SPECIAL REPORT

Zeroing in on Emissions

Canada's clean power pathways – A review

Clean Power PATHWAYS

DAVID SUZUKI FOUNDATION

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By: Tom L. Green, PhD, David Suzuki Foundation

CONTRIBUTORS

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This is the first in a series of reports from **Clean Power Pathways: Fast-tracking Canada's energy transition.**

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Foreword

Clean Power Pathways: Fast-Tracking Canada's Energy Transition is Canada's first nationally focused research project on integrated renewable energy and clean electricity. This report, **Zeroing in on Emissions: Charting Clean Canada's Clean Power Pathways**, lays the foundation with an extensive review of decarbonization research and models.

Human-caused climate change is reaching a tipping point. Canada is warming at twice the global average rate emphasizing the urgent need to examine the many opportunities to meet our emissions targets and commitments under the Paris Agreement. The research and engagement that form this study will contribute to the work needed to steer us to that path.

Accelerating clean power and electrifying as much as possible are central to Canada's efforts to become carbon-neutral by mid-century. Clean energy can be produced with zero operational emissions, close to where it is needed. It can provide a wide array of services, quietly, cleanly and efficiently.

Clean Power Pathways is a multi-year collaboration between university researchers and the Foundation that is working to build broad and enduring support for a suite of actions that will transition Canada's energy system at a scope, scale and speed commensurate with the scientific consensus on climate breakdown.

The work builds on a foundation of government, academic, non-profit and business research to identify the most effective mix of priorities and approaches to meet Canada's climate and energy objectives. This is the next chapter in work that started with the Trottier Energy Futures Project, a research and modelling effort to determine how Canada can substantially reduce its greenhouse gas emissions, sponsored by the Canadian Academy of Engineering and the David Suzuki Foundation, with support from the Trottier Family Foundation. The Foundation's partnership with university researchers for Clean Power Pathways will expand on the Trottier Project's innovative and collaborative approach.

Addressing the challenges posed by climate change can seem overwhelming, but studies illuminate the many opportunities and solutions available to meet our targets. By tapping into the best research and brightest policy minds, we can act on our shared concerns about the urgent need to address climate change, and steer Canada to a brighter, cleaner path for generations to come. Our future will not be determined by chance, but by the choices we make today. I hope you'll join us in fast-tracking Canada's Clean Power Pathways.

Ian Bruce
Director of Science and Policy, David Suzuki Foundation

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Executive summary

Zeroing in on Emissions: Charting Canada's Clean Power Pathways is the first stop in a three-year initiative we're calling Clean Power Pathways: Fast-tracking Canada's energy transition. The report lays the foundation through an extensive review of global and Canadian decarbonization models and studies. It highlights 10 technically feasible strategies, actions and considerations that a wide range of experts agree will be front and centre in any credible effort to zero out Canada's emissions by the middle of this century, as science on climate change says is required. Together, these strategies are a litmus test for credible climate plans.

Here, we summarize the 10 recommended actions we outline on the pages that follow.

1. ACCELERATE CLEAN POWER

Much of Canada's power is already non-emitting, and there's a strong consensus among researchers that it's possible to accelerate this trend and meet our climate goals. Canada will not decarbonize its energy system, however, unless provinces and utilities aggressively dial down the greenhouse gas emissions associated with electricity generation until they reach zero. Diverse opportunities such as homeowner-generated clean power are appearing. Further, if we are to reach our climate goals, we'll need to clean up our grids and generate a great deal more clean power than we do today.

2. DO MORE WITH LESS ENERGY

Of all potential energy investments, efficiency offers the best return. Every sector of Canada's economy can pursue energy-efficiency measures and reap multiple rewards. Governments generally do so by regulating the energy performance of new buildings, appliances, vehicles and industrial equipment, and by incentivizing retrofits of existing assets. Companies also pursue their own internal targets. At present, Canada wastes a great deal of energy, which points to a large untapped opportunity.

3. ELECTRIFY JUST ABOUT EVERYTHING

Electricity is Canada's cleanest energy source for many provinces, but as of 2016 it only powered about 20 per cent of our energy needs. Studies suggest that by mid-century clean electricity will make up half or more of our energy mix. As grids get cleaner, clean electricity will power a growing share of our economy. It can heat our buildings and power our cars, trucks and buses. Even steel mills and oilsands operations can electrify. Multiple research projects have concluded that electrifying as much as possible will be a pillar of Canada's decarbonization effort.

4. FREE INDUSTRY FROM EMISSIONS

Canada will still need cement, iron, steel, aluminum and chemicals in 2050. And while companies collectively emit a great deal of carbon to produce those commodities, recent research suggests that need not always be the case. Industry can decarbonize its processes while minimizing risk of stranded assets, and while maintaining competitiveness and healthy employment. Solutions will involve a mix of electrification, carbon capture and evolving technologies.

5. SWITCH TO RENEWABLE FUELS

Although batteries and electricity can do a lot of heavy lifting, they are not ideally suited for all of Canada's energy services. The aviation, marine and other heavy transportation sectors, for example, will likely require some combination of biofuels, renewable gas and hydrogen. Reducing renewable electricity costs and expanding supply could make Canada a leader in hydrogen and other zero-carbon fuel production. Identifying, growing and responsibly harvesting the resources needed to produce biofuels challenges us to consider carefully land-base management and species selection. We must also take care to avoid negatively affecting ecosystems and the land we need to grow food.

6. MOBILIZE MONEY

The energy transition will require directing investment flows away from carbon-intensive sectors of the economy toward clean-economy sectors. Much of this investment will shift to the electricity sector where decarbonization will require significant investment. Recent research suggests that the costs associated with decarbonization will be more modest than widely assumed – and confirms that the costs of inaction will be far higher.

7. LEVEL THE PLAYING FIELD

To redirect investment throughout the Canadian economy, government needs to send the right price and policy signals. All credible assessments indicate that Canada will need steadily escalating carbon pricing to drive innovation and clean technology adoption on the path to successfully decarbonize by 2050. The policy works to steadily “level the playing field” between polluting energy and cleaner energy. It incentivizes efficiency and fuel switching, and drives innovation and investment in the clean energy economy. Other federal, provincial and municipal policies and price signals can help clean the air in congested cities, and improve transit and the energy efficiency of buildings.

8. REIMAGINE OUR COMMUNITIES

Canada’s cities, towns and villages will play a central role in any credible decarbonization effort. Abundant evidence indicates that complete, compact, livable communities are less carbon-intensive than their low-density counterparts. Well-designed communities unlock affordable public transit and active transportation while enhancing quality of life and health. Local governments can access myriad policy tools to lower emissions, such as provincial and municipal building codes and incentives to drive clustered, transit-oriented development. Research suggests that smart city design could reduce Canada’s emissions by 15 per cent or more.

9. FOCUS ON WHAT REALLY MATTERS

Soaring economic growth offers benefits but also carries real costs that are all too easily brushed aside. The necessary high-energy inputs of increasing growth take a toll on people and ecosystems. Canadians can choose to revisit the fundamental metrics that we use to define prosperity, such as GDP, and instead embrace those that measure well-being. In doing so, they will lessen the engineering challenges required to zero out carbon emissions. When we shift our thinking toward outcomes like healthier urban living, more creative solutions like active transportation infrastructure and transit hubs start to arise.

10. BRING EVERYONE ALONG

As Canada zeroes out its emissions, changes in the economy are inevitable. They must be carefully managed. Some sectors and communities will face job losses, while clean tech will be hiring. To ensure the transition does not result in hardships, governments must proactively support vulnerable workers and communities. The clean energy transition can be a driver to create more good jobs, invest in upgrading existing jobs and reduce inequality.

While broad agreement exists among both models and experts that these 10 strategies and actions will be important ingredients to thoughtfully fast-track decarbonization, Canada has yet to land on a consensus on the best ways to move forward.

Canada’s efforts are more likely to succeed if there is a broadly shared vision of the low-carbon, clean future and its myriad health and quality-of-life benefits. We offer this report to shine light on the building blocks of a zero carbon future and the choices that will put the country on that path.

> Perhaps the most dangerous misconception about the climate crisis is that we have to lower our emissions. Because that is far from enough. Our emissions have to stop if we are to stay below 1.5/2C warming.

- Greta Thunberg

Photo by Green Energy Futures

Introduction: the challenges and opportunities of getting to zero

Cutting Canada's greenhouse gas[1] emissions to zero by mid-century will be a challenge. But it is a challenge that can be met.

In this report, we outline 10 key strategies for reducing Canadian GHG emissions to zero or near zero by mid-century. These include cleaning up the electricity sector, electrifying sectors like transportation and industry and using energy wisely. The strategies outlined in this report are focused on Canada but are relevant to countries and regions around the world working to get to zero.

This report is motivated by a desire to see effective action on climate change and to improve the information being used in public policy decisions that shape the economy and its emissions. Climate change endangers the planet's life-support systems and threatens to undermine human quality of life and to harm the economy.[2] A recent assessment of the impact of human-caused climate change and GHG emissions on Canada offered a sobering assessment of the changes that can be anticipated under different degrees of warming.[3] Already, Canada faces double the warming of the world average, with Northern Canada's warming even more pronounced. More weather extremes can be expected, entailing more floods, droughts and forest fires; more precipitation will fall as rain, less as snow. The oceans around Canada's shores have warmed, are more acidic and have lowered oxygen levels, putting stress on marine ecosystem health.

Economies can and must be decarbonized to avoid extreme weather, food security risks and other harms. Decarbonizing can also spur innovation and create economic benefits, as companies develop new technologies in energy, transportation, industry and other sectors. Reducing reliance on fossil fuels also results in less damage to air, water and land from extractive processes. A zero-emissions economy can improve health outcomes and quality of life as air pollution levels decline. Decarbonizing the Canadian economy will be a challenge, requiring society-wide efforts, but it also offers hope for a better future. And it's absolutely necessary to keeping our Paris Agreement commitment to "holding the increase in the global average temperature to well below 2.0C above pre-industrial levels and pursuing efforts to limit the temperature to 1.5C above pre-industrial levels."[4]

Photo by Green Energy Futures

Economies can and must be decarbonized to avoid extreme weather, food security risks and other harms. Decarbonizing can also spur innovation and create economic benefits, as companies develop new technologies in energy, transportation, industry and other sectors.

Global greenhouse gas emissions, specifically CO_2, associated with fossil fuel combustion have been rising steadily since the early 1800s, but at an especially fast rate since 2000. The global average temperature has already risen almost 1C due to human emissions since the pre-industrial era, and temperature rise in Canada has been double the global average and especially pronounced in the North.[5] Global temperatures are now increasing 0.2C per decade. If not moderated soon, trends in global CO_2 emissions imply global temperature increases of 4C or more by 2100, with high risks to human well-being, according to the International Panel on Climate Change, which gathers and synthesizes high-quality, peer-reviewed scientific evidence on climate change science and economics.

To avoid more than 2C of temperature rise, the IPPC reports that CO_2 emissions must decline 25 per cent from 2010 levels by 2030, and reach zero by 2070. The IPPC has recently outlined that there is considerably more risk to health, livelihoods, security and economic prosperity with 2C versus 1.5C. To avoid more than 1.5C of temperature rise, the IPPC reports that CO_2 emissions must decline 45 per cent from 2010 levels by 2030, and reach zero by 2050.[6] Canada's emissions peaked in the mid-2000s at around 750 Mt, and have since decreased by five per cent, reaching 708 Mt in 2016. Canadian per capita emissions, at 22 tonnes per year, are among the world's highest.

Photo by Green Energy Futures

TEMPERATURE RISE LIMIT	2030 GLOBAL EMISSIONS	TIME FRAME FOR MEETING ZERO EMISSIONS
1.5C	45% LOWER THAN 2010 LEVELS	BY 2050
2C	25% LOWER THAN 2010 LEVELS	BY 2070

A further issue is that it is not merely the level of emissions that matter but the accumulated stock of GHGs in the atmosphere. To bring the concentration of GHGs in the atmosphere back down to a level that would avoid overshooting 1.5C or even 2C, the IPPC projects that wide-scale deployment of carbon dioxide removal measures will be necessary. Yet there are many risks and unknowns related to carbon dioxide removal.[7] While acknowledging this challenge, we do not address carbon dioxide removal in this report, retaining our focus on the urgent matter of how emissions can be reduced to zero by 2050.

