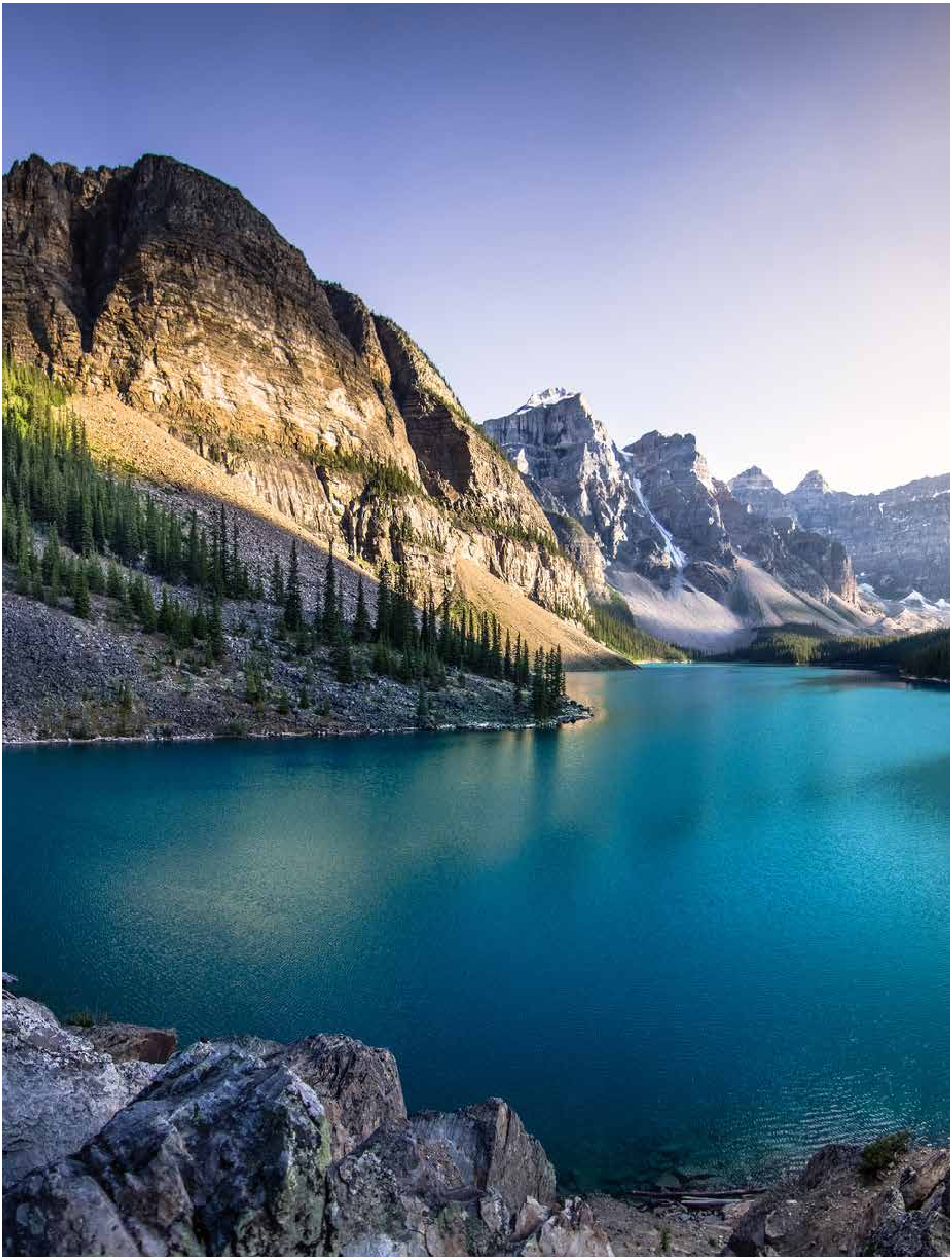
Contents

Foreword

Canada views this initial Mid-Century Strategy report as an opportunity to begin the conversation about what a long-term low-greenhouse gas emission society would entail. The report provides a basic framework regarding what challenges and opportunities have currently been identified in academic literature and expert based analyses regarding deep emissions reductions in the mid to long-term.

Canada submits this strategy to the *United Nations Framework Convention on Climate Change* (UNFCCC) under the premise that the content of the report will continue to be updated and adjusted as Canada advances on the implementation of its low-carbon development pathway. As such, Canada's position is that the Mid-Century Strategies should be submitted in an iterative or cyclical process, where Parties provide regular updates as low-GHG technologies and national circumstances continue to evolve.

This iterative process will allow the Canadian public, experts, and stakeholder communities, to provide substance to this framework as Canada moves towards a common global objective of reducing greenhouse gas emissions.



Executive Summary

Canada is committed to creating a cleaner, more innovative economy that reduces emissions and protects the environment, while creating well-paying jobs and promoting robust economic growth.

A low-greenhouse gas future represents an opportunity to increase prosperity and the well-being of Canadians, to improve the livability of the built environment, modernise transportation, and enhance the natural environment.

Canada's actions on climate change will help communities in Canada in tangible and meaningful ways, since clean growth is not just good for the planet — it's also good for the economy. The benefits include: reducing air pollution and congestion, modernising infrastructure to provide more inclusive and sustainable cities, creating cleaner and more modern communities, growing Canada's clean technology sector, increasing economic productivity and efficiency, saving energy and reducing energy costs, and enhancing resilience to the impacts of climate change.

Addressing climate change paves the way towards innovation and jobs in the clean energy and technology sectors. This represents an opportunity to adopt innovations that can enhance quality of life. Canada is investing in a cleaner future for our children and grandchildren, and creating the right conditions for communities everywhere to create good jobs in a modern, clean global economy.

For the purpose of the Mid-Century Strategy, Canada examines an emissions abatement pathway consistent with net emissions falling by 80% in 2050 from 2005 levels. This is consistent with the Paris Agreement's 2°C to 1.5°C temperature goal.

The Paris Agreement, adopted at the 21st Conference of the Parties (COP21) to the *United Nations Framework Convention on Climate Change (UNFCCC)*, represents the first time in history that virtually all of the world's nations agreed to pursue their highest possible ambition to combat climate change under a common framework. Through the Paris Agreement over 195 countries representing 97% of global GHG emissions agreed to strengthen the global response to the threat of climate change, including by holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels.

Building on analyses from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, the United Nations Environment Programme (UNEP) states that GHG emission reductions in the order of 70 to 95% below 2010 levels would be required by 2050 to remain on a pathway consistent with a >50% likelihood of limiting average global temperature rise to 1.5°C. Achieving this temperature goal is only possible through actions on carbon dioxide and short-lived climate pollutants (SLCPs) together. For the purpose of the *Mid-Century Strategy*, Canada examines an emissions abatement pathway consistent with net emissions falling by 80% from 2005 levels.

Reducing greenhouse gas emissions to levels consistent with the reasonable probability of maintaining this temperature goal will not be easy. It will require substantial effort on the part of all Canadians, with a fundamental restructuring of multiple sectors of the economy. Cost-effective abatement opportunities will need to be realised from virtually every greenhouse gas emissions source and activity. In the energy sector, this will include enhanced energy efficiency and conservation, finding cleaner ways to produce and store electricity, and switching towards non-emitting electricity or other low-GHG alternatives.

Although this will require thoughtful and significant effort on the part of all Canadians (including robust government policy such as carbon pricing, regulatory measures, and support for technology development), the cost of inaction poses a dire risk that cannot be ignored. This risk is threefold:

- Ongoing emissions of anthropogenic GHGs will cause atmospheric concentrations to continue to rise, leading to higher global average temperatures and a cascade of related impacts, including increases in severe weather, and rising sea level.
- Failure to act now means that costs will likely rise in the future as the required pace of decarbonisation increases. This raises the probability of misallocation of investment and infrastructure, as well as stranded assets.
- As the world moves to address climate change, Canada should not be left behind in the emerging global markets for clean energy and related goods and services.

A global clean growth economy offers considerable economic opportunities and co-benefits such as growing Canada's clean technology sector, using more efficient technology globally, mitigating other types of pollutants, improving health and air quality, and increasing productivity through more efficient life cycle production.

Responding to climate change presents an opportunity for Canada to discover and adopt new and innovative ways to enhance our quality of life, while ensuring that this prosperity is sustainable given finite natural resources and environmental concerns. For example, designing low-carbon buildings can save on energy requirements and heating, cooling, and electricity costs, while increasing natural light and airflow. As another example, reducing traffic congestion through more sustainable movement of people and goods would reduce GHG emissions as well as air and noise pollution, save travel time, and lead to healthier and more productive cities. Often through analysing supply chains, or life-cycle assessments of final products, solutions can be found that are environmentally, socially, as well as economically preferable.

Finding low-GHG solutions will also provide Canada with opportunities to help other countries that are also pursuing low-GHG objectives. Canada's clean technology sector has grown substantially over the last few years, and there continues to be considerable prospects for continued growth in the sector. Further investments in research, development and deployment (RD&D) of clean technology, will support Canada's competitiveness in the short and long term, both in emerging and traditional market, creating higher paying jobs, and stimulating exports.

Through "Mission Innovation", Canada along with 20 governments and the European Union, have agreed to double their respective investments in transformative, clean energy research and development over five years, encourage private sector investment in clean energy technology, and increase collaboration among participating countries. Canada is making key investments in clean energy and emissions-reducing technology to accelerate domestic adoption and to deploy our energy know-how and technology to markets around the world. Adopting innovative technologies in the natural resources sectors (energy, mining, forestry, agriculture, and fisheries) will promote Canada's international leadership in sustainable resource development, providing prosperity to Canadians.

While today's technologies and knowledge can significantly reduce emissions, the transition to a low-carbon economy can be eased through innovation, a scale up of RD&D investment, and private sector investment.

Most international and Canadian greenhouse gas mid-century abatement analyses note that deep cuts in emissions are possible with today's technology, although mitigation costs remain high in certain areas. For example, an assessment from the Council of Canadian Academies published in 2015, suggests that Canada can significantly reduce GHG emissions by using commercially available technologies in key sectors of the economy. Studies consistently point to currently deployed technologies as being essential components to the climate change solution, such as expanding the use of non-emitting electricity across end-use sectors, increasing the use of alternative fuels, and improving energy conservation and efficiency.

Many studies also note that new and emerging technologies can help to smooth our transition to a low GHG economy. For example, the International Energy Agency (IEA) demonstrates that a sustainable energy transition is possible with currently deployed or near-commercial technologies, but that the long-term transition will be eased (in terms of investment requirements and timing) with the near-term acceleration of deployment of clean energy options, or the development of more innovative technologies. The IEA highlights that current global RD&D investments are well below what is required to achieve our international climate goals.

Likewise, substantial financial investments are needed from the private sector to move towards a low-GHG future, and related risks and opportunities associated with these investments should be identified early. Carbon pricing can provide the market signal required for private sector investment and innovation. Technology developers and users are best positioned to bring forward new technologies that will ultimately succeed. Innovation in clean technologies, whether it is a breakthrough technology or one that improves the efficiency of an existing process, can lead to significant GHG abatement internationally as the new technology becomes utilised globally.

Canada's mid-century and long-term objectives will be ultimately realized though short-term concrete action.

Canada's Mid-Century Strategy is not a blueprint for action, and it is not policy prescriptive. Rather, the report is meant to inform the conversation about how Canada can achieve a low-carbon economy. This includes describing modelling analyses that illustrate various scenarios towards deep emissions reductions. Canada's Mid-Century Strategy outlines potential GHG abatement opportunities, emerging key technologies, and identifies areas where emissions reductions will be more challenging and require policy focus in the context of a low carbon economy by 2050.

To deliver on Canada's short term action, the Government of Canada is working closely with provinces and territories, and with National Indigenous Organizations to finalize a pan-Canadian framework for clean growth and climate change, which will include actions to reduce emissions, build resilience, and spur innovation and create jobs.

This will develop Canada's plan for meeting the 2030 target of reducing GHG emissions to 30% below 2005 levels, and also includes a carbon pricing framework. The pan-Canadian framework will pave the way towards innovation and jobs in the clean energy sector, and help Canadians manage the effects of climate change, by building capacity for adaptation and strengthening resilience.

On March 3, 2016, Canada's First Ministers and Indigenous Leaders met in Vancouver and committed to developing a concrete plan to achieve Canada's international greenhouse gas reduction commitments through a pan-Canadian framework for clean growth and climate change. Canada's First Ministers released the Vancouver Declaration in which they agreed to build on commitments and actions already taken by provinces and territories in order to meet or exceed Canada's GHG emissions targets. They highlighted the need to foster investment to promote clean economic growth and create jobs that support the transition to a low-carbon economy, while benefitting individual Canadians and addressing competitiveness impacts on businesses. They committed to deliver mitigation actions by adopting a broad range of domestic measures, including carbon pricing mechanisms, adapted to each jurisdiction's specific circumstances. Commitments were also made to develop and implement strong, complementary adaptation policies and action on climate resilience to address climate risks facing our populations, infrastructure, economies and ecosystems, and Canada's northern regions in particular.

The Mid-Century Strategy will help inform the pan-Canadian framework, while long term planning is essential to infrastructure and energy investments, setting the course for a low-carbon future.

The development of a Mid-Century Strategy is an essential step to set the course towards a low-carbon economy as it will inform longer term planning and investment. Long-term planning is fundamental for creating and managing robust energy systems, and careful and far-sighted policy making is essential to combat climate change in an economically efficient, socially acceptable, and effective manner. Because of the long-lived nature of some energy supply and demand equipment, investments and policy decisions made today will affect the level of greenhouse gases in 2050. For example, many of the buildings and electricity generating facilities built today will continue to be operational in 2050. Once these assets are locked-in, replacing them with cleaner alternatives will impose additional costs and complexity. Likewise, government policies should be designed with both a shorter term as well as longer-term focus, ensuring that greenhouse gas emissions will continue to decline towards a low-GHG future.

By aligning its goals to the UNFCCC temperature goals, Canada now has an opportunity to integrate climate change objectives into its long term planning processes. Although this report does not propose specific policies, it identifies key options for Canada's low-GHG development. For example, the anticipation of significant growth in Canadian electricity demand should underpin mid-century investment and planning. Planners should keep in mind that this increased demand will stem from both Canadian applications as they switch away from more carbon intensive energy sources, as well as potentially supplying clean electricity to our continental neighbours. As another example, planners should note that regional differences will be a key consideration due to the variation in electricity generating portfolios, and technical capacities from one jurisdiction to another.

Carbon dioxide removal is fundamental to limiting the increase in the global average temperature to well below 2°C.

Forests play a key role in carbon sequestration. This can be enhanced through forest management activities, increased use of long-lived harvested wood products, and increased utilization of waste wood biomass.

In order to increase the likelihood of limiting global temperature rise to well below 2°C, net "negative" carbon dioxide emissions (i.e., more emissions sequestered through anthropogenic means than are released to the atmosphere) will be required this century. Negative carbon dioxide emissions may be achieved with large-scale afforestation, or bioenergy with carbon capture and storage (BECCS), the latter being a key feature in the great majority of 1.5°C and 2.0°C scenarios in the current literature.

Carbon capture and storage (CCS) technologies offer one avenue for preventing emissions to the atmosphere. For example, the oil and gas sector can take advantage of its proximity to geological reservoirs to store carbon emissions captured on site. The iron and steel, pulp and paper, chemical, and cement sectors also have potential for emissions reduction through CCS. Negative carbon dioxide emissions can be achieved when carbon capture and storage technologies are combined with the use of energy from biomass (BECCS). In this case, the carbon that is removed from the atmosphere, and sequestered through vegetation growth, is captured and stored when the plant material is used to generate energy. If BECCS were to be deployed at sufficient scale, there is the potential to achieve net negative global carbon dioxide emissions, although the feasibility of large scale deployment of negative emissions technologies is still unknown.

A number of other options are also being investigated globally that have the potential to remove carbon dioxide from the atmosphere and contribute to the achievement of global net negative emissions (e.g. conversion of carbon dioxide into algal biomass). These options are at various stages of research, development and deployment. Much more investment and innovation is needed to fully assess the potential of these measures to contribute to achieving global temperature goals and sustainable development objectives.

All regions and sectors must act to reduce emissions, but specific abatement pathways could differ from one jurisdiction to another. Regional cooperation will be key to our success.

The Strategy that we present constitutes a growing consensus over possible avenues for low-carbon development informed by independent expert analysis.

This Strategy identifies key objectives and building blocks that could underlie our transition to a low-GHG economy. These building blocks frame the foundation of Canada's long term climate change mitigation strategy:

- Electrification has been identified as an essential step in all deep GHG mitigation analyses. The electrification of end use applications that are currently using fossil fuels is fundamental, for example, using electricity to power certain cars, trucks, building appliances and heating systems, and energy requirements for some industries.
- Concurrent trends towards decarbonisation of the electricity generating sector are needed. Electricity generation in Canada is already more than 80% non-emitting, with a trend towards non-emitting generation expected to continue, including through increased government action.
- The significant increase in electricity demand resulting from electrification policies (e.g., doubling or more by 2050), and electricity exports, should be satisfied through low-carbon sources.
- Canada, and North America's, electricity future will be shaped by interprovincial and intercontinental cooperation. Enhanced interjurisdictional electricity transmission interties could allow areas with hydropower, or other forms of non-emitting generation, to sell electricity to other provinces or U.S. States that rely on fossil fuels.
- Energy efficiency and demand side management are key to achieving deep GHG reductions. For example, the International Energy Agency (IEA) estimates that 38% of the required global emissions reductions associated with a 2°C pathway could be met through energy efficiency improvements. Efficiency gains are also key enablers of electrification technologies and consumer savings.
- Some sectors such as heavy industries, marine transportation, some heavy freight transportation, and aviation could move to lower or low-carbon fuels such as second generation biofuels or hydrogen. Alternatively, new and emerging technologies in synthetic hydrocarbons or energy storage would be needed.
- Abatement of non-carbon dioxide greenhouse gases, such as methane and hydrofluorocarbons, is a priority given their high global warming potentials. Reductions of these pollutants can often help slow the rate of near-term warming and contribute to achievement of the global temperature goal. Although black carbon is not classified as a greenhouse gas, it has strong global warming effects that must also be addressed.
- Behavioural changes will also contribute to a low-GHG economy. For example, innovative approaches to moving people and freight are likely to become more widely adopted over the next 35 years, as well as changes in the way people live, work, and consume.
- Cities are home to 70% of the world's energy-related carbon dioxide emissions. Canadian cities host 80% of the national population, compared to 62% sixty years ago. With a continuing trend in urbanization for the upcoming decades, cities across Canada cannot afford to wait to increase climate change mitigation and adaptation efforts.
- Canada's forests and lands will continue to play an important role in sequestering substantial amounts of carbon dioxide from the atmosphere. This sequestration can be augmented through policies and measures that better manage our forests and forest products. Without consideration of the global land sector, the 1.5 to 2°C temperature goal will be very hard to achieve.
- Innovation will also be crucial. A sustainable energy transition is possible with currently deployed or near-commercial technologies, but the long-term transition will be eased with the near-term accelerated deployment of clean energy options, or the development of more innovative technologies. The private sector has an important role to play in this respect including spurring investment and innovation towards low GHG alternatives. Carbon pricing will be an important element to achieving this objective.
- Collaboration with provinces and territories, Indigenous peoples, municipalities, business and other stakeholders will be essential to Canada's long-term success in enabling clean growth, reducing emissions and seizing the opportunities of the low-carbon global economy.

1 Context

KEY MESSAGES:

- Most Canadians recognise the need to mitigate climate change and limit the increase in the global average temperature, but the magnitude of the challenge is less well understood, with a requirement for very deep emissions cuts from every sector by mid-century.
- Mitigating greenhouse gas emissions is necessary to avoid the increasing threat presented by climate change. Benefits of action to reduce climate risk will outweigh costs and the international community is moving towards low-greenhouse gas economies. A particular focus on short-lived climate pollutants is also required if we are to stay below the 1.5°C - 2°C temperature goal.
- Canada has worked closely with the United States and Mexico in the development of this report. Our continental partners have also described ambitious mitigation action by 2050 in their respective strategies.
- Encouraging international efforts, including reducing emissions in other countries will be key to the global response.
- Working collaboratively with Indigenous peoples by supporting their on-going implementation of climate change initiatives will be key. Consultations with Indigenous communities must respect the constitutional, legal, and international obligations that Canada has for its Indigenous peoples.
- The Mid-Century Strategy will help inform the pan-Canadian framework (PCF) for clean growth and climate change.

1.1 Most Canadians recognise the need to mitigate climate change and limit the increase in the global average temperature, but the magnitude of the challenge is less well understood, with a requirement for very deep emissions cuts from every sector by mid-century.

Canada played a leadership role in advancing the adoption of the Paris Agreement and supporting the global temperature goal of holding the increase in the global average temperature to well below 2°C and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. Ensuring that the global temperature remains well below 2°C will require global greenhouse gas emissions to peak as soon as possible with a rapid decline in emissions thereafter. It will also require fast concurrent actions on short-lived climate pollutants (SLCPs) (see chapter 5).

The latest assessment report from the Intergovernmental Panel on Climate Change (IPCC) relied on a range of models to examine feasible scenarios for global emissions trajectories consistent with limiting global warming to less than 2°C. Building from this analysis, a recent study from the United Nations Environment Programme (2015)[1] found that scenarios consistent with limiting warming to 2°C, with a >66% chance, reach net zero global anthropogenic carbon dioxide emissions by about 2070, while those consistent with limiting warming to 1.5°C with a > 50% chance reach net zero carbon dioxide emissions by about 2050.

1 United Nations Environment Programme, *Emissions Gap Report 2015*.

Net "*negative*" carbon dioxide emissions (i.e., more emissions are sequestered through anthropogenic means than released to the atmosphere) would then be required later in the century to meet the temperature goal. Negative carbon dioxide emissions may be achieved, for example, with large-scale afforestation or bioenergy with carbon capture and storage. Negative CO_2 emissions are required in these scenarios to offset hard-to-mitigate non-CO_2 emissions (e.g., methane and nitrous oxide emissions associated with food production), in order to achieve net zero global anthropogenic GHG emissions.

In terms of total greenhouse gas emissions, according to the IPCC's Fifth Assessment Report, a limited number of studies provide scenarios that are more likely than not to limit warming to 1.5°C by 2100; these scenarios are characterized by GHG concentrations below 430 ppm CO_2-eq by 2100 and 2050 emission reduction between 70% and 95% below 2010.[2]

In this context, the United States noted that its Intended Nationally Determined Contribution target is consistent with a straight line emission reduction pathway from 2020 to deep, economy-wide emission reductions of 80% or more by 2050. Other jurisdictions such as Japan and the EU have adopted similar goals. For the purpose of the *Mid-Century Strategy*, Canada examines an emissions abatement pathway consistent with net emissions falling by 80% from 2005 levels.

1.2 Mitigating greenhouse gas emissions is necessary to avoid the increasing threat presented by climate change. Benefits of action to reduce climate risk will outweigh costs and the international community is moving towards low-greenhouse gas economies. A particular focus on short-lived climate pollutants is also required if we are to stay below the 1.5°C - 2°C temperature goal.

The consequences of inaction to reach the temperature goals are severe, and will have an impact on the global environment, health, and quality of life. The global average temperature is projected to continue to increase well beyond 2°C over the 21st century if no further action is taken. With some regions of the world experiencing severe effects earlier than others, including in some of the most vulnerable areas.

The IPCC concluded that global climate change risks are high to very high with global mean temperature increases of 4°C or more above preindustrial levels, consistent with expected levels by 2100 under a business-as-usual scenario. These risks include substantial species extinction, large risks to global and regional food security, and compromised normal human activities such as growing food or working outdoors due to the combination of high temperature and humidity. These risks are reduced substantially under scenarios which limit global warming to 2°C or lower.[3]

Several studies have shown that the cost to address climate change decreases if early action is taken. For example, in 2014, the White House's Council of Economic Advisers published a report stating that for the same level of temperature stabilisation, each decade of delayed mitigation effort leads to a 40% increase in net mitigation costs.[4] A 2012 Navius Research report, which considered the implications of policy delay in the context of an aggressive 2050 target, suggested that a delay in domestic GHG policy action from 2012 to 2020 could cost Canada an additional $87 billion over the 2020 to 2050 period, which represents an increase of about 27% in the cost of abatement.[5]

In addition, several studies suggest that the benefits of mitigation action can often outweigh the cost over the long run in terms of energy and fuel savings though resource efficiency gains. For example, a recent New Climate Economy Report shows that cities globally could save $16.6 trillion over the 2015-2050 period through investments in projects such as mass transit and energy efficient buildings.[6] Although there is inherent uncertainty around predicting far into the future, the agreement in the literature reinforces the point that early action on climate change is crucial to reducing the overall cost of climate change over time.

1.3 Canada has worked closely with the United States and Mexico in the development of this report. Our continental partners have also described ambitious mitigation action by 2050 in their respective strategies.

As described in the *Leaders' Statement on a North American Climate, Clean Energy, and Environment*

2 IPCC, Climate Change 2014: Synthesis Report. *Summary for Policymaker*

3 Intergovernmental Panel on Climate Change, *Climate Change 2014; Impacts Adaptation and Vulnerability.*

4 Executive Office of the President of the United States, *The Cost of Delaying Action to Stem Climate Change.*

5 Navius Research Inc., *Investment and Lock-In Analysis for Canada: Low Carbon Scenarios to 2050.*

6 Global Commission on the Economy and Climate, *The Sustainable Infrastructure Imperative: Financing for Better Growth and Development.*

Partnership, North America has the capacity, resources, and the moral imperative to show strong leadership building on the Paris Agreement, which entered into force on November 4, 2016. We recognize that our highly integrated economies and energy systems afford a tremendous opportunity to harness growth in our continuing transition to a clean energy economy. Our actions to align climate and energy policies will protect human health and help level the playing field for our businesses, households, and workers.

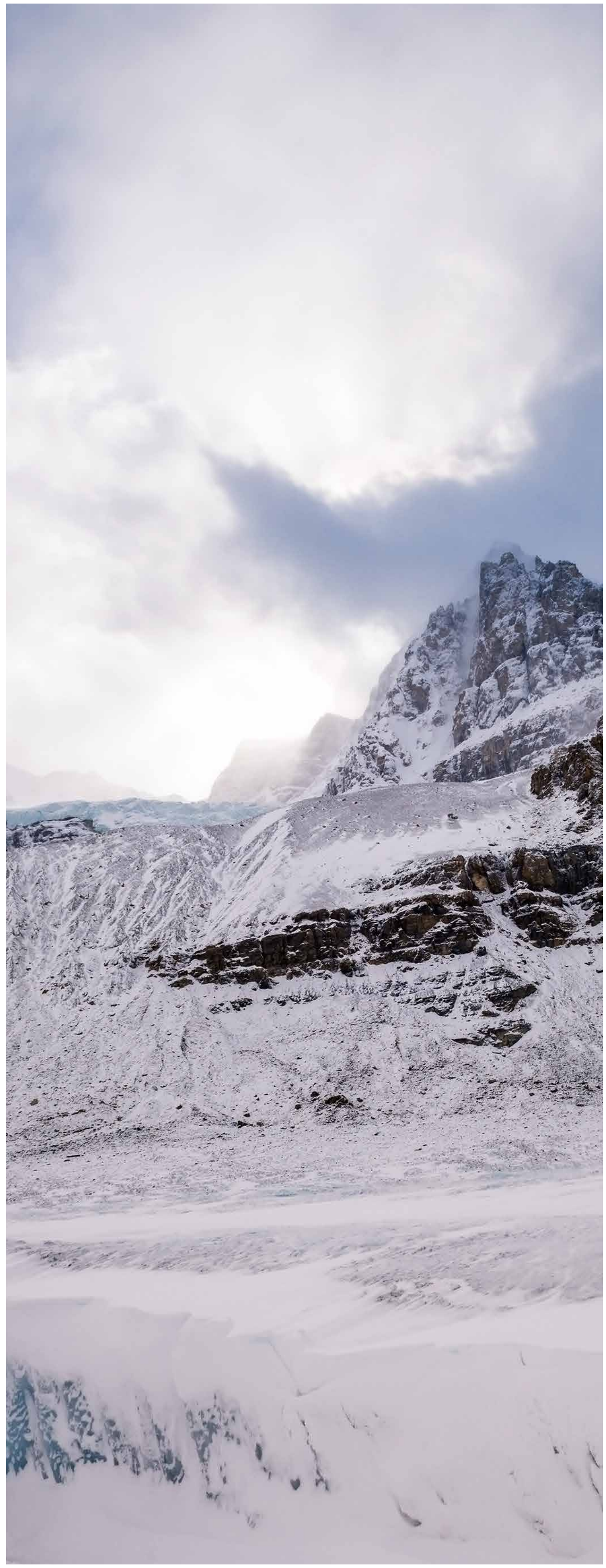
In recognition of our close ties and shared vision, Canada has worked closely with the U.S. and Mexico in the development of this report, including sharing analyses and key insights. Our partners' respective *Mid-Century Low-GHG Emissions Development Strategies* outline ambitious mitigation action by 2050.

1.4 Encouraging international efforts, including reducing emissions in other countries will be key to the global response.

The Paris Agreement recognises that addressing climate change through adaptation, technology, and capacity building will require significant international cooperation and finance, especially in the context of sustainable development. International collaboration is also fundamental to building an innovation and knowledge based economy.

Collaboration on technology innovation will underpin successful global efforts. The Carbon Trust, a global leading think tank on GHG emissions and energy technologies, was commissioned by the United Kingdom to analyse the benefits of energy technology innovation. Their paper *United Innovations* concludes that through collaborative energy technology innovation, "the world could save US$550 billion on the cost of deploying clean energy technologies over the next decade".

International cooperation to mitigate greenhouse gas emissions will be fundamental to limiting temperature rise. This is because GHG abatement costs differ substantially from sector to sector and jurisdiction to jurisdiction, but the environmental benefits of reducing a given amount of emissions are always the same. Cooperating to mitigate emissions in the most cost effective areas will ensure that financial resources are used in the most efficient way, resulting in larger reductions in emissions per unit of capital investment.



Article 6 of the *Paris Agreement* recognises that countries may choose to use internationally transferred mitigation outcomes, including emissions trading, to help access more cost effective abatement opportunities, as well as to help other countries mitigate emissions and promote sustainable development. International market-based approaches to reduce emissions (e.g., linked cap-and-trade programs; bilateral cooperative approaches; etc.) can stimulate cost effective and economically efficient greenhouse gas mitigation. Some regions of the world, including subnational governments, are already working cooperatively, or link carbon markets. These "bottom-up" type approaches could continue to develop and grow moving forward. For example, the province of Quebec has linked its emission trading system to California's through the *Western Climate Initiative*, with other subnational regions planning or considering doing the same. By 2050, it is hoped that there will be an international emissions trading system in place that would ensure robust environmental integrity and transparency at a global level.

In Canada, there are challenges to reducing greenhouse gas emissions from emissions-intensive heavy industry, primary extraction, and certain applications in the transportation sector. In the short-to-medium term, there may be more cost effective GHG reduction opportunities in other sectors or regions, where abatement technologies are more effective or lower-GHG alternatives exist. Emissions trading, or accessing internationally transferred mitigation outcomes, can provide a lower cost method of reducing GHG emissions, allowing more time for GHG intensive capital stock to turn over and allow low-carbon alternatives to be introduced without stranding assets. Canada recognises that sustainable development is a key principle pertinent to this type of cooperation. Canada will consider internationally transferred mitigation outcomes as a short-to-medium term complement to reducing emissions at home. Likewise, Canada intends to take into account internationally transferred mitigation outcomes arising from cross-border subnational emission trading as part of its international contribution to addressing climate change.

1.5 Working collaboratively with Indigenous peoples by supporting their on-going implementation of climate change initiatives will be key. Consultations with Indigenous communities must respect the constitutional, legal, and international obligations that Canada has for its Indigenous peoples.

There are a number of statements and agreements[7] that highlight Canada's commitment to consult, collaborate, and engage Indigenous peoples. Work to address climate change and related interactions with Indigenous peoples, must be consistent with Canada's approach to implementing the United Nations Declaration on the Rights of Indigenous peoples, in accordance with Canada's constitution.

This is especially relevant given the disproportionate challenges that First Nations, Inuit, and Métis communities face because of climate change. Despite the changes that are facing both traditional resources and the land, indigenous citizens and communities alike are taking tangible steps to become active drivers of change. For them, building resilience in the face of climate change is fundamentally about food, water, and energy independence, where Indigenous communities are self-sufficient.

Indigenous peoples, communities, and organisations across Canada are implementing a range of climate change initiatives.[8] Above and beyond renewable energy projects, Indigenous peoples are implementing ground-breaking initiatives on sustainable land use management, food security, and education informed by traditional values. Advancing cross-cultural learning on climate change mitigation and adaptation is one step in the journey towards reconciliation in Canada.

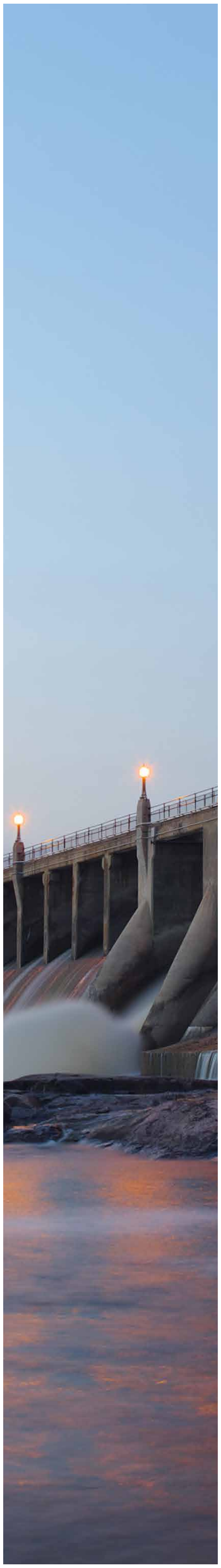
In order to move forward, Canada will encourage the development of green infrastructure in northern and remote Indigenous communities. It is also important for municipalities, provinces and territories to promote energy security for Indigenous peoples. For example, through its Feed-in Tariff program, Ontario has been able to set aside 10% for community and Indigenous engagement in renewable energy projects, with many Indigenous communities as partners or owners in renewable energy systems as a result.[9]

7 For example: the United Nations Framework Convention on Climate Change's Paris Agreement; the Vancouver Declaration; the Leader's Statement on a North American Climate, Clean Energy, and Environment Partnership.
8 Scurr, C., and Beaudry, J., *Gap Analysis First Nations Climate Change Adaptation South of 60 Degrees Latitude.*
9 Indigenous Economic Development Indigenous Affairs Working Group, *Ontario Aboriginal Energy Partnerships Program.*

1.6 The Mid-Century Strategy will help inform the pan-Canadian framework (PCF) for clean growth and climate change.

On March 3, 2016, Canada's First Ministers and Indigenous Leaders met in Vancouver and committed to developing a concrete plan to achieve Canada's international greenhouse gas reduction commitments through a pan-Canadian framework for clean growth and climate change. Canada's First Ministers released the Vancouver Declaration in which they agreed to build on commitments and actions already taken by provinces and territories in order to meet or exceed Canada's GHG emissions target for 2030. They highlighted the need to foster investment to promote clean economic growth and create jobs that support the transition to a low-carbon economy, while benefitting individual Canadians and addressing competitiveness impacts on businesses. They committed to deliver mitigation actions by adopting a broad range of domestic measures, including carbon pricing mechanisms, adapted to each jurisdiction's specific circumstances. Commitments were also made to develop and implement strong, complementary adaptation policies and action on climate resilience to address climate risks facing our populations, infrastructure, economies and ecosystems, and Canada's northern regions in particular.

Canada's *Mid-Century Strategy* will help inform the pan-Canadian framework for Clean Growth and Climate Change, but does not outline any further specific policies. Instead, Canada's Mid-Century Strategy outlines potential GHG abatement opportunities, emerging key technologies, and identifies areas where emissions reductions will be more challenging and require policy focus – in the context of achieving very low greenhouse gas objectives by 2050. The strategy also outlines the importance of addressing other pollutants, such as black carbon, that are significant climate warmers.



2 Existing Analyses on Decarbonisation

The study and analysis of what low-carbon futures might look like and the pathways for how we might achieve them is relatively recent. There is, however, a rapidly growing body of international research on low-carbon futures, including a few analyses that have focused on Canada. From this work, a number of common themes and conclusions have emerged that inform the development of this report. This work involves examining various pathways that Canada can take to achieve a low-carbon economy in 2050 and identifying associated opportunities and challenges. The studies also highlight Canada's achievements in decreasing GHG emissions to-date, provide wide-ranging insights on potential transformational low-emitting GHG technologies, and point to policies and measures that could be implemented to achieve deep reductions in GHG emissions and the necessary innovation required to ease this transition.

This literature review aims to highlight the principle themes and key messages from relevant research in order to inform the development of Canada's Mid-Century Low GHG Strategy. The review focuses on Canada-wide approaches and does not consider provincial-level pathway assessments.

KEY MESSAGES:

- Substantial decarbonisation by mid-century is possible with current technologies.
- Decarbonisation presents opportunities to improve social welfare and economic productivity.
- Challenging areas for abatement require increased policy focus, research and development, and investment.
- Decarbonisation objectives should underlie long-term, coordinated planning in key areas such as investments towards new infrastructure and clean technologies.

2.1 Substantial decarbonisation by mid-century is possible with current technologies.

Canada has already started to decarbonise and can do even more with currently available technologies. In its *Canada 2015 review*, the International Energy Agency (IEA) mentions that Canada has achieved important reductions to date through federal and provincial/territorial initiatives. The report underlines that in 2013, more than 75% of Canada's current electricity generation mix is non-emitting due to significant production from hydro and nuclear and that, over the past decade, Canada has decreased its energy intensity by 20%. It also mentions the progress made in the industrial sector with four carbon and capture storage projects, including the Boundary Dam CCS project, which is the world's first commercial application of CCS to a coal-fired power plant.[10]

An assessment from the *Council of Canadian Academies* published in 2015 suggests that Canada can significantly reduce GHG emissions by using commercially available technologies in key sectors of the economy.[11] The assessment identifies many existing

10 International Energy Agency, *Energy Policies of IEA Countries: Canada 2015 Review, p. 10.*
11 Council of Canadian Academies, *Technology and Policy Options for a Low-Emission Energy System in Canada.*

technologies that are able to achieve further energy efficiency improvements and increase production of non-emitting electricity. These technologies are commercially available, can deepen current energy efficiency improvements, and further decarbonise the electricity generation sector. The report also highlights the opportunity to stimulate the low carbon transition at the time of infrastructure renewal.

The *Deep Decarbonization Pathways Project*[12] is a global initiative of 16 countries covering 74% of energy emissions that aims at providing country specific pathways to meet a mitigation goal consistent with limiting global temperatures to 2°C above pre-industrial levels. The project suggests that current and developing technologies can achieve decarbonisation if sufficiently broad, wide, and nationally appropriate climate policy is imposed. The Canadian study published in 2015 provides six decarbonisation pathways, several of which rely on pushing deployment of currently available technologies. The results suggest that Canada can make significant progress through the decarbonisation of the electricity grid using mainly renewable energy sources (e.g., hydro, wind, solar), some fossil fuels with CCS, and replacement of combustion-based energy sources with electricity in many sectors (including the transportation, buildings, manufacturing, and heavy industry sectors). The study employed a highly detailed, behaviourally realistic technology stock turnover model (CIMS) to capture changes in energy, process an fugitive emissions, linked to regionally and sectorally disaggregated macroeconomic model (RGEEM) to capture changes in GDP, economic structure, employment and trade. Emissions reductions in both models were driven by a policy package of performance based technology regulations and hybrid (i.e., general tax and cap and trade) carbon pricing.

The *Trottier Energy Futures Project* looks at 11 different scenarios for Canada to achieve different levels of GHG reductions by 2050 using one optimisation model and one simulation model that integrate energy and economic systems with different sets of strategies to achieve reductions at a minimum cost. The projections presented in the report provide detailed information on Canada's sectoral energy consumption and production for each scenario and take into account specific regional circumstances. The report states that "for most scenarios, the approach was based on currently deployed technologies with plausible extrapolations for future improvements and cost reductions".[13] These include expanding the use of non-emitting electricity across end-use sectors, increasing the use of biofuels in the transportation sector, and improving energy conservation and efficiency. The report also noted that further research is needed on ways to achieve net-negative GHG emissions, including through bioenergy with carbon capture and storage (BECCS), increased use of wood products for carbon retention in buildings, and carbon sequestration through afforestation and reforestation.

The Canadian study *Acting on Climate Change: Solutions from Canadian Scholar*s also provides an insight into how current technologies and appropriate policy options are sufficient to decarbonise the Canadian economy. A concerted effort of sixty Canadian scholars, the report suggests that Canada can rely 100% on low-carbon electricity production by 2035, due to the availability of renewable energy sources in the country, making it possible to achieve an 80% reduction in GHG emissions by 2050. In addition, an evolving smart urban design, drastic changes in the transportation sector and a broader sustainability agenda are all fundamental factors that will help change energy consumption in Canada. To this end the authors suggest numerous policies, such as east-west interprovincial electricity trade, and emphasise the benefit of a carbon pricing policy.

2.2 Decarbonisation presents opportunities to improve social welfare and economic productivity.

The Smart Prosperity roadmap, *New thinking*, provides a vision of Canada's potential low-carbon future with healthy, vibrant, and green communities. The Canadian think tank proposes a future Canadian society in which smart cities and towns provide sustainable means of living in communities with hyper-efficient insulated buildings with roof tiles made of solar panels, plenty of public parks and community gardens, and streets and sidewalks filled with electric plug-in stations for next-generation electric cars. In this green economy, clean innovation would provide many job opportunities using human ingenuity to efficiently produce goods and services while continuously seeking new ways to reduce greenhouse gas emissions. Smart grid systems endowed with advanced technologies would allow home appliances, such as water heaters, to act as electric batteries and transportation modes

12 Bataille, C. et al., *Pathways to Deep Decarbonization in Canada.*

13 Trottier Energy Futures Project, *Canada's Challenge & Opportunity, p. 6.*

to recharge and start their duties at inexpensive, low-peak load times. Under this vision, connected communities could become more efficient by sharing resources and knowledge. The roadmap states that Canada's future prosperity depends on the investment choices we make today and that the development of clean infrastructures will "offer substantial economic opportunities for Canadian companies, many of which are already among the leaders in energy technology, water infrastructure, and transportation innovation".[14]

A transition to a low-carbon economy could present significant benefits beyond GHG abatement that could improve Canadian's well-being by producing jobs in the clean technology industry and improving productivity in other sectors. The International Energy Agency (IEA) report *Energy Technology Perspectives (ETP) 2016* underscores Canadian success stories.[15] For example, in Alberta, the Drake Landing Solar Community (DLSC) integrates solar thermal energy to its district system to store significant amount energy underground during the summer so it can be used in the winter for space heating. According to the DLSC, each of the single family homes reduces about 5 tonnes of GHG per year and is 30% more efficient than conventionally built homes.[16] Another success story relates to the use of applications for traffic signals (e.g., communications systems, adaptive control systems, traffic-responsible, real-time data collection and analysis, maintenance management systems) in British Columbia to allow motorists to turn off their engines while they wait at the Peace Arch Border Crossing. The system reduces GHG emissions by 45% while decreasing levels of air pollution which result in improvements in human health. Vehicle users also incur fuel savings.[17]

Data analysed in the *2016 Canadian Clean Technology Industry Report*, published by Analytica Advisors, suggests that the Canadian clean technology sector has grown considerably over the last decade and that a pathway toward decarbonisation would further stimulate the sector by increasing domestic demand for clean technologies, thereby developing domestic knowledge and innovation. The report mentions that the Canadian clean technology sector delivers "high-skill, high-wage, knowledge-based jobs"[18] and that it continues to out-perform other industries on that aspect. Clean technologies can also increase the productivity and efficiency of other sectors of the economy, including traditional industries, and make them more competitive. Nevertheless, the report also highlights that these same Canadian companies are losing market share world-wide, and that moving swiftly towards decarbonisation could provide significant opportunities to the sector.

The *Trottier Energy Futures Project* also points to other kind of economic opportunities, such as taking advantage of potential mutual benefits from a greater integration of the electricity network and trade between the U.S. and Canada. More specifically, Quebec could increase exports of zero-emitting electricity to the U.S. North East region, and Manitoba could do the same with the U.S. Mid-West region. The benefits include higher electricity sale revenues for Quebec and Manitoba and lower cost electricity supply for American States, opportunities for optimal integrated system dispatch

14 Smart Prosperity, *New Thinking-Canada's Roadmap to Smart Prosperity*, p. 50.
15 International Energy Agency, *Energy Technology Perspectives*, p. 199, p. 231 & p. 326.
16 Drake Landing Solar Community, *Welcome to Drake Landing Solar Community*.
17 Government of British Colombia, *Greening the Border*.
18 International Energy Agency, *Energy Technology Perspectives 2016*, p. XXII.

which could generate revenue through trading of energy, minimised overall cost of system supply (complementing Canadian hydro production with U.S. low cost nuclear and thermal baseload), the sharing of emergency reserve, and a more stable system. The report also mentions that there may be further opportunities for reducing overall electricity costs since the peak demands in Canada and the U.S. occur at different periods of the year (most of Canadian provinces' peak periods are in the winter, while U.S. peak period is in the summer), and for complementing the baseload with more intermittent renewables.[19]

2.3 Challenging areas for abatement require increased policy focus, research and development, and investment.

Decarbonisation pathways also present challenges which require effective and flexible policies that encourage innovation. The academic literature stresses the need for Canada to capitalise on its vast knowledge and expertise to spur innovation and develop clean technologies to cost-effectively reduce emissions in some areas, particularly industrial process emissions and freight transportation. In order to succeed in making major scientific breakthroughs and ensuring clean reliable energy systems, the literature emphasises the need for private and public actors to strengthen research, development and deployment (RD&D) in all sectors of the economy, and continuously engage with the international community. In their 2015 report, the *Council of Canadian Academies* provides an overview of the key challenges faced by industries. These are mainly associated with the lack of cost-effective, low emission-intensive ways to produce high levels of heat, and that energy-related emissions are scattered across many different processes and applications. The report points to R&D, technological development, and flexible policies as key solutions to reduce the costs and encourage commercialisation of low-emitting technologies.

The *National Round Table on the Environment and the Economy* (NRTEE) provided their recommendations in a report titled *Getting to 2050: Canada's Transition to a Low-emission Future*. The report established many "enabling conditions" which would guide Canada in formulating a long-term strategy to achieve its long-term GHG emission and air pollution targets. The report pointed out that long term policy certainty is central to provide predictability to attract new durable investments in clean technology and innovation. The report proposed to establish an economy wide price signal, through a market-based policy. The NRTEE also highlights the need to create a level playing field for energy investments with the goal of enhancing Canadian firms' access to fast-growing low-carbon markets and mobilising investments in low-carbon infrastructure and technology.

Mark Jacobson from Stanford University and other researchers have also looked at energy roadmaps to convert 139 countries to 100% clean and renewable energy use. The roadmaps represent pathways for converting the energy systems of these countries to ones powered by wind, water, and sunlight (WWS). The roadmaps are based on IEA energy consumption data projected to a 2050 BAU scenario. They rely on existing WWS electricity generation technologies and exclude nuclear, CCS, biofuels or natural gas, and do not include the construction of new hydropower dams.

In the wake of the COP21 Conference, the Royal Dutch Shell company published the report *A Healthy Planet: Pathways to Net-Zero Emissions: A New Lens Scenarios Supplement*. The report highlights current societal challenges in achieving a net zero GHG world. The report recognises the important role of renewable energy in decarbonising the energy system but points out other challenges that many industrial sectors are facing (e.g., iron and steel, cement manufacturing, heavy freight and air transportation, chemical and fertilizers). To make progress on reducing these emission sources, the report suggests mass deployment of carbon capture and storage technologies combined with sustainable biomass use. The report also recommends policies to accelerate the world's transition to a low-carbon economy including economy-wide carbon pricing and financial investment for research and development in low-carbon technologies.

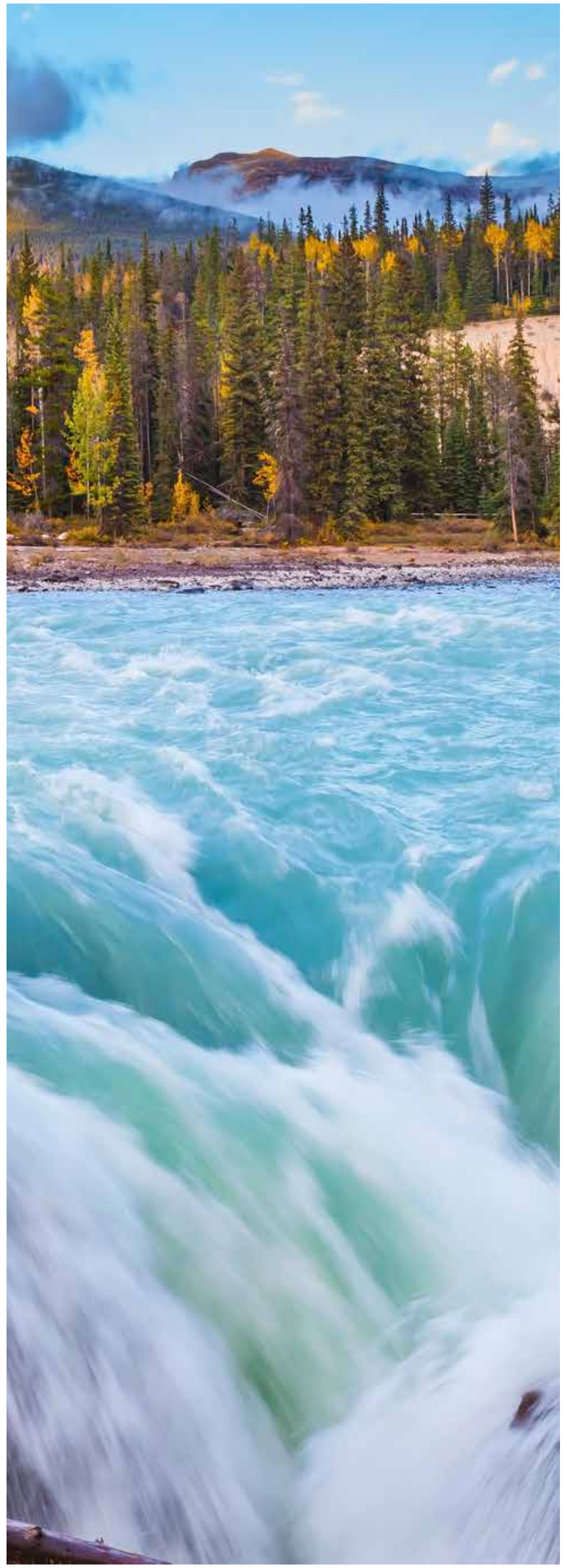
19 Trottier Energy Futures Project, *Canada's Challenge & Opportunity*, pp. 217-224.

2.4 Decarbonisation objectives should underlie long-term, coordinated planning in key areas such as investments towards new infrastructure and clean technologies.

Smart Prosperity's roadmap stresses the importance of building smart infrastructure to facilitate the penetration of clean transportation modes and non-emitting energy. The roadmap also points to municipal governments having a key role in planning zoning and permitting in order to favour clean development of cities. This vision will require strong coordination from federal and provincial governments, National Indigenous Organisations across the country, municipalities, and the public.

As cities are becoming the heart of economic development and strategic centres for innovation in clean technologies, they offer significant opportunities to contribute to reducing GHG emissions. IEA's *Energy Technology Perspectives (ETP) 2016* presents an extensive modelling exercise including projections of three pathways using four interlinked models of the energy supply, and the buildings, industry, and transport sectors. The results present the structural changes required to shift the world toward clean energy and transform cities into innovation powerhouses. The report also highlights the role cities play in driving energy demand and the solutions they may offer to lower the carbon content of the world's energy systems. According to the report, increasing energy demand from urban economic and population growth will need to go hand in hand with innovation and massive deployment of clean technologies and significant behavioral changes. It also emphasises the role of cities in supporting higher efficiency transport and buildings, with dense urban development being a structural prerequisite. Increased demands in space heating and cooling could be decoupled by connecting households to district energy networks. Sustainable land-use planning, the implementation and electrification of transportation modes, and the installation of rooftop solar photovoltaics present attractive solutions to propel cities toward a low-carbon pathway. All of these solutions will require careful planning of today's investments in infrastructure by all levels of government.

The report from the *Council of Canadian Academies* also mentions that many investment decisions such as transmission and distribution systems and strategic planning of urban, land-use and infrastructure developments will allow for a better integration of low-emitting electricity use.



3 Decarbonisation and Expansion of Canada's Electricity System

KEY MESSAGES:

- Canada's electricity generating portfolio is already more than 80% non-GHG emitting, with the trend towards cleaner generation expected to continue. This provides Canada with an international comparative advantage relative to countries seeking to decarbonise their fossil fuel dominated portfolios.

- A low carbon electricity system will allow for GHG emissions reductions in other sectors (e.g., transportation, buildings, industrial processes) through electrification. The anticipation of significant growth in electricity demand should underpin long term investment and planning.

- Further decarbonisation of the electricity sector will facilitate the transition to a low-GHG future. Non-emitting sources will need to be considered for all new and existing needs, but generating portfolios will differ from one jurisdiction to another. Regional differences will need to be a key consideration for electricity climate change policies.

- Interprovincial, interjurisidictional, and intercontinental cooperation will enhance integration of clean electricity generation to satisfy growing demand. Canada's contribution towards global GHG abatement could include providing clean power to our continental neighbours, as well as clean power services to the international community.

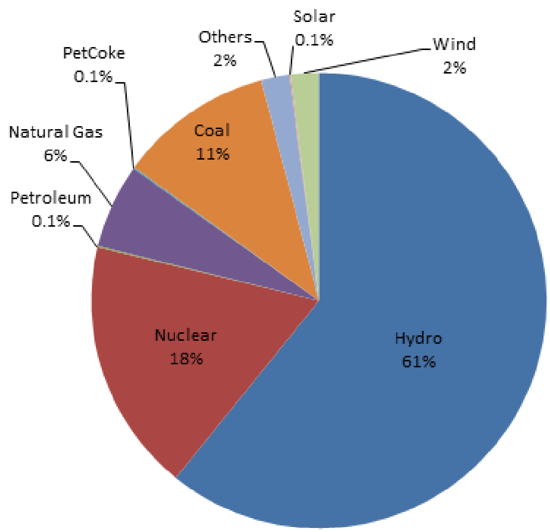
- Energy conservation and energy efficiency measures should increase and be implemented alongside efforts to reduce emissions from electricity generation. Electricity savings should underlie decarbonisation pathways: demand side management and reducing equipment and transmission losses makes electrification far more effective and feasible

3.1 Canada's electricity generating portfolio is already more than 80% non-GHG emitting, with the trend towards cleaner generation expected to continue. This provides Canada with an international comparative advantage relative to countries seeking to decarbonise their fossil fuel based portfolios

Canada already has one of the cleanest electricity systems in the world, with more than 80% of electricity generated from sources that do not produce greenhouse gas emissions such as hydro, wind, solar, and nuclear power. Canadian rivers provide immense hydroelectric generating capability, and Canada is second largest producer of hydroelectricity globally. In 2014, Canada produced 379 terawatt hours (TWh) of hydroelectricity, representing 9.8% of global production[20] with further capacity remaining untapped. There is also significant potential for the development of other renewable energy sources across Canada.

20 National Energy Board, *Canada's Energy Future 2016: Energy Supply and Demand Projections to 2040.*

Figure 1: Canadian Utility by Source (2014)



Source: CANSIM Tables 127-0006 for fossil fuel sources and 127-0007 for other sources. Total generation data is extracted from CANSIM 127-0007.

In 2014, nuclear power provided 18% of Canada's electricity generation from electric utilities (63% of Ontario's generation and 34% of New Brunswick's generation). Canada is the world's second-largest producer and exporter of uranium—representing over 20% of world production—and ranks fourth globally in identified resources of uranium. There are 4 operating nuclear power stations in Canada—3 in Ontario and 1 in New Brunswick, with a combined total of 19 reactors. In Ontario, planned investments of $25 billion over the next 15 years will extend the life of 10 nuclear reactors for another 25 to 30 years.

Electricity-related emissions have been declining in Canada due to a return to service of a number of nuclear units, fuel switching from coal to natural gas, and government policies to phase out coal-fired electricity. This trend is expected to continue as hydropower generation and electricity generation from renewables, such as wind and solar, are expected to increase throughout Canada.

Although electricity generation is already moving in a positive direction with respect to a low-GHG future, government policy and long-term planning can help accelerate this trend. For example, as Canadian provinces continue to move away from coal-fired electricity, they will face decisions regarding what type of fuel should replace and augment generating capacity. Natural gas might provide a lower-GHG option than coal in the short run, but its place in a decarbonised system is less clear over a longer-term horizon.

As the global community moves to reduce greenhouse gas emissions, many countries will face challenges with regard to the decarbonisation of their electricity generating sectors. In this respect, Canada is already ahead of many of its peers. Currently, Canada is the second largest producer of hydropower after China, fourth globally for generation from a combination of hydro, wind, solar and biomass,[21] and sixth for generation from nuclear energy.[22] Given this comparative advantage, Canada has the opportunity to increase its clean electricity exports, as well as leverage its expertise in current and emerging technologies (e.g., electrification technologies; smart grids for intermittent sources) that could help other countries reduce their emissions.

3.2 A low-carbon electricity system will allow for GHG emissions reductions in other sectors (e.g., transportation, buildings, and industrial processes) through electrification. The anticipation of significant growth in electricity demand should underpin long term investment and planning

Although electricity generation only accounted for 11% of Canada's emissions in 2014, continuing to move towards a non-emitting electricity generating sector would help decarbonise other sectors, such as, transportation and buildings. Increasing the share of non-emitting electricity generation is fundamental to Canada's low-carbon future.

A near decarbonisation of the electricity sector is underscored in most of the deep-decarbonisation literature, both nationally and internationally. For example, in the IEA Energy Technology Perspective 2016, the global electricity power sector is almost completely decarbonised by 2050 under a scenario consistent with the global 2°C temperature goal. Domestically, virtually all of the academic and expert analysis on deep decarbonisation in Canada point to non-emitting electricity and the electrification of buildings and passenger vehicles as fundamental aspects to a low-carbon future given current technologies. For example, the *Trottier Energy Futures Project* shows that one of the lowest cost options to decarbonise Canada is to move the electricity generation sector toward a zero-emitting transition by expanding renewables, especially hydro, and other non-emitting sources.

21 International Energy Association, *IEA's Electricity Information Report.*
22 Nuclear Energy Institute, *Top 10 Nuclear Generating Countries.*

The near term focus on mitigation in this sector also reflects the technological availability of abatement options including the ability to tackle large point sources of emissions over a shorter time period. From an investment perspective, Canada is at a point in time where its traditional coal-fired generating sources are facing closures or refurbishments with carbon capture and storage, primarily due to government policies; therefore, there is an opportunity to transition to a decarbonised system at more limited incremental cost.

Meanwhile, the price of renewable electricity such as wind and solar continues to decline dramatically, making these options increasingly economically attractive. Recent *Bloomberg New Energy Finance* analysis projects the levelised cost of electricity for onshore wind and photovoltaics solar to decrease by 41% and 59%, respectively, from 2016 to 2040.[23] The levelised cost of electricity (LCOE) is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. It can also be regarded as the minimum cost at which electricity must be sold in order to break-even over the lifetime of the project.

The U.S. Energy Information Agency (EIA) describes the average levelised costs for plants entering service in 2022 and 2040 in the U.S. (see Table 1). The EIA notes that some renewables such as wind power are expected to be cheaper than fossil-fuel based forms of generation within the U.S by 2022. These costs take into account building and operating a plant over its lifetime, fuel costs (where appropriate) and the federal tax burden, but do not include regional factors or utilisation rates. Government subsidies are not included in the estimates but would decrease the costs even further.[24] It should be emphasized that these are future costs in the United States and cannot be directly compared to Canada.

In Canada, the Canadian Council on Renewable Electricity (CanCORE)[25] states that hydropower and wind are already cost-competitive. Solar energy is quickly catching up and is on track to be the least-cost generation technology in most countries around the world by 2030.

Table 1: Average Levelised Costs of Electricity (2015 $/MWh) for Plants Entering Service in 2022 & 2040; United States[26]

Energy Source	2022	2040
Wind	64.5	58.8
Wind Offshore	158.1	133.7
Natural Gas-fired Conventional Combined Cycle	58.1	57.6
Hydroelectric	67.8	65.3
Advanced Nuclear	102.8	93
Biomass	96.1	78.7
Geothermal	45.0	57.0
Solar Photovoltaics	84.7	71.2
Coal with CCS	139.5	125.8

3.3 Further decarbonisation of the electricity sector will facilitate the transition to a low GHG future. Non-emitting sources will need to be considered for all new and existing needs, but generating portfolios will differ from one jurisdiction to another. Regional differences will need to be a key consideration for electricity climate change policies.

Modeling analyses that examine deep aggregate cuts to GHG emissions in Canada by mid-century indicate that Canada's future non-emitting electricity portfolio could take various forms, and different non-emitting options exist for each Canadian jurisdiction. The following section outlines the various scenarios developed around non-emitting electricity generation scenarios for Canada and explains the modelling results of each scenario.

23 Bloomberg New Energy Finance, *Coal and Gas to Stay Cheap, but Renewables Still Win Race on Costs*.
24 U.S. Energy Information Administration, *Levelized Cost and Levelized Avoided Cost of New Generation Ressources in the Annual Energy Outlook 2016.*
25 Canadian Council on Renewable Electricity, *Powering Prosperity Climate Report.*
26 U.S. Energy Information Administration, *Levelized Cost and Levelized Avoided Cost of New Generation Ressources in the Annual Energy Outlook 2016.*

MODEL AND SCENARIO DESCRIPTION

Deep Decarbonisation Pathways Project – High Ambition (DDPP):

Ambition:

The DDPP modelled its scenarios in line with achieving 89% GHG emission reductions from overall emission levels projected for 2050, excluding agriculture, which corresponds to an emissions reduction of 88% from 2015 levels by 2050 (78Mt CO_2e).

Model Description:

The DDPP uses an energy and economic model to forecast demand for GHG-intensive goods and services, energy balances, technology and ultimately emissions (CIMS model). CIMS is a bottom-up technology-focused model that competes and selects technology market shares based on firm and household responses to the DDPP policy package, including carbon pricing and technology regulations. To forecast GDP, employment, economic structure and trade, a macroeconomic regionally and sectorally disaggregated Computable General Equilibrium (CGE) model called GEEM, is used.

Scenario Description:

- This modelling work assumes GDP growth ranging from 2% to 2.2% per year from 2015 to 2050.
- The scenario discussed here is based on oil prices of $80 ($US2014) per barrel in 2050.

Trottier Energy Futures Project:

Ambition:

The Trottier Energy Futures Project modelled its scenarios based on achieving a 60% GHG emission reduction target from the 1990 levels in combustion emissions. This corresponds to a 65% reduction from 2015 combustion emission levels. This analysis excludes process emissions. Scenarios 3 (Current Tech Trottier) and 8 (New Tech Trottier) of the report are shown in this section.

Model Description:

The Trottier Energy Futures Project uses two models to develop its scenarios, the North American TIMES Energy Model (NATEM) and CanESS models. Both models include separate representations of the sectors in Canada's economy, split for all provinces and territories.

Scenario Description:

- Scenarios 3 (Current Tech Trottier) and 8 (New Tech Trottier) of the report are shown, both of which aim to achieve a 60% GHG emission reduction target from the 1990 levels in the energy sector.
- This work relies on the National Energy Board's GDP per capita growth rate from 2010 to 2035, which is 1.9%, with somewhat slower growth after 2035.
- This modelling exercise assumes an oil price of about $135 ($2011) per barrel in 2050.

Environment and Climate Change Canada: Global Change Assessment Model (GCAM) – High Non-Emitting:

Ambition:

This modelling work was based on a net 80% GHG emission reduction from 2005 levels. This is modelled as a combination of full reductions achieved in the combustion and non-combustion sectors, as well as the addition of scenarios representing a 65% reduction in Canadian economy emissions, with a 15% achievement through Internationally Transferable Mitigation Outcomes and Land sector credits.

Model Description:

GCAM is a dynamic-recursive model with technology-rich representations of the economy, energy sector, land use and water linked to a climate model. GCAM is a Representative Concentration Pathway class model that can be used to simulate scenarios, policies, and emission targets from various sources.

Scenario Description:

The first scenario (High Nuclear) is heavily dependent on nuclear electricity production, while the second scenario (High Hydro) relies on a mix of hydro and wind to produce a majority of its electricity generation.

- This modelling work was based on a 65% and net 80% GHG emission reduction from 2005 levels.

Environment and Climate Change Canada: Computable General Equilibrium Model (CGE) – High Demand Response:

Ambition:

- This modelling work was based on a net 80% GHG emission reduction from 2005 levels. This is modelled as a combination of full reductions achieved in the combustion and non-combustion sectors, as well as the addition of scenarios representing a 65% reduction in Canadian economy emissions, with a 15% achievement through with the addition of scenarios including Internationally Transferable Mitigation Outcomes and Land sector credits.

Model Description:

- This is a multi-sector, multi-regional open-economy recursive-dynamic computable general equilibrium model of the global economy. The model captures characteristics of country-specific or regional production and consumption patterns through a detailed input-output table and links countries/regions via bilateral trade. The model incorporates rich detail in energy use and greenhouse gas emissions related to the combustion of fossil fuels and tracks non-energy related greenhouse gas emissions. Economic activities in regions involve 28 industrial sectors, final consumption by the household, the governments and investment.

In the figure below, results from these scenarios are presented with respect to electricity generation. Comparing results across models, or across modelled scenarios, provides us with overarching high-level messages and key takeaways for Canada's decarbonised electricity sector. The graph depicts various electricity generating portfolios in the year 2050 from the four different models, and compares these to the current generating mix (2014), labelled as "Historical" in the graph.

In all of the scenarios, Canadian electricity generation will increase substantially to fulfill end-use electrification requirements. Essentially, additional electricity is required to power cars, light trucks, buildings, and industrial production processes that are switching away from fossil fuel generation to electricity to power their needs. In the ECCC analyses, total electricity generation increases by 113 to 189% between 2013 and 2050, whereas it increases by 184 to 295% in the Trottier analyses and by 160% in the DDPP analyses.

Depending on the modelling scenario, there is a huge variation in potential electricity demand growth. This is dependent on the level of energy efficiency/consumption changes emerging from the modelling results. However, in all of the low GHG economy modelling analyses, non-emitting sources such as hydro, nuclear, wind, and solar replace fossil fuel generation well before mid-century.

All scenarios demonstrate growth in hydropower electricity generation between 2013 and 2050. The ECCC High Hydro scenario illustrates a 172% increase in hydropower generation. In the DDPP analyses, hydro increases by 120%, whereas in the Trottier analyses it increases by 134% in both scenarios.