In this report we examine models and studies that explore deep decarbonization for Canada, which we define as greenhouse gas emissions reductions of 80 per cent or more by 2050. The objective is to understand what the zero carbon future of 2050 will look like, and what we need to do to get there. The studies and models we considered are listed in the references. Prominent among them are the Deep Decarbonization Pathways Project (DDPP), the Trottier Energy Futures Project (TEFP) and the Perspectives Énergétiques Canadiennes (PEC). We focus especially on these reports since they provide an economy-wide evaluation of how Canada can achieve deep decarbonization by 2050. Despite major methodological differences between studies on the potential for deep decarbonization (and not accounting for some significant technological advancements for clean energy since the modelling was undertaken), they each support the conclusion that emissions reductions of up to 70 per cent (or more), in Canada by 2050 are possible.

Our report shows that the task ahead is both challenging and full of promise.

Photo by Green Energy Futures

What we did

The focus of this report is on decarbonizing Canadian society by 2050. To examine this question, we:

- surveyed the range of decarbonization models, studies and road maps that were relevant to understanding how to decarbonize Canada by 2050.
- considered the peer-reviewed literature on decarbonization, and equivalent studies for other countries and for the world as a whole.
- examined future projections of energy use and the deployment of renewables and clean technologies by IEA, IRENA, Shell and the IPPC.
- Synthesized our findings in a list of 10 key strategies for "Getting to Zero" and achieving deep GHG emission reductions in Canada.

Of note, our analysis focused on the energy system and does not address emissions from agriculture, waste, land-use change and forestry.[8] Meeting Canada's climate commitments will require that these emissions also be addressed and that ecosystems throughout Canada are managed in a way that maintains or enhances carbon stocks in soil and vegetation. However, these important matters are beyond the ambition of this report. Furthermore, while we recognize that economic and political interests have influenced past energy and climate policies, we do not delve into the politics of climate action in Canada or the relative feasibility of enacting various measures. Nor do we address the need to tackle the GHG emissions embodied in imported goods, even though these can be significant due to carbon-intensive production in many countries.[9]

Table A1 in the appendix provides a summary view of the decarbonization studies or models we considered.

Below we describe 10 strategies for getting to zero emissions in Canada. We are confident in these strategies because there is a convergence in modelling studies and in the decarbonization literature that they are essential to bringing emissions down to zero.

Following the presentation of these strategies we discuss the implications of these findings and share our recommendations for getting to zero emissions in Canada.

Photo by Thomas Kolnowski

BOX 1 WHY USE MODELS TO UNDERSTAND THE ENERGY TRANSITION?

Modelling offers many advantages for identifying the most cost-effective path to the zero-emissions economy of the future. Many of the policies that governments might make or the actions that municipalities, businesses or homeowners could take in reducing emissions entail a considerable commitment of time and resources. But not all of these actions are equally effective. Modelling allows us to explore the effectiveness of different policies before municipalities, businesses or households actually make any changes or invest in new technologies. By working from where we want to end up – a zero-emissions economy in 2050 – we can explore what policies can get us there, and how quickly they need to be implemented, and what investments will be required.

Models have their limits and each model has its strengths and limitations. In analyzing different low-carbon scenarios, modellers acknowledge that it is difficult to anticipate future technological innovations. The verdict is still out on which energy storage technologies will prevail in 2050, how big a role fuel-cell vehicles will play in Canadian long-haul transport, or how air travel emissions will be mitigated. As trillions are invested in clean technologies around the globe, new technologies will emerge. This technological evolution and its cost implications are difficult to anticipate and represent in models. There is also considerable uncertainty about how urban form will evolve as autonomous vehicles become more common. Models are also limited in representing how values, priorities and lifestyles evolve over time; for instance, how work will shift due to automation and how this will affect energy used in commuting to and from work. So the outputs of models, while indicative of possible futures, need to be interpreted with care. They are not intended to predict the future, especially since the future will be influenced by the policy and investment decisions we make in the coming years. By synthesizing across models, common findings can be identified, strengthening our confidence in their validity.

Photo: National Renewable Energy Lab via Flickr.

This report, like the models it draws upon, is not intended to predict or dictate which particular low-carbon technologies are deployed. Rather, modelling can form the foundation of a detailed and credible renewable energy blueprint to achieve Canada's Paris Agreement commitments and to support the Pan-Canadian Framework on Clean Growth and Climate Change. It allows us to explore "what if" questions and to compare different configurations of a clean energy system – say comparing two scenarios, one with greater dependence on wind and more focus on energy efficiency, while another scenario builds out more solar and bioenergy. Modelling can also support municipal governments as they work to achieve renewable energy goals.


Photo by Green Energy Futures

10 Strategies for deep greenhouse gas emissions reductions

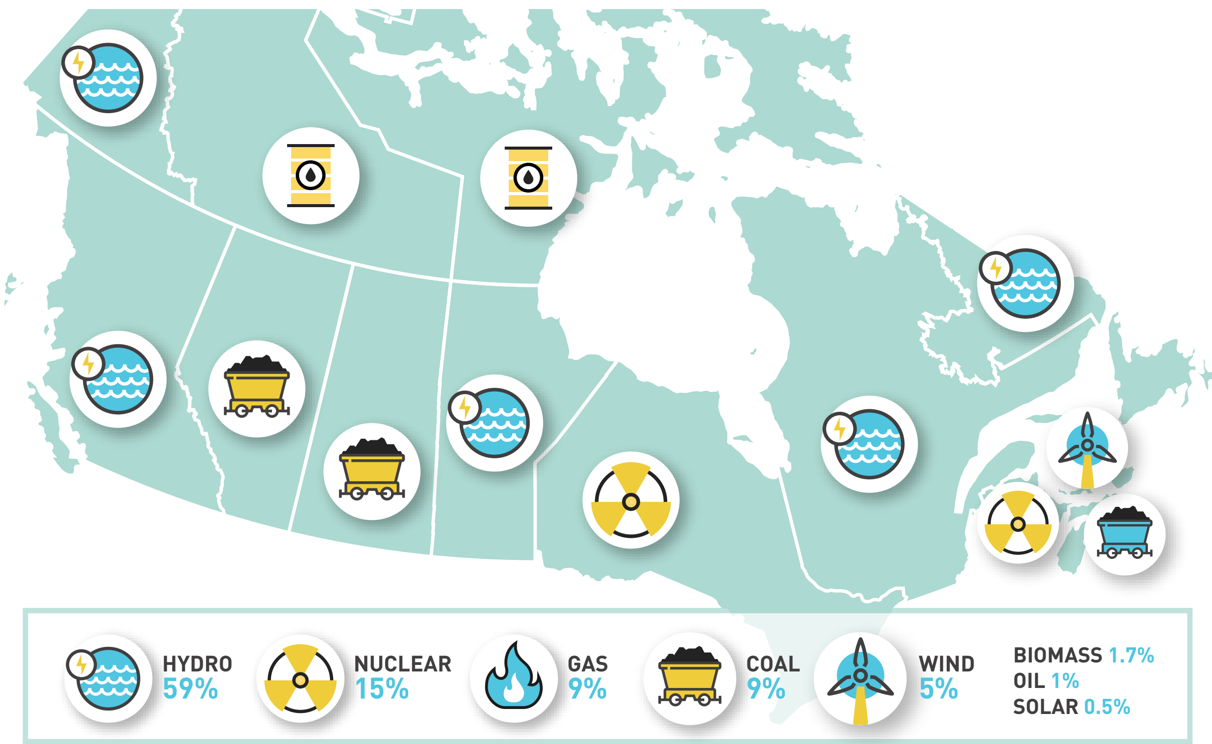
1

Accelerate clean power

"Canada is in the fortunate position of being able to move relatively quickly to decarbonize its electricity supply." – TEFP, p. 280

Canada has made a lot of progress in reducing emissions from its electricity sector over the past two decades, making it among the cleanest in the world. Nearly 60 per cent of Canadian electricity is generated at hydroelectric power plants, while wind energy provides close to five per cent and is growing in importance. Provinces like British Columbia, Manitoba, Quebec and Newfoundland use their hydroelectric plants to supply low-emissions electricity to homes and businesses.[10] Ontario and New Brunswick also rely on nuclear power.[11]

Leading source of electricity generation in each province or territory



Further work remains to achieve a zero-emissions electricity future in Canada. Alberta, Saskatchewan, New Brunswick and Nova Scotia still rely on coal to generate electricity. Together, Alberta, Saskatchewan and Ontario account for almost 90 per cent of natural gas–generated electricity in Canada, and new natural gas plants continue to be built. Even with the climate policies proposed or in place, including federal regulations requiring coal plants to retire or be equipped with carbon capture

Photo by Patricia Lightburn

and storage units by 2030, Canada must prioritize clean electricity with additional policies to be on track to meet its commitment to 90 per cent non-emitting power generation by 2030. [12]

Getting electricity sector greenhouse gas emissions down to zero will be critical to achieving deep decarbonization in Canada. There are competing pathways for how Canada could clean up the electricity sector.

- The **Trottier Energy Futures Project** report presents electricity futures scenarios involving a large expansion of hydroelectric and nuclear power plants.
- The **Deep Decarbonization Pathways Project** lays out a future where renewable energy sources like wind and solar would play a greater role in electricity generation. The DDPP model assumed that carbon capture and storage technologies would be commercially and technically viable. CCS technologies capture the carbon dioxide emissions released by natural gas power generation and store the emissions underground. The DDPP electricity future includes significant deployment of CCS in Alberta.
- The **Sustainable Canada Dialogues** report Acting on Climate Change suggested that tapping the country's abundant renewable energy resources could help Canada achieve 100 per cent reliance on low-carbon electricity by 2035.
- The **Perspectives Énergétiques Canadiennes'** 80 per cent emissions reduction scenario shows strong growth in renewable energy and biofuel production and a slow decline in fossil fuel production. Efficiency gains enabled by widespread electrification result in slow growth of overall energy production despite economic and population growth. By 2050, wind generates more electricity than hydro and solar more than nuclear.

A lively debate is occurring as to whether renewables, including wind, solar and small hydro projects, will be able to replace existing fossil fuel and nuclear plants, or whether large-scale nuclear, hydroelectric and plants using fossil fuel equipped with CCS will be required to bring electricity sector GHG emissions down to zero (see Box 2).

BOX 2 IS AN ENERGY SYSTEM POWERED 100 PER CENT BY WIND, WATER AND SUN POSSIBLE?

Stanford Prof. Mark Jacobson and his collaborators have written several studies outlining pathways to a 100 per cent renewable energy future.[13] They envision broad-scale electrification of heat, transport and industry, large gains in energy efficiency, and an energy mix comprising onshore and offshore wind, solar photovoltaic and solar thermal, geothermal, tidal and hydroelectric energy. In these scenarios, fossil fuels and nuclear power plants are no longer required. Adding support to a renewable future, in 2012 the National Renewable Energy Laboratory demonstrated the technical feasibility of renewable energy meeting 80 per cent of electricity needs in the United States by 2050.[14]

Criticism of 100 per cent renewable scenarios has focused on the ability of variable renewable energy sources to reliably meet demand, the cost of 100 per cent renewable scenarios relative to scenarios involving nuclear power and carbon capture and storage, the feasibility of constructing sufficient energy storage to ensure reliable energy supply, the feasibility of transitioning to a hydrogen-based liquid fuel system, the lack of spatial detail in models used to create the scenarios, and the feasibility of the assumed rapid energy efficiency gains.[15] Questions remain as to whether and at what cost a 100 per cent renewable scenario can supply Canada's electricity where demand has grown substantially by 2050 as a result of electrification across the economy.