Figure 2: Scenarios of Canada's Non-Emitting Electricity Generating Supply

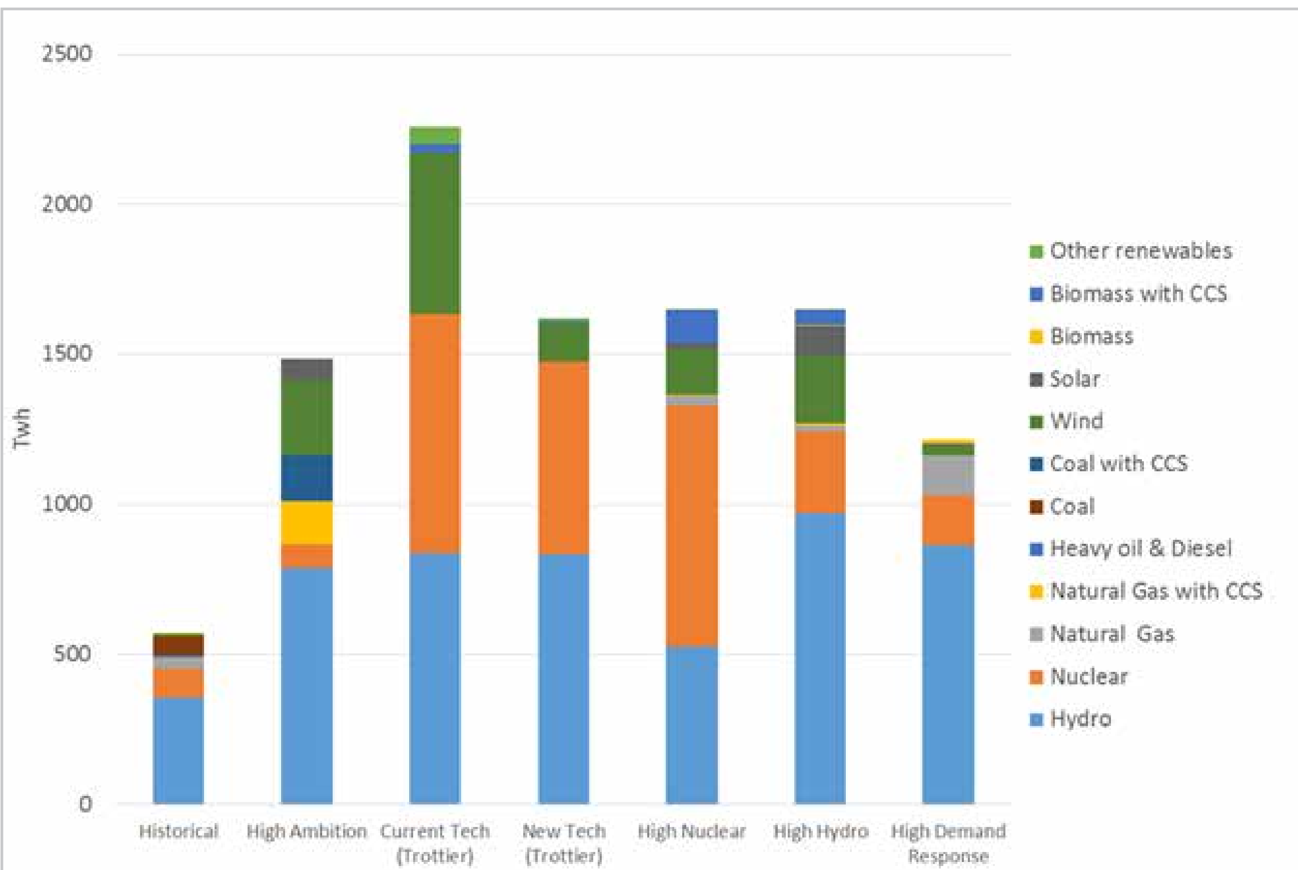
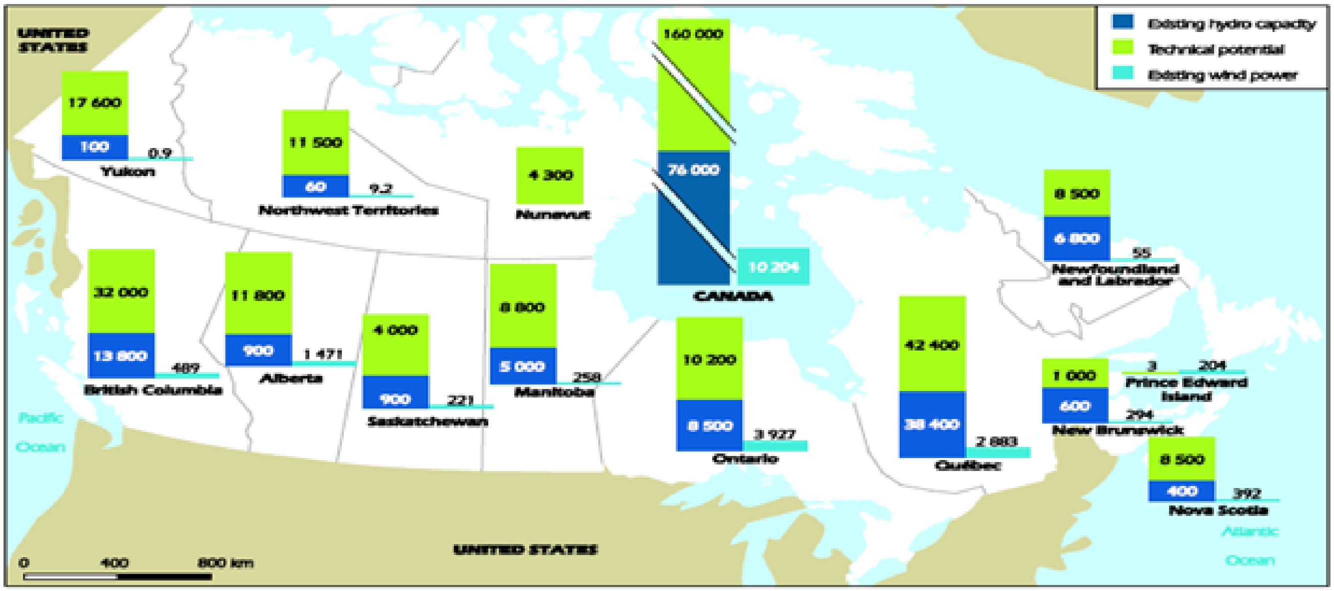


Figure 3: Canada's installed hydro power capacity against theoretical technical potential (MW), and installed wind power: by province and territory in 2014;



Source: International Energy Agency[28]

The different scenarios correspond to different levels of additional hydro capacity that needs to be built by 2050 to reach the greenhouse gas mitigation objectives. The DDPP scenario requires about 101,500 MW of additional capacity, while the Trottier scenarios require about 111,000 MW of additional capacity. ECCC's High Nuclear scenario would require 36,000 MW of capacity to be built, while the High Hydro scenario would require 130,000 MW to be built. Finally, ECCC's High Demand Response modelling run indicates that 108,000 MW of additional capacity would need to be built.

Although this is a significant increase in hydropower capacity, a study conducted for the Canadian Hydropower Association shows that in 2006 Canada had 160 GW of hydro potential, a large portion of which is economically viable. Canadian rivers provide close to 7% of the world's renewable water supply and this resource provides tremendous hydroelectric generating capability.[27] Currently, over 10 GW of hydro capacity have been proposed or planned in Canada, tapping the Churchill, Nelson, Slave, Athabasca, and Peace river systems. Over 3500 MW of this capacity is already under construction in Canada.

Figure 3 depicts the theoretical technical potential for hydro power generation by province. The above scenarios are all below the technical potential of hydro power capacity, indicating that this type of generation could be possible. The DDPP modelling exercise is 29% below technical potential, whereas both Trottier scenarios are 25% under this threshold. The High Nuclear scenario is 52% under technical potential, while the High Hydro scenario is closer, at 13%. Finally, ECCC's high Demand Response scenario is 22% below the technical potential of hydro power.

Hydro power also provides a good "coupling" to intermittent sources generated by renewables such as wind and solar power. Since renewable electricity is generated at intervals when the wind is blowing or the sun is shining, a high degree of coverage of electricity demand by wind or solar is possible only with access to energy storage or an adequate complementary form of electricity that can be ramped-up during periods of low generation. Fortunately, hydroelectric plants are well suited for this in Canada, and can store water in hydroelectric reservoirs that could be used when solar or wind generation is not available.

Hydro power may have negative implications, mainly based on the impact of dams on fisheries and water flows since dam reservoirs have an impact on flows, temperatures, and silt loads of rivers and streams. There have been examples of large dams blocking migrating fish from reaching their spawning grounds. For these reasons, the construction of future large hydro projects will require careful consultation processes.

27 National Energy Board, Canada's Energy Future 2016: Energy Supply and Demand Projections to 2040

28 International Energy Agency, Energy Policies of IEA Countries: 2015 Canadian Review.

Generally, further innovation will be required if hydro power is to increase substantially in Canada.[29] However, much of this increase in hydropower generation can be accomplished without building new dams. Many technologies allow for an increase in electricity generation from existing hydro dams, such as through increased efficiency turbines, at a relatively low cost.

While hydro power increases in all scenarios, nuclear energy varies depending on the modelling assumptions. The ECCC High Hydro scenario, assumes that nuclear power generation is maintained at today's levels, with the addition of expected refurbishments. The DDPP assumes that existing nuclear power is maintained, but no new capacity is added out to 2050. In comparison, under the Trottier analyses as well as the second ECCC GCAM analyses (High Nuclear) the model chooses a significant increase in nuclear power between now and 2050. Scenarios from the Trottier analyses show nuclear growing to about the same level as ECCC's High Nuclear scenario, although it grows slightly less for the New Technologies scenario, which assumes less electricity generation needs based on energy efficiency technologies.

The amount of nuclear capacity from the ECCC High Nuclear scenario, as well as the Current Tech Trottier scenario, corresponds to 797 TWh of generation per year in 2050, which is much higher than the current share of nuclear in the electricity mix, which corresponds to about 98 TWh of generation. There are significant challenges to building sizeable infrastructure projects like these, mainly because of high capital costs, delays in construction, and other potential issues. However, benefits to nuclear power include emissions free generations, reliable baseload capabilities, and a lower levelised cost of electricity. As such, new and emerging nuclear technologies could become an increasingly attractive option for a

29 Potvin, C. et al., *Acting on Climate Change: Extending the Dialogue Among Canadians: Some reflections on Climate Change Response Policy.*

POTENTIAL INNOVATIVE NUCLEAR TECHNOLOGIES

In the short term, Canadian Deuterium-Uranium (CANDU) reactors enable the use of alternative fuels in current nuclear generation. Canadian industry is currently working with China to run CANDU reactors on depleted uranium by-products and spent fuel recycled from other reactors.

Canadian and international developers are working on Small Modular Reactors (SMRs), which are compact nuclear reactors that can be scaled to generate power to communities ranging from several hundred people up to 300,000 homes. Compared with conventional nuclear power plants, SMRs require lower capital investment and offer scalability, siting flexibility, and enhanced safety features—including passive features that could prevent meltdowns even in the absence of power. SMRs are seen as a potential replacement for coal-fired power plants, or as a complement to intermittent renewables in transitioning remote communities off of diesel generation.

A transition from uranium to thorium-based fuels is possible over the longer term. Thorium is three to four times as abundant as uranium, and thorium-based fuels could reduce the amount of nuclear waste produced by reactors. Advanced nuclear reactors, including those using thorium-based fuels, could also achieve higher efficiencies than existing nuclear plants. China is investing heavily into thorium technologies, including the potential for CANDU reactors—which can support thorium fuel cycles more readily than other currently-available reactor types—and development of an advanced thorium reactor it hopes to demonstrate within the next decade.

Nuclear fusion represents a potentially game-changing technology for clean energy. Fusion differs widely from fission, the process used in conventional nuclear power generation. A Canadian company is developing a novel fusion reactor that could unlock large amounts of energy from hydrogen, a near-infinitely abundant resource on earth, in a process that would not generate any long-lived radioactive waste and entails no risk of a meltdown. For these reasons, nuclear fusion is a potentially transformative technology. While it still has hurdles to pass before making it to market, if it were to succeed, it would alter the landscape of clean energy permanently.

GHG-constrained energy system by 2050 (*see feature box on Potential Innovative Nuclear Technologies*).

Both ECCC High Non-Emitting scenarios point to a higher penetration of wind energy. Wind energy generation in 2050 represents 154 TWh, 9% of total generation, in Scenario 1, and 228 TWh, 14% of total generation, in Scenario 2. In comparison, wind energy increases to 17% of the generating mix in the DDPP analysis, whereas it increases to 24% in the Current Tech Trottier scenario and 8% in the New Tech Trottier scenario. Although these scenarios represent sizeable figures, a Pan-Canadian Wind Integration study[30] has demonstrated that Canada can reliably and cost-effectively integrate enough wind energy to meet 35% of Canada's electricity demand.

In both High Non-Emitting scenarios, solar power generation increases significantly reaching levels of 18 TWh, 1% of total generation, and 99 TWh, 6% of total generation in 2050. In comparison, solar energy increases to 5% of the generating mix in the DDPP analysis, and is only part of the solution for Alberta and Saskatchewan in select Trottier scenarios. The Trottier project notes that when deriving minimum cost solutions for electricity generation in Canada, solar did not compete well with wind.

However, the National Energy Board notes that Canada has a strong solar photovoltaic (PV) potential that is largely unexploited and that certain prairie cities including Regina, Calgary and Winnipeg have well above-average solar potential. Furthermore, it noted that in much of Canada, solar potential is higher than in Germany, the country with the most installed solar PV capacity in the world in 2014.[31]

In order to fully exploit Canada's solar potential, solar PV generation must reach competitive delivery costs to stimulate the large scale investments needed for significant deployment. Incentive programs such as Ontario's Feed-in-Tariff and microFIT programs may determine the pace of growth of solar generation across Canada in the near term. Household production of solar electricity through rooftop solar panels can also be beneficial and could provide more electricity than the household uses, providing an opportunity to sell electricity back to the grid. Fully realising the potential of distributed PV will likely require utility investments to upgrade existing distribution networks to handle two-way power flow. The NEB also highlights potential technological breakthroughs, such as utility-scale electricity storage options, which could provide a boost to the solar industry in Canada (*see box on energy storage*).

In the Deep Decarbonisation Pathways Project analyses, natural gas and coal with carbon capture and storage (CCS) technology is apparent throughout the projection period. In Saskatchewan, CCS was retrofitted to the Boundary Dam coal-fired electricity-generation plant in 2014 and is expected to generate reductions of up to 1 megatonne CO_2 per year. The project, implemented by SaskPower, shows that generating reliable, low-emitting electricity using coal is feasible. The project is key to better understanding the technical, economic, and environmental performance of CCS technology and could produce worldwide spillover effects if other countries choose to implement similar projects. The DDPP analysis also features natural gas generation with CCS as a significant proportion of electricity generation in 2050. Although no large scale demonstration projects have gone forward with this technology, it has the benefit of allowing CCS technology developed for coal electricity generation plants to extend to natural gas generation, which provides more flexibility to utilities in reducing emissions from their generation. Furthermore natural gas with CCS is estimated to be generally cheaper than using coal with CCS because of the lower capital cost of natural gas plants and their lower GHG intensity.[32]

Current Tech Trottier (in figure 2) models Canada's electricity generation with current technologies, a better interconnection between provinces, and allows the use of lowest cost electricity technologies available anywhere in Canada. In comparison, New Tech Trottier models the same GHG reduction target with a set of new technologies reaching market, including CCS and energy efficiency technologies. This technology application results in energy efficiency measures in end-use applications, reducing required electricity demand from 2,257 to 1,622 TWh between the two scenarios.

Other renewable energies offer potential in the mid-to-long term. For example, generating zero-emitting electricity with geothermal power is possible using hot subsurface water or steam coming from underneath the earth's surface. Standard well drilling technology can provide access to high temperature sources and power to turbines that offer reliable electricity.

Tidal energy is a type of renewable energy produced from ocean currents. Since tides are predictable, the generation potential of tidal energy is more

30 GE Consulting Group, *Pan-Canadian Wind Integration Study*.

31 National Energy Board, Canada's Energy Futures 2016: Energy Supply and Demand Projections to 2040.

32 Bataille, C. et. al., *Policy Uncertainty and Diffusion of Carbon Capture and Storage in an Optimal Region.*

INDIGENOUS RENEWABLE ENERGY INITIATIVES

Indigenous peoples, communities and organisations across Canada are implementing a range of climate change initiatives.[33] A database compiling Indigenous climate change initiatives has so far identified 79 renewable energy initiatives with a web-based presence, 16 of which are presented on the Nations' or communities' websites.[34] Renewable energy initiatives can yield multiple benefits, such as protection of the land, air and water, while creating much-needed employment.

The T'Sou-ke Nation of Vancouver Island in British Columbia, dubbed Canada's first Aboriginal Solar Community, developed three community-owned solar demonstration projects. These include a stand-alone system with battery storage on a community office building, a grid-connected solar PV system that can be used as a backup power source, which that can sell surplus power back to the grid for communities that wish to have net-zero energy use, and a kilowatt grid-connected, net-metered solar PV system on the community canoe shed, which powers its administration buildings. Surplus energy created in summer is sold to the grid and bought back in winter.

Additionally, the T'Sou-ke have installed solar hot water on 42 of the 86 private residences in the community, begun a comprehensive energy conservation program for all houses, and installed two solar-powered electric car charging points. The Government of Canada has just announced funding for a partnership between T'Sou-ke Nation and Schneider Electric to develop energy storage for a worldwide market. In Quebec, the First Nation's political and administrative organisations of Mashteuiatsh, Pekuakamiulnuatsh Takuhikan, and the Regional County Municipalities of Maria-Chapdelaine and Domaine-du-Roy in Saguenay-Lac-Saint-Jean have formed a non-profit 100% regional partnership to identify and develop renewable energy projects using a sustainable development approach. Since its creation, the partnership has contributed to the development of two mini hydro projects. Company profits are transferred to the communities.

Many power project developments occur in the traditional territories of Indigenous Peoples and many in remote areas. By proactively partnering in power developments, Indigenous Peoples can create long-term sustainable value for their members through investment, employment, infrastructure and new business opportunities. By working with the power developers at the earliest stages of project planning, indigenous communities have input into the design to meet local needs which include reducing environmental impacts. For example, "First Nations Power Authority" was mandated to facilitate the development of First Nations-led power projects and promote indigenous participation in procurement opportunities with the crown utility in Saskatchewan, SaskPower.[35]

predictable than that of wind and solar sources. These water flows can turn underwater turbines without the use of dams or reservoirs. Similarly, wave energy is generated by harnessing the motion of waves. Canada has significant tidal and wave energy resources, which can, in the future, contribute to emission free electricity generation. These technologies are currently at the demonstration stage and it is therefore too early to consider modelling their potential contribution to Canada's energy mix.

Additionally, as an alternative to fossil fuels, biomass can be used to generate renewable and sustainable energy. While trees and other plants grow, they absorb carbon from the atmosphere. Over time, the carbon dioxide sequestration from growing trees and plants will offset the short-term carbon dioxide emission from bioenergy, and could deliver substantial carbon savings when compared to fossil fuel use over time (*see more on biomass in Chapter* 6).

33 Assembly of First Nations, *Gap Analysis First Nations Climate Change Adaptation South of 60 Degrees Latitude.*
34 Sustainable Canadian Dialogues, *Acting on Climate Change: Indigenous Innovation.*
35 First Nations Power Authority; *About First Nations Power Authority.*

As mentioned, wind, solar, and run of river (or low-head hydro) only produce electricity when their resource is available (e.g., when the wind is blowing). For this reason, it is necessary to pair these technologies with hydro or other firm power sources, or with grid interties or management operations (*see box on energy storage*). Energy storage, grid interconnects, and smart grids could improve grid-stabilisation and buffer peak electricity demands, which could in-turn, support a larger share of renewables in the electricity grid.[36]

Storage technologies and smart grids may also be particularly useful in incorporating renewable technologies in remote and off-grid communities, since they have the potential to reduce or eliminate transmission costs. Between today and 2050, it is likely that significant developments will occur in storage technology with the potential to transform the energy system.

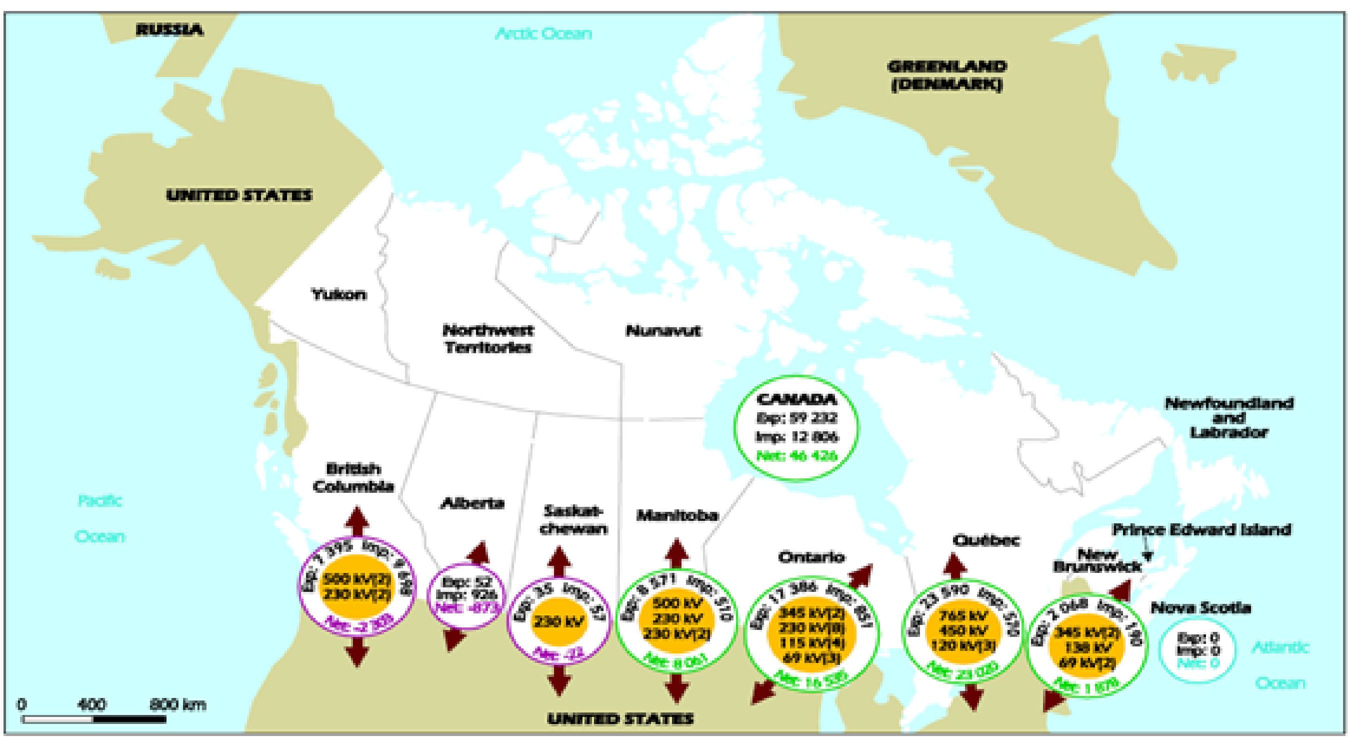
36 National Energy Board, *Canada's Energy Future 2016: Energy Supply and Demand Projections to 2040.*

37 International Energy Agency, *Energy Policies of IEA Countries, 2015 Canada Review.*

3.4 Interprovincial, interjurisidictional, and intercontinental cooperation will enhance integration of clean electricity generation to satisfy growing demand. Canada's contribution towards global GHG abatement could include providing clean power to our continental neighbours, as well as clean power services to the international community.

Canada, and North America's, electricity future will be shaped by interprovincial, interjurisdictional, and intracontinental cooperation. Since Canadian provinces and territories have purview over energy decisions within their jurisdictions, they have traditionally designed electricity infrastructure with consideration towards meeting their own energy demands. However, interprovincial electricity trade is becoming an important component of many provinces' supply and demand considerations. This type of cooperation becomes more important when considering climate change objectives, including maximising use of non-emitting sources (e.g., hydro), as well as when increasing the amount of intermittent electricity sources in the grid (e.g., solar, wind, tidal, wave). The recent Ontario-Quebec Trade and Cooperation Agreement provides a good example of interprovincial electricity trade.

Figure 4: Electricity exports and imports between Canada and the U.S., by province, 2014[38]



Expansion of electricity grid interties could allow more areas with surplus hydropower, or other forms of non-emitting generation, to sell electricity to other provinces or U.S. States that rely on fossil fuels. The integration of electricity markets between Canada and the U.S. includes 35 physical interconnections crossing the border and over $2.3 billion in Canada-U.S. electricity trade revenue.[38] In August 2015, the U.S. Environmental Protection Agency released the final version of the *Clean Power Plan* which could reduce GHG emissions from the U.S. power sector by 32% from 2005 levels. Under certain conditions, U.S. states can help meet their emissions reductions targets through imported clean electricity from Canada.

This is expected to create a significant new market opportunity for Canadian electricity exports and increase the profitability of various clean electricity projects, such as large hydroelectric facilities.

It will be important to maximise the benefits from this trade from both an economic as well as a global greenhouse gas standpoint. Under the North American Leaders' Statement on Climate, Clean Energy, and Environment Partnership, leaders announced a goal for North America to strive to achieve 50% clean power generation by 2025, which will require further cross-border transmission projects, including for renewable energy.

REDUCING CANADIAN NORTHERN, REMOTE AND INDIGENOUS COMMUNITIES' RELIANCE ON FOSSIL-FUEL GENERATED ENERGY

According to the Remote Communities Energy Database, there are 288 remote and off-grid communities in Canada, 190 of which rely on diesel fuel for their electricity needs, either completely or partially.[39] Most of these communities also rely on diesel fuel for home heating.[40] In addition to remote communities, a number of governmental and private buildings also rely on diesel fuel for electricity and heating. Sixty percent of Canada's remote and off-grid communities are First Nations, Inuit, or Métis communities. In many cases the diesel must be flown in at great expense.

There are various environmental and human health concerns associated with the transportation, storage and combustion of diesel fuel. Further, high fuel costs associated with diesel generation and power plants already operating at capacity represent barriers to improving living conditions and facilitating economic development. The cost of producing off-grid electricity from diesel generators in Canada's northern and remote communities can be up to 10 times higher than electricity generated on the main grid, and can significantly add to the cost of living for northern and remote communities.[41]

Circumstances of specific communities will affect the costs and viability of options to increase the share of non-emitting electricity generation. While connecting small and distant communities to existing grid infrastructure is not economically feasible, in some cases, hybrid wind/solar-diesel generation systems could be deployed in communities to decrease reliance on diesel fuel. Other potential non-emitting energy alternatives to diesel generation include hydro, tidal, geothermal, small modular nuclear reactors, and biomass. Diesel is also used to provide home heating in northern and remote communities. There may be opportunities to further displace diesel with lower emitting technologies.

A number of renewable energy projects have already been deployed to displace diesel in northern and remote communities. In many circumstances, diesel infrastructure is reaching the end of its life providing an opportunity to shift to cleaner technologies. Although the upfront capital costs to building non-emitting supply are high, these may be partially offset by lower operating/fuel costs. Long-term planning and investment is pertinent to the success of this transition.

38 National Energy Board, *Electricity Exports and Imports Summary*.

39 Natural Resources Canada, *Remote Communities Database*.

40 Carleton School of Public Policy and Administration, *Report of the State of Alternative Energy in the Arctic*.

41 Government of Canada, *Status of Remote/Off-Grid Communities in Canada*.

Moreover, non-emitting electricity infrastructure investments can help address issues of energy security for Indigenous communities and help set the conditions required for stable, and favorable policy climates for establishing mini and micro grids for rural and remote electrification, including those that are First Nation community or family owned.

Currently, the electricity sector requires major investments in new infrastructure, as many facilities are about to be retired or refurbished. The majority of investments in the sector will be in electricity generation; however, transmission and distribution will also see significant investments. There are estimated investment requirements of as much as $350 billion in electricity infrastructure in Canada between now and 2030.[42] The Deep Decarbonisation Pathways Project estimates that $16 billion in additional annual investments will be necessary to achieve Canada's low-carbon future, of which 87% ($13.5B) will be required in the electricity sector.[43] As conventional new sources of low-carbon electricity become less viable, or available (e.g., hydro), new investments in emerging technologies will become increasingly targeted.

Given the long-term nature of electricity related infrastructure, planning and investment decisions will need to be made in the near term to have the desired effect on the 2050 time horizon. For example, infrastructure spending, loan guarantees, and low-interest loans could potentially help fund new hydro projects and transmission lines to facilitate clean electricity projects.

3.5 Energy conservation and energy efficiency measures should increase and be implemented alongside efforts to reduce emissions from electricity generation. Electricity savings should underlie decarbonisation pathways: demand side management and reducing equipment and transmission losses makes electrification far more effective and feasible.

Improvements in energy efficiency and demand side management are core elements of a long-term low-GHG strategy and present economic opportunities. In many cases, energy efficiency is a cost-effective way to reduce GHG emissions as it provides substantial monetary savings for residential consumers and businesses through lower electricity bills, as well as other benefits such as reduced maintenance and improved durability. In addition, several commercialisation opportunities exist; for example the International Energy Agency (IEA) estimates the global energy efficiency market at $221 billion in 2015. The IEA also notes that efficiency investments helped drive a global energy intensity improvement of 1.8% in 2015 however "the intensity improvement needs to immediately step up to 2.6% per year from now until 2030 to get on a 2°C pathway".[44]

The IEA argues that energy efficiency is key to reaching global emissions levels consistent with the 2°C temperature goals. They estimate that electricity savings, through efficiency measures, could avoid 5,100 GW of new capacity by 2050. Likewise, Torrie Smith Associates notes that low-carbon future analysis typically include per capita levels of fuel and electricity use that are about half the current Canadian average, and energy productivity (GDP/energy) four times higher than current Canadian levels.[45] Energy efficiency trends are already positive in Canada as energy efficiency improved from 1990 to 2013 by 24%.[46] The National Energy Board projects that total end-use energy demand will increase at an average annual rate of 0.7% from 2014 to 2040, almost half the rate of increase from 1990 to 2013.

Higher electricity efficiency can be achieved with targeted demand-side management measures and technological improvements. Changes in behaviours such as consuming electricity during low-demand periods could reduce peak power demand which could contribute to reduce GHG emissions from load generation.[47] Energy efficiency can also defer transportation and distribution investments, reduce line losses and avoid capacity reserve requirements. As technology develops, further electricity productivity gains should be realised with devices like smart meters helping to reduce and optimise end-use.

42 Conference Board of Canada, *Canada's Electricity Infrastructure: Building a Case for Investment.*

43 Bataille C., *Pathways to Deep Decarbonization in Canada.*

44 International Energy Agency, *Energy Efficiency Market Report.*

45 Torrie, R., *Acting on Climate Change: Extending the Dialogue Among Canadians; Some Reflections On Climate Change Response Policy.*

46 Natural Resources Canada, *Improving energy efficiency in Canada.*

47 Energy efficiency can also defer transport and distribution (T&D) investments, reduce line losses and avoid capacity reserve requirements (IEA 2016)

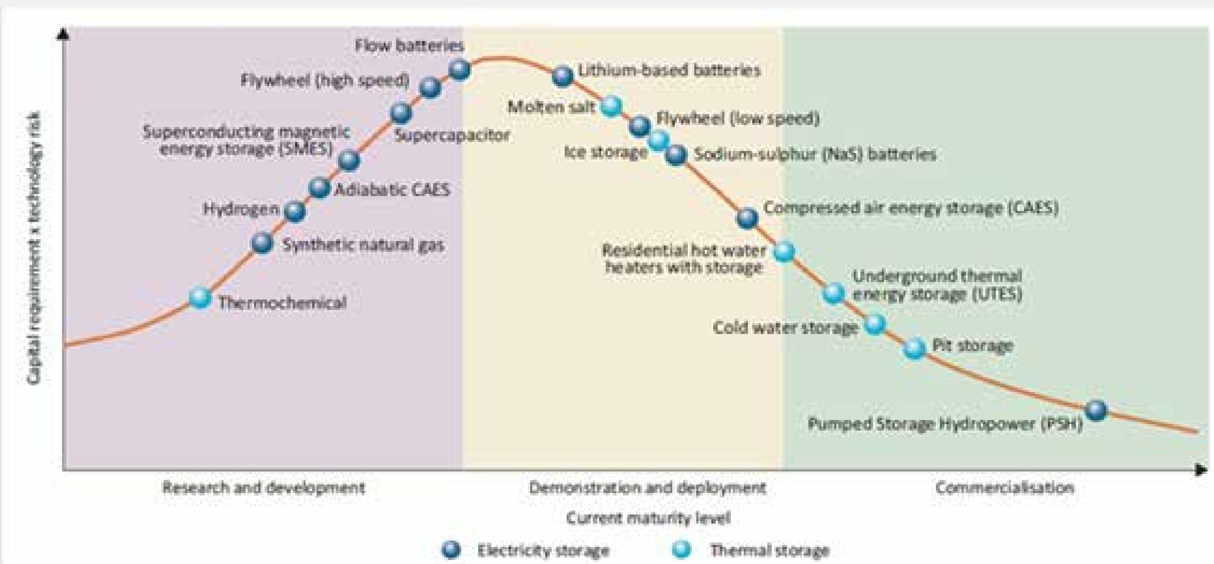
Modernizing the electricity grid could also contribute to improved electricity efficiency by reducing losses when electricity is generated and transmitted. Grids generally follow north-south orientations since most of Canada's population live in southern jurisdictions along the international border with the United States, while the largest hydroelectric projects are located in scarcely inhabited areas to the north. Since the Canadian transmission networks extend over 160,000 km, losses are significant between generation and end-use sources. However, by 2050, it is highly probable that distributed generation will play a bigger role, reducing the requirement for electricity to travel long distances from point of generation to end use.

ENERGY STORAGE

The principal challenge with variable renewable energy such as wind or solar is that they are intermittent, meaning that power is not available when the wind is not blowing or the sun is not shining. As such, improvements in energy storage would make these intermittent sources much more attractive to grid operators, ensuring that power is available to meet demand cycles. Additionally, increase in energy density and charging rates for battery energy storage technologies can provide the improvements in the transport sector that will be required for a widespread adoption of electric means of transportation.

Incorporating intermittent power flows to existing grids requires added flexibility elsewhere on the grid, which can increase system costs. However, such costs could be offset by the adoption of technologies that can store excess power for weather conditions that are unfavorable to power generation and support the grid during peak demand time. Storage technologies could also allow households to rely on their own energy production, thus increasing the growth of local energy production, potential of smart grid systems, and energy availability for remote communities.