Photo by Patricia Lightburn

In a Canadian context, the TEFP and DDPP scenarios assume a broader electricity mix than renewables alone. The TEFP report showed that deep emissions reductions could be achieved at a similar cost with or without nuclear power. Studies by General Electric[16] and Dolter & Rivers[17] show the potential for wind energy to provide 30 to 35 per cent of Canada's electricity supply in the medium term. New interprovincial transmission lines can allow hydro reservoirs to act as batteries and help balance the supply of variable wind energy.[18] The value of new interprovincial transmission lines is explored in Natural Resources Canada's Regional Electricity Cooperation and Strategic Infrastructure Initiative (RECSI) studies[19] and modelling work that looked at expanding interconnections between Hydro-Quebec and the northeastern United States.[20] **However, it should be noted that no studies have fully explored the cost-effective potential of renewable energy generation by considering all available energy storage technologies and transmission options.**

A further concern that has been raised regarding the viability of increased reliance on renewables is the extent to which the energetic investments required to manufacture solar, wind or other renewable generating capacity will pay itself off through the electricity generated.[21] Energy Return on Energy Invested (EROI) is an indicator used to measure the net energy payoff. It is calculated by dividing the energy produced by an energy source by the energy required to extract, construct and operate the energy source. An EROI of 1:1 or below implies the investment is energetically futile; it generates the same amount of energy used to create the energy and so no surplus energy is generated for use. Conventional oil historically had a relatively high EROI of around 30:1, although this has declined as better oilfields were depleted. Especially in the early days of solar and wind, it was feared that a low EROI could make the shift to renewables a futile project and leave society with unmet energy needs. However, as production of renewable capacity has grown, technological improvements have allowed per unit environmental impacts and required energetic investments to decline.[22] Recent research suggests that wind projects can achieve an EROI of 30:1 or more,[23] while even in Switzerland, with moderate insolation, the EROI of solar energy is 9:1.[24] Even this score compares favourably with Canada's oilsands, which has an EROI of 5:1 or below.[25] A further complication is that in most end uses, fossil fuels result in high energy conversion loss (e.g., poor conversion of the energy in gasoline to move the vehicle), whereas electricity offers high end-use efficiency (e.g., high conversion of energy stored in battery to vehicle's motion). An analysis for electricity generation in the U.K. found that biomass offered an EROI of 3.1:1, oil 4.8:1, while solar ranged from 10:1 to 25:1 and wind was 50:1, implying that a transition away from fossil fuels toward renewable energy is possible.[26] As solar and wind technologies continue to advance with increased deployment, further improvements in the EROI may prove possible. However, countering this trend, as the sites with the best wind and solar resources are used up, further capacity additions will eventually have to use sites with lower-quality wind or solar resources. Given limited carbon budgets, it is essential that some of the budgets be set aside to account for the emissions entailed in manufacturing renewable generating capacity in economies that have yet to be decarbonized.[27]

Some studies see an expanded role for distributed renewable energy wherein homes and businesses install rooftop solar photovoltaics and energy storage systems and adopt next-generation technologies like smart appliances. This could transform the electricity sector as many households and businesses seek to generate more of their own electricity and reduce their reliance on utilities.

Although studies are less certain on whether Canada will use more, or less, energy in a near-zero carbon future, all studies converge on the fact that much more clean electricity will be needed (see also Strategy 3).[28] For example, DDPP projects the low-carbon economy will require 2.5 times more electricity production by 2050, while TEFP estimates three times more electricity will be needed. This new electricity supply needs to be low cost to ensure the financial viability of using electricity and hydrogen to decarbonize industry.[29]

BOX 2B FUTURE MODELLING OF RENEWABLE INTEGRATION FOR CANADA'S ELECTRICITY GRID

Canada has abundant renewable energy resources and large hydro reservoirs with high potential to store energy and dispatch it when needed. We have a track record of ingenuity in the energy sector. Even with these advantages, a number of important questions remain that will affect the role that renewables can play in advancing electrification, addressing the nation's energy needs and meeting Canada's climate targets:

- Where and when is electricity generation capacity needed?
- What zero-emissions energy source should be built?
- How can the existing system be optimized to accelerate the transition?
- What future investments are needed in storage and transmission?
- What role might generation with CCS play?
- What pre-commercial technologies offer the most promise?
- Can energy efficiency and new business models that offer innovative approaches to fulfilling the need for energy services make a sizeable dent in our appetite for energy?
- What are the potential energy savings created by using smart growth principles to plan our communities?
- How will the energy needed for commuting evolve as autonomous vehicles become more common and work life adjusts to increased automation?
- How might the set of technologically and economically optimal solutions be constrained by social and environmental values?


Photo by Patricia Lightburn

Further effort to advance modelling of Canadian energy systems, from the municipal to the national level, would help advance Canada's path to a zero-emission future and support the optimization of investments in infrastructure.

2 Do more with less energy

"The first option should always be to reduce energy use, especially use of fossil fuels."
– TEFP, p. 280

In its Mid-Century Strategy, the Government of Canada calls energy efficiency "the first fuel."[30] The DDPP project lists energy efficiency as one of the three pillars of decarbonization. Energy efficiency means providing the same energy services with less energy. It is a strategy that can be pursued in every sector of Canada's economy with measurable savings. Investments in the energy-efficiency measures identified in the Pan-Canadian Framework would result in Canadian consumers saving an estimated $1.4 billion (translating into $144 per year for the average household) while businesses, industry and institutions would save $3.2 billion each year.[31]

Globally, the economy has been getting more energy efficient at a rate of 1.8 per cent per year, but this is far from sufficient to meet climate targets[32] and these gains are more than cancelled out by a global GDP growth rate that has averaged 2.9 per cent from 2000 to 2017.[33] The International Energy Agency has called for efforts to increase that rate of improvement to 2.6 per cent a year in order to meet the Paris 2030 targets.[34] The IPCC's special report on 1.5 C indicated that annual investments in low-carbon technologies and energy efficiency should be increased by a factor of six relative to levels in 2015.[35]

In Canada there are opportunities to improve the energy efficiency of new buildings through passive solar design, greater levels of insulation, heat pumps and smart thermostats.[36] The Passivhaus standard – developed in Germany based on of pioneering research in Saskatchewan in the 1970s – reduces energy demand by up to 90 per cent compared to conventional construction techniques. Net zero building designs incorporating solar PV panels can create homes and buildings that generate more energy than they use. Deep energy retrofits of the existing building stock are also required to address their generally poor energy

> "Energy efficiency could provide more than 40% of the abatement required by 2040 to be in line with the Paris Agreement."
> - International Energy Agency

Energy-efficient buildings are much more comfortable for occupants since drafts are eliminated, air quality is improved and street noise is reduced.

Photo by Green Energy Futures

performance. Permits issued for major renovations could specify energy efficiency requirements that support deep emissions reductions.[37]

Energy-efficient buildings are much more comfortable for occupants since drafts are eliminated, air quality is improved and street noise is reduced. Investments in energy efficiency typically save governments, businesses and households money by reducing energy costs, in many cases with payback times of under five years.[38]

The energy intensity of the economy is a measure that indicates how much energy is necessary to produce a given amount of GDP (i.e., primary energy use per dollar of gross domestic product). An economy with a low energy intensity is more efficient at converting energy into GDP. From 1995 to 2010, the energy intensity of the Canadian economy improved by 23 per cent.[39] Almost half of this improvement came from structural shifts in the economy toward activities with high added value but low carbon emissions, such as a shift away from heavy industry toward the financial sector or health care. Only about a fifth of this improvement was due to actual energy efficiency improvements within a sector.

Sixteen cross-country studies of deep decarbonization pathways find on average that "the energy intensity of the economy falls by 65% from 2010 to 2050" in scenarios that achieve deep decarbonization.[40] This concurs with a more recent assessment that the energy intensity of the global economy must fall by 75 per cent from 2015 to 2050 in a 1.5 C scenario.[41] These results demonstrate the important role energy efficiency can play in reducing an economy's energy intensity, thereby lowering the amount of clean energy needed to meet our decarbonization goals.

Increased use of materials also drives energy use. From 1900 to 2015, human extraction of materials grew by a factor of 12, and without course correction, is projected to grow 2.5 times again by 2050.[42] Extraction and processing of raw materials and manufacturing of goods and infrastructure requires energy and entails emission of wastes.[43] It is estimated that eight per cent of global energy use is related to primary production of metals.[44] Energy requirements to extract these metals are projected to rise as higher quality ore bodies are depleted.[45] Increasingly, shifting from our linear, "throwaway" economy to a circular economy is recognized as a strategy to reduce the energetic requirements to power the economy and to achieve the rapid reductions in emissions prescribed by the IPCC.[46] A circular economy approach entails minimizing the need for resource inputs and waste outputs by reducing the emphasis on consumption, and designing for durability, repair, reuse and recycling. When Canadian governments, firms and institutions improve material efficiency they support efficient energy use.[47]

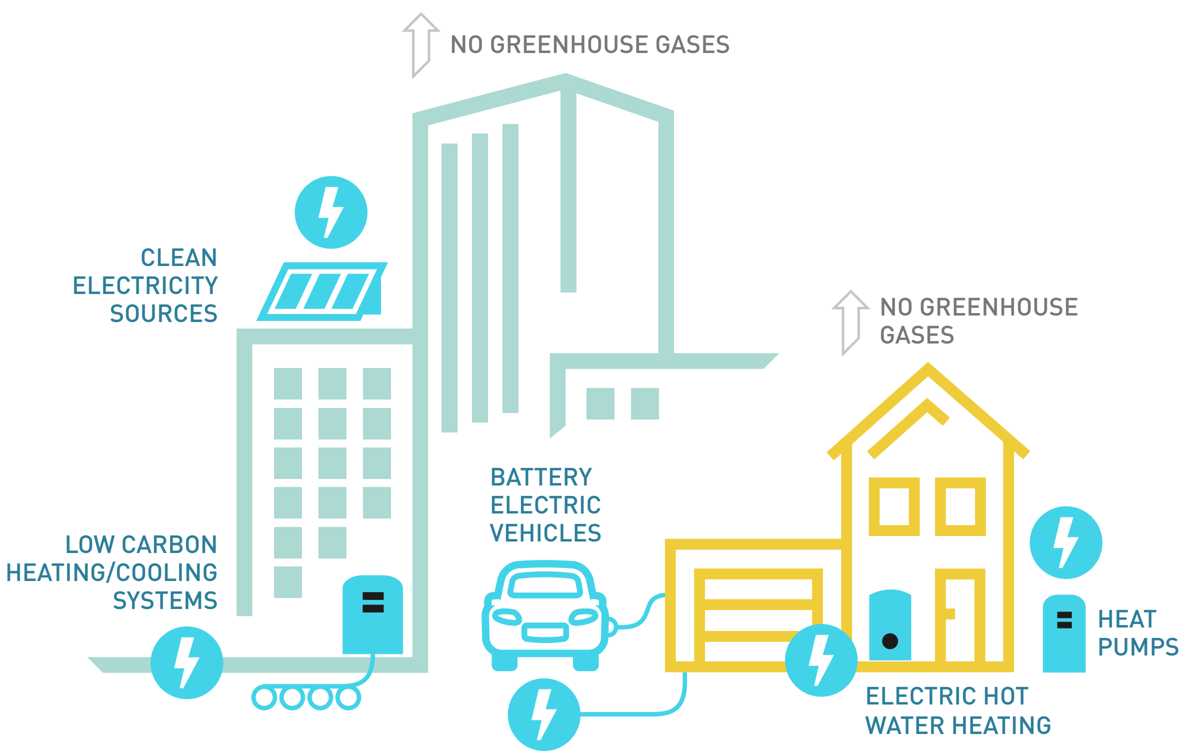
Photo by Green Energy Futures

3 Electrify just about everything

"Fuel switching to decarbonized electricity is the single most significant pathway toward achieving deep emissions reduction globally." – DDPP, p. 24

Electricity is our cleanest source of energy, but as of 2016 it only supplied 20 per cent of Canada's energy needs.[48]

As the electricity supply is cleaned up and decarbonized, we can power more of the economy with clean electricity. In the buildings sector we can move from natural gas furnaces and boilers to electric heat pumps. In the transportation sector we can switch from combustion engines to electric vehicles. To supply heat and steam for industrial processes, industry can switch from natural gas cogeneration to electric boilers and heat pumps. The steel industry can adopt electric arc steel production methods. Oilsands emissions can be reduced by using electricity to produce oxygen for direct contact steam extraction. The Canadian Energy Research Institute finds that electrification in the residential and commercial sectors[49] (excluding industrial) and passenger road transportation can reduce GHG emissions 13 per cent below 2005 levels in Atlantic Canada by 2050 and 35 per cent below 2005 levels in Quebec by 2050.[50]



The pathways presented in the TEFP and the DDPP reports assume significant electrification. Scenarios in the TEFP see electricity's share of total energy supply increasing from its current 22 per cent to 53 to 55 per cent in 2050. In the DDPP scenarios, electricity reaches 43 per cent of total energy share by 2050. The DDPP scenarios assume that by the 2030s, fossil fuels are excluded as a heat source for new buildings, and most heating requirements in these highly efficient buildings will be met using electric heat pumps or resistance heaters, with a limited role for solar hot-water heaters and district energy. Industrial electric boilers achieve a market share of 40 per cent in 2050, which is a major increase from their current share of seven per cent. The DDPP scenarios also assume that nearly 100 per cent of light-duty passenger vehicles can be electric by 2050.