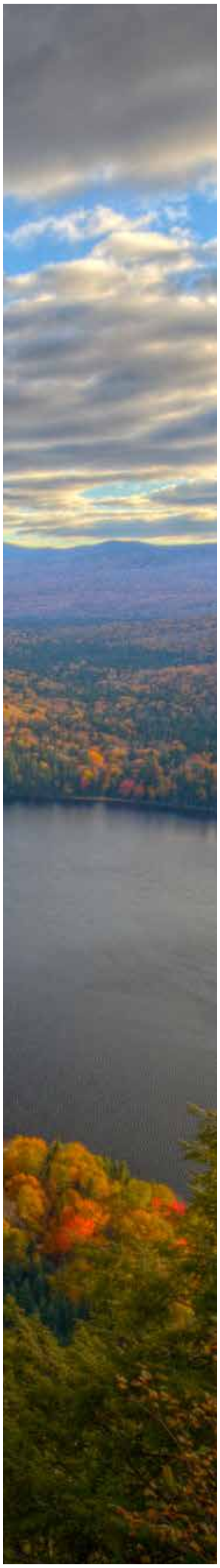
Figure 5 : Technology Roadmap : Energy Storage



Source: International Energy Agency, 2014. Technology Roadmap: Energy Storage

The private sector has been a major leader in energy storage research. Specifically, battery storage technologies for cellphones, computers and electric vehicles, have seen tremendous growth in recent years. Already, the costs of lithium ion batteries are being significantly reduced by the production of electric transportation companies, such as Tesla Motors. Moreover, other cheaper and more efficient options are being developed, with possibilities for the entire energy sector. For example, sulfur-based and graphene-based battery technologies offer tremendous potential for cheaper and more powerful battery storage. Other energy storage options are available, with some of them already adopted by Canadian electricity providers. Recently, the Toronto Hydro Company's compressed air energy storage pilot project was deployed in Lake Ontario and now provides 1 MW of storage capacity that can be sent to the city grid during peak demand times. Thermal energy storage is also being used in the community of Okotoks, Alberta. Nevertheless, the most promising option for some Canadian provinces is likely to be pumped storage hydropower (PSH). The technology is readily available, has low operation and maintenance costs, and is not limited by cycling degradation.

Although recent improvements achieved by the private sector are encouraging, much more innovation is needed to allow for widespread renewable energy production by 2050. Consequently, due to the essential role of energy storage technologies in the electrification of numerous processes, including transportation, it is fundamental that energy storage technologies continue to improve over time. In order to accomplish this, governments and private actors have a shared responsibility to scale up investments throughout the innovation chain in order to allow breakthrough technologies as well as incremental improvements to be brought to market.



4 Energy Consumption in End Use Applications

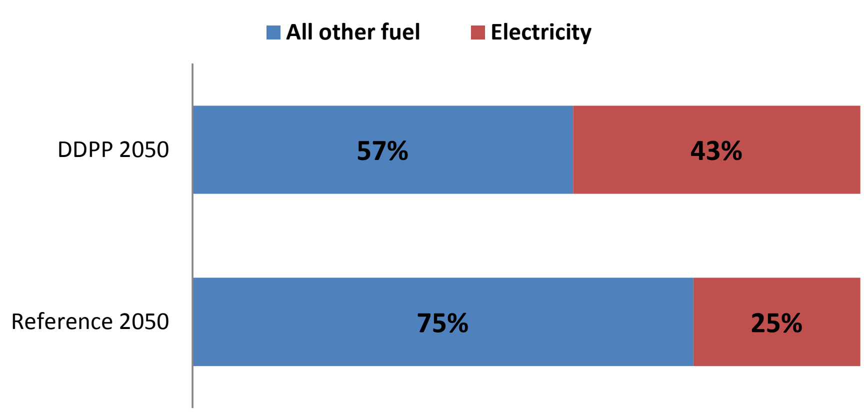
Under a low-carbon future, Canada's electricity demand is expected to increase substantially by 2050, partly as a result of traditional pressures such as population and industrial growth, but also because of the electrification of end use applications that currently use other forms of energy. Many applications (e.g., cars, trucks, boilers, heaters) can use clean electricity to fulfil their power requirements, reducing emissions by switching away from refined petroleum products, natural gas, and other fossil fuels. This greater use of electric power is often accompanied by important efficiency gains, especially in the transportation sector, leading to an expected reduction in overall energy demand under low GHG scenarios. Maximising the abatement potential from electrification requires the simultaneous near decarbonisation of existing electricity generation and the large expansion of new zero or low emissions electricity sources, as discussed in the previous chapter.

All academic and expert analyses that pertain to low-GHG pathways show an increase in electricity supply and greater proportion of electricity in total energy demand. For example, the *Deep Decarbonization Pathways Project* shows electricity rising to 43% of total energy by 2050 compared to 25% currently, more than doubling the current supply between now and 2050. Moreover, the *Trottier Energy Futures Project* shows electricity generation more than tripling between now and 2050.

Given Canada's relatively cheap and clean electricity generating portfolio, implicit carbon costs for electric power are lower than in many other countries. This means that clean electricity is a comparative advantage for Canada. It will be important to examine any change or rise in electricity costs associated with the new demand requirements, and ensure that Canada continues to have access to affordable and reliable electricity going forward.

Apart from electrification technologies, renewable and low carbon fuels are low or non-emitting options to fulfil many of Canada's energy requirements. These fuels will be particularly important in areas where electrification is not currently possible or too costly, such as aviation and marine transport, some heavy freight transportation, and many industrial activities. Likewise, renewable or low carbon fuels can often be used in existing cars and trucks or building furnaces in higher blends, without affecting equipment performance, safety or warranties.

Figure 6: Electricity as a share of National energy consumption



Source: Bataille, C. *et al. Pathways to deep decarbonization in Canada.*

It is important to recognize that all energy related emissions reduction activities work best when paired with increasing energy efficiency. For example, increasing the number of homes heated by clean electricity will be much more viable when building envelopes are designed to minimise heat loss. Importantly, a reduction in demand through energy efficiency, conservation, and demand side savings will partially offset the increased Canadian electricity requirements from the electrification of end use applications.

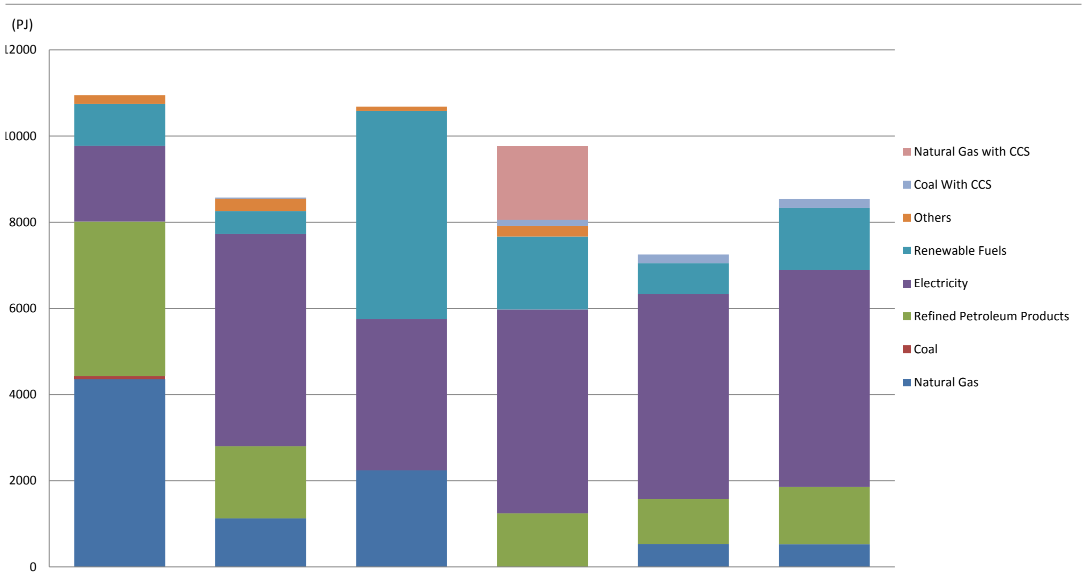
Figure 7 presents several analyses of total energy use in Canada by 2050 under low-GHG scenarios. The current energy use (2014) is presented, as well as DDPP and Trottier Institute 2050 results. While there is population and economic growth during the period, even stronger energy efficiency gains allow for decreases in total energy consumption in most analyses. For example, total energy consumption decreases from 10 950 PJ in 2014 to 7971 PJ on 2050 (ECCC GCAM scenario, labelled "High Non-Emitting") or even 7 251 PJ in 2050 (New Tech Trottier). The central role of energy efficiency gains in the projections is consistent with Chapter 2 that depicted energy conservation as the "first fuel", the foremost criteria to meet the 2050 GHG emissions reduction levels.

Apart from a reduction in total energy consumption, the switch from fossil fuels use to electricity and renewable fuels alternatives is another cross cutting theme of all scenarios presented. Clean electricity production across the country, achieved before 2050 in all scenarios, allows for deep GHG emission reductions from the electrification of end uses and industrial processes. Electricity use in 2050 is predicted to reach between 40 to 72% of total energy consumption, up from 16% in 2014.

Renewable fuels provide the last alternative in most scenarios to decarbonise the intensive GHG sectors of the economy. In key sectors, notably in heavy industry and freight transport, renewable fuels replace conventional petroleum and natural gas usage. Those alternative fuels are essential to attain deep GHG emissions reductions, since it is not likely that technological advances will allow electrification of all sectors of the economy by 2050.

Specifically, ECCC presents two scenarios where electricity generates either 33% (High Demand Response) or 57% (High Non-Emitting) and renewable fuels supply either 45% (High Demand Response) or 6% (High Non-Emitting) of total energy consumption in Canada by 2050. ECCC's High Non-Emitting projection estimate refined petroleum products will still account for around 20% of total energy consumption by 2050, with natural gas generating 13%. ECCC's High Demand Response scenario projects a use of natural gas falling to 21% of total energy consumption by 2050, and no future use of refined petroleum products. In contrast, the DDPP estimates that electricity will generate 48% of total energy consumption in Canada by 2050, with 17% supplied by renewable fuels, 17% by natural gas (with Carbon Capture Storage Technologies [CCS]), 2% by coal (with CCS) and 13% by refined petroleum products. Trottier estimates electricity to take between 59-66% of total energy consumption in Canada, with renewable fuels supplying either 9 and 17%, refined petroleum products supplying between 14-16%, natural gas 6-7%, coal 2-3% (retrofitted with CCS).

Figure 7: 2050 Projections of Total Energy Consumption by End Use Fuel



4.1 Transportation

KEY MESSAGES:

- Electrification of the transportation sector presents the potential for significant emission reductions; for personal vehicles, electric vehicle technology is commercially available and continues to improve.
- Greater uptake and broad use of electric vehicles will require more widespread acceptance of the technology supported by information and understanding around: cost of ownership and performance, charging availability and times, and range expectations. All of which are expected to improved significantly over the coming years.
- Low-carbon and renewable fuels are consistent with low-GHG scenarios, particularly in areas that face challenges with electrification.
- Freight transport is a challenging sector, but there are a number of solutions that show potential towards deeper emissions reductions.
- Emerging technologies such as energy storage or advanced lightweight materials will increase energy efficiency and decrease emissions; innovative approaches to moving people and freight are likely to become more widely adopted by mid-century.
- Modal shifts, such as moving passengers and freight to less GHG intensive modes, could offer notable emissions reductions, which would be further strengthened through clean technology deployment, such as electrified passenger rail.
- 62% of Canada's black carbon emissions arise from the Transportation sector. In addition to being linked to climate warming, black carbon emissions are also a public health concern. Canada continues to take complementary action to reduce black carbon emissions.

4.1.1 Electrification of the transportation sector presents the potential for significant emission reductions; for personal vehicles, electric vehicle technology is commercially available and continues to improve.

The transportation sector plays a vital role in the lives of Canadians and in the Canadian economy. Almost 82% of Canadians live in urban areas and 80% of commuters drive to work in their own vehicles. Canada's transportation system moved over $1 trillion worth of goods to international markets and employed 896,000 Canadians (5% of total employment) in 2014. Compared to other countries, Canada depends heavily on cars for urban mobility, and has a relatively high share of large cars. Canada has large distances between its cities, increasing intercity travel emissions.

Currently, the transportation sector is a major contributor to Canadian GHG emissions. Roughly one quarter (28%) of Canada's GHG emissions come from the transportation sector, such as from cars, buses, trucks, motorcycles and recreational vehicles.[48] About 57% of these emissions come from passenger transport, while heavier freight transport accounts for 37% of transport emissions.[49] However, given increasing efficiency improvements in passenger vehicles (mainly driven by federal regulations) and challenges in achieving efficiency improvements in freight, the share (and net amount) of GHG emissions from freight transportation is expected to increase into the future.

Road transportation activity can be broken down into two components: how people and freight travel (mode choice) and how far they travel (activity level).[50] Emissions reductions could result from a greater market penetration of alternative vehicle technologies and modal shifts (e.g., away from single-occupancy vehicles). Activity level changes could be achieved through consumption patterns shifting with technological advances (e.g., teleworking) or urban densification. Canada will continue to encourage cities to improve public transit and bike lanes, and design urban spaces that reduce the need for vehicle transportation.

Battery electric vehicles provide the opportunity to emit zero GHG emissions when renewable or

48 Environment and Climate Change Canada, *National Inventory Report 1990-2014: Greenhouse Gas Sources and Sinks in Canada.*

49 Based on Canada's *Emission Trends Report 2014.*

50 Conference Board of Canada, *A Long, Hard Road: Reducing GHG Emissions in Canada's Road Transportation Sector by 2050.*

clean electricity is used. In addition, electric vehicles reduce local air pollutant emissions. Electric vehicle technology is well known, proven, and available for purchase in Canada with increasing variation and choice: in total, there are 22 different plug-in models on the road in Canada, made by 12 different manufacturers.[51] Alternatively, plug-in hybrid vehicles offer increased driving range by switching to fossil fuels when the electric battery charge diminishes. While these vehicles still use fuel, most of them are used in a way that relies solely on electricity about 90% of the time. [52]

4.1.2 Greater uptake and broad use of electric vehicles will require more widespread acceptance of the technology supported by information and understanding around: cost of ownership and performance, charging availability and times, and range expectations. All of which are expected to improved significantly over the coming years.

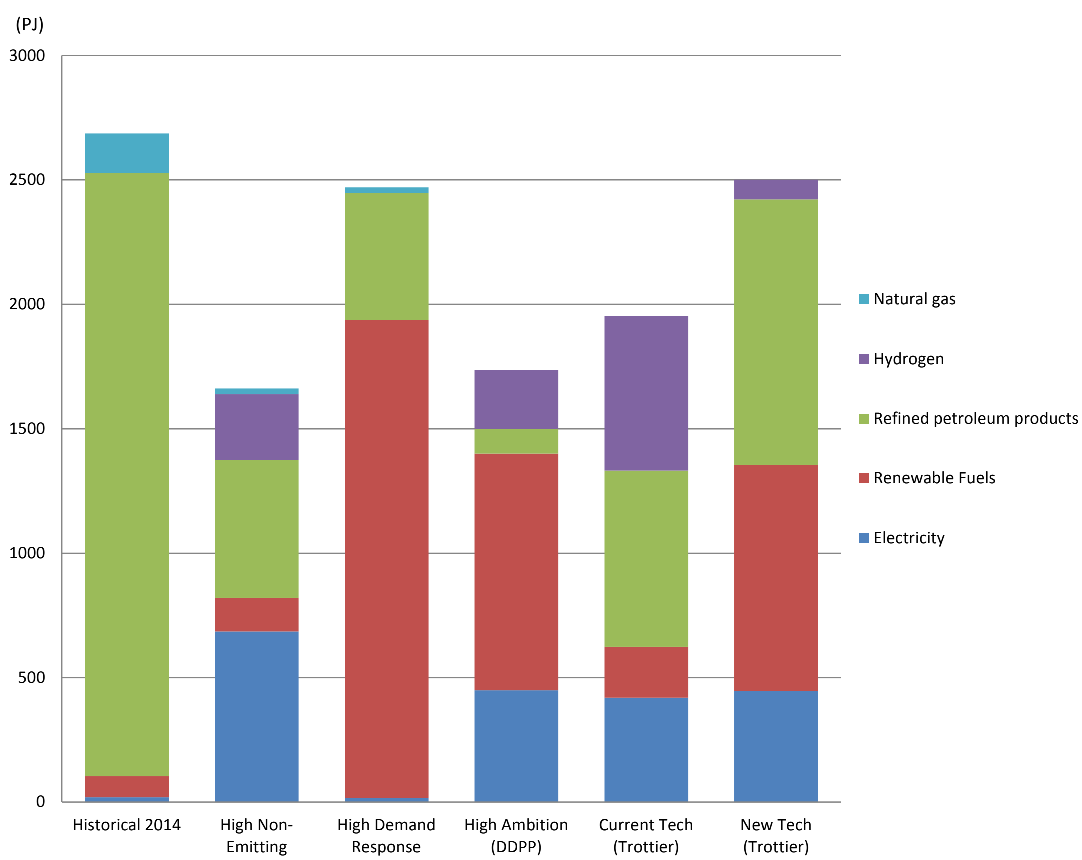
51 CAA, *Electric Vehicles: What You Need to Know.*
52 EVObsession, *Best Electric Car for the Average American.*

In spite of Canada's ambitious mitigation objectives and clean electricity portfolio, we lag behind many of our peer countries with respect to electric vehicle penetration. For example, Norway reached annual sales of almost 40,000 fully electric vehicles in 2015, reaching a market share of 23% of passenger vehicles sold. China has grown its electric vehicle fleet by 207,000 passenger vehicles in 2015, with an additional 123,700 electric buses and commercial trucks on the road.[53] Meanwhile, there are now more than 40,000 electric vehicle charging stations in Japan, including in personal homes and commercial buildings. Charging stations are now more common than the roughly 35,000 gas stations in the country.[54]

Although only about 24,000 plug-in vehicles have been sold in Canada thus far, sales increased by 32% between 2014 and 2015, and are projected to continue to increase as prices converge with those of conventional vehicles, charging infrastructure is built out, and more vehicle selection becomes available.[55] For example, out of the roughly 400,000 reservations

53 International Energy Agency, *Energy Technology Perspectives 2016.*
54 Coulter, T., *Japan Has More Car Chargers Than Gas Stations.*
55 Fleet Carma, *Electric Vehicle Sales in Canada: 2015 Final Numbers.*

Figure 8: 2050 Transportation Sector Energy Use Projections (PJ)



of the upcoming Tesla Model 3 electric vehicle, an estimated 36,000 have been made in Canada.[56]

While the production costs of electric vehicles remain higher than traditional gasoline vehicles, a more significant challenge limiting electric vehicle adoption is consumer concerns regarding the range of the battery charge. Charging speeds and battery range currently do not allow for comparable refueling times when benchmarked against traditional gasoline vehicles. In some circumstances, cold weather can also reduce electric vehicle driving range. However, studies have found that the current battery range for electric vehicles is sufficient to satisfy close to 90% of personal vehicle use. For example, a study from the Massachusetts Institute of Technology used GPS data to estimate the energy requirements of personal vehicles across the United States, determining that 87% of requirements could be met with current electric vehicles.[57]

In addition, there are significant efforts put in place to increase fast charging infrastructure in some Canadian jurisdictions, which can allow the average electric car to charge 80% of its battery capacity in 30 minutes. Although needs for infrastructure investments will be important in the coming years, it is important to note that chargers will not need to be as abundant as fuel dispensers are today, as more than 95% of charging is done at home, and public charging stations generally only need to be used when motorists travel long distances.

4.1.3 Low-carbon and renewable fuels are consistent with low-GHG scenarios, particularly in areas that face challenges with electrification.

Low-carbon, renewable fuels, and hydrogen are of particular importance for areas that are hard to electrify. A number of renewable fuels are already commercially available such as ethanol, biodiesel or biofuels. Fuel blends contain varying renewable content, and environmental benefits expand when second-generation biofuels are used. Unlike other modes of transportation, the aviation industry has few options available for reducing GHG emissions. Improved technological and operational measures will have their role, but only low-carbon alternative fuels (biojet) have the potential to offer significant life-cycle GHG emission reductions.

Renewable natural gas offers the potential to achieve considerably greater emissions reductions than natural gas. Biogas, generated from biomass from landfill sites, agriculture, wastewater, or other sources is upgraded to natural gas quality. It can then be directed to the grid for use in buildings or transportation applications in the form of compressed natural gas (CNG) or liquefied natural gas (LNG).

Natural gas vehicles are used in several fleets around the world. Up to a 25% reduction in carbon dioxide equivalent emissions can be achieved on a well-to-wheel basis when replacing gasoline with compressed natural gas in light-duty vehicles. Natural gas can be an effective solution for transportation that is harder to electrify such as on-road freight, marine shipping and rail, featuring relatively quick refueling times and long ranges. As such, it has been a key area for research and development for these modes. Natural gas also has the advantage of significantly improving air quality and reducing noise when compared to diesel.

Hydrogen fuel cell technology can also help decarbonise the transportation sector. The process of producing electricity with a fuel cell involves hydrogen and oxygen as inputs, and produces water vapor and heat at the tailpipe, therefore emitting no GHG emissions. However, hydrogen production currently either requires significant amounts of electricity to be produced through electrolysis, or can be produced with methane reforming, which is an emitting process.

Hydrogen fuel cell vehicles provide the benefit of having similar refueling times when compared with internal combustion engine vehicles, but they also face important barriers such as the cost of fuel cells, cost and energy intensity of hydrogen production, and the need for new infrastructure for hydrogen refueling stations. Nonetheless, hydrogen is a key component of several modelling exercises including the IEA and Deep Decarbonization Pathways Project. For example, the IEA has modelled different levels of Fuel Cell Electric Vehicle adoption. So far, Toyota and Hyundai have commercialised fuel cell electric vehicles in Europe, South Korea, California, Vancouver and Japan and further investments could help to accelerate infrastructure deployment. For example, there are already several hydrogen stations and buses in Whistler, British Columbia. Hydrogen is used widely in industry for ammonia production and refining, and can be used for storing the energy in excess renewable electricity. Canada is well placed in the development of hydrogen and alternative fuels with companies such as Westport innovations and Ballard, developing and exporting these low carbon technologies.

56 Model 3 Tracker, *Known Sport of Model 3 Vehicles by Status.*
57 Needell, Z., *Potential for Widespread Electrification of Personal Vehicle for Travel in the United States.*

Modelling results from very low greenhouse gas scenarios for 2050 point to various avenues to power Canada's transportation sector (*see description of models and scenarios in Modelling and Scenario Box in Chapter* 2). Currently, refined petroleum products (e.g., gasoline, diesel) power over 90% of Canada's transportation energy requirements. Under scenarios where aggregate Canadian emissions decline dramatically in 2050, the energy portfolio of the transportation sector shifts considerably (*see Figure 8).*

Under ECCC's first High Non-Emitting scenario, electricity powers 41% of transportation energy requirements in 2050, whereas renewable low-carbon fuels account for 8%. The remaining requirements are met with hydrogen (16%) and natural gas (1%), although refined petroleum products continue to power 33% of the vehicle fleets including air and marine transportation. In comparison, ECCC's High Demand Response model points to renewable and low-carbon fuels dominating the transportation energy portfolio (78%). In this modelling scenario, electric vehicles do not penetrate the market.

The Deep Decarbonization Pathway Project also points to a high penetration of renewable and low-carbon fuel powered vehicles (55%). Electricity makes up 26% of the power requirements from the transportation sector, whereas hydrogen accounts for 14%. Under the Trottier analyses scenarios, renewable or alternative fuels power 10-18% of the transportation requirements in 2050. Electricity powers 18-21% and hydrogen powers 3-32%. Refined petroleum products continue to power 36-43% of the sectors energy requirements.

4.1.4 Freight transport is a challenging sector, but there are a number of solutions that show potential towards deeper emissions reductions.

Freight transportation, *such as heavy duty on road vehicles, aviation and marine is a challenging area for GHG mitigation*. Improving the fuel efficiency of freight transportation is essential to reducing greenhouse gas emissions from this subsector. Moreover, alternatives to conventional internal combustion engines exist including vehicles that run on fuels such as biofuel blends, liquefied petroleum gases, or natural gas. The use of these fuels can reduce the GHG intensity of road transportation, sometimes significantly.

Electrification of freight transport is currently limited due to technological constraints such as insufficient range for long-haul shipping, long charging times for delivery requirements, as well as the significant energy requirements and engine sizes required to transport heavy loads. However, some companies have revealed plans to develop electric freight transport in the coming years. For example, last July

CANADIAN BUSINESSES ADOPTING LIGHT FREIGHT ELECTRIFICATION

A number of Canadian companies, and companies operating in Canada, have opted to green their fleet through the use of hybrid-electric vehicles or fully electric vehicles. For couriers and other shipping companies, fleet management and fuel use has a major impact on operating costs, and is constantly being reviewed to minimise costs and increase performance. Some companies have opted for electric vehicle technology for both economic and environmental benefits.

As a few examples, Canada Post, Purolator, the United Postal Service, Fedex, and Novex have moved towards more sustainable transportation solutions for shipping. Other initiatives, such as a fully electrified taxi company, have been developed, for example in Montréal by Téo Taxi. Although information gaps appear to be an important barrier to adoption of electric vehicles by small and medium enterprises, several companies are providing support services to demonstrate the business case for greening vehicle fleets. This involves procedures such as calculating expenditure impacts, renting out vehicles to allow for trials, and providing technical support for charging infrastructure management.

Another company, Communauto, North America's oldest and largest car-sharing company, has recently announced its purchase of 600 hybrid-electric or fully electric vehicles. Among these vehicles, 515 are destined to the Québec market, while the remainder will be distributed to Communauto's European market. Ride-sharing services also displace a significant amount of personal vehicle requirements, thereby reducing GHG emissions further.

Mercedes-Benz unveiled its latest electric prototype, the Urban eTruck, conceived for dense urban areas. The fully electric vehicle has two electric motors, can hold 3 batteries, and will be able to support up to 26 tons. Conceived for short distances (200 kilometers) and use in heavy traffic, Mercedes-Benz expects to commercialise the vehicle by 2020.[58]

Despite continuous progress, there are some challenges associated with reducing emissions from freight transportation. Finding economical means of producing biofuels and alternative means of transporting merchandise will be key.

Figure 9: An Urban eTruck[59]

A large deployment of heavy electric trucks may take longer than cars since the turnover rate of heavy trucks is significantly lower than for cars (30 years for trucks compared to 20 years for cars). Emissions from aviation, marine, and rail transport are also challenging to reduce due to the high energy density of fuel required with these modes. Despite these challenges, the energy intensity of the freight transportation sector decreased from 1.38 MJ/Tkm in 2011 to 1.30 MJ/Tkm in 2013. A recent report from the Conference Board of Canada suggests that much greater performance and efficiency improvements will be needed to help bring Canada to deep decarbonisation in the transportation sector.[60]

In 2013, new federal regulations imposing GHG emission standards for new on-road heavy-duty vehicles and engines were implemented to align with U.S. national standards and move the Canadian heavy truck fleet toward more fuel efficient vehicles. In the marine and rail sectors, where fuel represents a significant share of overall costs, operators are actively seeking improvements in fuel efficiency and GHG performance through new technologies, designs and system efficiencies, and are exploring a shift to low-carbon fuels. For marine shipping, mandatory technical and operational emissions reduction measures established by the International Maritime Organization (IMO) are also driving efficiency improvements. However, significant emissions reductions will take time as the existing stock of ships and locomotives turn over. Electric and alternative fuel solutions can also achieve meaningful reductions from port and cargo handling equipment at transportation hubs.

4.1.5 Emerging technologies such as energy storage or advanced lightweight materials will increase energy efficiency and decrease emissions; innovative approaches to moving people and freight are likely to become more widely adopted by mid-century.

Looking forward, improvements in energy storage technology will facilitate the adoption of electric vehicles. The most anticipated technological development related to battery storage is the use of graphene in batteries, which would allow for a significantly higher energy density (battery capacity per unit of weight), significantly faster recharging times, and lower costs. Graphene is abundantly available and the emergence of graphene batteries could be a tipping point where electric vehicles will become more affordable and convenient, broadening adoption.

Connected and automated vehicles, combined with smart infrastructure, are expected to be increasingly deployed by automakers, and have the potential to not only make driving more convenient, but considerably safer, and more efficient, which can lead to improved environmental outcomes. While not as significant as the impact of electrifying transportation, efficiency improvements from autonomous driving could be important. With quicker reaction times than humans, connected and autonomous vehicles can circulate with less distance between cars, allowing for much more efficient traffic movement (e.g., reduced idling, smoother acceleration), and perfectly safe slipstreaming (i.e., cars avoiding wind resistance by following others closely), resulting in less energy wasted. The expected safety improvements and reduced congestion could add up to large fuel savings, with significant co-benefits for the economy and the environment.

Finally, advanced lightweight materials and manufacturing methods will need to be integrated

58 Mercedes-Benz, *Electric Truck for the City*.
59 Mercedes-Benz, *Urban eTruck*.
60 Conference Board of Canada, *A Long Hard Road: Drastically Reducing GHG Emissions in Canada's Road Transportation Sector by 2050*.

ELECTRIFIED PUBLIC TRANSPORT AND SMART URBAN PLANNING

In the transition to a low-carbon economy, public transportation provides significant GHG emission reductions as compared with personal vehicles, but diesel buses still emit a sizeable amount. More recently, advances in the development of batteries for electric vehicles have spilled over to city buses. For example, the city of Gothenburg has been using three electric buses on one line of its public transport service, and has been using seven hybrid electric buses. Although the buses are significantly more expensive than diesel buses upon purchase, the fuel savings rapidly compensate this difference. The buses are charged for six minutes between trips, allowing for more than enough range for the route they serve, while providing outlets to charge phones and providing Wi-Fi to users inside the buses.[61] Similar projects are under way in Montreal, starting with hybrid-electric buses.[62]

Another important consideration in transitioning to a low carbon economy is how to plan and design cities in order to support low-emission technologies and lifestyles, and correct for the traffic congestion levels that are seen in large Canadian cities. Congestion is an important cost to the economy, evaluated in 2008 as costing the regional economy of the Greater Toronto and Hamilton Area, directly and indirectly, $6 billion annually.[63] This kind of structural change will take time to realise, but governments can start building momentum in the short-term by deciding to take a holistic approach to development through integrating land use, transportation, energy production and community planning.

More and more, cities are looking into innovative solutions to reduce congestion on their roadways. For example, the city of Edmonton is one of two Canadian cities taking part in a North American program aimed at developing Connected Vehicle Technology.[64]

This technology can improve many elements of transportation in cities, by preventing collisions between cars, by guiding drivers through detours when there is a slowdown or an accident on the road, and even adjusting traffic lights along the detour routes to minimise congestion. Other technological advances are leading to autonomous vehicles and greater use of vehicle sharing, which stand to have important impacts of the future movement of people within cities. Technological advances also help pave the way for new management approach by cities and governments, such as the use of efficient pricing of tolling mechanisms. For example, High Occupancy Tolls Lanes allow for both vehicles with enough passengers and permit holders to drive in these lanes, allowing for reduced congestion and revenues that can be invested into public transit.

across all modes of transportation to increase efficiency, from on-road electric vehicles to aviation. Other considerations to reduce transportation emissions include: retrofit of heavy-duty vehicles including tractors with GHG-reducing technologies (aerodynamics, auxiliary power units) and the scrappage of less efficient vehicles.

61 Electricity, *The electric bus – quiet, exhaust emission-free and passenger-friendly.*
62 Canadian Press, *Electric bus pilot project to hit Montreal streets in 2015.*
63 Urban Transportation Task Force, *The High Cost of Congestion in Canadian Cities.*
64 City of Edmonton, *On the Front Edge of Smart Vehicle Technology.*

4.1.6 Modal shifts, such as moving passengers and freight to less GHG intensive modes, could offer notable emissions reductions, which would be further strengthened through clean technology deployment, such as electrified passenger rail.

Given the emissions profile and current limitations in electrifying freight transportation, a shift towards rail transit for a majority of freight could reduce the amount of energy needed to move goods around the country. Although rail transportation entails issues such as longer shipping times, and less flexibility in terms of routing of goods, it has the potential to reduce emissions per unit of goods moved by about 75% compared with on-road vehicles for the same distance travelled.[65] As for passenger transportation,

65 Association of American Railroads, *Freight Railroads Help Reduce Greenhouse Gas Emissions.*

rail offers another potential avenue for intercity travel, which could reduce emissions compared to personal vehicles or bus transportation. Other benefits to shifts toward rail transportation include reduced wear and tear on roads and reduced road congestion.

In addition to being less GHG-intensive than on-road modes of transportation, there may be an opportunity to reduce emissions even further through electrification of Canada's passenger rail systems moving on dedicated tracks. Heavily populated corridors, such as the Windsor-Quebec axis, represent prime areas for such a system. Although this type of project requires significant capital expenditures, important savings can be realised through reduced energy costs, increased performance allowing better optimisation (e.g., allowing more units to be attached to the same locomotive), and reduced maintenance costs.[66] Electrification of trains also provides other benefits in the form of smoother rides, reduced power load at higher altitudes compared with diesel, and service to underground locations (which is not possible for diesel given emissions of pollutants).

Electric light-rail trains represent an interesting mode of transportation for public transit, as it is up to 10 times cheaper than underground metro systems for the same distance covered.[67] At this cheaper cost per kilometer, light-rail trains become particularly appealing for bringing commuters from suburban areas into cities faster, while reducing the amount of vehicles in downtown areas. Light-rail trains are also easier to electrify than buses, which makes it a less GHG-intensive transit option than buses, while also reducing the cost of electrification.

4.1.7 62% of Canada's black carbon emissions arise from the Transportation sector. In addition to being linked to climate warming, black carbon emissions are also a public health concern. Canada continues to take complementary action to reduce black carbon emissions.

The transportation sector emits significant amounts of black carbon mostly through diesel engines and vehicles. Canada continues to take regulatory action to address air pollutant emissions from transportation, which also reduces black carbon, including regulations for on- and off-road diesel vehicles and engines manufactured or imported for sale in Canada. Regulations to implement the North American Emissions Control Area to reduce emissions from shipping also reduce black carbon emissions.

In addition to being linked to climate warming, black carbon emissions are also a public health concern. As a component of $PM_{2.5}$, black carbon particles are small enough to be inhaled and absorbed into the lungs and bloodstream. Reductions in black carbon emissions from the transportation sector have important co-benefits for the health of Canadians.