Electrification would also contribute to doing more with less energy (see Strategy 2). The best available internal combustion engine cars today are approximately 38 per cent efficient at turning energy into motion, with most of the energy lost as engine heat. While advanced engine technologies can help reduce this energy loss, the laws of thermodynamic impose an upper limit on the energy efficiency of combustion engines, limiting the margin for future improvements in the efficiency of gasoline- and diesel-powered cars.[51] Electric motors are 85 to 98 per cent efficient at turning energy into motion, allowing battery electric vehicles to turn 65 to 70 per cent of the energy in the battery into motion when accounting for other onboard energy use.[52] This efficiency means that a move to electric vehicles could reduce the energy required per passenger kilometre by 70 per cent by 2050 (DDPP, p. 30). Such efficiency gains due to electrification extend to many applications beyond vehicles, including electric motors and heat pumps in industry.

BOX 3 HOW TO INTEGRATE MORE RENEWABLES

Fossil fuels have come to dominate the economy in large part because they offer a concentrated form of energy that can be transported, stored and used with a high degree of flexibility. Those who are skeptical of renewable energy sometimes point out that the sun doesn't always shine and the wind doesn't always blow, but hospitals, homes and factories require a reliable electricity supply. As fossil fuels are phased out in favour of renewables, the challenge of energy storage must be addressed.

By investing in a combination of energy storage, demand response, smart grids and expansion of transmission and distribution systems, Canada can increase its reliance on renewable energy while ensuring a reliable electricity supply.

Photo by Green Energy Futures

ENERGY STORAGE

Zero-emission energy can be stored using hydro dams, pumped hydro (requiring two water reservoirs with a height differential), grid-scale lithium-ion batteries and emerging battery technologies, compressed air, gravitational potential energy (lifting a weight), kinetic storage (e.g., a flywheel), and power to gas (using electricity to make hydrogen or another gas that can subsequently be used in a fuel cell or generator to make electricity again). Canada is well-positioned for renewable integration with many existing large hydro dams that can serve as giant batteries. To put the scale and strategic value of these reservoirs for decarbonization into context, while the largest grid-scale lithium-ion batteries currently being commissioned are designed to store enough energy to supply 100 to 1,000 MW for up to four hours, one reservoir in B.C., the Williston, could theoretically supply 2,700 MW continuously for six months.[53] With lower costs, solar PV plus storage projects are displacing gas-fired peaking plants in U.S. and Australian markets, enhancing solar's potential to contribute to meeting peak evening demand even after the sun has set.[54]

EXPANSION OF TRANSMISSION SYSTEM

In a large country with diverse landscapes, when regions are interconnected through an expanded transmission system, if one region is generating surplus power, it can transmit electricity to a region where renewable output is low due to low wind speeds or grey skies.[55] By expanding and building a higher-capacity transmission system that accesses regions with high-value wind, solar or run-of-river resources, a greater number of renewable projects can be brought online to produce clean electricity. Recent assessments found that reinforcing regional electricity transmission would enable greater reliance on renewable generation and help contain costs.[56]

PRICING, DEMAND RESPONSE AND SMART GRIDS

Pricing schemes (such as time-of-use charges), standards and conservation programs can help reduce peak demand. This reduces the need for generation capacity that will largely be idle (unless harnessed for electricity-to-gas), reducing overall system costs.

Demand flexibility can ensure that grids are responsive to the variability of renewable energy. To reduce peak demand, a smart grid can shift loads, such as EV charging or electric water heaters, to times when electricity is plentiful and prices are lower. Likewise, when electricity rates are low, a building might draw on the grid to heat up a thermal mass; later, when electricity demand and prices are high, this stored heat can be released for space or hot-water heating without the need for grid electricity.

4

Free industry from emissions

"Decarbonization is not about shuttering industry but rather using policy and enabling markets to realign investment across Canada's entire economy to compete in a decarbonizing world." – DDPP, 2015:40

The industrial sector has traditionally been regarded as difficult to decarbonize because it is heterogeneous and GHG-intensive, and industrial facilities in Canada must compete internationally.[57] Furthermore, most industrial processes were developed over decades around a plentiful and relatively cheap supply of fossil fuel inputs with little to no attention to the resulting emissions. A strategic approach to decarbonizing Canadian industry recognizes that we need to decarbonize without de-industrializing. We will still require cement, iron, steel, aluminum, chemicals and other industrial products in a decarbonized future. There is no climate win when Canadian policies cause an industrial facility to relocate to a country with lax environmental standards, a phenomenon known as carbon leakage (see Box 8).[58]

Recent research has shown that it is possible to decarbonize the industrial sector while minimizing stranded assets, preventing the "social trauma" of unemployment, and avoiding carbon leakage.[59] Decarbonization for industry may consist of electrifying industrial processes, using carbon capture and storage to capture the emissions from existing fossil-fuelled processes, and pursuing next-generation processes using energy carriers like hydrogen.[60] Many of the required technologies are commercial or near commercial but "but not currently competitive without carbon pricing or other market interventions" (see Section 6).[61]

Strategies for decarbonization will differ by industry. Taking the cement industry as an example, options to decarbonize include using less "clinker" (calcium carbonate with CO_2 removed) in cement; incorporating wood, hemp or carbon fibre into concrete to increase shear strength and reduce the need for cement; or using CCS to capture the CO_2 that is removed from the calcium carbonate when making clinker.

Because industrial facilities are long-lived, government regulations, price signals, corporate planning and investment policies must be put in place today to ensure that new industrial investments do not lock in GHG-emitting processes (see Box 4). Strategic government support of industrial decarbonization can ensure that Canadian industry can continue to compete in a carbon-constrained world.

BOX 4 LOCK-IN

Further investment in long-lived infrastructure and equipment that are emissions-intensive, like power plants, pipelines and industrial processes can “lock in” future emissions, since investors are focused on recouping their investment. Lock-in acts as a barrier to climate change action. Once an investment in GHG-intensive infrastructure or equipment is made, society is either burdened with the emissions generated by these projects over their lifespan or must pay to decommission it prematurely. Pathways to zero emissions require investors to write off their investment and replace the equipment with a non-polluting substitute, or invest in retrofits to capture emissions or change to zero-carbon fuels. Alternatively, governments are forced to absorb these costs. Any of these options makes getting to zero more expensive.

Photo by Green Energy Futures

5

Switch to renewable fuels

"Shipping and aviation are more challenging to decarbonize, while their demand growth is projected to be higher than other transport modes. Both modes would need to pursue highly ambitious efficiency improvements and use of low-carbon fuels." – IPCC 1.5, 2018

In some applications, like international flights, long-haul freight and marine shipping, the energy density of batteries may not be sufficient to make these transportation options both zero emissions and cost-competitive (see Box 5). In these instances, alternative low-carbon fuels are necessary to reduce greenhouse gas emissions to zero.[62]

In California and British Columbia, biofuels such as ethanol and biodiesel have already helped to lower the carbon intensity of fuels used in the transportation sector[63] and show promise for increased deployment.[64] Some early biofuel projects, especially those using corn or other feedstocks to make ethanol, were found to have no net climate benefit.[65] Research is ongoing in this field to reduce production costs and to better utilize cellulosic materials such as wood residues and other waste streams as a feedstock. The climate benefits of switching from fossil fuels to biofuels depend on land-base selection, land-management practices and the species grown, and avoiding releasing carbon already sequestered in the soil and pre-existing vegetation.[66] Furthermore, care is needed to ensure that biofuel production does not harm biodiversity[67] or compete with food production. Lastly, if biofuels are to play a role

Photo by Green Energy Futures

in supplying liquid fuels in a zero-carbon world, research must confirm that net energy production is positive[68] and climate benefits are real.[69]

Zero-emissions hydrogen can be produced by electrolysis using zero-emissions electricity. The availability of low-cost wind energy and improvements to the electrolysis process have made zero-emissions hydrogen cost-competitive in some niche applications, and the economics of hydrogen are likely to improve in coming years.[70] Hydrogen does pose storage challenges that require further innovation before it can play a major role in a low-carbon energy system. For bulk storage and transportation in liquid form it must be kept in tanks cooled to below -253C. In today's fuel cell vehicles, it is usually stored as a compressed gas in large, very high-pressure tanks. Considerable research and development is underway into storage systems that use materials that can absorb hydrogen and release it when needed.[71]

Liquid ammonia (NH_3) produced from electricity also offers potential as a zero-carbon fuel. It has greater energy density than liquid hydrogen, it can be stored as a liquid using moderate pressure, and since it is an input for fertilizer production and the chemical industry, the technology for storing and transporting it is already mature.[72]

The low-carbon economy gives us a new lexicon. Electrofuels are carbon-based fuels – just like gasoline, diesel and jet fuel – but are produced using electricity and CO_2 and are cleaner burning than fossil-derived fuels. Carbon Engineering, with a pilot plant in Squamish, B.C., is working on commercializing direct air capture of CO_2 from the atmosphere for conversion into synthetic fuel.[73] If an airplane were fuelled with synthetic aviation fuel produced using a direct air capture powered by renewable electricity, CO_2 emissions would be cancelled out; the CO_2 to create the fuel would be extracted from the atmosphere, and would be released back to the atmosphere when the fuel is burned. The availability of plentiful low-cost renewable electricity and improvements to CO_2 capture processes will improve the prospects for electrofuels to displace fossil alternatives.

Photo by Green Energy Futures

BOX 5 ENERGY DENSITY

A measure of available energy per unit of volume (e.g., GJ/litre for liquid fuels) or per unit of mass (e.g., GJ/kg of battery). Higher-energy density is generally advantageous.

6 Mobilize money

"Energy investment under deep decarbonization does not represent a large increase in the total energy investment required in the absence of climate policy, but a shift in investment away from fossil fuels toward low-carbon technologies." - Bataille et al[74]

The DDPP analysis finds that achieving zero emissions by 2050 means a modest increase to the overall level of investment in the Canadian economy. The DDPP report finds that overall investment in Canada must increase by $13.2 billion per year. Analysis of the TEFP scenarios by the Conference Board of Canada[75] finds that investment in Canada must increase by $44 to $100 billion a year. These higher estimates are likely influenced by the TEFP scenarios the Conference Board chose to model. The Conference Board report analyzes scenarios[76] that include growing oil and gas production that follows the forecasts made by the National Energy Board.[77] The future of oil and gas production is uncertain, and production levels will have a significant impact on the ability of Canada to reach zero emissions by mid-century. Continued growth of oil and gas output for export will require more clean-energy production to power the sector, increasing the investment required to meet Canada's climate targets (see Box 6). Higher emissions from an emphasis on oil and gas production will require a steeper reduction in emissions from other sectors of the economy, and hence accelerated investment in zero-emission solutions. The IPPC's 1.5 C report projects that bringing emissions to net zero will require a "marked upscaling" of investment in the energy sector globally.[78] Another global assessment stresses that capital investments in a zero-emissions energy system are offset in part by fuel cost savings from a decarbonized energy system since the inputs to generate renewable energy – like wind, sunshine and water – are freely provided by nature.[79]

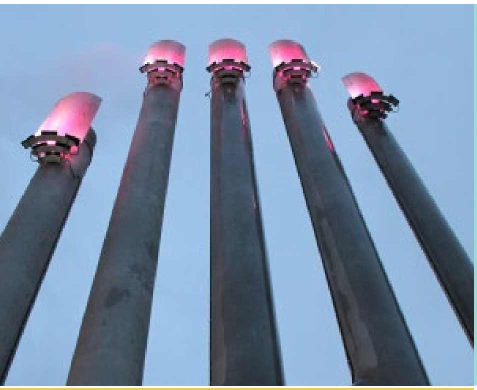


Photo by Green Energy Futures

The future of oil and gas production is uncertain, and production levels will have a significant impact on the ability of Canada to reach zero emissions by mid-century.

While an increase in annual investments of $13 to $100 billion in the zero-carbon economy may seem high, Canada is a $2.2 trillion economy with investment of approximately $500 billion annually, so the increase would range from 2.6 per cent (an increase of $13.2 billion) to 20 per cent (an increase of $100 billion).[80] The transition will also require reprioritizing where investment dollars flow, shifting away from sectors of the economy that have high-carbon footprints toward clean-economy sectors. For instance, investments in firms that make components for internal combustion engines will shrink, while investments will flow to those supplying batteries and components for electric and fuel cell vehicles. Decarbonization studies broadly concur on the need for significantly higher investment in the electricity sector. The DDPP analysis indicates an additional $13.5 billion a year is required to construct the clean, expanded electricity generation capacity necessary for decarbonization.

BOX 6 THE FUTURE OF OIL AND GAS PRODUCTION IN CANADA

The future production of oil and gas in Canada is an important unknown when evaluating pathways to zero emissions. The oil and gas sector uses significant quantities of electricity and natural gas in the extraction, refining and transportation stages. Extracting oil from Canada's oilsands is particularly energy-intensive, using 25 per cent of all natural gas consumed in Canada.[81] With this energy use comes significant GHG emissions. Leaks, venting and flaring of methane in this sector are also responsible for at least five per cent of Canada's greenhouse gas emissions,[82] and recent field measurements indicate that emissions recorded in the national inventory are underreported.[83] In total, the Canadian oil and gas industry was responsible for 27 per cent of Canada's GHG emissions in 2017[84] with a rising trend since 1990. The longer Canada continues to focus on production of oil and gas for export, the more challenging it will be to bring the country's emissions to zero, and the greater the efforts will need to be in other sectors of the economy.

Forecasts of future oil production vary widely. Oil and gas are globally traded commodities, so oil demand and prices are largely outside of Canada's control. The National Energy Board forecasts that a future with high oil prices could lead to oil production increases of 90 per cent above 2018 levels in Canada by 2040, while a future with low oil prices could lead to a production decline of 20 per cent in 2040 relative to 2018.[85] Whether we live in a world of high or low oil prices will depend on global oil demand and supply. Shell's "Sky scenario" outlines an energy future with net zero emissions from energy use by 2070. To achieve this scenario, Shell forecasts that global oil demand would peak in 2025 and global natural gas demand would peak in 2035.[86] Demand for these fuels would then decline throughout the rest of the century.

The Sky scenario is consistent with "holding global average temperatures to well below 2C."[87]

In a world of falling oil demand, Canadian production will be competing with producers around the world to retain market share. In this competition, Canada's bitumen and heavy oil resources face a disadvantage due to the high GHG-intensity of their production[88] and the fact that much of the output is heavy crude oil, with a higher sulphur and heavy metal content that is more costly, technically demanding and energy intensive to refine.[89] Unless bitumen is processed in refineries equipped for heavy oil, of which there are a limited number, the output is a higher proportion of low-value products, lowering profit margins.[90] The economic viability of oil and gas production in Canada also depends on the extent to which the federal and provincial governments subsidize the industry and what policies and carbon pricing regime they apply.[91] One-third of global oil reserves would need to remain unused in order to limit temperature increase to 2C.[92] Facing international competition from low-cost producers, oilsands expansion within Canada would likely be uneconomic under a 2C carbon budget.[93] This could mean that up to 75 per cent of Canadian oil reserves would be left in the ground to meet the 2C target, including between 85 and 99 per cent of bitumen reserves.[94]

Photo by Green Energy Futures

Recent modelling has shown that there is still a reasonable likelihood that global climate targets can be reached if, as of 2018, existing fossil fuel infrastructure in the energy, transport and industrial sectors is retired and replaced with zero-emissions alternatives once each asset reaches the end of its assumed design life.[95] However, if this date for cutting off new investments in fossil fuel infrastructure is pushed back to 2030, global climate targets are unlikely to be met.[96] Ensuring replacement with zero-emission infrastructure will require government policy direction. Oil demand may be reduced by either demand-side policies that discourage fossil fuel use (e.g., carbon pricing) or encourage the use of substitutes (e.g., electric vehicle incentives), or by supply-side policies that restrict the production of oil and gas (e.g., oil production caps, removing areas from exploration, oil tanker moratoriums, or putting a moratorium on the construction of new oil pipelines).[97] At the global level, a 1.5C-compliant scenario requires that the oil and gas sector reduce its output by three per cent per annum from present until 2050, while a 2C scenario requires a reduction of two per cent per year.[98] If the world is successful at meeting the climate targets set out in the Paris Agreement, Canada may see oil demand matching the lower end of the NEB's 2018 forecasts. Canada may then experience negative economic impacts (e.g., job losses in oil-producing provinces) as oil and gas assets become stranded.[99] These losses must be considered if Canada is to achieve a transition that brings everyone along (see Strategy 10).

The scale of investment required creates opportunities for Canadians to invest and share in the returns of a greener future.[100] Investment in green infrastructure may also be aided by the creation of a Canadian Infrastructure Bank and Climate Bonds that allow Canadians to redirect their investment from fossil fuels to the clean energy infrastructure of tomorrow. The sooner Canada aligns investment dollars with deep decarbonization pathways, the less likely investments will be made in technology that will be stranded by climate policy (see Box 7).

These investments help reduce the consequences and costs of climate change. The 2006 Stern Review on Economics of Climate Change documented that "the benefits of strong and early action far outweigh the economic costs of not acting."[101] Subsequent economic analysis has found that, at the global scale, investments to bring emissions to zero to avoid global warming of more than 1.5 to 2C are economically prudent because they help avoid damages from extreme weather and climate disruption.[102] Without action, the cost of property damage induced by climate change in Canada is estimated to reach $43 billion annually by 2050.[103]

BOX 7 STRANDED ASSETS

"Furthermore, some fossil investments made over the next few years – or those made in the last few – will likely need to be retired prior to fully recovering their capital investment or before the end of their operational lifetime." – IPCC Special Report of 1.5C, Chapter 2, p. 154

What are stranded assets? According to investment bank HSBC, "Stranded assets are those that lose value or turn into liabilities before the end of their expected economic life. In the context of fossil fuels, this means those that will not be burned – they remain stranded in the ground." It can also refer to assets such as pipelines or coal-generating stations that are abandoned due to their carbon intensity before the capital investment is paid off.

Analysis of the global carbon budget shows that much of the reserves held by fossil fuel companies and counted on their financial books as assets cannot be burned if the climate system is to be stabilized. Already, many coal companies, whose reserves are among the most carbon-intensive, have seen their share values decline.[104] Former Bank of Canada governor Mark Carney has warned of a carbon bubble if firms do not evaluate, disclose and manage their carbon exposure.[105] Security regulators in Canada have yet to require that Canadian corporations disclose climate risk to investors.[106] The Climate Risk Disclosure project is working internationally to identify companies that are likely to lose value as the world ramps up action on climate change. A recent British survey of fund managers with £13 trillion in assets under management found 89 per cent believed climate risks would impact the valuations of fossil fuel companies within five years.[107]

7 Level the playing field

“Innovation and commercialization signals provided by current provincial policies are far too weak to drive innovation consistent with longer-term decarbonization.” – DDPP, p. 6

To redirect investment throughout the Canadian economy, government needs to send the right policy signals. A long-standing policy adopted by OECD countries is the polluter-pays principle. Carbon pricing is a policy tool that embodies the polluter-pays principle and is present across the deep decarbonization scenarios we analyzed. Carbon pricing makes polluting more expensive and creates incentives to improve energy efficiency, switch to zero-emission energy sources, and innovate and create new technologies. A recent analysis of 18 developed countries that have managed to reduce their emissions confirms the important role that carbon pricing can play in mitigating emissions.[108]

British Columbia’s carbon tax, first introduced in 2008, is widely cited as demonstrating the effectiveness of carbon pricing.[109] Analysis of this policy has shown that carbon pricing reduced emissions[110] and did not lead to a net loss of jobs within the province.[111] Carbon pricing also promises to accelerate investment in the clean economy.[112]

The carbon pricing signal stipulated under the Canadian federal government’s Greenhouse Gas Pollution Pricing Act begins at $20 per tonne in 2019 and increases by $10 per tonne per year until it reaches $50 per tonne in 2022. A credible and effective carbon pricing signal would continue to escalate each year until 2050. Careful pricing design can avoid carbon leakage and minimize the negative impact of carbon pricing to the Canadian economy (see Box 8).

BOX 8 AVOIDING CARBON LEAKAGE

Carbon leakage occurs when climate policy in one jurisdiction leads industry to relocate to jurisdictions with weak climate policy. This threatens to decrease economic activity in places showing climate leadership, while failing to reduce global GHG emissions, which are now simply emitted in the climate-laggard jurisdiction. Carbon pricing can be designed to minimize carbon leakage, especially for energy-intensive, trade-exposed (EITE) industries like steel, chemicals and mining.

To protect its trade-exposed businesses, the Province of Saskatchewan has set up a performance-based GHG intensity standard for large industry (Government of

Saskatchewan, 2017). Firms that fail to reduce their GHG emissions intensity to a target level must pay a carbon levy for any emissions above the target threshold. These firms do not, however, pay a carbon price for every tonne of pollution. This allows firms to maintain competitiveness while still providing a signal to reduce emissions. The federal government's Output Based Price System works in a similar manner.

Measures to avoid leakage are a transitional tool that will become less justifiable as carbon pricing is adopted throughout the world.[113] Until carbon pricing is widely adopted, it may be advisable for countries that price carbon to enact "border carbon adjustments" as another tool to mitigate the risk of leakage. A BCA applies a tariff to imports based on their carbon content and accounts for the differential in carbon prices between Canada and the exporting nation. Life-cycle analysis can be used to estimate the carbon content of imports and calculate the appropriate tariff.[114] The goal of the tariff is to prevent goods produced without a carbon price from unfairly competing with domestic products.[115] For example, Canada could impose a BCA equivalent to our domestic carbon price on imports that come from countries that do not price carbon.[116] Likewise, Canada could offer rebates to firms exporting to markets that fail to price carbon.

Pricing carbon has equity impacts since costs and benefits are not borne equally across households. The net impact of carbon pricing on Canadian households will depend on how carbon pricing revenues are used. The DDPP scenarios model carbon pricing revenues being used to reduce personal and corporate income taxes (50 per cent of revenues to each sector, ensuring that carbon pricing is revenue-neutral). The Conference Board analysis of the TEFP scenarios assumes that only 50 per cent of carbon pricing revenues are returned as cuts to provincial and corporate income taxes, while 40 per cent is used for government spending, and 10 per cent is used to administer the policy. In the Conference Board analysis, even if carbon pricing were increased to $200 per tonne CO_2e by 2025, revenue recycling would ensure that the impact on GDP would mean only a difference of 0.1 to 0.2 per cent in output relative to business-as-usual GDP.[117]

In provinces subject to federal carbon pricing, 90 per cent of revenue raised by pricing carbon is returned to households as incentive payments.[118] This ensures that most households in backstop jurisdictions, especially those at the low end of the income distribution, come out financially better off after carbon pricing. The remaining 10 per cent of carbon pricing revenue raised is provided to municipalities, institutions like hospital and universities, and small businesses to offset increased energy prices.[119] Under B.C. and Alberta's carbon tax[120] and Quebec's cap and trade scheme, governments also use some of the revenue to promote investments in energy efficiency, clean technology, public transit and renewable energy.

Governments can also support decarbonization efforts by ending subsidies to the fossil fuel industry. Direct subsidies such as tax breaks on oil and gas investment, and indirect subsidies such as low royalty rates or royalty rate holidays encourage investment in the fossil fuel industry by increasing profits. In effect, fossil fuel subsidies act as negative carbon prices that favour high-carbon investments and delay the transition to a decarbonized future.[121] In Canada, methane – a potent greenhouse gas – is subject to new federal and provincial regulations, but methane emissions from the oil and gas sector are not subject to a carbon price.[122] This absence of a carbon price can also be seen as a subsidy.

There are other ways beyond pricing pollution that government can send signals to markets to accelerate the zero-carbon economy. By enacting a Clean Fuel Standard or a Low Carbon Fuel Standard, governments create market pressure for fuel refiners and distributers to find ways to lower the carbon content of fuels they produce and sell.[123] As a result, emissions from transportation are lowered without drivers necessarily being aware. The carbon content of fuel is calculated on a life-cycle basis. Those refiners that produce fuels with very low carbon content (e.g., containing biofuels or electrofuels) can sell excess credits to competitors whose fuel has high carbon content. Electricity supplied to power EVs and hydrogen produced with renewables for powering fuel cell vehicles can also count as a fuel and generate credits. Over time, the standard becomes more stringent, increasing pressure on fuel suppliers to innovate, resulting in lowered emissions. It also helps accelerate the deployment of zero-emission vehicles. California introduced the world's first LCFS in 2009, requiring a 10 per cent reduction in GHG intensity of transport fuels by 2020[124] and already, CO_2 emissions are estimated to have declined 10 per cent while innovation spurred by the regulation has meant the carbon content of alternative fuels has declined 15 per cent since the program's start.[125] British Columbia followed suit in 2010 with a renewable and low-carbon fuel requirement. The Government of Canada announced its intention to develop a Clean Fuel Standard in 2016, which will eventually go beyond transportation fuels to gaseous fuels used for heating and industrial applications. One model suggests the trucking sector in Canada could be run largely on hydrogenation-derived renewable diesel fuel, which unlike biodiesel, can be burned in today's fleet without engine modification.[126]

Photo by Alesia Kazantceva

Municipal governments can also use price signals to drive emissions reductions and improve quality of life for their residents. Congestion pricing, wherein road users face a higher price for driving during hours of high traffic volumes, has been shown to improve traffic flow, enhance use of public transit and carpooling and reduce urban air pollution.