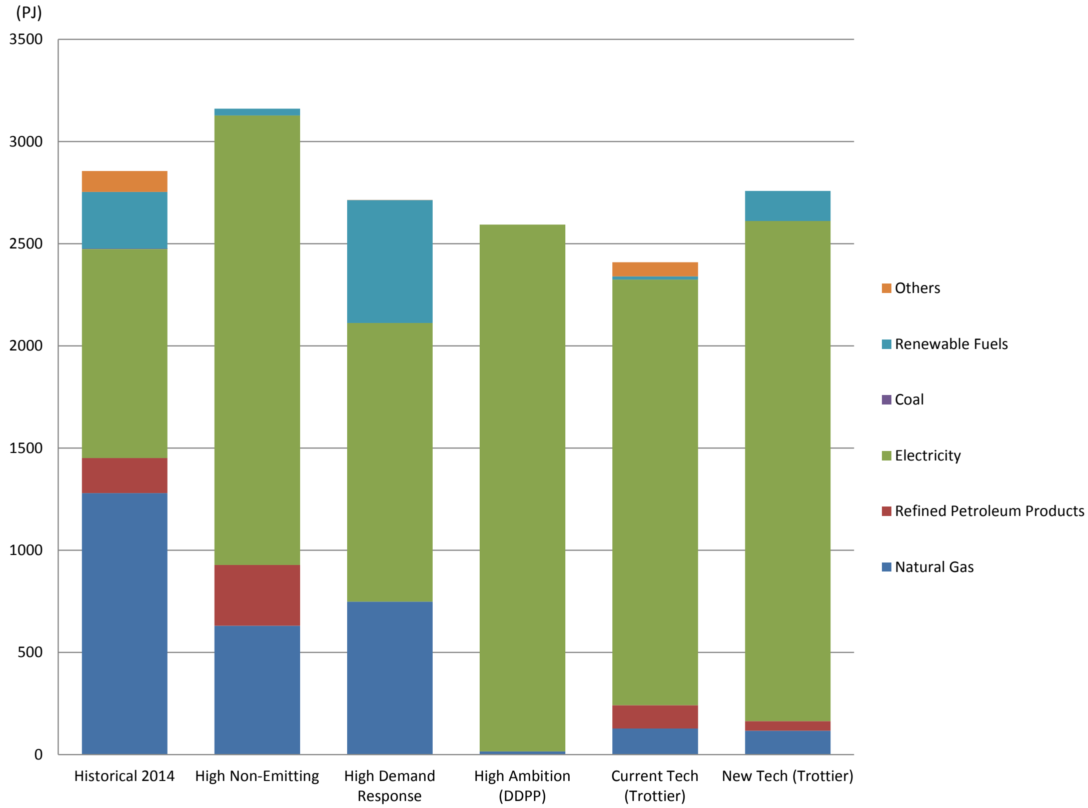
4.2 Buildings

KEY MESSAGES:

- Over one third of Canadian homes are already heated and cooled with clean electricity; emerging technologies will make this option increasingly economically attractive.
- Natural gas continues to play an important role in heating and power requirements. Renewable Natural Gas is a small but growing part of the supply mix meeting those energy needs.
- The electrification of the building sector should be matched with a scale-up of energy efficiency measures.
- District heating for residential and commercial buildings could help lower GHG emissions since heat is generated in a centralised location with non-emitting fuel options.
- Life cycle assessment quantifies holistic environmental impacts of buildings, enabling optimal decisions in sustainable design.
- Retrofitting existing buildings will be necessary to address the inefficient building stock that could otherwise stand well beyond mid-century.
- Smarter, more sustainable cities are key to a prosperous future.

66 Professional Engineers Ontario, *Towards a clean train policy: diesel versus electric.*
67 Condon P., *Don't Waste Billions on Bad Transit Projects.*

Figure 10: 2050 Building Sector Energy Use Projections



4.2.1 Over one third of Canadian homes are already heated and cooled with clean electricity; emerging technologies will make this option increasingly economically attractive.

Emissions from the buildings sector arise from residential, commercial, and institutional buildings, as well as the equipment in them. The building sector is currently one of the most GHG-intensive in Canada and is the third largest emitting sector representing 12% of Canada's emissions - with emissions currently projected to grow through 2030. However, a number of measures can help to achieve reductions in the sector including fuel-switching and energy efficiency.

Some Canadian homes and commercial buildings already rely on clean electricity to power their heating, cooling, lighting and appliances. Current technology such as electric boilers, electric baseboards, space heaters, and heat pumps can be used instead of fossil fuels, resulting in zero greenhouse gas emissions when combined with a non-emitting electricity portfolio. In 2011, 39% of Canadians households used electricity for their heating equipment. Electricity was the predominant energy sources for heating in Quebec (66%), Newfoundland and Labrador (56%) and New Brunswick (48%). [68]

Current technologies that may become more cost effective in the future include electrically driven geothermal and air source heat pumps, and increased use of ambient solar heating. Air-source heat pumps can draw heat from the air and transfer warm air inside during the winter or outside during the summer.[69] Ground-source heat pumps, also called earth-energy systems, can use energy from the ground to produce heating and cooling and are being increasingly used across Canada. Due to their high efficiency, ground-source heat pumps can yield energy savings of up to 40% higher than an air-source pump but require higher up-front installation costs.

Solar energy for homes also offers many advantages and helps lower grid-related energy requirements. New technologies are emerging to better generate photovoltaic energy for homes such as: solar roadways, solar shingles, solar panels installed on the sides of buildings, and thin solar films that can be applied to any metal roofing.

68 Statistics Canada, *Households and the Environment: Energy Use (11-526-S)*
69 Natural Resources Canada, *Coming to Terms with Heat Pumps*

Figure 10 illustrates the current use of energy in the building sector as comprising of natural gas (45%), electricity (36%), renewable fuels (10%) and refined petroleum products (6%). Modelling projections for a low GHG economy in 2050 take into account a variety of factors such as potential provincial energy codes amendments, regulations on new buildings requirements and technological costs. Note that the projections do not take into account a potential increase in the use of clean district heating systems in Canada.

In all of the low-GHG analyses, the share of energy met through clean electricity increases from today's levels. The first ECCC low-GHG analyses (High Non-Emitting) illustrates electricity at 70% of the energy use of the building sector by 2050, while the second projection (High Demand Response) estimates electricity to be 50% of energy use in the sector (renewable fuels represent 22%).

The DDPP scenario demonstrates that electricity increases to fulfill 99% of the building sector's energy requirements in 2050 (with 1% remaining for natural gas). The Trottier Institute, demonstrates two scenarios where the share of electricity increases to 86-89% of total energy use in the sector by 2050, where the remaining requirement is fulfilled through natural gas (4-5%), renewable fuels (4-5%) and refined petroleum products (2-5%).

4.2.2 Natural gas continues to play an important role in heating and power requirements. Renewable Natural Gas is a small but growing part of the supply mix meeting those energy needs.

Across most scenarios, natural gas, a relatively lower emitting fossil fuel, continues to power some heating and other requirements in the building sector. Natural gas can also be substituted for Renewable Natural Gas where desirable, without replacing capital or infrastructure, such as natural gas home furnaces. Generally, Renewable Natural Gas is fully interchangeable with conventional natural gas.

Methane that is released from sources such as landfills, agricultural residues, livestock production, sewage treatment plants, and forestry waste can be recovered, cleaned, and can be directly substituted for conventional natural gas.

4.2.3 The electrification of the building sector should be matched with a scale-up of energy efficiency measures.

Increasing energy efficiency is particularly important in the Canadian building sector, as Canadian households consume an average of 11,000 KWh of electricity per year (2010). By comparison, this is just under the U.S. average (12,960 KWh), and well above Australia (7,350 KWh) and EU countries' average such as France (5,760 KWh), the United Kingdom (4,510 KWh) or Germany (3,515 KWh).[70] This is generally attributable to Canada's cold climate and relatively large sizing in residential housing.

Energy efficiency improvements can be realised either through the design of a building's system, including air sealing, better construction materials, passive heating, insulation, white roofs, triple pane windows; or more energy efficient equipment and appliances including heat pumps, condensing boilers, high efficiency cooling, energy-efficient lighting and appliances, and energy management control systems. Development of highly efficient heating and cooling technologies, such as energy management systems and smart thermostats, can reduce costs and improve performance of heating, ventilation, and air conditioning.

In Canada, provincial and municipal building energy codes and federal energy-efficiency standards are important tools for driving energy productivity improvements. Future policies will need to ensure that energy efficiency programs and energy supply fuel-switching both correspond to low-GHG objectives.

Energy efficiency in the buildings sector has numerous co-benefits such as infrastructure resilience and lower operating and maintenance costs, as well as positive effects on national income and employment. Moreover, several studies have pointed to increased health benefits from better designed buildings in terms of lower risks of respiratory and cardiovascular conditions, rheumatism, arthritis or allergies. Lastly, energy efficiency savings can be beneficial for lower income Canadians.

4.2.4 District heating for residential and commercial buildings could help lower GHG emissions since heat is generated in a centralised location with non-emitting fuel options.

District heating (also known as heat networks or teleheating) is a system for distributing heat

70 World Energy Council Indicators, *Average electricity consumption per electrified household,*

generated in a centralised location for residential and commercial heating requirements such as space heating and water heating. These systems have the potential to help reduce GHG emissions, by utilising low-carbon fuel options such as waste heat or biofuel.

District heating is the dominant heating system in Nordic countries (except for Norway). In those countries, biomass, natural gas, and municipal solid waste biogas are commonly used as energy sources for district heating. Specifically, biomass is used as fuel for 60% of district heating system in the Swedish building sector, 40% in Denmark, and 70% in Finland. Canada has similar geographical and climatic conditions and has thus a vast and untapped potential for extensive district heating systems.[71]

4.2.5 Life cycle assessment quantifies holistic environmental impacts of buildings, enabling optimal decisions in sustainable design.

Life cycle assessment (LCA) is a scientific method for measuring the environmental footprint of materials, products and services over their entire lifetime. Applied to a building, LCA measures environmental impacts like energy consumption and greenhouse gas emissions at every stage of a building's life. It includes raw resource extraction, product manufacturing and transportation, building construction, operation and repair, and demolition.

LCA helps building designers consider the total environmental impact of material choices and other design decisions. Designers use LCA to examine trade-offs and alternatives, for the lowest possible lifetime environmental footprint of the building. This data-driven process allows building designers to test and validate their sustainability decisions.[72]

4.2.6 Retrofitting existing buildings will be necessary to address the inefficient building stock that could otherwise stand well beyond mid-century.

According to the *Canadian Housing and Mortgage Corporation*, Canadian residential construction has grown at an average rate of 1.5% in the past five years.[73] At this rate, the built residential environment would double in Canada in approximately 50 years from today, well past mid-century. New construction has been addressed in the previous sections, but the dominating remaining building stock could mostly remain standing in 2050. According to the IEA, close to 75% of the OECD countries building stock from 2010 will still be standing in 2050.

Therefore, new building energy code regulations on their own will not be enough to achieve significant GHG emissions reductions from by 2050 and additional efforts will be needed to address existing buildings. The same is true in the industrial and commercial building subsectors.

Making existing buildings more energy-efficient through retrofitting is an important step towards reducing GHG emissions reductions in Canada. Retrofitting requires investments, especially in the case of deep retrofits where significant parts of the building must be refurbished. Different retrofit rates are found around the world depending on type of buildings, climate and costs. For example, EU member countries have an energy savings retrofit target rate of 3%/year for government owned buildings.[74] Similarly, Germany has a target of thermal retrofitting 2% of total residential buildings per year.[75]

Energy management practices, including energy benchmarking, audits, and on-going building optimisation can help generate better understanding of buildings energy usage and costs, identify areas of opportunities, and make improvements where and when necessary. They can also provide green solutions for systems that are embedded in the building and may be harder or more costly to replace.[76]

4.2.7 Smarter, more sustainable cities are key to a prosperous future

Urban planning and design will be key to making building sites and designs work together to enable lower GHG solutions. In a low-GHG economy, for example, communities should be making effective use of local energy sources ranging from on-site renewable energy to waste heat and organic waste, allowing optimal use of clean energy grids. District energy networks will distribute thermal energy for

71 International Energy Association, *Canada Review 2015.*
72 O'Connor, J., and Bowick, M., *Advancing Sustainable Design with Life Cycle Assessment.*
73 Statistics Canada, 2011 Census of Canada. Canadian Mortgage and Housing Corporation, Total Housing Starts, Canada, Provinces and Metropolitan Areas, 1990–2015 (units).
74 Official Journal of the European Union, *Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on Energy Efficiency Amending Directives 2009/125/EC and 2010/30/EU and Repealing Directives 2004/8/EC and 2006/32/EC.*
75 Germany Federal Ministry of Economics and Technology, *Germany's New Energy Policy Heading Towards 2050 with Secure, Affordable and Environmentally Sound Energy.*
76 Natural Resources Canada. *Commissioning Guide for New Buildings.*

LOW EMISSIONS OPERATIONS AND GOVERNMENT PROCUREMENT

Governments have an important leadership role to play in the transition to a low-carbon economy given the size of their operations. By implementing ambitious policies, federal, provincial and territorial governments can lead by example on many aspects of the low-carbon transition. Canada's Federal Sustainable Development Strategy has developed objectives for greening government operations.[77] The federal government has adopted a target to reduce emissions by 40% from 2005 levels by 2030, with the aspiration to achieve it earlier, potentially by 2025. Furthermore, the government has committed for all operations run by Public Services and Procurement Canada to use 100% of their electricity purchased from clean power, and to significantly increase the energy efficiency of federal buildings, with the goal of cutting emissions almost in half. Several provinces, such as British Columbia, Quebec, and Ontario, have also adopted targets to reduce emissions or to achieve carbon neutral operations.

Governments can lead the way in many areas, such as green procurement, green buildings, energy efficiency measures, and other green investments. New government buildings could require a certain type of environmental certification, as green buildings are generally recognised to have a positive effect on the asset value.[78] For older buildings, the use of deep retrofits would help to substantially reduce energy costs and GHG emissions. The use of energy performance measurement could help to better understand and improve energy use. Governments could also encourage the use of public and active transportation as well as flexible working arrangements such as telework.

Green procurement is one way in which the government can reduce its environmental footprint and increase domestic demand for clean technologies and other environmentally preferable goods and services. For example, the federal government's Policy on Green Procurement targets specific environmental outcomes where procurement can effectively be used to mitigate the impact of environmental issues, such as climate change. Allowing climate considerations to be streamlined into the procurement process, such as the disclosure of climate performance, could more accurately benchmark and compare different product and services. The purchasing power of governments could also be used to support the development of green technologies. Governments could also help to accelerate the adoption of certain green products such as electric vehicles with charging stations at work locations.

In some sectors, there are opportunities to take a more important role in greening their operations. The defense sector is increasingly recognising the strategic importance of having alternative sources of power and the potential cost savings. The Pentagon has become the second largest purchaser of long-term renewable electricity contracts in the U.S., according to Bloomberg data.[79] Low-carbon opportunities exist for Department of National Defense and other government departments that have large fleets.

It is important that governments explore best practices on greening government operations by learning from other jurisdictions. This is important for developing knowledge and raising ambition over time in order to be innovative and creative in finding solutions.

heating and cooling, while smart electrical grids manage local energy supply and demand. Energy storage systems could help to balance variations in supply and demand for heating, cooling and power while local industrial, commercial, and agricultural enterprises approach energy in an integrated way. Finally, businesses could take advantage of waste heat, use renewable fuels, and capitalise on opportunities as energy producers.

77 Government of Canada, *Shrinking the Environmental Footprint – Beginning With Government*.
78 The Royal Institution of Chartered Surveyors, *Green Value*.
79 Financial Post, *How the Pentagon is Waging America's Wars Using Renewable Energy*.

AN ELECTRIFICATION SUCCESS STORY

Mining vehicles typically require energy-dense fuels to move and lift heavy loads. However, in 2008, SBC Case Industries, PapaBravo's parent company, initiated an R&D project to develop electric vehicles for use in potash mines. Later, PapaBravo developed a business plan based on R&D technology with the support of the National Research Council's Industrial Research Assistance Program. The company was able to develop many vehicles such as the Marmot-EV and a second-generation truck able to function in environments other than potash mines. The vehicles have a range of about 120 kilometres and can recharge in less than an hour. The Saskatoon firm PM&P which acquired PapaBravo in 2015 is now a global competitor in electric mining vehicles and is doing business in Canada, South Africa, Australia, and New Zealand.[80]

4.3 Industry

KEY MESSAGES:

- National circumstances represent challenges for the decarbonisation of Canadian industrial sectors.
- Electrification of industrial operations offers emissions reduction potential.
- Cogeneration reduces waste heat and generates thermal and electric energy, thereby producing environmental and economic benefits.
- Other improvements in energy efficiency through innovative ways of optimising energy production and consumption will be essential.
- Carbon capture and storage, fuel switching to non-emitting fuels, and recycling can also reduce emissions. These technologies continue to improve.
- Nevertheless, there remain challenges in reducing emissions from some sectors, for which innovation and research and development will be necessary.

4.3.1 National circumstances challenge the decarbonisation of Canadian industrial sectors

Historically, Canada has benefited from an internationally competitive economy based on low-cost natural resources and accompanying industrial activities. These activities face significant challenges to decarbonisation:

- Canada's energy sector is an important driver of the Canadian economy. Canada's exports of energy, extracted resources, and agricultural commodities are significant contributors to the gross domestic product. Also, Canada is a net energy exporter. It is the world's fourth largest exporter of crude oil and fifth largest exporter of natural gas.
- Canada's oil and gas sector is GHG intensive due to the energy required in the primary extraction of fossil fuel and other natural resources.
- Industries are concentrated in particular areas of the country, making distributional impacts of abatement policies a particular concern. Regional cooperation and progressive mitigation policies will be key to ensure that decarbonisation efforts do not disproportionally affect certain regions.
- Over 75% of Canada's total industrial energy use is consumed in the mining, pulp and paper, iron and steel, cement, smelting and refining,

80 National Research Council Canada, Revolutionizing Canada's Mining Industry with Electric Vehicles.

chemicals, and petroleum refining sectors. The greatest portion of energy (about 70%) is used for heating purposes such as thermal treatment (mainly in heaters and furnaces), drying, and steam generation. These emissions are more challenging to reduce than in other sectors due to the high heat requirements of certain processes. Technology solutions exist, often with deep GHG reduction potential, however market barriers to adoption are such that significant investments may be required to achieve large-scale commercial uptake.

4.3.2 *Electrification of industrial operations offers emissions reduction potential*

Many Canadian industries are already electrifying their operations or discovering other innovative ways to lower GHG emissions. For example, motor systems such as pumps, fans, conveyers, and compressors are almost entirely powered by electricity in some sectors. Electrified operations can be set for production during off-peak electricity periods to benefit from lower electricity prices. Specific sub-sectors, such as the aluminium industry, where smelting processes are highly energy intensive, are already relying on non-emitting electricity to fulfil their power demands. The energy intensity of aluminium plants has also decreased over time, leading to reduced electricity demand per unit of output.

In the iron and steel sector, some Canadian plants operate with electric arc furnaces that produce steel from recycled metal and require significantly less energy compared to conventional processes using ore. In the glass industry, electric glass melting tanks can be used, while in the pulp and paper industry, electricity can be used for mechanical pulping. In the mining sector, hybrid diesel-electric equipment could be used in underground mines and fully electric vehicles could further reduce emissions and diminish needs for ventilation.

In Canada's oil sands, extracting and upgrading bitumen is an energy-intensive process where large amounts of thermal energy and electricity are used. Further electrification of processes, including the electrification of heat (for example electro-thermal or radio frequency electromagnetic heating), provides an avenue to decarbonisation, but requires a clean electricity source.

The adoption of electric steam generators to replace natural-gas fired steam generators could reduce direct emissions. Electric steam generators use electric resistance elements to produce steam and heat, and the conversion of electricity into thermal energy is very efficient. It is technically possible for the separation of bitumen, hydrogen production for upgrading, and refining and pipelining operations to use electricity instead of natural gas.

A study by the Canadian Energy Research Institute has looked at scenarios for the electrification of oil sands production using hydropower and increased electricity transmission capacity. Overall, the study finds that the use of hydropower could potentially reduce the GHG emissions of oil sands operations by 13-16%. Reductions are possible from a range of technologies that could require significant investment in infrastructure as well as the application of new technologies. The potential for reductions could be even higher with the development of in-situ extraction using electricity for heating purposes, but many of these technologies are still under development.

In general, several options exist to decarbonise heavy industry, but significant R&D, piloting, and commercialisation support are required to allow their penetration.

4.3.3 *Cogeneration reduces waste heat and generates thermal and electric energy, thereby producing environmental and economic benefits.*

Cogeneration, also called combined heat and power (CHP), produces electrical and thermal energy simultaneously by using a single fuel for heating or cooling applications. Cogeneration allows for gains in energy efficiency as it can use waste from one process as an energy input into another. The main types of cogeneration systems include steam turbines, gas turbines, reciprocating engines, microturbines, combined cycle gas turbines and organic rankine cycles. Cogeneration requires maximizing electricity production, while matching thermal load requirements to the extent possible in terms of quantity and energy quality.[81] The energy savings from cogeneration relative to standalone generation range from 5% to 35%.

In Canada, about 7% of electricity generation is produced from cogeneration. Most energy generated from cogeneration (both electric and thermal) is from the utility, paper and wood products, and oil and gas extraction sectors. Growth in cogeneration occurred during two periods. In the

81 Canadian Industrial Energy End-Use Data and Analysis Centre, Cogeneration Facilities in Canada 2014, p. 7.

1970s cogeneration capacity increased in response to a significant increase in energy prices. The second period of growth occurred in the 1990s as a response to many socio-economic factors including increasing cost-effectiveness and full retail access to the electricity grid in Alberta. Cogeneration has the potential to achieve significant energy savings, particularly in the oil sands sector, as the extraction and upgrading processes require large amounts of heat and steam.

In order to fully maximise the potential of cogeneration to reduce GHG emissions, the adoption of certain technologies may be necessary, including those that optimise load matching, improve operations in harsh environments, and allow for biomass gasification, advanced power cycles, and high-penetration of renewables into fossil thermal cycles (e.g., solar thermal pre-heating of the inlet air to gas turbines).

4.3.4 Other improvements in energy efficiency through innovative ways of optimising energy production and consumption will be essential

Energy efficiency measures that improve processes and reduce heat loss can be implemented across sectors using current best available technologies. Heat management practices can improve heat production and heat transfer to and within process users. Innovative waste heat recovery technologies can help reduce energy consumption, production costs, and emissions in industrial facilities.

Energy efficiency measures include process optimisation; operation and control improvement; waste heat recovery and upgrading for heat, cold, or power production; and new technology and process development. Examples of process optimisation include adopting proper motor sizes to optimise power use, and using adjustable-speed drives. Frequent and proper maintenance and repair can also improve energy efficiency of equipment. In some industries, there are potential solutions which involve entirely changing production processes to reduce energy requirements. For example, the pulp and paper industry can use chemical additives to reduce the heat required to dry paper.[82]

For the oil and gas sector, energy efficiency and energy use optimisation can amplify the emissions abatement potential of electrification and other options. For example, deploying energy management systems to oil and gas facilities and improving energy efficiency through programs and standards could help drive significant reductions in the demand for energy. Although electrification is key, the recovery and use of waste heat should be pursued across subsectors concurrently. Other innovative ideas that could support energy use optimisation include the development of industrial eco-parks which facilitate the exchange of excess energy and industrial by-products, and minimise transportation requirements between facilities.

In oil sands operations, the adoption of innovative low-carbon extraction processes offers potential GHG emission reductions. Advanced technologies, such as solvent and electrothermal-based extraction methods for in situ, or direct contact steam generation, are at a stage of development whereby they offer a substantial opportunity to reduce emissions. These innovations could offer up to 50% GHG emissions reductions per barrel produced and could prove pivotal in delivering economically and environmentally competitive fossil fuel supplies to a decarbonising global market. Vacuum-insulated tubes can also be used to save heat in the process of moving the steam down the well and could accelerate the pre-heating process of the well significantly.[83] Further, some of these innovative extraction techniques leave the heavier contents of the bitumen in the reservoir, meaning less diluent is needed in pipelines. Not having to store these heavier contents, for which there are fewer markets, also reduces operating costs and GHG emissions.

In the mining industry, ventilation-on-demand can be adopted to reduce the energy consumption required to ventilate underground metal mines. For example, a medium-size nickel mine with diesel equipment and 10 operating levels emits about 10,000 tonnes of CO_2 annually. Estimated energy cost savings from the adoption of ventilation on demand technology can reach 50% depending on the size of the mine.

4.3.5 Carbon capture and storage, fuel switching to non-emitting fuels, and recycling can also reduce emissions. These technologies continue to improve

Beyond the electricity sector, carbon capture and storage (CCS) also has potential in the oil and gas, iron and steel, pulp and paper, chemical, and cement sectors. CCS is currently being used to capture emissions from steam methane reformers. The Shell Quest Project, which has been in operation since November 2015, captures and

82 Energy Economics, Optimizing the Energy Efficiency of Conventional Multi-Cylinder Dryers in the Paper Industry, p.35.

83 Council of Canadian Academies, Technology and Policy Options for a Low-Emission Energy System in Canada, p. 92.

THE USE OF BIOMASS FOR CEMENT MANUFACTURING

Bioenergy as a replacement for fossil fuels in cement making is currently at the commercial demonstration phase in Canada. For example, the Lafarge plant in Bath, Ontario, was funded under the ecoENERGY Innovation Initiative to demonstrate a 10% coal-to-biomass fuel switching project. This includes processing the raw materials into a useful form, developing and installing an injection system, running fuel trials, and compiling the results of the carbon savings resulting from this process. The results of these trials will inform the permanent use of low-carbon fuels at the Bath plant and could be used by other companies in the cement industry.[84]

sequesters 1 million tonnes of CO_2 per year from the Shell Scotford steam methane reformers. The Alberta Carbon Trunk Line (ACTL), a project under development, is a 240 km pipeline that will capture and use CO_2 emissions for enhanced oil recovery from the facilities in the Alberta Industrial Heartland. The initial industrial facilities that will capture and supply CO_2 are Agrium Inc. and the Sturgeon Refinery. The ACTL will have the capacity to permanently store about 14.6 million tonnes of CO_2 annually as of 2017.

Some barriers for deployment of CCS technology in these sectors remain, such as lack of economic capture technology and infrastructure to connect carbon source with sequestration formations. This will require significant investments and pipeline network construction. In the upstream oil and gas sector, relevant carbon capture technology for in-situ boilers and cogeneration units could be available within a 10 to 15 year timeframe. However, more technological advances would be required to make CCS economic. With the knowledge and technological advancements spurred from projects currently underway, the cost of CCS could go down in the future and be applied in other industrial sectors.

Fuel-switching options are also available to industrial sectors. As mentioned previously, the oil and gas sector can use solvents instead of natural gas in SAGD applications, despite being relatively expensive at the moment. Using electricity instead of fossil fuels is also a possibility. Finally, biomass waste can be used by many sectors, including oil and gas and cement, to replace more carbon intensive energies.

The recycling of materials in many industrial sectors is another option to reduce GHG emissions as it reduces needs for energy, raw materials, and landfill space. For example, in the pulp and paper sector, recovered paper can be recycled through chemical pulping instead of producing paper from new feedstocks.

84 Natural Resources Canada, Low Carbon Fuel Demonstration Pilot Plant.

Another example is the reuse of recycled plastic in the chemical and petrochemical sector as a substitute to polymer based inputs. Plastic waste that cannot be recycled can be used as an energy input - In the iron and steel sector it can be burned as a replacement for coal or coke – or as a feedstock in other sectors. The use of recycled scrap metal materials to produce iron and steel can also lead to emission reductions as producing iron and steel from iron ore requires more energy than from scrap.[85]

Figure 11 (below) illustrates the world GHG reduction potential estimated by the IEA from four types of industrial GHG emissions reductions technologies for IEA's low-demand and high-demand scenarios. According to the IEA, energy efficiency improvements, switching to low-carbon fuels, increased recycling, and new innovative processes such as CCS will all be needed to decarbonise large industrial emitters.

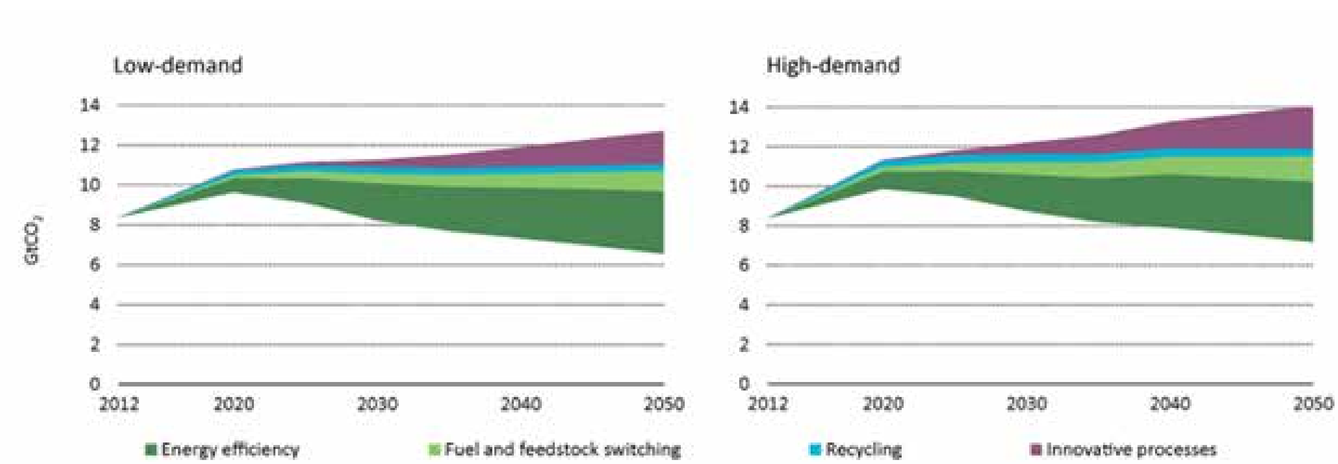
4.3.6 Nevertheless, there remain challenges in reducing emissions from some sectors, for which innovation and research and development will be necessary

Emissions-intensive industrial sectors often face challenges in reducing GHG emissions as many of their emission sources are difficult to address through cost-effective electrification, energy efficiency, or fuel-switching. These challenges are compounded as many industries also face competitive pressures due to their exposure to international trade competition, and their low profit margins. Bargaining power of suppliers and buyers, the threat of substitutes and new entrants, and the level of rivalry between competitors are some of the factors that determine how competitive industries are in global markets. Many companies face global prices for their outputs, meaning that they must contain their production costs in order to remain competitive. Canadian oil producers operate in a global market and they are essentially price takers for their outputs, which requires them to look at ways of reducing their production and transportation costs in order to remain competitive. Moreover, these companies may face additional challenges associated with decreasing global demand for their goods in the future as governments act to mitigate GHG emissions. Canadian natural gas producers are currently competing in a continental market. In the future, with additional liquefied natural gas plants expected to come online, the global natural gas market is expected to be increasingly integrated.

Innovation in these sectors is likely to yield significant benefits to companies that can improve processes and technologies to reduce emissions. Government and private sector funding will be required for further research and development to promote technology innovations in many strategic areas pertaining to industrial emissions. These include CCS technologies to reduce costs and improve efficiency, industrial efficiency improvements, fuel switching to bioenergy and the conversion of biomass into bio-based products and bioenergy, technologies to address process emissions, and enhanced recycling capabilities.

85 International Energy Agency, Energy Technology Transitions for Industry.

Figure 11: World reduction potential from existing technologies for large industrial emitters



Source: International Energy Agency, Energy Technology Perspectives 2015

5 Non-Carbon Dioxide Emissions

KEY MESSAGES:

- Non-carbon dioxide climate warming emissions include short-lived climate pollutants (SLCPs) and nitrous oxide, a long-lived GHG. Non-carbon dioxide emissions have significantly greater warming effects per tonne than carbon dioxide.
- The only way to meet the 1.5 to 2°C temperature goal encompassed in the Paris Agreement is to take early global action on carbon dioxide and short-lived non-carbon dioxide emissions together.
- Reducing short lived climate pollutants has considerable benefits beyond those that are climate related, such as improving air quality, human health, and environmental and ecosystem outcomes.
- Current technology and know-how has the potential to significantly reduce non-carbon dioxide emissions, often helping to slow the rate of near-term warming.

5.1 Non-carbon dioxide climate warming emissions include emissions of short-lived climate pollutants (SLCPs) and nitrous oxide, a long-lived GHG. Non-carbon dioxide emissions have significantly greater warming effects per tonne than carbon dioxide.

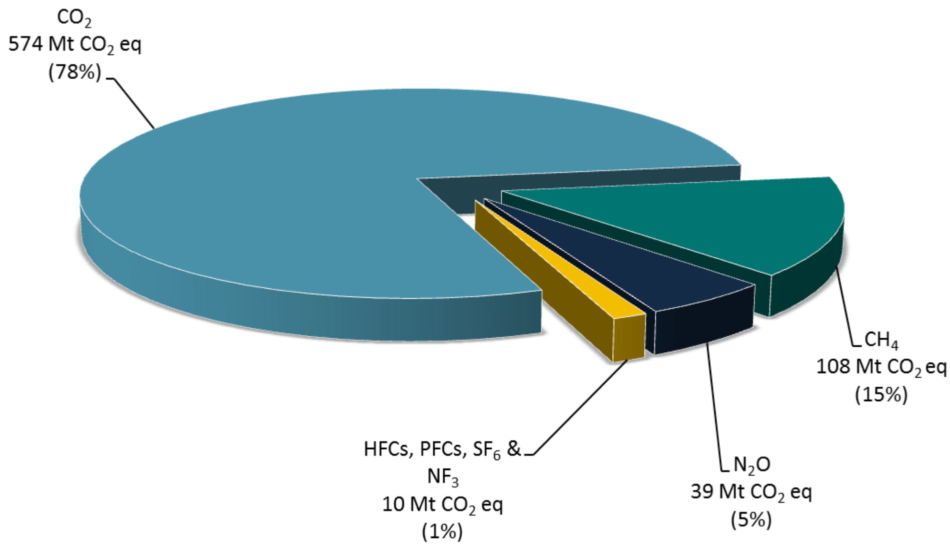
Short-lived climate pollutants (SLCPs) are potent greenhouse gases (GHGs) and air pollutants. They have relatively short atmospheric lifetimes compared to longer-lived GHGs such as carbon dioxide (CO_2), and have a warming impact on the climate. SLCPs include methane, hydrofluorocarbons (HFCs), and ground-level ozone, as well as black carbon, a component of particulate matter. Black carbon is also an air pollutant, resulting from the incomplete combustion of fossil fuels and biomass. Ground-level ozone is also an air pollutant and key contributor to smog, which is associated with adverse impacts on human and ecosystem health. Nitrous oxide is a long-lived GHG.