Photo by Green Energy Futures

Municipal governments can also use price signals to drive emissions reductions and improve quality of life for their residents. Congestion pricing, wherein road users face a higher price for driving during hours of high traffic volumes, has been shown to improve traffic flow, enhance use of public transit and carpooling and reduce urban air pollution.[127] Relatively modest fees are sufficient to shift the timing or mode of travel for enough drivers to reduce traffic volumes. The fees collected can be invested in public transportation and active transportation infrastructure. This approach has been used successfully in Stockholm, London and Milan, will be implemented in New York City, and has been proposed for Metro Vancouver.[128]

Feebates for vehicle purchases can be used to encourage investment in low-emission fleets and do not depend on government funding. New vehicles that are high-emitting are assessed a charge, and these funds are used to reduce the cost of low-emission vehicles.

Across decarbonization studies, a common finding is that carbon pricing is only one important tool in a well-designed, comprehensive climate policy. Also essential are well-designed regulations that reduce emissions while giving firms and households flexibility to respond in the most cost-effective way (Bataille et al. 2016b: S20). Mark Jaccard argues that well-designed regulations can be equally as effective as carbon pricing but less politically contentious.[129] In part, this is because the costs imposed by regulations are less obvious to consumers. Across decarbonization studies, there is support for regulations, including energy-efficiency standards for new buildings, fuel-efficiency standards for automobiles and regulations to reduce methane emissions in the oil and gas sector. Smart design of regulations would ensure they are flexible and are complementary to carbon pricing, rather than duplicating the carbon pricing effort.[130] Well-designed complementary policies, such as investments in electric charging stations, transit and active transportation infrastructure, improve the effectiveness of carbon pricing by providing zero-emission alternatives.

8 Reimagine our communities

"At the heart of the city lies an opportunity, as urban density presents a greener way of living. Urban density can create the possibility for a better quality of life and a lower carbon footprint through more efficient infrastructure and improved urban planning." – C40

With over 80 per cent of Canadians living in urban areas,[131] municipal governments have an important role to play in getting to zero emissions. City design and land-use planning affect the feasibility of transit, the proportion of residents able to use active transportation modes like walking and cycling and the length of the average commute.[132] A smart growth strategy to urban planning would concentrate growth in compact, complete, walkable urban centres. This approach favours diverse housing options and encourages a mix of building types, uses and tenures. As a result, workplaces, shops and households are found in close proximity to each other, reducing travel distances and encouraging active transportation and transit over personal vehicles. For older cities and neighbourhoods, where many of the key land-use and infrastructure decisions have already been made, a smart growth approach can still assist with increasing population density by encouraging infill housing and multi-storey housing developments.[133]

Photo by Paul Krueger

Photo by Dylan Passmore

Scenario analysis demonstrates that smart land-use planning by municipalities can reduce the overall cost of decarbonization. Scenario 4 in the TEFP was built with consideration for how smart city planning can increase demand for high-occupancy transit, decrease passenger kilometres travelled by 47 per cent, and cut energy use by 14 per cent.[134] These measure help reduce the marginal abatement cost of the Scenario 4 decarbonization pathway by $100 per tonne CO_2e (TEFP, p. 206).

A smart growth strategy for urban planning is desirable quite apart from GHG reduction. Walkable cities enhance quality of life and health.[135] Mixed-use neighbourhoods encourage social cohesion and community. The co-benefits of smart city design mean that decarbonization can go hand in hand with improved human well-being.

In the absence of a strong urban agenda, deep emission reductions will be onerous if not physically impossible.[136]

Apart from a smart growth strategy of urban planning, municipalities have other policy tools that can be used to reduce GHG emissions. Provincial and municipal building codes, as well as official plans and zoning designations, can encourage energy-efficient construction and net-zero-ready buildings. Municipalities can also specify that new condominiums and apartment buildings come with EV charging infrastructure. Property Assessed Clean Energy (PACE) programs or on-bill utility financing can provide low-cost financing for energy efficiency upgrades, installation of solar photovoltaic panels and electric heat pumps. Municipal electric vehicle charging stations and preferred parking for EVs can encourage zero-emissions vehicle adoption.[137]

9 Focus on what really matters

"...we must become two to six times more efficient at transforming resource use into human well-being if all people are to live well within planetary boundaries." – Daniel O'Neill

Canadians do not desire energy per se, but instead desire the services that energy provides, such as mobility, comfort, light and communication.[138] Innovative new technologies and business models can use much less energy by shifting the way we approach and understand the provision of energy services. Examples include ride-sharing apps, smartphones and co-share office workplaces.

Photo by James Wheeler

A 2018 study in Nature Energy documented a wide range of such innovations that can reduce energy use by 50 per cent or more and help meet the 1.5 C climate target.[139] For instance, many individuals are choosing to focus increasingly on the mobility services that cars provide, rather than aspects of status conveyed by car ownership, and are forgoing private ownership in favour of accessing vehicles by joining car co-operatives and/or signing up with car-sharing companies that are disrupting the market for mobility. Cities with shared fleets of highly energy-efficient electric vehicles would use half the energy needed for transportation compared to privately owned vehicles, all while reducing congestion and improving travel times. Likewise, a building designed for multiple functions (e.g., educational space by day, community centre in the evening) reduces the need for construction materials, heating and lighting compared to two distinct buildings that are often underutilized.

Providing energy services using less energy is likely to come from innovations that are desirable because they are in some sense better – cheaper, cleaner, safer, quicker, more convenient, more enjoyable or sociable. One notable example is the smartphone, which offers up to a 100-fold potential saving in energy consumption compared to separately manufacturing and powering the many devices for which it can substitute (e.g., GPS unit, portable stereo, camera, alarm clock, voice recorder, game console, etc.).[140]

On a similar tack, Canadians do not inherently desire growth in the production of goods and services (e.g., growing GDP), but instead desire the well-being that can be achieved when citizens have access to affordable goods and services and meaningful work. The task of decarbonizing the economy becomes easier when we focus our attention on enhancing human well-being rather than economic growth. Economic activity requires energy and materials. Even when the economy is becoming less energy-intensive (using less energy per dollar GDP), GDP growth can cancel out those gains.[141] Current rates of economic growth already increase the challenge entailed in reducing emissions to zero. If growth rates are higher, as many politicians and economic commentators advocate, then the rate of decarbonization needs to accelerate if climate targets are to be met.[142] As Tim Jackson has written, meeting our climate targets while growing the world economy at current rates would mean that "the carbon intensity of every dollar of output must be more than 200 times lower than it is today."[143] Conversely, many of the things that support well-being, such as time with friends and family, time in nature, volunteering and creative and artistic pursuits, do not require much by way of material and energy use.

Our economic system is structured in such a way that when the economy stops growing we experience negative effects like unemployment. A growing literature explores how prosperity can be enhanced without perpetually growing the size of the economy.[144] To avoid unemployment that would otherwise result in a non-growing economy, productivity gains can be converted into a reduction in the number of working hours in a week.[145] To reduce the allure of high-consumption lifestyles, taxes and restrictions can be placed on advertising.[146] Well-being in a "post-growth" economy is also supported by social investments in public goods like parks, a focus on cultivating trust, and strong, democratic institutions.[147]

By redirecting economic policy to ensure the economy provisions the services – nutrition, shelter, health, education, leisure, recreation – that add up to social and psychological functioning, well-being can be enhanced even as energy needs are moderated. Alternatives to GDP as measures of progress, such as the Genuine Progress Indicator (GPI)[148] or the Canadian Index of Wellbeing (CIW)[149], can help by offering a better indication of the true goal we seek: human well-being that is sustained over generations.

"Fortuitously, recent technological innovations that make knowledge and productive capacity widely available at little cost and promote creative and collaborative activity could facilitate a transition to a world of reduced environmental stress and enhanced human well-being. An affirmative vision of a future both resilient and fulfilling, rather one of dour work and sacrifice, should guide our way."
– Chris Barrington-Leigh

10 Bring everyone along

"Canadians have the skills, knowledge, and motivation to thrive during this transition and seize these opportunities. . . Governments, along with employers and unions, must ensure that workers are not left behind as we transition to a cleaner, low-carbon economy."
– Task Force on Just Transition for Canadian Coal Power Workers and Communities, 2018

Transition for workers

As Canada pursues deep emissions reductions, we need to consider the equity implications of decarbonization. Some fossil fuel facilities, such as coal-fired generating plants, will need to be shut down. New employment opportunities will arise in energy efficiency, deployment of renewables, and other green technologies, and the total number of these jobs is expected to significantly exceed the jobs lost in sectors that are emissions-intensive.[150] However, the new jobs in the clean economy will not necessarily be located in the same communities as the jobs they replace. Furthermore, job requirements, working conditions and pay will also be different. To ensure that getting to zero emissions does not cause socio-economic hardships or undermine quality of life, attention must be paid to achieving an inclusive transition.[151]

An inclusive transition can be advanced by policies designed to support workers in affected sectors and communities. Training, apprenticeship and tuition support programs can give workers in affected sectors the skills necessary to find new jobs with minimal disruption in their employment. Pension-bridging programs can ensure that workers who retire early due to an event like a coal plant closure have a bridge of financial support to their planned retirement.[152] Transition centres in impacted

Photo by Green Energy Futures

communities can provide information, training and employment insurance supports, and serve as one-stop centres that help workers transition to new employment.[153] A comprehensive inclusive transition strategy would ensure no worker is left behind during the transition to zero emissions in Canada. Transition planning should seek to identify a community's development priorities and consider ways to mitigate industry closure effects on culture and identity.

If well-managed, the clean-energy transition can be a strong driver of job creation, job upgrading, good jobs and reducing inequality.[154] Conversely, a poorly managed transition risks causing unnecessary economic hardship and undermining public support for needed emission-reduction policies. Transition should be seen as part of a broader green economic development strategy that supports community economic development and diversification.[155]

BOX 9 MAKING ENERGY AFFORDABLE WHEN PRICING CARBON POLLUTION

Carbon-pricing policies should be designed to be fair and effective. For consumers with limited means, paying for energy can create stark choices. The NEB estimated in 2015 that eight per cent of Canadians have difficulty paying for the energy they need, a situation known as energy poverty. Atlantic Canada has a higher rate of energy poverty (13 per cent) as do many remote and Indigenous communities. It would be undesirable if putting a price on carbon pollution further disadvantaged low-income Canadians. For this reason, governments usually combine putting a price on carbon pollution with a combination of tax credits and income support.