Figure 12 below illustrates Canada's greenhouse gas emissions in terms of CO_2 equivalency where non- CO_2 emissions account for around 21% of total emissions. Methane and nitrous oxide are the two main non-CO_2 GHGs emitted and originate mostly from fossil fuel related activities, livestock farming, and industrial processes. Although HFC emissions are not currently a significant contributor to total GHG emissions in Canada, in the absence of the recent phase-down amendment to the Montreal Protocol, they were projected to more than triple between 2013 and 2030.

Methane emissions, which account for 15% of total GHG emissions in Canada,[86] are significant contributors to climate impacts. In addition, methane contributes to the formation of ground-level ozone. The oil and gas sector accounted for 44% of Canada's methane emissions in 2014, largely from oil and natural gas fugitive sources, including venting . The remainder of Canada's methane emissions arises largely from agriculture and solid waste disposal.

86 The GHG estimate of 108 Mt for methane (15% of total Canadian GHG emissions) uses a global warming potential of 25 consistent with the IPCC fourth assessment report.

Figure 12: Canada's Emissions Breakdown by Greenhouse Gas (2014)



Source: National Inventory Report 1990-2014: Greenhouse Gas Sources and Sinks in Canada – Executive Summary, Environment and Climate Change Canada, 2016.

Nitrous oxide emissions account for 5% of total Canadian GHG emissions. The burning of fossil fuels results in the oxidization of the nitrogen contained in the fuel and the air creates nitrous oxide emissions. These emissions come mainly from coal-fired power plants as well as cars and trucks. Industrial processes, particularly those involved in the production of nitric and adipic acid, also cause nitrous oxide emissions through the oxidization of nitrogen compounds. Over 70% of total nitrous oxide emissions emitted in Canada are from the agricultural sector, mainly from crop and animal production. In crop production, nitrous oxide emissions arise mostly from the use of synthetic fertilizers where the addition of nitrogen to soils helps the nutrient absorption of plants and allows bacteria contained in the soil to produce extra energy to grow. Microbial processes involved in these activities then produce releases of nitrous oxide emissions.

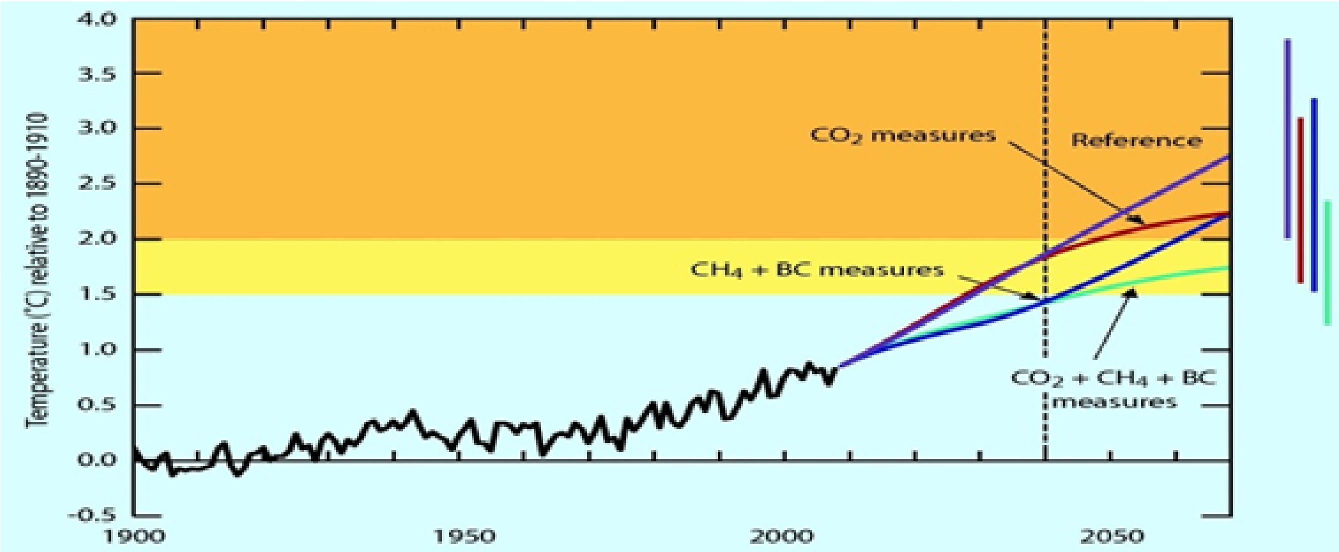
HFCs are synthesized chemicals used as replacements for ozone-depleting substances. Internationally, atmospheric observations show that the volume of HFCs in the atmosphere is increasing rapidly, about 10 to 15% per year. To address concerns regarding an estimated increase in HFC emissions to 10% or more of total CO_2 equivalent emissions by 2050, the 197 Parties to the Montreal Protocol agreed to an amendment to phase-down the use and production of HFCs on October 15th, 2016. The "Kigali Amendment" could help to avoid almost 0.5°C of global warming by the end of the century. Canada was a strong supporter of the HFC Amendment and will continue to play a leadership role in implementing the Montreal Protocol, including the HFC amendment, notably by hosting the 29th Meeting of the Parties in 2017, which marks the Montreal Protocol's 30th anniversary.

The potency of HFCs varies by species and ranges from <1 to 10,800 times that of CO_2 over a 20-year period, and <1 to 12,400 that of CO_2 over a 100-year period.[87] HFCs are used in the same applications which ozone-depleting substances have been used. In Canada, HFC use is mainly confined to the following sectors: insulating foam products (50%), refrigeration and air-conditioning equipment in buildings and industrial operations (30%), air-conditioning in vehicles (13%), and aerosols (7%). Since HFCs are being used as replacements for ozone depleting substances, including hydrochlorofluorocarbons (HCFCs) that are still in the process of being eliminated, their use and emissions are increasing as HCFCs are being phased out. In addition, in the absence of the recent phase-down amendment to the Montreal Protocol, HFC emissions would be expected to increase because of greater demand for refrigeration and air conditioning throughout the economy.

According to Canada's black carbon emissions inventory, 43 kt of black carbon were emitted = in 2014. Black carbon emissions are estimated to be the third largest contributor to current global warming, after CO_2 and methane. Black carbon

87 Myrhe et al., Anthropogenic and Natural Radiative Forcing.

Figure 13: Global Temperature Projections Relative to 1890-1910 averages



Source: UNEP Integrated Assessment of Black Carbon and Tropospheric Ozone, Summary for Policy Makers
Note: Bars on the right show estimated ranges for 2070.

influences the climate in multiple ways: by directly heating surrounding air when suspended in the atmosphere; by reducing the reflectivity of the earth's surface when deposited, an effect particularly strong over snow and ice; and through additional indirect effects related to interaction with clouds. Black carbon is estimated to be 3,200 (270 to 6,200) times more potent a warming agent than CO_2 over a 20-year period.[88] Reducing uncertainties related to quantifying the overall warming effects of black carbon represents an active area of scientific research internationally. Black carbon also has significant effects on human health, including respiratory and cardiovascular effects, as well as premature death. The transportation sector accounts for 62% of Canada's black carbon emissions, followed by residential wood-burning, accounting for about 27% of national emissions.

Ozone is not directly emitted, but forms in the atmosphere as a product of precursor gases including nitrogen oxides (NO_X), volatile organic compounds (VOCs) - including methane - and carbon monoxide (CO). Ground-level ozone is a powerful GHG, a significant contributor to current warming, and a key component of smog. It has deleterious effects on human health, damages plants, and affects agricultural crop production. In Canada, the transportation and oil and gas sectors are key sources of ozone precursors. Residential wood combustion is also a significant source of CO emissions.

5.2 The only way to meet the 1.5 to 2°C temperature goal encompassed in the Paris Agreement is to take early global action on carbon dioxide and non-carbon dioxide emissions together.

Recent scientific studies indicate that the only way to meet temperature commitments in the Paris Agreement is to take early global action on CO_2 and SLCPs, together. The *United Nations Environmental Program's (UNEP) Integrated Assessment of Black Carbon and Tropospheric Ozone* concludes that reducing black carbon and tropospheric ozone now will slow the rate of climate change within the first half of this century.

The UNEP assessment notes that deep and immediate CO_2 reductions are required to limit long-term warming, and this cannot be achieved by addressing short-lived climate forcers alone. However, it goes on to note that implementation of measures on black carbon and methane globally by 2030 could reduce future global warming by 0.5˚C by 2050 and by as much as 0.7˚C in the Arctic by 2040, and together with early action on CO_2, this is the only

88 GWP20 from Bond et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. The use of the GWP here is to help communicate the potential contribution of black carbon mitigation to reducing near-term warming. Given the very different ways black carbon and CO_2 influence climate and their vastly different lifetimes in the atmosphere, there is not yet scientific consensus on a metric to quantify black carbon relative to CO_2. Further research to reduce uncertainties and develop more appropriate metrics is needed.

way to limit the global average temperature rise to well below 2˚C (Figure 13).

The expected climate benefits of such an approach are particularly relevant for Canada as an Arctic nation. In Canada, the Arctic warmed by 2.2°C between 1948 and 2013 resulting in significant impacts to local populations and sensitive ecosystems. Black carbon is of particular significance in the Arctic due to its additional warming effect when deposited onto snow or ice, which accelerates melting.

5.3 Reducing short lived climate pollutants has considerable benefits beyond those that are climate related, improving air quality and human and ecosystem health.

Given that many SLCPs are also air pollutants, reducing emissions also provides a key opportunity to also improve air quality, generating local health benefits for Canadians and reducing impacts to ecosystems and agricultural productivity.

Ground-level ozone, a potent GHG, has several other deleterious environmental effects. As a key component of smog, ozone leads to significant human health impacts such as respiratory and cardiac problems. These health problems result in significant losses to Canada's economy through hospital visits and lost productivity.

Ground-level ozone also influences crop yield by interfering with the ability of sensitive plants to produce and store food, subsequently increasing their vulnerability to certain diseases, insects, harsh weather, and other pollutants. These negative impacts may translate into reduced crop yields and, consequently, lower sales revenue for crop producers. In addition, ground-level ozone may increase the risk of illness or premature death within sensitive wildlife or livestock populations, potentially resulting in significant treatment costs or economic losses for the agri-food industry. Thus, reducing emissions of ozone precursors, namely methane, VOCs, CO and NO_x, can reduce mortality and morbidity rates in the Canadian population, improve quality of life, as well as increase economic productivity.

Short-term and long-term exposure to $PM_{2.5}$, of which black carbon is a component, is also associated with a broad range of human health impacts, including respiratory and cardiovascular effects as well as premature death. In its 2012 assessment of the health effects of black carbon, the World Health Organization (WHO) noted that black carbon is a "carrier" of other pollutants, delivering them deep into the respiratory system, and further that a reduction in exposure to $PM_{2.5}$ containing black carbon should lead to a reduction in the health effects associated with $PM_{2.5}$.

5.4 Current technology and know-how has the potential to significantly reduce non-carbon dioxide emissions, often helping to slow the rate of near-term warming.

Many solutions exist to reduce important sources of non-CO_2 emissions. In general, measures that help promote the transition towards cleaner energy sources will reduce both CO_2 and SLCP emissions over the long term by reducing the use of fossil fuels. However, slowing the rate of near-term warming requires more targeted SLCP emissions reductions strategies, as many are emitted from a large number of small sources. Canada has made a number of recent significant commitments to advance SLCP mitigation priorities together with continental partners, under the Leaders' Statement on a North American Climate, Clean Energy and Environment Partnership (NALS Statement), including the commitment to develop and implement a national methane strategy that will consider how to address methane from key sources.

Most methane emissions from the oil and gas sector come from venting and fugitive emissions. These include venting from wells and batteries, fugitive equipment leaks, storage tanks, pneumatic devices, well completions, and compressors. Cost-effective technologies are readily available and tackling methane emissions from the oil and gas sector is one of the lowest cost reduction opportunities to achieve significant GHG reductions. Canada has committed to reducing methane emissions from the oil and gas sector by 40 to 45% below 2012 levels by 2025. To implement this commitment, Canada intends to publish proposed regulations to reduce venting and fugitive methane emissions from oil and gas sources by early 2017. Canada has also endorsed the World Bank's *Zero Routine Flaring by 2030* initiative, which will support reductions in black carbon emissions resulting from routine flaring at oil production facilities. Canada has been consulting with provinces, territories, industry, non-governmental organizations and Indigenous peoples on the development of the federal regulatory approach.

Accurately quantifying non-CO_2 emissions is challenging, particularly fugitive emissions. This can be explained by the fact that methane leaks are often only detected and repaired sometime after they start. Another source of uncertainty relates to fugitives arising from the hydraulic fracturing process required to extract shale gas, a growing source of natural gas supply in Canada. As a result, current inventory techniques are likely underestimating fugitive emissions. In response to this issue, many scientific initiatives have been initiated to better estimate these sources including research and development to estimate emissions such as undertaking atmospheric measurement campaigns, and new measurement technology such as infrared imagery.[89] The use of both top-down and bottom-up estimates will support improved understanding of methane from oil and gas sources. Canada has committed to working with continental partners to enhance the effectiveness of emission inventories for methane emissions from the oil and gas sector.

The March 10, 2016, Canada-U.S. Joint Statement recognizes the importance of improving the quantification of emissions. Canada is committed to working with continental partners to improve emission inventories of methane emissions from the oil and gas sector.

In the waste sector, technology for landfill gas recovery and utilization is well established and readily available for both new and existing landfills. Depending on landfill age and access to infrastructure, landfill gas recovery and utilization can also be highly cost-effective. Under the NALS Statement, Canada has committed to take action to reduce emissions from landfills, and to implement voluntary measures to reduce and recover food waste.

Technologies to reduce black carbon emissions from the transportation sector are also proven. Canada's low sulphur content in fuel regulations enable the use and effective operation of vehicle and engine exhaust after-treatment systems, such as diesel particulate filters, which can nearly eliminate black carbon emissions. Transportation sector air pollutant regulations for on- and off-road vehicles and engines are helping to drive down black carbon emissions from this sector.

Further reducing emissions from Canada's largest sources of black carbon emissions, existing diesel vehicles and engines, and wood-burning appliances, will require targeted actions to address barriers related to long vehicle, engine and appliance lifetimes, and influencing the consumers that own many of these small, distributed sources to retrofit or replace them with cleaner technologies.

Measures to address ozone precursors are often part of air quality policies, driven primarily by human health concerns. Measures to reduce ozone precursors in the transportation sector also often reduce black carbon as a co-benefit. Ozone precursors from industrial sources should also be addressed.

Adjusting fertilizer rates with plant needs, placing fertilizer near plant roots, applying fertilizer more frequently instead of only once, and using slow-release forms can limit nitrogen in soils and reduce nitrous oxide emission. In the same fashion, using manure more efficiently can also reduce nitrous oxide emissions. Other practices such as increased use of legumes as a nitrogen source, use of cover crops to remove excess available nitrogen, less use of summer fallow, and adjusting tillage intensity can also contribute to reducing emissions in the agriculture sector.[90] These options can yield co-benefits such as reducing the cost of production (as less fertilizer is used), saving on the use of fossil fuels needed to produce fertilizers, and reducing the pollution resulting from nitrates, ammonia, and other nitrogen substances released in the environment.

In the industrial sector, adipic acid plants can use proven and commercially available technology using catalytic and thermal destruction techniques with reduction efficiencies ranging between 90% and 99%. In nitric acid plants, the use of non-selective catalytic reduction and selective catalytic reduction is possible to reduce nitrous oxide emissions by as much as 90%.[91]

89 Glancy, R., Quantifying Fugitive Emission Factors from Unconventional Natural Gas Production Using IPCC Methodologies.

90 Agriculture and Agri-Food Canada. Nitrous Oxide.

91 International Energy Agency. Abatement of other Greenhouse Gases – Nitrous Oxide.

Several Canadian companies and end users have developed and implemented innovative technologies to transition from current HFC technologies, and have an opportunity to take a lead role in the transition to non-HFC technologies. For instance, some Canadian supermarkets are converting their refrigeration systems to enable the use of refrigerants with very low global warming potentials, that are more energy efficient, and yield significant cost savings. For example, Sobeys has converted over 70 of its stores to climate-friendly, home-grown innovative technologies and plans to extend such conversions to its 1,300 stores across the country.

Meanwhile, major automobile manufacturers operating in Canada have started to manufacture new models with air conditioners using climate-friendly alternatives instead of HFCs. Those actions are also helping to increase energy efficiency. For example, for some applications, replacing HFCs with climate-friendly refrigerants and technologies can improve energy efficiency by up to 50%. The Government of Canada plans to publish proposed regulatory measures to phase down HFCs in Canada, including prohibitions on the manufacture and import of products and equipment containing or designing to contain HFCs by the end of 2016.

6 Forests

KEY MESSAGES:

- The Paris Agreement highlights the critical role that forests play in achieving the global net-zero emissions objective in the second half of the century. With its vast managed forest land, Canada has significant potential for long-term forest-based GHG mitigation.
- Choices about mitigation strategies will be influenced by the slow-growing nature and high rate of natural disturbances in Canada's forests.
- Forest-related mitigation can involve either reducing or avoiding emissions, or enhancing carbon sequestration. The potential becomes even clearer when impacts are assessed on a life-cycle basis.
- A substantial reduction in emissions and increase in removals by 2050 is possible through measures such as changes in how forests are managed, greater domestic use of long-lived wood products, greater use of bioenergy from waste wood, and afforestation.
- There are a number of emerging opportunities in which the forestry sector could contribute to mitigation outcomes that require further consideration.

6.1 The Paris Agreement highlights the critical role that forests play in achieving the global net-zero emissions objective in the second half of the century. With its vast forest land, Canada has significant potential for long-term forest-based GHG mitigation.

Forests play an important role in the carbon cycle by sequestering a significant amount of carbon, thereby reducing net CO_2 emissions to the atmosphere. It is estimated that globally, forests offset the equivalent of about 24% of anthropogenic emissions from the atmosphere.[92] As noted in the Paris Agreement, a balance between emissions and removals of greenhouse gases in the second half of the century is needed to ensure that global warming is limited to well below two degrees Celsius.[93] It is therefore important to recognise that without actions to protect, conserve, and sustainably manage forests globally, it will not be possible to achieve the net-zero emissions required to reach this objective.

Considering the vast size and economic impact of its forest, Canada has a responsibility to carefully consider the mitigation potential of its forest sector. Canada's forest is the third largest in the world, at 347.6 million hectares,[94] and Canada's forest industry contributes significantly to the economy as a major employer nationwide, with nominal GDP of $22.1 billion in 2015.[95] By value, Canada is the world's leading exporter of softwood lumber, newsprint and chemical wood pulp.[96] Canada's forward-looking forest-related mitigation actions can thus have a significant impact.

Given their traditional relationship with forests, Indigenous peoples have an important role to play in planning and managing forest resources. In 2011, 70% of Indigenous

92 Smyth et al., Quantifying the biophysical climate change mitigation potential of Canada's forest sector.
93 United Nations Framework Convention on Climate Change, Paris Agreement, Art. 4.
94 Canada's National Forest Inventory Resources, Statistical Summaries for Canada: Forest Area.
95 Natural Resources Canada's calculations based on Statistics Canada's CANSIM table 379-0031.
96 Natural resources Canada, The State of Canada's Forests 2015.

communities were located in forested areas.[97] Indigenous peoples account for 4.8% of the total forest sector workforce in Canada, compared to 3% of the total workforce.[98] The participation of Indigenous people in land-use decisions and sustainable forest management will be a key component of the long-term contribution of Canada's forests to climate change mitigation.

6.2 Choices about mitigation strategies will be influenced by the slow-growing nature and high rate of natural disturbances in Canada's forests.

A large proportion of Canada's forests are old and slow-growing. When harvested, much of the biomass is converted to wood products that can store the carbon for a long period of time, depending on the product. Harvest residues left in the forest decompose over time or may be burned to reduce the risk of wildfire. All forests harvested on public land must be regenerated according to policies and legislation on sustainable forest management,[99] but it takes time for trees to grow in Canada's cold, northern conditions. Mitigation strategies that rely on forest growth to sequester carbon must therefore be implemented soon in order for significant mitigation benefits to be realised by 2050.

The factors described above, as well as considerations related to natural disturbances such as forest fires and the impact of climate change on the forest, will influence the development of forest-related mitigation. Sustainable forest management already balances multiple objectives but now must also increasingly tackle the twin challenges of mitigation and adaptation. This underscores the importance of developing a long-term strategy that will build on actions planned in the short- to medium-term and ensure that forest-related mitigation can make a substantial contribution to the mid-century target.

6.3 Forest-related mitigation can involve either reducing or avoiding emissions, or enhancing carbon sequestration. The potential for forest-based mitigation becomes even clearer when impacts are assessed on a life-cycle basis.

As noted in the IPCC Fourth Assessment Report, it is important to examine total mitigation effects across the forest and forest products system on a life-cycle basis, taking into account emissions and removals in the forest, storage of carbon in harvested wood

97 Government of Canada, Indigenous Peoples and Forestry in Canada.
98 Natural Resources Canada, Aboriginal Participation in the Forest Sector.
99 Ibid, p.26. All areas of provincial Crown land that are harvested for timber are required to be regenerated using natural or artificial means (i.e., planting and seeding), or a mix of the two. Standards and regulations for achieving successful regeneration vary by province.

products (HWP), land-use changes, and avoided emissions in other sectors from the substitution of HWP or bioenergy for other more emissions-intensive products and fossil fuels.[100]

Assessment of mitigation strategies must take into consideration biophysical, technical and economic factors. The biophysical mitigation potential sets the boundaries around what is physically possible to achieve in the forest, while the technical and economic costs determine what is feasible to accomplish.[101]

6.4 Analyses show that a substantial reduction in emissions and increase in removals by 2050 is possible through measures such as changes in how we manage forests, greater domestic use of long-lived wood products, greater use of bioenergy from waste wood, and afforestation.

Realising forest-related GHG mitigation potential will require a focus on actions that help reduce emissions and increase the carbon stored in trees, soils, and forest products. In general, in the short- to medium-term, options that avoid emissions and maintain forest and HWP stocks may offer the largest mitigation results. In the longer-term, significant mitigation can result from options that increase harvesting over time and substitute forest biomass for more emissions-intensive products and energy sources. In order to achieve longer-term mitigation, however, action is required in the near-term, even if mitigation benefits are not immediately visible. Moreover, in some cases, options that provide the greatest short-term results may not always provide the greatest mitigation in the long term. Therefore, when assessing forest-related mitigation options, it is important to consider the potential for a longer-term contribution to a low-carbon economy and not just the potential in the short and medium term.

Analyses show that the mitigation actions with the greatest potential for medium and long-term emissions reductions by mid-century in Canada include an integrated approach to changes in forest management practices, increased afforestation, increased use of harvested wood for long-lived products, and increased use of waste wood for bioenergy in place of fossil fuels. These findings are in line with the findings of the Fourth Assessment Report of the IPCC that indicate that sustainable forest management that produces harvested wood products annually while maintaining or increasing forest carbon stocks will generate the largest sustained mitigation benefit in the long run.[102]

6.4.1 Change in Forest Management Practices

Given that close to 90% of forests in Canada are owned by provinces and territories,[103] these jurisdictions will need to identify and implement changes in forest management practices most relevant to their region. Mitigation actions must be balanced with other sustainable forest management priorities, but could include higher utilisation of residual and harvested wood, reduced burning of harvest residues in the forests, increased planting to rehabilitate forests after natural disturbances, and increased planting intensity to improve forest growth after harvest.

In addition to their substantial long-term mitigation potential, changes in forest management practices could create co-benefits, including increased employment in the forest sector, reductions in black carbon emissions (where there is a reduction in slash burning), and increased adaptation efforts to improve the resilience of forests.

6.4.2 Afforestation

A future vision for Canada could include an expanded forest area, however this would need to be achieved without negatively affecting food production. There has historically been relatively little afforestation in Canada,[104] but this could provide substantial carbon sequestration in the long-term. Various levels of afforestation using mixes of fast-growing species and slower-growing species could be used. Because of the time it takes for trees to grow in Canada it would take time for afforestation activities to begin to show substantial carbon reductions.

Investments in afforestation could lead to co-benefits such as the diversification of rural economies, reduced forest fragmentation and enhanced forest habitat for wildlife, improved soil quality and watershed protection. Plantations generate revenue over the long term through harvesting and re-growth which act as an incentive to long-term management by landowners. Challenges in achieving large-scale afforestation include the need to ensure a sufficient

100 Nabuurs et al., Forestry: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
101 Smyth et al., Quantifying the Biophysical Climate Change Mitigation Potential of Canada's Forest Sector.
102 Nabuurs et al., Forestry: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
103 Natural Resources Canada, The State of Canada's Forests 2015, p. 50.
104 Natural Resources Canada, The State of Canada's Forests 2015, p. 23.

supply of seedlings and to engage the interest of a sufficient number of landowners, as well as concerns about the resilience of some tree species to changes in climate and natural disturbances.

6.4.3 Increased use of residual and harvested wood products for long-lived products

Life cycle research demonstrates that increased use of sustainably produced wood products could lead to avoided GHG emissions in other sectors. In particular, the substitution of wood-based materials for more emissions-intensive materials (such as concrete and steel) for construction and for fossil fuel in heating and energy applications provides some of the highest mitigation opportunities. Canada can further invest in projects and activities that increase the use of harvested wood products in domestic construction such as tall and mid-rise residential buildings, commercial and industrial buildings, and bridges.

The expansion of wood end-uses could also contribute to increasing the competitiveness of the Canadian forest sector by diversifying market opportunities and helping to maintain or create jobs. While the technologies to implement this option are already demonstrated, commercialised, and widely used in other countries, Canada will need to analyse its National Building Code to ensure that it promotes the use of wood products in building design.

6.4.4 Increased use of harvested wood products for bioenergy, advanced bio-material, and bio-chemicals

There are potential mitigation benefits from adopting waste wood biomass as a fuel source for electricity or commercial, residential, and industrial heating in place of fossil fuels or as a feedstock in the manufacturing of advanced bio-material and bio-chemicals. Mitigation benefits come from using local sustainably-sourced wood for bioenergy, with priority given to harvest residues and waste wood, which have lower emissions on a life-cycle basis compared to the use of fossil fuels.[105] Positive mitigation benefits from bioenergy-related harvesting could occur in remote communities where local electricity is produced from fossil fuels (e.g., diesel) that have been transported over long distances.

The co-benefits of using biofuels include diversification of market opportunities, leading to increased growth and competitiveness of the Canadian forest sector. In addition, there are direct and indirect benefits for rural forest-based communities including energy autonomy, regional investment, and employment opportunities. Technology to support this option includes modern wood heating systems such as biomass-fueled boilers and stoves and furnaces that use sustainable wood-based feedstock. While this technology is commercially available, a bioenergy heating initiative would depend on securing additional energy infrastructure investments as up-front costs would be high, particularly where the infrastructure in not in place.

Bio-based materials and chemicals are likely to gain importance over the long term. There is a general consensus that the mid-century will bring a larger, more urban population and along with this comes the need for primary resources to sustain urban growth. This, in turn, highlights the potential of forest-based cellulosic material to replace not only a vast array of other materials used in building and energy, as noted above, but also to replace materials and chemicals used in the manufacturing sector at large. The mitigation potential of cellulose-based products, their renewable nature, and their potential to further be recycled or to biodegrade is likely to spur increasing demand for these high value products. For example, natural fibers have already become crucial in technical composite applications due to the demand for recyclable and biodegradable raw materials. The mitigation potential of cellulose-based products is highly dependent on their life cycle and end uses as well as the uptake of bio-based material as substitutes for traditional alternative feedstock and cannot be clearly ascertained yet.

As a country advantaged with significant biomass resources and forest and agriculture sectors poised for transformation, the bioeconomy represents a substantial opportunity to generate wealth and jobs for Canadians.

6.5 There are a number of emerging opportunities in which the forestry sector could contribute to mitigation outcomes that require further consideration.

6.5.1 Reducing deforestation

Unlike tropical countries where deforestation is a major driver of emissions, deforestation (permanent forest loss) in Canada is relatively low. Of the approximately 0.01% of Canada's forest land that is lost annually, most is driven by agriculture and the

105 Nabuurs et al., Forestry: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

expansion of the oil and gas industry.[106] Given that the main drivers of deforestation vary across the country – and that the drivers of deforestation are usually outside of the forest sector – there has been limited ability within the forest sector to influence these emissions to date.

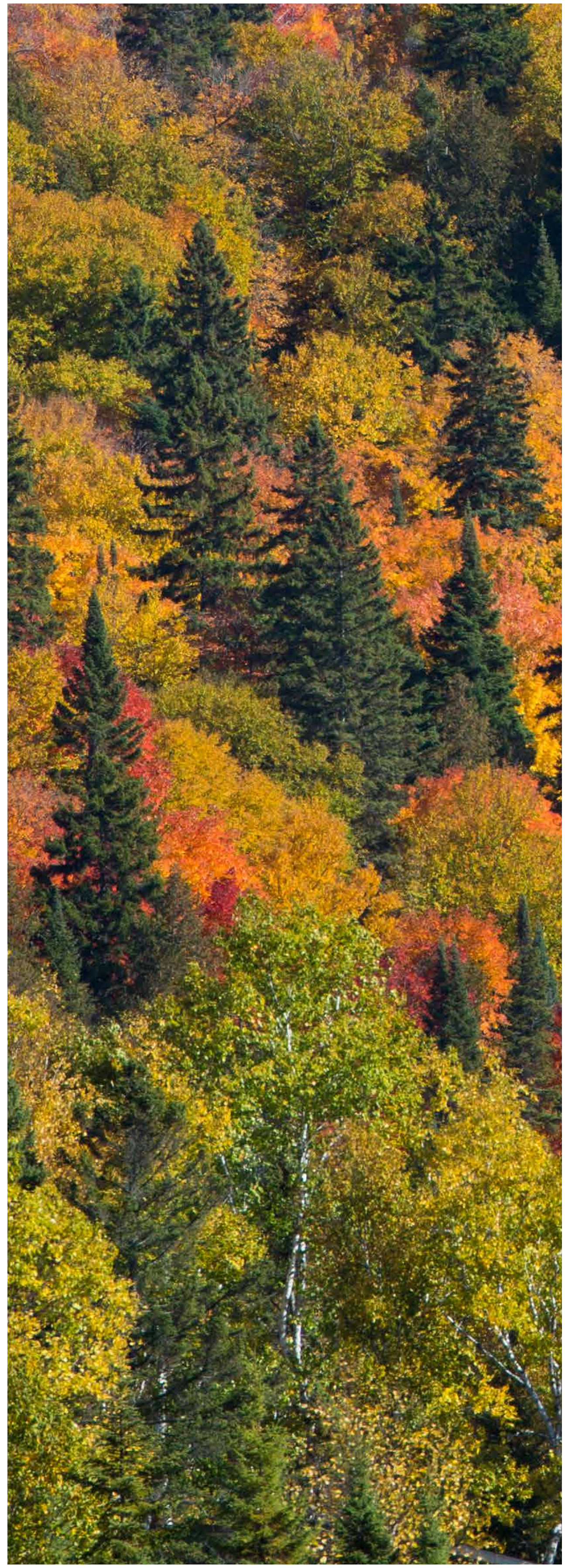
Nonetheless, reducing deforestation and its associated emissions is an area that Canada can explore, especially considering the role Canada plays in supporting reducing emissions from deforestation and forest degradation in developing countries, and that Canada is a signatory to the New York Declaration on Forests, which aims to end global net deforestation by 2030. Collaboration with provinces and territories is required given the need to consider how to address deforestation across jurisdictions and diverse sectors.

6.5.2 Research and Development in Advanced Bio-materials, Bio-chemicals, Bioenergy and Biofuels

The mitigation potential of using harvested wood products for bioenergy and biofuels can be further explored. Bioenergy with carbon capture and storage (BECCS) has received considerable global attention because it can generate negative emissions. A longer-term option for bioenergy could focus on reducing costs along the supply chain and increasing investments in research and development of second-generation biofuel production, advanced materials, and new platform chemicals, for example, converting cellulosic biomass into bio-crude and refining it into other biofuel products (e.g., biodiesel, bio-kerosene and bio-chemicals), as well as gasifying or liquefying biomass for power production. Further investment in research, development and deployment of such technologies could identify new areas with mitigation potential.

6.5.3 Urban Forestry

Urban forests provide a number of co-benefits in addition to sequestering GHG emissions, such as energy conservation through cooling and shade, provision of wildlife habitat, noise buffering and improved aesthetics and increased property values. Future research and analysis in improved monitoring and research to capture mitigation potential and enhance resiliency of urban forests is an option for Canada to explore.



106 Natural Resources Canada, The State of Canada's Forests 2015, p. 23.

7 Agriculture

KEY MESSAGES:

- The potential for greenhouse gas mitigation exists across the entire food system. There are opportunities and for consumers, farmers, food processors and municipalities to reduce and recycle energy and nutrients.
- Agricultural emissions result mostly from biological processes rather than from energy use.
- Technological innovations and sustainable land management practices will ensure that agricultural soils remain a net carbon sink in Canada over the long-term.
- Promoting the adoption of existing and emerging technologies and management practices could increase efficiency and reduce emissions from crop and livestock systems.
- The Agriculture sector has the potential to provide renewable energy solutions and bio-products to help reduce emissions in other sectors. In evaluating these options, consideration should be given to the full life-cycle environmental costs and benefits.

7.1 The potential for greenhouse gas mitigation exists across the entire food system. There are opportunities for consumers, farmers, food processors and municipalities to reduce and recycle energy and nutrients.

Addressing GHG emissions from agriculture requires the examination of the entire food system's life cycle from fertilizer manufacturing through to on-farm activities, food processing, distribution, and consumption. Moreover, the ultimate fate of food products, either as food waste, compost, or wastewater, needs to be taken into account.