Programs that target retrofits, energy conservation and distributed renewables to low-income households and Indigenous communities are other key measures for avoiding energy poverty, as are training programs for jobs in the clean economy. Conservation programs typically reduce costs for society as a whole, since they reduce the need for generation capacity.[156]

Equity and fairness

Increasing inequality has important implications as society transitions to a zero-emission future. People with low incomes tend to have lower emissions than the well-off, struggle to pay for housing, food, transportation and energy, and therefore do not have the means to invest in energy efficiency. Furthermore, they feel the impact of climate change more than those who are well-off. For instance, they may not be able to afford air conditioning, or their housing may be on land that is more vulnerable to flooding, and if an extreme weather event occurs, they do not have the assets needed to recover. A further divide can be seen between rural and urban Canada, since urban residents have access to public transportation and active transportation infrastructure, whereas rural residents often have to travel long distances to access public services. Attention is also required to how scaling back society's reliance on fossil fuels affects women, youth and Indigenous and minority populations. In the long run, getting to a zero-emission economy will benefit from policies that redress inequality and improve the resilience of diverse communities to a changing energy landscape.[157]

Photo by Green Energy Futures

Partnerships with Indigenous Peoples

Getting to zero emissions entails a substantial increase in Canada's clean energy infrastructure, including wind farms, large-scale solar projects, run-of-river hydro projects, expanded biofuel production, and an expanded electricity grid. Many of these projects will affect the traditional territories of Indigenous Peoples and thus will only succeed if Indigenous rights and interests are respected and project benefits are shared. Collaboratively with Indigenous Peoples, projects should be deployed in locations that respect important spiritual, cultural or fisheries values and protect traditional resource uses.[158] As described by the Assembly of First Nations' report, Powering Prosperity:

> A large percentage of new potential electricity generation projects in Canada are located on First Nation traditional territory and, activities related to clean energy production may interact with First Nation land use. Most clean energy projects now under development or consideration [are] on Crown lands, and consequently require First Nation approval (e.g., for water power access, grid connection, extraction and harvesting of resources, and more).[159]

Indigenous Peoples in Canada are particularly vulnerable to changes to their traditional territories due to climate change. Many have expressed a keen interest in the transition to clean energy for their communities, especially those that currently rely on expensive and polluting diesel for energy production. As of 2019, 70 per cent of Canada's 279 remote communities relied on inefficient, polluting diesel generation and almost two-thirds of these are Indigenous communities.[160] Beyond improved reliability and reduced costs, renewable energy and energy conservation is seen as an economic development strategy and a means to improve community well-being and pride. Not surprisingly, Indigenous participation in the clean energy economy has been growing steadily.[161]

The transition is only likely to succeed if clean energy is planned, developed and managed in a way that

- respects Indigenous rights and territories, the duty to consult, Aboriginal title and the United Nations' Declaration on the Rights of Indigenous Peoples (UNDRIP).
- enables Indigenous participation and ownership in energy projects and a share in the returns to ensure long-term benefits.
- addresses the energy needs of Indigenous communities and aspirations for self-reliance (e.g., energy security, providing affordable and reliable clean energy to transition off diesel grids, improve energy efficiency of housing stock).
- provides equitable access to jobs, training, education and employment for Indigenous Peoples.
- respects local Indigenous approaches to economic development (e.g., focus on broadly shared benefits) and supports economic diversification.
- prioritizes remediation of lands damaged by fossil fuel extraction and use.
- fosters collaborative governance and co-management agreements.

Conclusion: What getting to zero implies for Canada's energy system

"…results from our latest analyses suggest that marginal costs associated with deep decarbonization are rapidly decreasing: 2050 marginal costs in the stringent 80P scenario are significantly lower than those evaluated only a few years ago as part of the TEFP for a less ambitious scenario, indicating both how rapid technological changes can modify the cost of transition and how Canada could move rapidly to guarantee that it benefits from and contributes to these technological changes."
– Perspectives Énergétiques Canadiennes

We looked at decarbonization studies in Canada and around the world and identified 10 strategies for getting to zero emissions in Canada. These studies indicate that deep reductions in emissions are possible while maintaining our quality of life. Although the transition will require considerable effort by industry, government and people living in Canada, modelling results show that, in general, households and the business sector will face manageable costs, especially as improved energy efficiency and cleaner production deliver a range of ancillary benefits like improved air quality and health. Cleaner energy and fuel sources also create less air, water and land contamination than alternatives.[162]

Shifting from fossil fuels to cleaner energy also provides opportunities for technological innovation, as well as employment and economic opportunities in the growing clean tech sector. While some businesses, such as furnace manufacturers, may face falling sales and revenue if they do not adapt, others, such as heat pump manufacturers, will see rapid growth in opportunity.

To achieve the goal of deep GHG emissions reductions, it is necessary to put policies in place now and to shift investment toward the clean economy. Delay will be costly. Power plants, industrial boilers, buildings, transportation infrastructure and heavy machinery have long operational lifetimes – some of the plant and equipment built in the 2020s will still be in use in 2050. If investments continue in GHG-intensive infrastructure and equipment, the cost of meeting Canada's climate targets will increase.

Photo by Priscilla Du Preez

While tackling climate change is one of the greatest challenges facing humanity, and the path ahead may seem daunting, Canada has already had some successes in shifting to a cleaner economy:

- In 2002, Ontario decided to shutter its coal-fired generating stations. The last coal plant was shut down in 2014, resulting in North America's single-largest emissions reduction, the equivalent of taking seven million cars off the road.
- In 2008, B.C. banned construction of further fossil fuel–fired electricity plants, introduced Renewable and Low Carbon Fuel Requirements and put a price on carbon pollution, kick-starting B.C.'s clean tech sector and initiating the transition to a low-carbon economy.
- By 2016, Nova Scotia managed to reduce its emissions by 20 per cent from 1990 levels through investments in renewables, energy efficiency and heat pumps.
- In 2017, Alberta's first competitive auction for renewable power set a new record for low-cost renewables, securing 600 MW of capacity at 3.7 ¢/kWh – less than the cost of a modern gas plant.
- Despite growing populations and economies, Canada's largest cities have reduced greenhouse gas emissions: Toronto (-33 per cent from 1990 to 2016), Montreal (-23 per cent from 1990 to 2014) and Vancouver (-seven per cent from 2007 to 2017).
- Electricity generation from solar and wind has grown from 0.2 per cent of total generation in 2005 to 5.9 per cent in 2016.
- By 2019, Vancouver, Regina, Victoria, Saanich, Nelson, Charlottetown and Oxford County had committed to powering themselves to a 100 per cent renewable energy target by 2050 and are developing strategies to get to that goal.

Canadian companies leading the way on the low carbon transition:

ACCELERATE CLEAN POWER

Morgan Solar, based in Toronto's new high tech hub Stockyard District, has developed three disruptive products to improve the efficiency and affordablity of solar: SimbaX, a low concentrating technology for utility solar panels; SPOTlight, a translucent building integrated photovoltaic technology; and the Savanna Tracker, a foundationless tracking system.[163]

Deep Earth Energy Production Corp.[164] is developing scalable geothermal plants in Saskatchewan from wells drilled with conventional oil and gas drilling technology (drilled to the greatest depth in the province). When layers of hot rock are reached, steam is produced to drive a turbine to generate zero-emissions electricity around the clock. From a pilot project with a generation capacity of five MW, the company plans to ramp up to 100 MW.

ELECTRIFY JUST ABOUT EVERYTHING

Founded in 2009 and based in Richmond B.C., **Corvus Energy** is a manufacturer of high-power modular batteries designed for use in challenging marine environments, such as powering battery-electric or hybrid-electric ships and portside cranes. The world's first battery-electric ferry, Ampere, was commissioned in 2015 using batteries from Corvus energy. It cut costs by 80 per cent and emissions by 95 per cent.[165]

Since 2015, a 9.2 MW wind farm in N.W.T. at the **Diavik Diamond Mine** has helped reduce diesel fuel use by 5.2 million litres annually. The wind turbine blades were equipped with de-icing technology and can operate at temperatures as low as -40 C.[166]

FREE INDUSTRY FROM EMISSIONS

In 2018, Rio Tinto and Alcoa, two large Canadian aluminum producers based in Quebec, embarked on a joint venture named **Elysis** to commercialize a new smelting technology to eliminate all greenhouse gas emissions from the conventional aluminum smelting process.[167] The venture has received financial support from the governments of Quebec and Canada. Research and development operations will be based in the Québec's Saguenay–Lac-Saint-Jean region. This technology will be deployed commercially in 2024. Eventually, it could reduce Canada's emissions by 6.5 million tonnes.

Founded in 2007 and based out of Halifax, **CarbonCure**[168] allows existing cement plants to be retrofitted with technology that injects carbon dioxide into the concrete as it is mixed. The CO_2 mineralizes (into solid calcium carbonate), making the concrete more durable while reducing its carbon footprint. Already, more than 300,000 truckloads of CarbonCure concrete have been used on construction projects.

SWITCH TO RENEWABLE FUELS

Based in Squamish, B.C., **Carbon Engineering** is commercializing technology that enables it to directly capture carbon dioxide from the air (DAC technology). This captured carbon is then synthesized into a fuel using hydrogen derived from electrolysis using electricity from renewable sources to create synthetic fuels. Since these fuels are derived from atmospheric carbon, they offer the prospect of lowering the carbon footprint in the transportation sector where batteries would be poorly suited, such as long-distance flights and long-haul trucking. The company's technology is made economically viable by pricing carbon pollution and setting clean fuel standards.[169]

Further facilitating the transition, the cost of renewable energy has continued to fall. By 2018, the levelized cost of electricity from a utility-scale photovoltaic project dropped 88 per cent over costs in 2009, while the levelized cost of wind energy dropped 69 per cent from 2009 to 2018.[170] The improving economics of renewables explains why in 2017, renewable electricity capacity additions eclipsed fossil fuel capacity additions by a ratio of 2:1.[171] Likewise, the economics of battery storage continue to improve dramatically, leading to increased deployment of grid-connected batteries. Innovations are growing in energy efficiency, green buildings, bioenergy and electric vehicles, and Canadian firms are beginning to capitalize on these opportunities. However, counterbalancing the optimism offered by these advancements, in other areas research and development in clean technology has been disappointing. For instance, early optimistic assessments of the rate at which CCS could be deployed have not materialized.[172] Decarbonization of industrial processes, international shipping and aviation is lagging far behind the rate necessary to meet climate targets.[173] This underscores the need for Canadian governments to create a policy and investment environment that favours innovation in low-carbon technologies.

Collaboration and partnerships at the regional scale can also help reduce costs. For instance, Denmark's ability to decarbonize and become a renewable energy leader is facilitated through cooperation with Norway. Through electricity trade, Denmark has been able to use Norway's hydro reservoirs as batteries to be charged while wind is plentiful and discharged when winds are slight. Likewise for Canada, there are already better north-south grid connections than exist between Canadian provinces. Regional collaboration via expanded electricity trade across the Canada-U.S. border offers opportunities to address variability in renewable generation.[174] Knowledge transfer also helps accelerate decarbonization. The City of Vancouver, for example, has been sharing its expertise in developing mitigation and renewable energy strategies with smaller municipalities with less capacity.

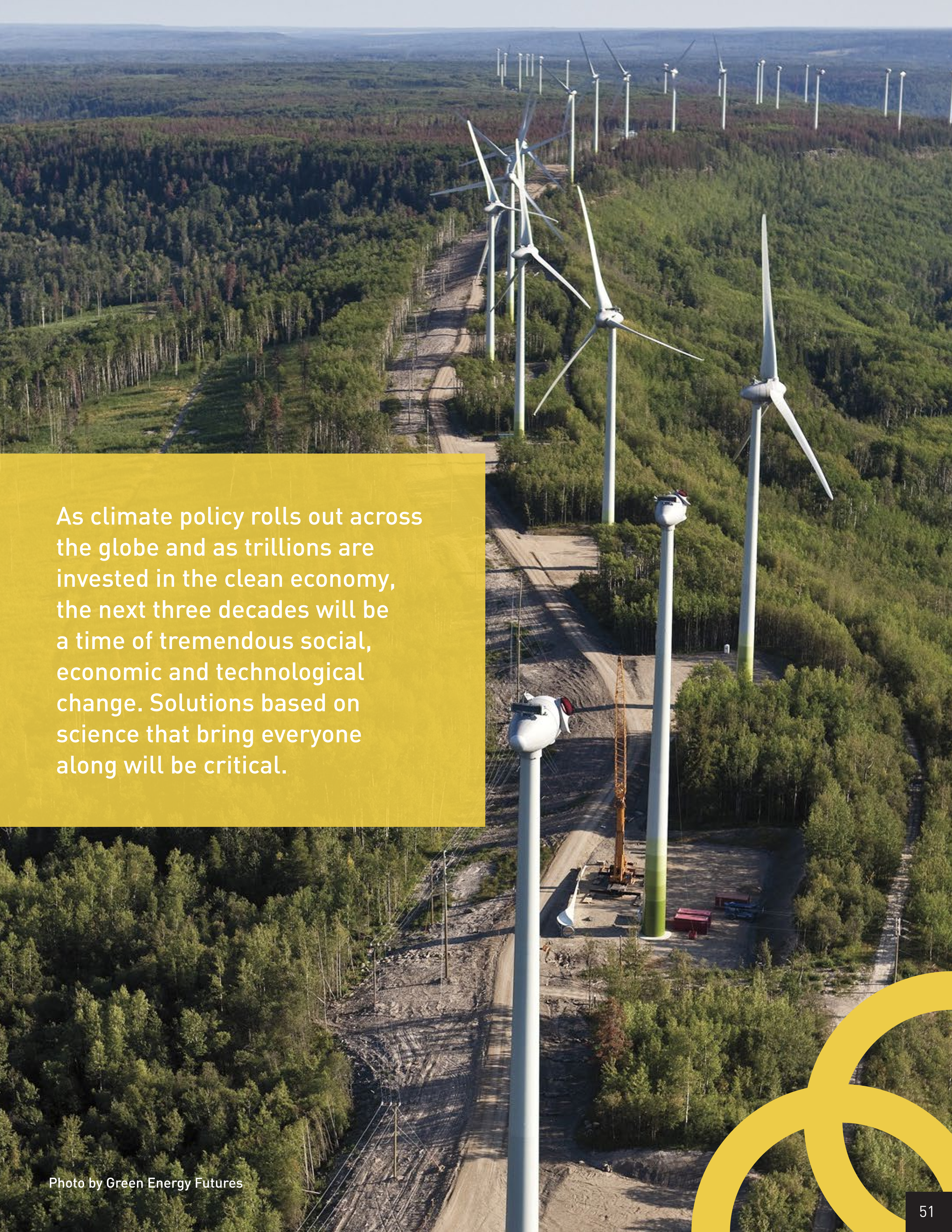
Historically, the federal and provincial governments have set emissions targets and typically missed them by a large margin. A more effective approach is needed to ensure this pattern is not repeated. Targets, metrics and accountability mechanisms informed by science need to be incorporated into legislation and government planning frameworks.

Zeroing in on emissions will take a coordinated effort that goes beyond partisanship.[175] One option to improve accountability and to de-politicize carbon-emissions reductions would be to create credible, independent bodies at provincial and federal levels to monitor progress toward targets, evaluate the effectiveness of policies and recommend incremental increases in policy stringency, rebates and carbon pricing. Thus, just like the Bank of Canada tries to meet an inflation target by controlling key parameters like interest rates, an equivalent "Emissions Management Canada" organization would seek to adjust parameters like carbon prices to help Canada stay within its carbon budget.[176]

Businesses have an easier time making investment decisions when governments set out clear policy direction and sudden changes in regulatory approaches are avoided. When a change in government results in wholesale changes in how government pursues emissions reductions, certainty for business is undermined and the investment climate can deteriorate. Furthermore, the value of past government investment in decarbonization can be eroded. The more robust the climate targets and the clearer and more credible the policy, the lower the transition costs.[177]

While we have focused on the urgent challenge of addressing climate change, it must be kept in mind that this problem needs to be addressed in a way that contributes to solving other pressing environmental problems such as biodiversity loss, contamination of the biosphere and disruption of other natural process such as the nitrogen cycle.[178] National and global strategies are needed that concurrently address environmental priorities and socio-economic needs.[179]

As climate policy rolls out across the globe and as trillions are invested in the clean economy, the next three decades will be a time of tremendous social, economic and technological change. Solutions based on science that bring everyone along will be critical.



As climate policy rolls out across the globe and as trillions are invested in the clean economy, the next three decades will be a time of tremendous social, economic and technological change. Solutions based on science that bring everyone along will be critical.

Photo by Green Energy Futures

Endnotes

1. In this report, we use *carbon* (and its absence, decarbonization) as a stand-in for all of the greenhouse gases (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, perfluorocarbons, hydrofluorocarbons and nitrogen trifluoride).

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11. There is considerable uncertainty over the role that nuclear power will play in getting emissions to zero and a lack of convergence across decarbonization studies, both in Canada and globally. In part, this is explained by some researchers modelling scenarios that preclude

nuclear expansion, due to value orientations or pessimistic assessment of the technology's potential role. This is tied to problems with cost escalation, construction delays and cancellations experienced in many Western countries, compounded by the falling prices of renewables (Amory B. Lovins et al., "Relative Deployment Rates of Renewable and Nuclear Power: A Cautionary Tale of Two Metrics," *Energy Research & Social Science* 38, [2018]: 188–92, https://doi.org/10.1016/j.erss.2018.01.005). While nuclear power does not generate greenhouse gas emissions on-site at the generation plant and it can help with the integration of variable resources, it creates long-lived radioactive waste that is harmful to the living world and must be disposed of in deep geological repositories (while research is ongoing, no geological repositories have yet been constructed in North America). Nuclear power may prove difficult to deploy in many regions, as it elicits public concern over the risk of accidental release of radioactive materials. Canada's nuclear power sources are aging and even if existing plants are refurbished, current projections suggest a 39 per cent reduction in nuclear capacity by 2037 (compared with 2015 output) unless new reactors are constructed. See J. David Hughes, *Canada's Energy Outlook: Current Realities and Implications for a Carbon-Constrained Future,* Canadian Centre for Policy Alternatives and Parkland Institute (2018).

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Appendix

Short form	Authors and/or sponsors	Study name	Year	Sectors	Geographic region	Time horizon	Methodology
CANADA							
PEC	Langlois-Bertrand, Vaillancourt, Bahn and others / Institut de L'Energie Trottier, e3Hub, ESMIA	Perspectives Énergétiques Canadiennes	2018	Economy-wide	Canada	2050	Modelling
ARECSI	Hatch / Natural Resources Canada	Atlantic Regional Electricity Cooperation and Strategic Infrastructure	2018	Electric power	Atlantic Canada	Unspeci-fied	Modelling
WRECSI	GE Energy Consulting / Natural Resources Canada	Western Regional Electricity Cooperation and Strategic Infrastructure	2018	Electric power	Western Provinces	2030 and 2040	Modelling
REC	Potvin, Burch, Layzell and others. Sustainable Canada Dialogues / Natural Resources Canada	Re-Energizing Canada: Pathways to a Low-Carbon Future	2017	Economy-wide	Canada	2050	Synthesis
EDDP	Vaillancourt, Bahn, Frenette and Sigvaldason	Exploring Deep Decarbonization Pathways to 2050 for Canada Using an Optimization Energy Model Framework	2017	Economy-wide	Canada	2050	Modelling
CCF	Coad, Gibbard, Macdonald and Stewart / Conference Board of Canada	The Cost of a Cleaner Future: Examining the Economic Impacts of Reducing GHG Emissions	2017	Economy-wide	Canada	2050	Modelling (economic impacts)
TEFP	The Canadian Academy of Engineering, David Suzuki Foundation, Trottier Family Foundation	Trottier Energy Futures Project: Canada's Challenge & Opportunity	2016	Economy-wide	Canada	2050	Modelling
IWWP	Jaccard, Hein and Vass	Is a Win-Win Possible? Can Canada's Government Achieve Its Paris Commitment . . . and Get Re-Elected?	2016	Economy-wide	Canada	2020–2030 focus, to 2050	Modelling
PCWIS	GE Energy Consulting	Pan-Canadian Wind Integration Study	2016	Electric power	Canada	2025	Modelling
CMCS	Government of Canada	Canada's Mid-Century Long-term Low Greenhouse Gas Development Strategy	2016	Economy-wide	Canada	2050	Synthesis
CAVRE	Canadian Council of Renewable Energy	Canada's Advantage: A Vision for Renewable Electricity in Canada	2016	Electric power	Canada	2050	Synthesis
DDPP	Bataille, Sawyer and Melton. SDSN / IDDRI	Pathways to Deep Decarbonization in Canada	2015	Economy-wide	Canada	2050	Modelling
ACC	Potvin, Aitken, Anctil and others / Sustainable Canada Dialogues, Trottier Institute for Science and Public Policy	Acting on Climate Change: Solutions from Canadian Scholars	2015	Economy-wide	Canada	2050	Synthesis

TPOLEES	Canadian Council of Academies	Technology and Policy Options for a Low-Emission Energy System in Canada	2015	Economy-wide	Canada	Unspeci-fied	Synthesis
NRTREE	National Roundtable on the Environment and the Economy	Framing the Future: Embracing the Low Carbon Economy	2012	Economy-wide	Canada	2050	Modelling
U.S.							
DDNEUS	Williams, Jones, Kwok and Haley / Evolved Energy Research and Hydro-Québec	Deep Decarbonization in the Northeastern United States and Expanded Coordination with Hydro-Québec	2018	Economy-wide	Northeast-ern US	2050	Modelling
GCRSWP	Shaner, Davis, Lewis and Caldeira	Geophysical Constraints on the Reliability of Solar and Wind Power in the US	2018	Renewable energy	United States	n/a	Modelling
ACEF	Gowrishankar and Levin / NRDC	America's Clean Energy Frontier: The Pathway to a Safer Climate Future	2017	Economy-wide	United States	2050	Modelling
USMCS	Government of the United States	United States Mid-Century Strategy for Deep Decarbonization	2016	Economy-wide	United States	2050	Modelling
PDDUS	Williams, Haley, Kahrl and Moore	Pathways to Deep Decarbonization in the United States	2015	Economy-wide	United States	2050	Modelling
EU							
100REEU	Zappa, Junginger and van den Broek	Is a 100% Renewable European Power System Feasible by 2050?	2019	Economy-wide	EU	2050	Modelling
OEUES	Capros, Kannavou, Evangelopoulou and others	Outlook of the EU Energy System up to 2050	2018	Economy-wide	EU	2050	Modelling
EPTLCES	Hainsch, Burandt, Kemfert and others	Emission Pathways Towards a Low-Carbon Energy System for Europe: A Model-Based Analysis of Decarbonization Scenarios	2018	Economy-wide	EU	2050	Modelling
CPFA	European Commission	A Clean Planet for All: A European Long-Term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy	2018	Economy-wide	EU	2050	Modelling
GLOBAL							
APAG	Teske (editor)	Achieving the Paris Agreement Goals: Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5C and +2C	2019	Economy-wide	Global	2050	Modelling
GESRE	Ram, Bogdanov, Aghahosseini and others	Global Energy System Based on 100% Renewable Energy: Power, Heat, Transport and Desalination Sectors	2019	Economy-wide	Global	2050	Modelling
Sky	Shell International	Sky: Meeting the Goals of the Paris Agreement	2018	Economy-wide	Global	2070	Modelling

IPPC1.5	Intergovernmental Panel on Climate Change	Global Warming of 1.5C: An IPCC Special Report on the Impacts of Global Warming of 1.5C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty	2018	Economy-wide	Global	2100	Modelling
DCS	Harvey, Orvis and Rissman	Designing Climate Solutions: A Policy Guide for Low-Carbon Energy	2018	Economy-wide	Global	2050	Modelling
GZCEEPS	Jenkins, Luke and Thernstrom	Getting to Zero Carbon Emissions in the Electric Power Sector	2018	Electric power	Global	2050	Synthesis
PET	International Energy Agency / International Renewable Energy Agency	Perspectives for the Energy Transition	2017	Economy-wide	Global	2050	Modelling
ETP	International Energy Agency	Energy Technologies Perspectives 2017: Catalysing Energy Technology Transformations	2017	Economy-wide	Global	2060	Modelling
RRD	Rockstrom, Gaffney, Rogelj and others	A Roadmap for Rapid Decarbonization	2017	Economy-wide	Global	2050	Synthesis
BEGP	Energy Transitions Commission	Better Energy, Greater Prosperity: Achievable Pathways to Low-Carbon Energy Systems	2017	Economy-wide	Global	2040	Modelling
ER	Greenpeace International, Global Wind Energy Council, SolarPower Europe	Energy [R]evolution: A Sustainable World Energy Outlook 2015	2015	Economy-wide	Global	2050	Modelling
BGBC	Global Commission on the Economy and Climate	Better Growth, Better Climate: The New Economy Report	2014	Economy-wide	Global	2050	Synthesis
OTHER REGIONS							
ARE2030	Aghahosseini, Bogdanov, Barbosa and Breyer	Analysing the Feasibility of Powering the Americas with Renewable Energy and Inter-regional Grid Interconnections by 2030	2019	Electric power	Americas	2030	Modelling
PRA	Ison, Lyons and Atkinson / Repower Australia	A Plan to Repower Australia: 100% Clean Energy	2019	Economy-wide	Australia	2050	Synthesis
SECTORAL							
DDPEII	Bataille, Åhman, Neuhoff and others	A Review of Technology and Policy Deep Decarbonization Pathway Options for Making Energy-Intensive Industry Production Consistent with the Paris Agreement	2018	Industry only	Global	2035–60	Synthesis
MP	Energy Transitions Commission	Mission Possible: Reaching Net-Zero Carbon Emissions from Harder-to-Abate Sectors by Mid-Century	2018	Industry, heavy duty transport and materials	Global	2050	Modelling
SFEC	Favier, De Wolf, Scrivener and Habert	A Sustainable Future for the European Cement and Concrete Industry: Technology Assessment for Full Decarbonization of the Industry by 2050	2018	Cement and concrete	Europe	2050	Modelling