This *holistic* approach seeks to improve the efficiency of the overall food system from "cradle to grave to cradle", and can often draw out synergies between the environmental and health impacts of food choices. In this respect, more can be done to foster positive societal engagement and cooperation to help lower GHG emissions. There are increasingly higher expectations for transparency and product environmental attributes, including the relative amount of GHGs embodied in different food choices.

In the context of a global and growing demand for food products, alternative approaches like local food movements, organic and/or urban agriculture or family farmers networks can play an important role in shaping the future of agriculture.[107] Any approach that helps to minimise waste (see Chapter 8) and helps to conserve energy and water will decrease emissions in other sectors indirectly related to agriculture, for example, during fertilizer manufacturing, or by removing nitrogen and phosphorus from wastewater.

107 Equiterre, Family Farmers Network.

7.2 Agricultural emissions result mostly from biological processes rather than from energy use.

Primary agriculture is at the heart of a complex and integrated agri-food system which provides one in eight jobs and accounted for more than 6% of GDP in 2014.[108] The agriculture sector contributes to making Canada one of very few countries currently in a position to produce more food than it consumes, and Canada is the fifth largest exporter of agriculture and agri-food products internationally.[109] Efficiency gains, sustainable land management, and innovation will enable Canadian agriculture to reduce emissions, store carbon, and meet a growing global food demand.

Most agricultural greenhouse gas emissions are not driven by energy use but rather take the form of methane and nitrous oxide resulting predominantly from biological processes inherent to animal and crop production. Nitrous oxide emissions can originate from field-applied fertilizers, crop residue decomposition, cultivation of organic soils, and from the storage of manure. Methane emissions are mainly a result of enteric fermentation in ruminant animals and decomposition of stored manure.

108 Agriculture and Agri-food Canada, *An Overview of the Canadian Agriculture and Agri-Food System 2016.*
109 Ibid.

Total emissions from agriculture have been relatively stable since the year 2000 and are not projected to significantly increase toward 2030.[110] In 2014, non-energy emissions accounted for 59 megatonnes of carbon dioxide equivalent (Mt CO_2 eq) – approximately 8% of Canada's total GHG emissions – while GHG emissions from on-farm fuel use generated 14 Mt CO_2 eq.[111] The two main sources of non-combustion agricultural emissions are enteric fermentation and fertilizer application.

7.3 Technological innovations and sustainable land management practices will ensure that agricultural soils remain a net carbon sink in Canada over the long-term.

For over twenty years, Canadian farmers in the Prairie provinces have been able to increasingly substitute conventional tillage with no-till or conservation tillage seeding techniques due to innovations such as improved seeds, fertilizers and pesticides, and changes in machinery and farm equipment, including the evolution of technologies such as global positioning systems. Increased crop rotation

110 Environment and Climate Change Canada, *Canada's Second Biennial Report on Climate Change.*
111 Environment and Climate Change Canada, *National Inventory Report 1990-2014: Greenhouse Gas Sources and Sinks in Canada.*

REDUCING METHANE EMISSIONS FROM ENTERIC FERMENTATION

Enteric fermentation is a natural process that occurs in the digestion of feed by livestock. The digestion process is not 100% efficient and releases methane as a by-product. In Canada, GHG emissions from enteric fermentation were 25 Mt CO_2e in 2014 down from 31 Mt in 2005. Dairy and beef cattle produce around 95% of these emissions while others ruminants such as buffalo, goats, horses, sheep and swine, make up the rest of the emissions.

There are a number of options to reduce methane emissions from enteric fermentation but many of these are still in the research phase. Since the demand for meat and milk is expected to increase in the future, decreasing methane output per unit or animal is important. For example, it is possible to select lower-methane producing animals through consideration of genetic characteristics. In addition, research into methane vaccines and inhibitors is ongoing in some jurisdictions.

High quality feed could lead to more efficient digestion and reduce emissions. For example, research has shown that mixing seaweed in cattle feed could reduce methane emissions. In this respect, a company from Prince Edward Island, North Atlantic Organics Ltd., is proposing organic seaweed products that can be used by dairy cattle.[112] The use of seaweed for animal feed is in fact a traditional method that has been used by coastal farmers in the past.

112 NAO organics. http://www.naorganics.com/index.asp

options have also allowed reduced reliance on summer fallow (the practice of allowing land to lie idle during the growing season).

As a result, agricultural soils in Canada have been a net sink of carbon since 2000 and will remain so over the long-term, although the rate at which carbon will be sequestered is projected to slowly diminish. Greater use of cover crops, biochar application and the use of precision agriculture to avoid disturbance of more fragile soils, among other sustainable land management practices, will help maintain the agricultural carbon sink in the future.

7.4 Promoting the adoption of existing and emerging technologies and management practices could increase efficiency and reduce emissions from crop and livestock systems.

On-farm GHG emissions are closely tied to management practices and technologies such as fertilizer types and application methods, manure storage and spreading methods, land management and tillage regimes, feeding and nutrition, as well as crop and animal genetics.

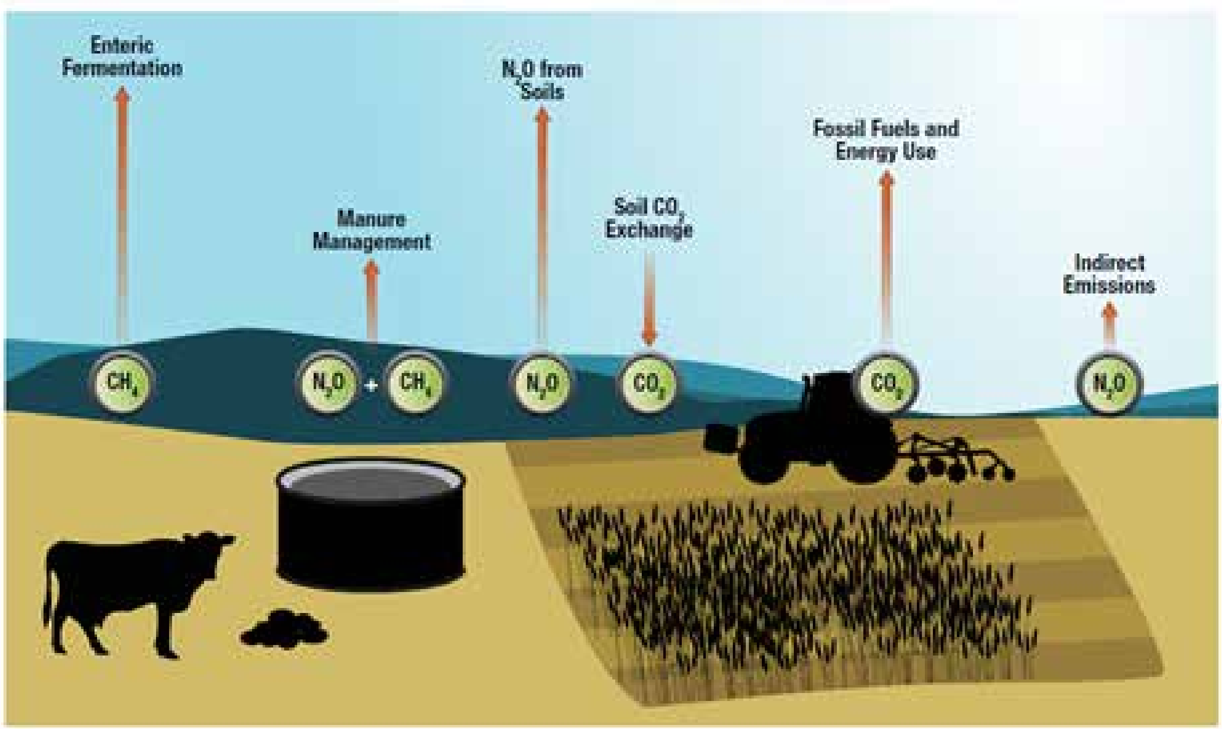
Mitigation options aimed at enhancing fertilizer use efficiency and reducing methane emissions from livestock are promising as innovative technologies such as methane inhibitor feeding additives, livestock genetics, smart-fertilizers, and precision agriculture approaches are being developed.

Encouraging the continued adoption of nutrient management practices, such as soil nutrient testing, optimisation of the timing of fertilizer application, incorporation of solid and liquid manure and fertilizer, and increased manure storage capacity, will continue to increase performance while minimising emissions in the sector.[113] For example, in the beef cattle sector, Canadian farmers have made significant improvements in feeding and breeding practices, and as a result, cattle reach slaughter weight sooner, and spend fewer days eating, ruminating, producing methane, and generating manure.[114]

In the livestock sector, upcoming methods to reduce methane emissions are showing significant potential.

113 Agriculture and Agri-Food Canada, *Farm Environmental Management Survey 2011.*
114 Agriculture and Agri-Food Canada, *Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series – Report #4.*

Figure 14: Agricultural GHG emissions in Canada in 2011



The arrow length is proportional to the magnitude of the emissions; arrow direction upwards indicates a source and downwards indicates a sink. Source: *Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series – Report #4*

These include switching to lower-methane producing ruminants, methane inhibitors and feed supplements, or even vaccines to reduce methane production in the rumen.

Technology will also continue to make a profound impact on agricultural production. Bioengineering, precision agriculture, sensors, robotics, and automated data capture and transfer, all hold promise for further agriculture GHG emission reductions. Although additional scientific validation work is still needed, preliminary, partial results point to substantial reductions in nitrous oxide emissions when an optimised nutrient management approach is adopted.

Continuing to seek improvements in efficiencies can yield further emission reductions but this will depend on the development and deployment of transformative technologies (e.g., methane inhibitors and smart-fertilizers), some expected to be ready for commercial deployment over the short-term (i.e., 5 years) while others could possibly be made available over the medium-term (i.e., 10-15 years).

On the farm inputs side, deeper penetration of precision agriculture practices, technologies and equipment should translate into lower consumption of production factors such as fertilizers and fuels, with a corresponding decrease in the GHG emissions associated with the use of these inputs. More efficient and precise production decisions should also lessen the pressure on natural resources like land and water.

As a more specific example, the province of Saskatchewan highlights the underdeveloped use of pulse crops to mitigate the use of fertilizers, as well as the potential associated with seeding marginal land for carbon sequestration, through permanent covers like legumes, or by converting them into forest stands. The province is also hopeful that advances in beef genetic selection, genomics and food additives will significantly lower the rate in which the agriculture sector emits GHG emissions. The province notes that the role of innovation and increased research in mitigation options for the agriculture sector is critical due to the challenge represented by a global population growth and the subsequent pressure on global food demand and production.

7.5 The Agriculture sector has the potential to provide renewable energy solutions and bio-products to help reduce emissions in other sectors. In evaluating these options, consideration should be given to the full life-cycle environmental costs and benefits.

From a life cycle perspective, the agriculture sector could also contribute to long-term mitigation by helping to reduce emissions in other sectors through displacement of more emission-intensive materials and fossil fuels with biomass-based energy and products.

There is an opportunity to convert growing agricultural waste, as well as agricultural by- and co-products into eco-efficient, bio-based products with direct benefits for the environment, the economy, and consumers, for example, sustainable bio-energy, bio-fertilizers and bio-chemicals. Both feedstock and technology exists to convert more wastes, agriculture and forest biomass into high quality, low GHG-emitting biofuels, for use in road transportation to air travel.

In evaluating these options, consideration should be given to net GHG savings along the full life cycle, as well as to other environmental impacts, that could result from the intensification of agricultural production.

8 Waste

KEY MESSAGES:

- The waste sector directly accounts for 3% of Canada's GHG emissions; however from a life cycle perspective, waste related activities are responsible for significant indirect GHG emissions from various sectors of the economy not typically associate with waste.
- Currently, the relatively low cost of waste disposal at landfills in many parts of Canada provides a disincentive for waste prevention and diversion activities.
- Effective management strategies, focusing on waste prevention and diversion, can bring deep cuts in direct and indirect waste-related GHG emissions.
- New policies could instigate behavioral change away from wasteful consumption patterns, as well as shift the responsibility for end-of-life management of products from consumers to producers.
- Co-benefits of waste prevention, diversion, and landfill gas capture include: greater food security, increased supply of renewable natural gas and electricity, creation of a soil amendment (i.e., compost); and a reduction in volatile organic compounds emissions, smog formation and unpleasant odours.
- In the future, progress in landfill gas capture and flaring technologies could further reduce any remaining direct landfill emissions.

Canada has performed poorly in terms of quantity of waste generated per capita compared to its OECD peers. At 777 kg of municipal waste generated per capita in 2008, the average Canadian city generated more waste than any other OECD country, twice as much as an average Japanese city, and slightly more waste than an average American city (722 kg).[115] While substantial efforts have been taken by municipalities and provinces/territories across the country, for example Nova Scotia has reduced waste generation to 386 kg per capita as of 2012, much more needs to be done.[116]

8.1 The waste sector directly accounts for 3% of Canada's GHG emissions, however from a life cycle perspective; waste related activities are responsible for significant indirect GHG emissions from various sectors of the economy not typically associate with waste.

The waste sector officially accounts for 3% of total GHG emissions and 22% of Canada's total methane emissions. This includes emissions from municipal solid waste landfills, wood waste landfills, wastewater treatment, as well as waste discharge, incineration, and open burning.

115 Conference Board of Canada, *Municipal Waste Generation. Note: For comparison purposes, construction, renovation and demolition waste were not included in the OECD definition.*

116 Conference Board of Canada, *Waste Generation: Provincial and Territorial Ranking. Readers should note that municipal waste generation per capita and waste generation per capita differs slightly, the latter being slightly more important.*

As the IPCC's fourth assessment report indicates, a life cycle approach is required to evaluate the emissions reductions potential for waste prevention and diversion. As such, waste management activities will affect GHG emissions accounted for under sectors such as transportation, forestry, energy and industrial processes. For example, the U.S. Environmental Protection Agency (EPA) estimated that approximately 42% of total U.S. greenhouse gas emissions are associated with the energy used to produce, process, transport, and dispose of commodities and food.[117] Waste prevention and diversion strategies would therefore reduce emissions in other sectors.

8.2 Currently, the relatively low cost of waste disposal at landfills in many parts of Canada provides a disincentive for waste prevention and diversion activities.

Waste disposal is relatively inexpensive in Canada compared to many peer countries. Available land for waste disposal is not in short supply in Canada, relative to many European countries. Canadian jurisdictions are using a variety of policy approaches to counter the low cost of landfill disposal. For example, Nova Scotia, Quebec, and Prince Edward Island have implemented material disposal bans from landfills (e.g., organic waste and in some instances recyclables). Quebec and Manitoba have also instituted landfill levies to provide an incentive for greater waste diversion and to support municipal recycling programs.[118] In 2014, the City of Edmonton opened its new *Waste-to-Biofuels and Chemicals Facility*, the first industrial scale waste to biofuels facility of its kind, that will help the city divert up to 90% of residential waste from landfills, as well as produce up to 38 million litres of ethanol each year.[119]

117 United States Environmental Protection Agency, *Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices.*

118 Giroux Environmental Consulting, *State of Waste Management in Canada.*

8.3 Effective management strategies, focusing on waste prevention and diversion, can bring deep cuts in direct and indirect waste-related GHG emissions.

The greatest untapped potential for GHG emissions reductions rests with waste prevention and diversion activities (e.g., composting or anaerobic digestion). Reducing avoidable food waste and increasing diversion of other organic material and recyclable materials from landfills could procure most significant emissions reductions for the sector.

In Canada, avoidable food waste is valued at $31 billion per year. Moreover, the national organics diversion rate stands as a low 7% of the total waste stream, with the recyclable materials diversion rates standing at 16%. In total, Canada's overall diversion rate stand at 25%, lower than other peers countries such as Germany or the US.[120] Nevertheless, it is important to remember that some Canadian municipalities are leading the way for diversion strategies, with Halifax, Hamilton, and Sherbrooke achieving total diversion rates between 40 and 60%.[121] An enforced target, such as the EU's 50% diversion rate by 2020, could prove useful to engage the different Canadian authorities in a concerted waste management effort. [122]

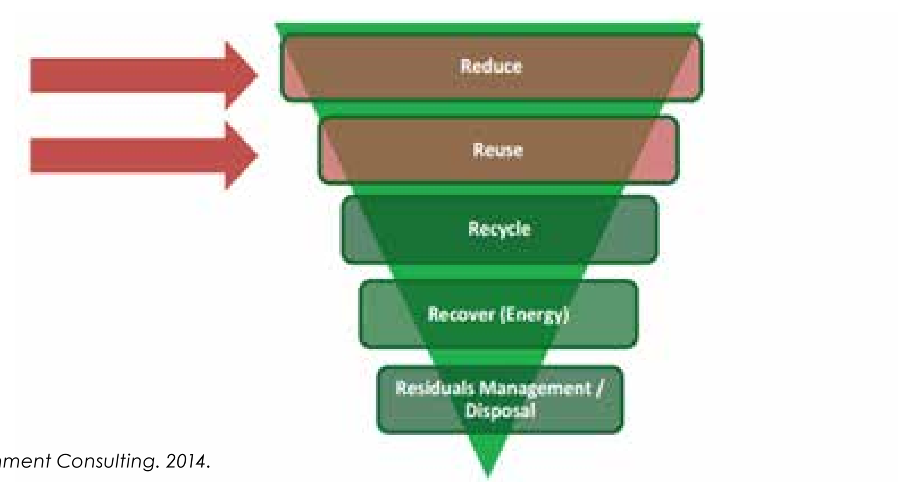
119 City of Edmonton, *Waste to Biofuels and Chemicals Facility.*

120 Statistic Canada, *Waste Management Industry Survey: Business and Government Sectors.*

121 Federation of Canadian Municipalities, *Waste Diversion Success Stories from Canadian Municipalities.*

122 Ontario Waste Management Association, *Rethink Waste: Evolution Towards a Circular Economy.*

Figure 15 - Location of Waste Prevention and Reduction in the Waste Management Hierarchy.



Source: Giroux Environment Consulting. 2014.

WASTE DIVERSION IN NOVA SCOTIA

The province of Nova Scotia is a North American leader in waste diversion, creating significant environmental benefit and economic advantage. Its disposal rate is 50% lower than the Canadian average and continues to decrease.

Starting in 1996 the Province implemented a strategy that included disposal bans on food and yard waste, some paper, plastic, metal and electronic items.

Some other highlights of Nova Scotia's successful and ongoing 'circular economy approach' to solid waste include:

- Financial incentives to municipalities based upon diversion performance
- A strong partnership with municipalities through a regional (solid waste) chairs committee
- Effective and sustained education, enforcement, and innovation programs
- Stewardship programs for beverage containers, tires, mercury containing products, and dairy containers
- Extended producer responsibility programs for electronics, paint, and cell phones
- Municipal commitments to implementing clear bag programs for garbage that decrease waste disposal by 15 to 30%

As a result, tonnes of materials that used to be wasted now contribute to Nova Scotia's economy, creating jobs and reducing GHG emissions.

8.4 New policies could instigate behavioral change away from wasteful consumption patterns, as well as shift the responsibility for end-of-life management of products from consumers to producers.

Effective policies can help increase waste diversion through source reduction, reuse, recycling, composting, and anaerobic digestion. For example, information and incentive programs can help shift public behavior to less wasteful practices by helping to close information gaps (e.g., public education programs), or providing financial incentives such as advance disposal fees policies. Another example can be found in the Swedish initiative to introduce a tax break for repairing activities, such as repairs of bicycles or appliances. Such policies are instrumental in shifting consumption behaviors towards waste prevention.

The true cost of landfill disposal also needs to be adequately reflected in tipping fees to account for loss of arable land and the creation of environmental liabilities. Regulatory or market-based policies could include disposal bans, higher landfill tipping fees, and differential tipping fees for unsorted waste. Practices such as keeping products for longer, reusing products, or repairing items and spare parts that can be re-used, are amongst the many ways that need to be promoted and rewarded by municipalities and provinces/territories. There are innovative solutions to reducing food waste by connecting consumers and producers in the food industry, such as industry and non-governmental organisation-led initiatives to encourage the sale and purchase of imperfect produce.

A significant step towards increasing diversion, and in turn reducing emissions associated with waste, is to shift the responsibility for end-of-life management of products from consumers and municipalities to producers. Over the past 20 years, significant progress on extended producer responsibility programs has been made in Canada on a wide variety of products and materials. The next phase will be to implement diversion programs for complex product categories such as construction, renovation, demolition materials, furniture, textiles and carpets.[123]

123 Canadian Council of Ministers of the Environment, *Progress Report on the Canada-wide Action Plan for Extended Producer Responsibility*.

Regulations and support for producers to minimise material inputs, optimise reuse and recovery of products, and develop markets for recycled materials will be essential.[124] Extended producer responsibility programs and performance-based regulations are two policies put forward to pursue that shift.[125] Improved systems for generators to manage certain materials on-site instead of relying on costly centralised infrastructure could also be further explored (e.g., plastic to oil conversion, renewable natural gas recovery from organics).

8.5 Co-benefits of waste prevention, diversion, and landfill gas capture include: Greater food security, increased supply of renewable natural gas and electricity, creation of a soil amendment (i.e., compost); and a reduction in volatile organic compounds emissions, smog formation and unpleasant odours.

There are many co-benefits to improve waste management strategies apart from reducing greenhouse gas emissions, in particular methane. Waste prevention increases food security and organic waste diversion can produce renewable biogas and/or a soil amendment. Recycling can save resources and energy, while limiting the amount of plastic discharged in the oceans. Landfill gas capture can also provide energy and electricity to municipalities and industries. In addition, cement manufacturers across the country have shown interest in using a variety of waste products (solid waste, carpets, wood waste, asphalt, non-recyclable plastics) as an alternative energy source.[126] Finally, the reduction of volatile emissions, smog formation, and unpleasant odours, will provide health and lifestyle benefits to landfill-adjacent neighborhoods and communities.

8.6 In the future, progress in landfill gas capture and flaring technologies could further reduce any remaining direct landfill emissions.

Even with waste prevention and diversion efforts, it is likely that landfill disposal will still be a practice in some parts of Canada in 2050 and that not all sources of GHGs will be diverted. In addition, there is a lag in the decomposition of organic waste in a landfill such that the organic waste disposed today, will be the source of emissions for decades to come if not mitigated. Currently, only 36% of total methane gases generated by landfills are captured, partly due to current stringency and performance standards on gas capture regulations across the country. Nevertheless, landfill gas capture technologies are widely available and expected development in flaring, gas capture and gas utilisation technologies could easily increase the ongoing reduction in landfill GHG emissions and produce more heat and electricity. In the future, thermal treatment facilities with energy recovery, small-landfill gas capture technologies or even waste mining, could become proven and commercially viable options in Canada.

124 Giroux Environmental Consulting, *State of Waste Management in Canada.*
125 Ibid.
126 Ibid.

9 Clean Technology Sector

As our society moves to address its environmental challenges, the clean technology sector has seen an increase in demand for its products and processes. Clean technologies are products or processes that significantly reduce environmental impacts of a given economic activity. This subset of the economy makes a compelling case for itself as it provides economic development while improving the environmental performance of the economy. As the world moves to deep decarbonisation, the clean technology sector is faced with a tremendous opportunity to produce further economic and social co-benefits for all Canadians.

KEY MESSAGES:

- The clean technology sector is growing very quickly both domestically and globally.
- Utilities, equipment suppliers, and policymakers should work together to identify strategies for reducing deployment costs of critical clean technologies and barriers to adoption.
- Further investments in RD&D and innovation in clean technology, combined with market pull mechanisms such as carbon pricing, will support Canada's competitiveness, creating high paying jobs and increased exports.
- Innovation will result in economic and environmental spill-over effects, thereby increasing resource efficiency and productivity in other sectors and reducing other types of pollution.
- Providing a clear and predictable signal for long-term investments and disclosing climate-related information will allow the market to better anticipate the transition to a low-carbon future.
- Canada has confirmed its commitment to clean energy innovation by joining the Mission Innovation international commitment, which aims to accelerate innovation by doubling investments in clean energy RD&D across the world.

9.1 The clean technology sector is growing very quickly, both domestically and globally.

Recent historical performance of the clean technology sector in Canada has been very strong, despite a leveling off between 2013 and 2014. The sector grew at a pace of 8% annually between 2011 and 2013, which represents more than three times the overall economic growth in Canada.[127] Over the same time period, global clean technology revenues increased by 10% annually. Employment in the clean technology sector in Canada has increased from 41,000 in 2012 to 55,600 in 2014, an increase of more than 16% per year.

Solutions from clean technology producers can help address challenges in high-emitting sectors, providing positive economic and environmental outcomes. Investment opportunities in clean technology are increasing at a rapid pace. For example, the

127 Analytica Advisors, *Canadian Clean Technology Industry Report.*

IEA estimates that around $1 trillion per year of incremental investment are required in renewable energy and energy efficiency investments to keep the global average temperature to well below 2°C in 2050.[128] This represents a significant opportunity for Canadian clean technology companies to tap into this growing market. Exports accounted for 50% of the clean technology sector's revenues in 2014, meaning Canadian firms are positioned to benefit from comprehensive efforts to export unique technologies and expertise to new and growing markets.

9.2 Utilities, equipment suppliers and policymakers should work together to identify strategies for reducing deployment costs of critical clean technologies and barriers to adoption.

To advance the deployment of clean technologies in Canada, it will be critical to coordinate between actors, in order to reduce the cost of achieving emission reductions and mitigate barriers to adoption. Important actors in the economy, such as Governments and utilities can play a key role in accelerating the development and adoption of clean technologies. Given their financial capacity, these actors can use their purchasing power to demonstrate clean technologies and provide a visibility that will encourage broader adoption.

Canada has a strong financial sector, which it can use as a powerful lever to encourage further low-carbon development both domestically and abroad. Although there are many significant low-cost GHG reduction opportunities in developing countries, barriers to investment such as higher perceived risk and imperfect information prevent these opportunities from being realised by Canadian companies. Through its $2.65 billion climate finance commitment, Canada will contribute to making these investments more accessible to Canadian companies, allowing for Canadian low-carbon technologies to help reduce emissions at a lower cost, while leading to significant export opportunities.

Private sector participation is of utmost importance at all stages of technology development. Technology developers and users are best positioned to bring forward new technologies that will ultimately succeed. Governments also need to play a role in providing the appropriate incentive framework for this to happen, as the private sector typically underinvests in R&D. For this to happen, there must be a good alignment of policies to allow for technology developers to most effectively advance their goals. Finally, sufficient investment is paramount to allowing good technology solutions to reach the market.

9.3 Further investments in RD&D and innovation in clean technology, combined with market pull mechanisms such as carbon pricing, will support Canada's competitiveness, creating high paying jobs and increased exports.

Clean technology is a sector that defines itself in the improvement of environmental outcomes related to economic activities in a broad sense. As such, it is a sector where innovation is of utmost importance, and therefore is very RD&D-intensive. RD&D can help solve environmental problems with current technologies, but it can also contribute to developing new clean technologies that will make it easier to reduce emissions in the future. However, for technologies to actually make a difference, successful commercialisation has to take place. For this to happen, market demand has to be there.

The right policies and frameworks can work to promote a low-carbon economy by helping to address the double market failure traditionally faced by the clean technology sector. As with innovation spending more broadly, there is a tendency for the private sector to underinvest in RD&D given that the benefits may not be fully captured by the investing firms. As well, there is the issue of businesses not accounting for environmental externalities in their decision-making. Existing and potential government policies can help address these market failures. For example, carbon pricing allows for the consideration of GHG emissions in the final price of a product, which provides a market value to the environmental benefits of clean technologies.

Other types of approaches, such as government procurement of clean technologies and regulations, could also increase demand for Canadian clean technologies. Governments will have to display leadership in providing broad support for clean technologies, coordinating innovation efforts and catalyzing private-sector involvement, particularly for early-stage R&D.

These initiatives would address an important barrier for Canada, which has historically struggled with demonstration and commercialisation of its clean technologies, increasing the challenge for companies to export untested products. Given the important growth of clean technology globally, this would position Canada favorably in terms

128 Hamilton T., *The $36-Trillion Question.*

of competitiveness in this market. Canada's competitiveness in the clean technology market would bring significant benefits to Canada, such as high paying jobs and significant increases in exports.

9.4 Innovation will result in economic and environmental spill-over effects, thereby increasing resource efficiency and productivity in other sectors and reducing other types of pollution.

Innovation in clean technologies, whether it is a breakthrough technology or one that drastically improves the efficiency of an existing process, can bring significant benefits to the economy as well as spill-over effects. Economic benefits of clean technologies can take different forms, depending on the nature of the technology. If a technology provides an efficiency improvement, benefits will be seen as reduced input costs, while they can take different forms in the case of a breakthrough technology. The internalisation of environmental externalities with the help of tools such as carbon pricing will ensure that technologies that reduce emissions have tangible economic benefits.

Another dimension where spill-over effects are tangible is the potential to reduce production costs and pollution through industrial ecology. Industrial ecology is a concept that could potentially transform the industrial sector into a highly efficient integrated ecosystem. Industrial ecology "seeks to emulate mature ecological systems in order to reduce environmental impacts through maximised efficiency of energy resource inputs and the minimisation of unutilized waste".[129] This concept promotes more interconnections between industrial sectors to optimise the flows of inputs and outputs from each industry such that all industrial processes together minimise energy use and disposal of waste products to improve resource efficiency and economic competitiveness. In other words, industrial ecology allows for output perceived as non-valuable (waste heat, wood residues, etc.) to be used as inputs by other companies within an industrial park, allowing for improved competitiveness and environmental outcomes.

9.5 Providing a clear and predictable signal for long-term investments and disclosing climate-related information will allow the market to better anticipate the transition to a low-carbon future.

> "Green investment represents a major opportunity for both long-term investors and macroeconomic policymakers seeking to jump-start growth."
>
> - Mark Carney, Governor of the Bank of England and Chairman of the G20's Financial Stability Board

The financing of climate-related initiatives is a crucial dimension of the climate change challenge with both a domestic and international component. Significant investments, most notably in adaptation measures, need to be made in order to deal with the costs of climate change, some of which may materialise over a long-term horizon. There are risks and opportunities associated with these investments that many businesses and political actors are taking steps to address. For example, the insurance sector has already been significantly exposed to climate change risks.[130] Those risks could be physical risks, where investments can be affected by major events like floods or disruption of global supply chains and could have important impacts for insurers and re-insurers. Liability risks could also arise as investors may be subject to lawsuits for carbon damages. Finally, transition risks may occur as structural change in the economy drive re-pricing of assets and values of companies.

Another key aspect of tackling climate change risks and opportunities is to provide investors with reliable and detailed information of climate change activities. Many companies, including 822 investors with US $95 trillion in assets, have chosen to disclose information on their action on climate change through the Carbon Disclosure Project or the Montréal Carbon Pledge. The Financial Stability Board's Task Force on Climate-related Financial Disclosures is working to develop voluntary, consistent climate-related financial risk disclosures for use by companies in providing information to investors, lenders, insurers, and other stakeholders. Such initiatives will allow a better understanding of the link between decarbonisation and the financial performance of firms. Further development of similar initiatives could create a virtuous circle where action is encouraged and best practices are shared. This would, in turn, provide a clear and predictable

129 McKinley A., *Industrial Ecology: A Review with Examples from the Canadian Mining Industry, Canadian Journal of Regional Science.*

130 Bank of England, *Breaking the Tragedy of The Horizon - Climate Change and Financial Stability - Speech by Mark Carney.*

signal for investments, allowing the market to better anticipate the transition. [131]

Finally, pricing carbon will give Canadian businesses, investors, and consumers a clear, predictable basis for decision making. Confidence that carbon pricing in Canada will continue to increase over time will encourage businesses and consumers to invest in cleaner appliances, vehicles, and technology. It will also encourage firms to invest in research into low-carbon technology, which will better position Canadian firms to compete in the rapidly-growing, low-carbon economy.

9.6 Canada has confirmed its commitment to clean energy innovation by joining the Mission Innovation international commitment, which aims to accelerate innovation by doubling investments in clean energy across the world.

On November 30, 2015, Canada announced its participation in the Mission Innovation international commitment, along with 20 other countries. This commitment is to double clean energy innovation investments from governments over the next five years, while encouraging greater levels of private-sector investment. This commitment also entails working with the Breakthrough Energy Coalition, an independent initiative that features 28 influential investors from 10 countries that commit to providing patient, early-stage capital (as opposed to venture capital, which seeks returns on investment on a much shorter time horizon) to advance clean energy technology innovation.

As part of this initiative, it is recognised that clean technology innovation often faces a so-called "valley of death", which typically appears at the pre-commercialisation stage, where the conversion of a proven concept into a compelling product will determine whether a company will survive or not. This commitment aims to bridge that gap with increased government funding to enable more basic research, as well as more patient private capital, which will allow good concepts the time required to make it to market commercialisation. Given Canada's particular challenges in commercialisation, this initiative could fill an important need for Canadian companies to succeed in clean energy innovation that can significantly reduce GHG emissions.

131 "[R]isks to financial stability will be minimised if the transition begins early and follows a predictable path, thereby helping the market anticipate the transition to a 2 degree world". (Bank of England, Breaking the Tragedy of the Horizon - Climate Change and Financial Stability - Speech by Mark Carney.)

10 Achieving a Low-Carbon Future through Infrastructure Investments

Infrastructure investments are key to supporting Canada's deep decarbonisation efforts over the longer term and will help reshape the economy consistent with low-carbon pathways. Investing in infrastructure today will provide Canadians with increased employment opportunities, and cleaner, more modern communities, while also addressing climate change and air pollution.

Investing in public transit, green infrastructure, social infrastructure, Canada's trade and transportation corridors, as well as rural and northern communities, will provide a strong foundation for more inclusive and sustainable cities, and can also help to both address greenhouse gas emissions and enhance resilience to the impacts of climate change. For instance, Canadian communities building new urban transit networks and service extensions will transform the way that Canadians live, move and work.

In addition to committing significant resources (over $186 billion through to 2027-28), Canada is also establishing a new Infrastructure Bank, an arm's-length organization dedicated to increasing investment in growth-oriented infrastructure, transforming the way infrastructure is planned, funded and delivered across the country.

Considering the magnitude of investments required to develop key infrastructure projects, key linkages between infrastructure decision-making and long-term decarbonisation include:

- Investments are influential in setting long-term greenhouse gas pathways as the lifespan of infrastructure assets are long-lived, often ranging from 25 to 60 years.
- Once infrastructure investments are made, the behaviours and carbon emissions associated with infrastructure investments are more or less 'locked-in' and the shift to a new pathway can become very costly.
- Deploying infrastructure investments strategically can attract low-carbon infrastructure investments, creating a critical mass of funding for low-carbon solutions or the ability to 'anchor' future low-carbon investments. For example, making strategic investments in alternative fuel or electric vehicle infrastructure would underpin further investments in low-carbon vehicles.
- The transformative nature of infrastructure projects plays a complementary and enabling role to support the transition to a low-carbon economy. For instance, infrastructure that is designed to withstand the projected impacts of climate change can lead to cost savings over the longer term by avoiding maintenance and rehabilitation costs.

Canada is committed to working closely with all stakeholders, including provinces, territories and Indigenous peoples, to develop and implement an infrastructure plan that delivers investments across the country. As part of this plan, investments in green infrastructure and other streams, such as social and transportation, will reduce GHG emissions and support the resilience of infrastructure assets. Examples may include supporting further electrification of sectors currently reliant on fossil fuels, improving electricity transmission systems through inter-provincial transmission lines and the expansion of smart grids.

Investments in sustainable infrastructure will enable greater climate change adaptation and resilience; ensure that more communities can provide clean air and safe drinking water for their citizens; and support the transition toward more sustainable economic growth. Canada will ensure that our mid-century climate change objectives inform our infrastructure development going forward.

Conclusion

Dealing with climate change will ultimately require net-zero anthropogenic greenhouse gas emissions over the course of this century. Canada will need to fundamentally transform all economic sectors, especially patterns of energy production and consumption. Over time, this requires major structural changes to the economy and the way people live, work, and consume.

A low-greenhouse gas future also represents a massive opportunity to increase prosperity and the well-being of Canadians, to improve the livability of the built environment, modernise transportation, and enhance the natural environment. The benefits include: reducing air pollution and congestion, modernising infrastructure to provide more inclusive and sustainable cities, creating cleaner and more modern communities, growing Canada's clean technology sector, increasing economic productivity and efficiency, saving energy and reducing energy costs, and enhancing resilience to the impacts of climate change.

Much of the transformation can be achieved with existing technology, but innovation, such as through the Mission Innovation initiative, and significant investments in research, development, demonstration & deployment, and related infrastructure, will be fundamental to the transition.

Additional collaboration across industry leaders to identify common innovation priorities will be needed to seize opportunities to integrate innovation into business strategies. Funding environments, intellectual property regimes, research agendas, and communication strategies will need to be shaped to stimulate innovation investments.

Decarbonisation will require a sustained societal effort that will take many years to accomplish. This will require a technological ramp up of low greenhouse gas alternatives, and also societal engagement and action by all Canadians. Working collaboratively with Indigenous peoples by supporting their on-going implementation of climate change initiatives will be key. Likewise, all levels of government will need to implement a vast array of the various policy options that are available to them. In this respect, Canada will continue to work collaboratively with provinces and territories including through the pan-Canadian framework on clean growth and climate change. Although the pace of this transition may vary from Canadian jurisdiction to jurisdiction, the direction and orientation are clear.

Reference List

Reports:

Agriculture and Agri-Food Canada. (2016). Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series – Report #4. Retrieved from http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/environmental-sustainability-of-canadian-agriculture-agri-environmental-indicator-report-series-report-4/?id=1467307820931

Analytica Advisors. (2016). 2016 Canadian Clean Technology Industry Report. Retrieved from http://www.analytica-advisors.com/publications

Association of American Railroads. (2016). Freight Railroads Help Reduce Greenhouse Gas Emissions. Retrieved from https://www.aar.org/BackgroundPapers/Railroads%20and%20Greenhouse%20Gas%20Emissions.pdf

Bataille, C. et al. (2015). Pathways to Deep Decarbonization in Canada. Retrieved from http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_CAN.pdf

Canadian Council of Ministers of the Environment. (2014). Progress Report on the Canada-wide Action Plan for Extended Producer Responsibility. Retrieved from http://www.ccme.ca/files/Resources/waste/extended/CAP-EPR%20Progress%20Report.pdf

Canadian Council on Renewable Electricity. (2015). Powering Prosperity Climate Report.http://renewableelectricity.ca/wpcontent/uploads/2015/11/CanCORE_Report_FINAL.pdf

Carleton University School of Public Policy and Administration. (2015). Report of the State of Alternative Energy in the Arctic. Retrieved from https://curve.carleton.ca/system/files/faculty_staff_research_publication/08515c6b-3b39-4c41-ad7b-2c6306cf0379/fac_staff_res_pub_pdf/d9833b6ff19ff098e44032a87026605f/cherniak-etal-alternativeenergyarctic.pdf

Conference Board of Canada. (2008). Municipal Waste Generation. Retrieved from http://www.conferenceboard.ca/hcp/details/environment/municipal-waste-generation.aspx

Conference Board of Canada. (2011). Canada's Electricity Infrastructure: Building a Case for Investment. Retrieved from http://www.conferenceboard.ca/e-library/abstract.aspx?DID=4132

Conference Board of Canada. (2012). Waste Generation: Provincial and Territorial Ranking. Retrieved from http://www.conferenceboard.ca/hcp/provincial/environment/waste.aspx

Conference Board of Canada. (2015). A Long, Hard Road: Reducing GHG Emissions in Canada's Road Transportation Sector by 2050. Retrieved from http://www.conferenceboard.ca/e-library/abstract.aspx?did=7491

Council of Canadian Academies. (2015). Technology and Policy Options for a Low-Emission Energy System in Canada. Retrieved from http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/magna/energyuse_fullreport_en.pdf

Energy Economics. (2010). Optimizing the Energy Efficiency of Conventional Multi-Cylinder Dryers in the Paper Industry.

Environment and Climate Change Canada. (2014). Canada's Emission Trends Report 2014. Retrieved from https://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=E0533893-1

Environment and Climate Change Canada. (2015). Technical Guidance on Reporting Greenhouse Gas Emissions. Retrieved from http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=47B640C5-1&printfullpage=true#ws800EC2BC

Environment and Climate Change Canada. (2016). Canada's Second Biennial Report on Climate Change. Retrieved from https://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=02D095CB-1

Environment and Climate Change Canada. (2016). National Inventory Report 1990-2014: Greenhouse Gas Sources and Sinks in Canada. Retrieved from https://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=662F9C56-1

Executive Office of the President of the United States. (2014). The Cost of Delaying Action to Stem Climate Change. Retrieved from https://www.whitehouse.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf

Federation of Canadian Municipalities. (2009). Waste Diversion Success Stories from Canadian Municipalities. Retrieved from https://www.fcm.ca/Documents/tools/GMF/Getting_to_50_percent_en.pdf

GE Consulting group. (2016). Pan-Canadian Wind Integration Study, Retrieved from http://canwea.ca/wind-energy/wind-integration-study/

German Federal Ministry of Economics and Technology. (2012). Germany's New Energy Policy Heading Towards 2050 With Secure, Affordable And Environmentally Sound Energy. Retrieved from http://www.bmwi.de/English/Redaktion/Pdf/germanys-new-energy-policy

Giroux Environmental Consulting. (2014). State of Waste Management in Canada. http://www.ccme.ca/files/Resources/waste/wst_mgmt/State_Waste_Mgmt_in_Canada%20April%202015%20revised.pdf

Glancy, R.P. (2013). Quantifying Fugitive Emission Factors from Unconventional Natural Gas Production Using IPCC Methodologies. IGES, Hayama, Japan. Retrieved from http://www.ipcc-nggip.iges.or.jp/tsu/intern_report/TSU_InternshipReportRyan.pdf

Global Commission on the Economy and Climate. (2016). The Sustainable Infrastructure Imperative: Financing for Better Growth and Development. Retrieved from http://newclimateeconomy.report/2016/wp-content/uploads/sites/4/2014/08/NCE_2016Report.pdf

Government of British Columbia. (2008). Greening the Border. Retrieved from http://www.th.gov.bc.ca/greening_the_border/docs/greening_the_border.pdf

Government of Canada. (2011). Status of Remote/Off-Grid Communities in Canada. Retrieved from http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/files/pubs/2013-118_en.pdf

Government of Canada. (2016). Indigenous Peoples and Forestry in Canada. Retrieved from http://publications.gc.ca/collections/collection_2016/rncan-nrcan/Fo4-58-2016-eng.pdf

Government of Canada. (2016). Shrinking the Environmental Footprint – Beginning with Government. Retrieved from https://www.canada.ca/en/services/environment/conservation/sustainability/federal-sustainable-development-strategy/2015-progress-report/environmental-footprint.html

ICF International. (2014). Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries. Retrieved from https://www.edf.org/sites/default/files/methane_cost_curve_report.pdf

International Energy Agency. (2009). Energy Technology Transitions for Industry: Energy Technology Transitions for Industry. Retrieved from https://www.iea.org/publications/freepublications/publication/industry2009.pdf

International Energy Agency. (2000). Abatement of other Greenhouse Gases – Nitrous Oxide. Retrieved from http://www.ieaghg.org/docs/General_Docs/Reports/PH3-29%20nitrous%20oxide.pdf

International Energy Agency. (2015). Energy Efficiency Market Report. Retrieved from https://www.iea.org/publications/freepublications/publication/energy-efficiency-market-report-2015-.html

International Energy Agency. (2016). Energy Policies of IEA countries: Canada Review 2015. Retrieved from http://www.iea.org/publications/freepublications/publication/EnergyPoliciesofIEACountriesCanada2015Review.pdf

International Energy Agency. (2016). Energy Technology Perspectives 2016. Retrieved from http://www.iea.org/bookshop/719-Energy_Technology_Perspectives_2016

International Energy Association. (2016). IEA's Electricity Information Report. Retrieved from http://www.iea.org/bookshop/727-Electricity_Information_2016

Jacobson, M. Z. et al. (2016). 100% Clean and Renewable Wind, Water, and Sunlight (WWS) All-Sector Energy Roadmaps for 139 Countries of the World. Retrieved from http://web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html

National Energy Board. (2015). Electricity Exports and Imports Summary. Retrieved from https://www.neb-one.gc.ca/nrg/sttstc/lctrct/stt/lctrctysmmr/2015/smmry2015-eng.html

National Energy Board. (2016). Canada's Energy Future 2016: Energy Supply and Demand Projections to 2040, Retrieved from https://www.neb-one.gc.ca/nrg/ntgrtd/ftr/2016/index-eng.html

National Research Council Canada. (2016). Revolutionizing Canada's Mining Industry with Electric Vehicles. Retrieved from http://www.nrc-cnrc.gc.ca/eng/irap/success/2016/papabravo.html

National Round Table on the Environment and the Economy. (2007). Getting to 2050: Canada's Transition to a Low-emission Future. Retrieved from http://publications.gc.ca/site/eng/325043/publication.html

National Round Table on the Environment and the Economy. (2008). Getting to 2050: Canada's Transition to a low-emission Future. Retrieved from http://nrt-trn.ca/wp-content/uploads/2011/08/Getting-to-2050-low-res.pdf

Natural Resources Canada. (2010). Commissioning Guide for New Buildings. Retrieved from http://www.nrcan.gc.ca/energy/efficiency/buildings/research/optimization/3827

Natural Resources Canada. (2015). The State of Canada's Forests 2015. Retrieved from http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/36553.pdf

Natural Resources Canada. (2015), Coming to Terms with Heat Pumps. Retrieved from http://www.nrcan.gc.ca/energy/publications/efficiency/heating-heat-pump/6829

Natural Resources Canada. (2016). Aboriginal Participation in the Forest Sector. Retrieved from http://www.nrcan.gc.ca/forests/canada/aboriginal/16515

Natural Resources Canada. (2016). The Energy Innovation Program: Clean Energy Innovation. Retrieved from http://www.nrcan.gc.ca/energy/science/programs-funding/18876

Natural Resources Canada. (2016). Improving Energy Efficiency in Canada. Retrieved from http://oee.nrcan.gc.ca/publications/statistics/parliament/2013-2015/pdf/parliament13-15.pdf

Navius Research Inc. (2012). Investment and Lock-In Analysis for Canada: Low Carbon Scenarios to 2050. Retrieved from http://warming.apps01.yorku.ca/library/wp-content/uploads/2013/03/NRTEE-2012-Investment-and-Lock-in-Analysis-for-Canada_Low-Carbon-Scenarios-to-2050-CP6.pdf

Ontario Waste Management Association. (2015). Rethink Waste: Evolution Towards a Circular Economy. Retrieved from http://www.owma.org/Publications/OWMAReportsandPolicies.aspx

Potvin, C. et al. (2015). Acting on Climate Change – Solutions from Canadian Scholars. Retrieved from http://www.sustainablecanadadialogues.ca/files/PDF_DOCS/SDC_EN_30marchlr.pdf

Professional Engineers Ontario. (2010). Towards a Clean Train Policy: Diesel Versus Electric. Retrieved from http://www.academia.edu/5399500/Toward_a_clean_train_policy_diesel_versus_electric

Torrie, R. (2015). Acting on Climate Change: Extending the Dialogue Among Canadians: Some Reflections On Climate Change Response Policy. Retrieved from http://sustainablecanadadialogues.ca/pdf_2015/extending_dialogue/RalphTorrie.corr.pdf

Scurr, C. and Beaudry, J. (2011). Gap Analysis First Nations Climate Change Adaptation South of 60 Degrees Latitude. Submitted To: Indian and Northern Affairs Canada.

Shell Global. (2016). A Better Life with a Healthy Planet: Pathways to net-zero emissions. Retrieved from http://www.shell.com/energy-and-innovation/the-energy-future/scenarios/a-better-life-with-a-healthy-planet/_jcr_content/par/textimage.stream/1475857466913/a1aa5660d50ab79942f7e4a629fcb37ab93d021afb308b92c1b77696ce6b2ba6/scenarios-nze-brochure-interactive-afwv9-interactive.pdf

Smart Prosperity. (2016). New Thinking – Canada's Roadmap to Smart Prosperity. Retrieved from http://institute.smartprosperity.ca/sites/default/files/newthinking.pdf

Statistics Canada. (2010). Waste Management Industry Survey: Business and Government Sectors. http://www.statcan.gc.ca/pub/16f0023x/2010001/part-partie1-eng.htm

Statistics Canada. (2011). Census of Agriculture. Retrieved from http://www.statcan.gc.ca/eng/ca2011/index

Statistics Canada. (2013). Farm Environmental Management Survey 2011. Retrieved from http://www.statcan.gc.ca/pub/21-023-x/21-023-x2013001-eng.htm

Sustainable Canadian Dialogue. (2016). Acting on Climate Change : Indigenous Innovation. Retrieved from http://www.sustainablecanadadialogues.ca/en/scd/indigenousinnovations

Swiss Re and Institute of International Finance. (2015). Infrastructure investing: It matters. Retrieved from http://www.swissre.com/rethinking/financial_stability/infrastructure_investing_it_matters.html

The Royal Institution of Chartered Surveyors. (2005). Green Value. Retrieved from http://hatchdesign.ca/wordpress/wp-content/uploads/2011/12/greenvaluereport1.pdf

Trottier Energy Futures Project. (2016). Canada's Challenge & Opportunity. Retrieved from http://iet.polymtl.ca/tefp/

United Nations Environment Programme. (2015). Emissions Gap Report. Retrieved from http://www.unep.org/publications/ebooks/emissionsgapreport/

United Nations Environment Programme and World Meteorological Organization. (2011). Integrated Assessment of Black Carbon and Tropospheric Ozone. http://www.unep.org/dewa/Portals/67/pdf/BlackCarbon_report.pdf

United States Energy Information Administration. (2016). Levelized Cost and Levelized Avoided Cost of New Generation Ressources in the Annual Energy Outlook 2016. Retrieved from https://www.eia.gov/forecasts/aeo/electricity_generation.cfm

United States Environmental Protection Agency. (2009). Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices. Retrieved from https://www3.epa.gov/region9/climatechange/pdfs/ghg-land-materials-management.pdf

Urban Transportation Task Force. (2012). The High Cost of Congestion in Canadian Cities. Retrieved from http://www.comt.ca/english/uttf-congestion-2012.pdf

World Bank Group. (2016). Zero Routine Flaring by 2030. Retrieved from http://www.worldbank.org/en/programs/zero-routine-flaring-by-2030

World Energy Council. (2010). Average Electricity Consumption per Electrified Household. Retrieved from https://www.wec-indicators.enerdata.eu/household-electricity-use.html

Websites:

Agriculture and Agri-Food Canada. (2016). An Overview of the Canadian Agriculture and Agri-Food System. Retrieved from http://www.agr.gc.ca/eng/about-us/publications/economic-publications/alphabetical-listing/an-overview-of-the-canadian-agriculture-and-agri-food-system-2016/?id=1462288050282

Agriculture and Agri-Food Canada. (2016). Nitrous oxide. Retrieved from http://www.agr.gc.ca/eng/science-and-inovation/agricultural-practices/agriculture-and-climate/greenhouse-gases/nitrous-oxide/?id=1329321974453

Agriculture and Agri-Food Canada. (2011). Farm Environmental Management Survey 2011. Retrieved from http://www.statcan.gc.ca/pub/21-023-x/21-023-x2013001-eng.htm

CAA. (n.d.). Electric Vehicles, What You Need to Know. Retrieved from http://electricvehicles.caa.ca/electric-vehicles-available-in-canada/

City of Edmonton. (n.d.). On the Front Edge of Smart Vehicle Technology. Retrieved from http://www.edmonton.ca/city_government/initiatives_innovation/smart-vehicle-technology.aspx

City of Edmonton. (n.d.). Waste to Biofuels and Chemicals Facility. Retrieved from https://www.edmonton.ca/programs_services/garbage_waste/biofuels-facility.aspx

Drake Landing Solar Community. (n.d.). Welcome to Drake Landing Solar Community. Retrieved from http://www.dlsc.ca/

Electricity. (n.d.). The Electric Bus – Quiet, Exhaust Emission-Free and Passenger-Friendly. Retrieved from http://www.goteborgelectricity.se/en/node/19505/about-electric-bus/

Equiterre. (n.d.). Family Farmers Network. Retrieved from http://www.equiterre.org/en/project/family-farmers-network/

EVObsession. (2015). Best Electric Car for the Average American. Retrieved from http://evobsession.com/best-electric-car-for-the-average-american/

Fleet Carma. (2015). Electric Vehicle Sales in Canada: 2015 Final Numbers. Retrieved from http://www.fleetcarma.com/ev-sales-canada-2015/

Force. (n.d.). FORCE. Retrieved from http://fundyforce.ca/about/

Indigenous Economic Development Indigenous Affairs Working Group. (n.d.). Ontario Aboriginal Energy Partnerships Program. Retrieved from http://www.aawgecdev.ca/ontario-aboriginal-energy-partnerships-program.html

Mercedes-Benz. (2016). Electric truck for the city. Retrieved from https://www.mercedes-benz.com/en/mercedes-benz/next/e-mobility/electric-truck-for-the-city/

Mercedes-Benz (2016). Urban eTruck [Digital Image]. Daimler Co. Ltd. Retrieved from https://www.daimler.com/products/trucks/mercedes-benz/urban-etruck.html

Model 3 Tracker (2016) Known Spots of Model 3 Vehicles by Status. Retrieved from https://www.model3tracker.info/public_graphs_world_map.php

Natural Resources Canada. (2014). Low Carbon Fuel Demonstration Pilot Plant. Retrieved from http://www.nrcan.gc.ca/energy/funding/current-funding-programs/eii/16134

Natural Resources Canada. (2015). Algal Carbon Conversion Program. Retrieved from http://www.nrc-cnrc.gc.ca/eng/solutions/collaborative/algal_index.html

Nuclear Energy Institute. (2015). Top 10 Nuclear Generating Countries. Retrieved from http://www.nei.org/Knowledge-Center/Nuclear-Statistics/World-Statistics/Top-10-Nuclear-Generating-Countries/

Orkuveita Reykjavikur. (n.d.) The CarbFix Project. Retrieved from https://www.or.is/english/carbfix-project#page-7214

News Articles:

Bloomberg New Energy Finance. (2016, June). Coal and Gas to Stay Cheap, but Renewables Still Win Race on Costs. Bloomberg. Retrieved from https://about.bnef.com/press-releases/coal-and-gas-to-stay-cheap-but-renewables-still-win-race-on-costs/?utm_source=neowebsite&utm_medium=link&utm_content=pressrelease&utm_campaign=NEO2016

Canadian Press. (2013, November). Electric Bus Pilot Project to Hit Montreal Streets in 2015. CBC News. Retrieved from http://www.cbc.ca/news/canada/montreal/electric-bus-pilot-project-to-hit-montreal-streets-in-2015-1.2436725

Condon, P. (2016, January). Don't Waste Billions on Bad Transit Projects. The Tyee. Retrieved from http://thetyee.ca/Opinion/2016/01/25/Bad-Transit-Projects/

Coulter, T. (2015, February). Japan Has More Car Chargers than Gas Stations. Bloomberg. Retrieved from http://www.bloomberg.com/news/articles/2015-02-13/japan-has-more-car-chargers-than-gas-stations-carbon-climate

Government of Canada. (2016, March). Reducing Methane Emissions from Canada's Oil and Gas Industry. Governement of Canada News. Retrieved from http://news.gc.ca/web/article-en.do?nid=1039219

Hamilton, T. (2013, January). The $36-Trillion Question. Corporate Knights. Retrieved from http://www.corporateknights.com/channels/climate-and-carbon/the-36-trillion-question-13587867/

Oron, A. (2016, March). World's Top 7 Electric Vehicle Adoption Countries for 2015. Inside EVs. Retrieved from http://insideevs.com/worlds-top-7-electric-vehicle-adoption-countries-for-2015/

Roston, E. and Echouse, B. (2016, July). How the Pentagon is Waging America's Wars Using Renewable Energy. Financial Post. Retrieved from http://business.financialpost.com/news/energy/how-the-pentagon-is-waging-americas-wars-using-renewable-energy?__lsa=0699-fa33

Peer Review Articles:

Bataille, C., Melton, N., and Jaccard, M. (2015). Policy Uncertainty and Diffusion of Carbon Capture and Storage in an Optimal Region. Climate Policy, 15(5), 565-582. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/14693062.2014.953905

Bond, T. C., *et al. (*2013*).* Bounding the Role of Black Carbon in the Climate System: A Scientific Assessment*.* J. Geophys. Res. Atmos.*,* 118*,* 5380–5552. *Retrieved from* http://onlinelibrary.wiley.com/doi/10.1002/jgrd.50171/abstract

McKinley, A. (2008). Industrial Ecology: A Review with Examples from the Canadian Mining Industry. Canadian Journal of Regional Science/Revue canadienne des sciences régionales, XXXI(1), 163-174.

Needell, Z.A, et al. (2016). Potential for Widespread Electrification of Personal Vehicle for Travel in the United States. Massachusetts Institute for Technology, Nature Energy. Retrieved from http://www.nature.com/articles/nenergy2016112

O'Connor, J., and Bowick, M. (2014). Advancing Sustainable Design with Life Cycle Assessment. SAB Magazine. Retrieved from http://www.athenasmi.org/wpcontent/uploads/2015/09/Advancing_Sustainable_Design_with_LCA.pdf

Smyth, C.E. et al. (2014). Quantifying the Biophysical Climate Change Mitigation Potential of Canada's Forest Sector. Biogeosciences, 11, 3515-3529.

Smyth, C.E. et al. (2016). Climate Change Mitigation Potential of Local Use of Harvest Residues for Bioenergy in Canada. CB Bioenergy. Retrieved from http://onlinelibrary.wiley.com/journal/10.1111/(ISSN)1757-1707/earlyview

Chapters in a Book or Report:

Intergovernmental Panel on Climate Change. (2014). Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1-32.

Myhre, G. et al. (2013). Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 659–740.

Nabuurs, G.J., et al. (2007). Forestry. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 541-584.

Databanks and Inventories:

Canada's National Forest Inventory. (2013). Resources: Statistical Summaries for Canada: Forest Area [Data file]. Retrieved from https://nfi.nfis.org/resources/general/summaries/en/pdf/CA3_T4_FOR_AREA_en.pdf

Canadian Forest Service. (2016). Satellite Forest Monitoring in Canada [Data file]. Retrieved from http://forests.foundryspatial.com

Canadian Industrial Energy End-Use Data and Analysis Centre (2015). Cogeneration Facilities in Canada 2014 [Data file]. Retrieved from http://www2.cieedac.sfu.ca/media/publications/Cogeneration_Report_2015_Final.pdf

Natural Resources Canada. (2013). Remote Communities Database [Data file]. Retrieved from http://www2.nrcan.gc.ca/eneene/sources/rcd-bce/index.cfm?fuseaction=admin.home1&new=true

Statistics Canada (2011). Households and the Environment: Energy Use (11-526-S) [Data file]. Retrieved from http://www.statcan.gc.ca/pub/11-526-s/11-526-s2013002-eng.htm

Statistics Canada (2012). 2011 Census of Agriculture [Data file]. Retrieved from http://www.statcan.gc.ca/eng/ca2011/index

Regulations, Treaties, Laws & Directives:

Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on Energy Efficiency Amending Directives 2009/125/EC and 2010/30/EU and Repealing Directives 2004/8/EC and 2006/32/EC, 2012 O.J. L 315/1. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:en:PDF

Environmental Protection Agency. (2010). NSPS OOOOa Technical Support Document. 40 CFR 60. 2010. Retrieved from https://www.regulations.gov/document?D=EPA-HQ-OAR-2010-0505-5021

UNFCCC. (2015). Adoption of the Paris Agreement. Dec. 12, 2015, UNTS, FCCC/CP/2015/L.9/Rev.1

Speeches:

Bank of England (2015). Breaking the Tragedy of the Horizon - Climate Change and Financial Stability. Bank of England Publications. Retrieved from http://www.bankofengland.co.uk/publications/Pages/speeches/2015/844.aspx

Annex 1: Detailed Modelling Results from 2050 Scenarios

This annex provides modelling results for the aggregate energy economy or total economy of Canada under the described low greenhouse gas modelling analyses (see model and scenario descriptions in Chapter 3). The tables are provided for illustrative purposes only and should not be interpreted as optimal pathways. Moreover, the sectoral aggregation may differ from one model to another.

The table below illustrates results from ECCC's modelling, where a 2050 target of 80% below 2005 levels is achieved by reductions in emissions from the energy sector, industrial processes, agriculture and waste. The reductions are influenced by a common price on greenhouse gas emissions.

As illustrated by the table, the greatest emissions reductions are projected to come from energy-related emissions (89% below the 2005 level), followed by emissions from waste (55% below the 2005 level), industrial process emission (50% below the 2005 level) and agriculture (36% below the 2005 level). As there are currently relatively few moderate cost reduction opportunities for industrial process sector, a project reduction in output drives the decline in emissions.

Table A1: Environment and Climate Change Canada - Gross Emissions (2050)

Canada's 1990–2050 GHG Emissions by Sector (Mt CO_2e)				
Greenhouse Gas Categories	1990	2005	2050	% Change Relative to 2005
TOTAL: EXCLUDING LULUCF	**613**	**748**	**149**	**-80%**
ENERGY	482	597	67	-89%
Stationary Combustion Sources	285	342	46	
Transport	148	195	38	
Fugitive Sources	49	61	6	
CO_2 Capture, Transport and Storage	-	0	-23	
INDUSTRIAL PROCESSES AND PRODUCT USE	56	58	29	-50%
Mineral Products	8	10	2	
Chemical Industry	17	10	19	
Metal Production	24	20	5	
Production and Consumption of Halocarbons, SF_6 and NF_3	1	6	1	
Non-Energy Products from Fuels and Solvent Use	5	12	2	
Other Product Manufacture and Use	0	1	0	
AGRICULTURE	49	61	39	-36%
Enteric Fermentation	23	31	20	
Manure Management	8	10	6	
Agriculture Soils	17	19	12	
Field Burning of Agricultural Residues	0	0	0	
Liming, Urea Application and Other Carbon-containing Fertilizers	1	1	0	
WASTE	26	31	14	-55%
Solid Waste Disposal	24	28	13	
Biological Treatment of Solid Waste	1	1	1	
Wastewater Treatment and Discharge	1	1	0	
Incineration and Open Burning of Waste	1	1	0	

The table below illustrates results from ECCC's modelling of a scenario in which a 2050 target of 80% below 2005 levels is achieved by a 65% reduction in the combined emissions of the energy sector, industrial processes, agriculture, and waste, plus an assumed contribution from credits due to improved land sector sequestration and internationally transferred mitigation outcomes.

As depicted in the table, the greatest reductions are projected to come from energy-related emissions (74% below the 2005 level), followed by emissions from waste (55% below the 2005 level), industrial process emission (28% below the 2005 level) and agriculture (15% below the 2005 level).

Table A2: Environment and Climate Change Canada-Net Emissions (2050)

Canada's 1990–2050 GHG Emissions by Sector (Mt CO_2e)				
Greenhouse Gas Categories	1990	2005	2050	% Change Relative to 2005
TOTAL: EXCLUDING LULUCF	**613**	**748**	**262**	**-65%**
ENERGY	482	597	155	-74%
Stationary Combustion Sources	285	342	86	
Transport	148	195	77	
Fugitive Sources	49	61	8	
CO_2 Capture, Transport and Storage	-	0	-17	
INDUSTRIAL PROCESSES AND PRODUCT USE	56	58	50	-15%
Mineral Products	8	10	4	
Chemical Industry	17	10	28	
Metal Production	24	20	12	
Production and Consumption of Halocarbons, SF_6 and NF_3	1	6	2	
Non-Energy Products from Fuels and Solvent Use	5	12	4	
Other Product Manufacture and Use	0	1	0	
AGRICULTURE	49	61	44	-28%
Enteric Fermentation	23	31	23	
Manure Management	8	10	7	
Agriculture Soils	17	19	14	
Field Burning of Agricultural Residues	0	0	0	
Liming, Urea Application and Other Carbon-containing Fertilizers	1	1	1	
WASTE	26	31	14	-55%
Solid Waste Disposal	24	28	13	
Biological Treatment of Solid Waste	1	1	1	
Wastewater Treatment and Discharge	1	1	0	
Incineration and Open Burning of Waste	1	1	0	

The table below illustrates modelling results from Trottier Energy Futures Project, where a 2050 target of 60% below the 1990 levels is achieved by reductions in emissions from the energy sector, industrial processes, agriculture and wastes. The table below illustrated the reductions when current technologies are available, with the addition of interprovincial interconnections to the electricity grid.

As illustrated by the table, the greatest reductions are projected to come from electricity emissions (99% below the 2015 level), followed by emissions from the residential sector (87% below the 2015 level), commercial emissions (76% below the 2015 level), transportation (71% below the 2015 level) and agriculture (64% below the 2005 level).

Table A3: Trottier Energy Futures Project (Current Technology Scenario)

Canada's 1990–2050 GHG Emissions by Sector (Trottier) Mt CO_2e			
Greenhouse Gas Categories	2015	2050	% Change Relative to 2015
CURRENT TECHNOLOGY SCENARIO:			
TOTAL (EXCLUDING PROCESS EMISSIONS)	488	171	-65%
TOTAL (INCLUDING PROCESS EMISSIONS)	560	282	-50%
AGRICULTURE	16	6	-64%
COMMERCIAL	36	9	-76%
INDUSTRIAL PROCESSES AND PRODUCT USE	53	35	-34%
RESIDENTIAL	43	6	-87%
TRANSPORTATION	169	49	-71%
ELECTRICITY	60	0	-99%
SUPPLY - COMBUSTION	112	66	-41%
SUPPLY – PROCESS	71	112	56%

The table below is also from the Trottier Energy Futures Project. It illustrates the reductions when other new technologies are available to reduce GHG emission reduction costs. The contribution of new technologies increases the reduction from agriculture, commercial, residential and supply-combustion.

As illustrated by the table, the greatest reductions are projected to come from electricity emissions (99% below the 2015 level), followed by emissions from the residential sector (89% below the 2015 level), commercial emissions (88% below the 2015 level), agriculture (66% below the 2015 level) and supply process emissions (56% below the 2005 level).

Table A4: Trottier Energy Futures Project (New Technology Scenario)

Canada's 1990–2050 GHG Emissions by Sector (Trottier) Mt CO_2e			
Greenhouse Gas Categories	2015	2050	% Change Relative to 2015
NEW TECHNOLOGY SCENARIO:			
TOTAL (EXCLUDING PROCESS EMISSIONS)	488	171	-65%
TOTAL (INCLUDING PROCESS EMISSIONS)	560	282	-50%
AGRICULTURE	16	5	-66%
COMMERCIAL	36	4	-88%
INDUSTRIAL PROCESSES AND PRODUCT USE	51	35	-32%
RESIDENTIAL	43	5	-89%
TRANSPORTATION	166	76	-54%
ELECTRICITY	64	0	-99%
SUPPLY - COMBUSTION	113	45	-60%
SUPPLY - PROCESS	71	112	56%

The table below illustrates modelling results from DDPP Study, where a 2050 target of 88% below the 2015 levels is achieved by reductions in emissions from all sectors of the economy except for agriculture, which was not included as part of this modelling work.

As illustrated by the table, the greatest reductions are projected to come from residential and commercial buildings emissions (99% below the 2015 level), followed by emissions from the personal transportation sector (97% below the 2015 level), freight transportation emissions (95% below the 2015 level), industrial minerals (93% below the 2015 level) and chemical products (75% below the 2005 level).

Table A5: Deep Decarbonization Pathways Project

Canada's 1990–2050 GHG Emissions by Sector (DDPP) Mt CO_2e			
Greenhouse Gas Categories	2015	2050	% Change Relative to 2015
TOTAL	**651**	**78**	**-88%**
Residential Buildings	37	0	-99%
Commercial Buildings	38	1	-99%
Transportation Personal	88	3	-97%
Transportation Freight	112	5	-95%
Chemical Products	13	3	-75%
Industrial Minerals (Cement & Lime)	16	1	-93%
Iron and Steel	12	4	-66%
Metal Smelting	11	3	-73%
Mineral Mining	5	3	-52%
Paper Manufacturing	6	1	-84%
Other Manufacturing	21	5	-77%
Waste	8	5	-44%
Electricity	86	6	-93%
Petroleum Refining	21	1	-96%
Petroleum Crude Extraction	134	19	-86%
Natural Gas Extraction	37	14	-62%
Coal Mining	2	2	-27%
Ethanol Production	2	0	-85%
Biodiesel Production	0	3	677%