Getting to Net-Zero in Canada

Scale of the problem, government projections and daunting challenges

BY DAVID HUGHES

February 2024

CCPA
CANADIAN CENTRE
for POLICY ALTERNATIVES
BC Office

CORPORATE
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ABOUT THE AUTHOR

David Hughes is an earth scientist who has studied the energy resources of Canada and the world for more than four decades, including 32 years with the Geological Survey of Canada as a scientist and research manager. Since 2008, Hughes has been President of Global Sustainability Research Inc., a consultancy dedicated to sustainability issues including energy resources, resource depletion, environmental degradation and government policy.

Over the past two decades, Hughes has researched, published and lectured widely on global energy and sustainability issues in North America and internationally. His work for the Canadian Centre for Policy Alternatives includes the following reports: *Canada's Energy Sector: Status, evolution, revenue, employment, production forecasts, emissions and implications for emissions reduction* (2021); *Reassessment of Need for the Trans Mountain Pipeline Expansion Project* (2020); *BC's Carbon Conundrum: Why LNG exports doom emissions-reduction targets and compromise Canada's long-term energy security* (2020); *Canada's Energy Outlook: Current realities and implications for a carbon-constrained future* (2018); *Will the Trans Mountain Pipeline and tidewater access boost prices and save Canada's oil industry?* (2017); ***Can Canada increase oil and gas production, build pipelines and meet its climate commitments?*** (2016); *A Clear Look at BC LNG (2015)*; as well as shorter articles. Hughes has also authored numerous reports on unconventional oil and gas development in the United States, the most recent of which is *Shale Reality Check 2021: Drilling into the U.S. government's optimistic forecasts for shale gas & tight oil production through 2050* (2021) for the Post Carbon Institute.

Hughes has also consulted for environmental groups, First Nations and the private sector on energy and environmental issues and served as an expert witness at hearings for energy projects in the US and Canada. He is a board member of Physicians, Scientists & Engineers for Healthy Energy of Oakland, CA, and an advisor to the Post Carbon Institute of Corvallis, OR. His work has been featured in Nature, Canadian Business, Bloomberg, Postmedia, USA Today, as well as other popular press, radio and television.

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Contents

1. Summary

The urgency of mitigating climate change through significant emission reductions is globally recognized—most recently with the call to transition away from fossil fuels at the United Nations Framework Convention on Climate Change Conference of the Parties (COP28). Canada has long accepted this challenge: its latest pledge is to reduce emissions to 40–45% below 2005 levels by 2030 and net-zero by 2050. While it is easy to make long-range political promises, it is much harder to have a realistic plan to achieve these important goals.

In June 2023, the Canada Energy Regulator (CER) published *Canada's Energy Future 2023,* which offered—for the first time—energy supply scenarios that align with Canada's 2050 net-zero target. These scenarios call for major changes in Canada's energy supply, including reducing oil and gas production, a several-fold increase in renewable generation from solar, wind and biomass, a near tripling of nuclear capacity, and a many-fold increase in technologies such as carbon capture, utilization and storage (CCUS). For comparison, CER also provided a scenario which showed that with policy measures in place as of March 2023, emissions would be only 16% lower than 2022 levels by 2050.

This report reviews the evolution and scale of the emissions problem during the fossil fuel era and the current energy supply picture in Canada; examines the CER net-zero energy supply projections as well as their assumptions and policy implications; and makes recommendations for modifications and policy emphasis that would increase the chances of Canada meeting its net-zero commitments.

Canada's current energy usage is assessed to paint a clear picture of the challenges of reaching net zero emissions by 2050. Despite years of promises and plans to reduce emissions, by 2021 emissions had decreased by only 8.5% from 2005 levels, and the Canadian Climate Institute's early estimates indicate a 2.1% increase in 2022, moving Canada further from its goals.

Canada's heavy reliance on fossil fuels for domestic energy supply and export revenue only deepens this challenge. In 2022, these fuels met 77.4% of the nation's end-use energy demand, and the country exported 63% of its oil, 34% of its gas, and 67% of its coal production. The energy sector was responsible for 8.9% of Canada's overall GDP, with more substantial impacts in specific provinces: 21% of Saskatchewan's GDP, 30% of Newfoundland and Labrador's, and 31% of Alberta's.

On a per capita basis, Canadians consume nearly five times as much energy as the global average and emit three times the global average of emissions. While over 80% of Canada's electricity supply is emissions-free due to generation from hydro, nuclear, wind and solar, electricity represented only 17.6% of end-use energy demand in 2022.

The CER net-zero scenarios are based on an economic analysis of current and announced government policies, technical factors and the most comprehensive knowledge base of Canadian energy data available, and hence provide an important starting point for understanding what a transition to net-zero emissions might require. Although some of the assumptions made in CER's net-zero scenarios on price trends and technology deployment are extremely optimistic and therefore unlikely to be realized, they provide a useful foundation for understanding the true scale of the policies and changes that will be needed in order to achieve Canada's net-zero mandate.

Key conclusions and recommendations include:

- **Major policy improvements are required:** Policies in place as of March 2023 would see only a 16% reduction of emissions from 2022 levels by 2050.
- **Overreliance on industrial carbon removal introduces high risk:** CER's projections of a 34 to 39-fold increase in CCUS and a several thousand-fold expansion of direct air capture (DAC) introduce very high risk given the cost and slow rate of deployment of CCUS and the very high cost and early stage of development of DAC. Reliance on these technologies must be reduced to lower risk in a credible net-zero strategy. This will require significantly reduced reliance on fossil fuels compared to the CER scenarios.
- **Overreliance on hydrogen introduces high risk:** CER's projection that hydrogen can grow from almost nothing to 11–12% of end-use energy supply by 2050 is extremely optimistic. Current production of hydrogen is very energy- and emissions-intensive and producing it from electricity consumes 54–82% of the electrical energy in the conversion process. Although some hydrogen will be needed, a more realistic goal may be the more conservative 5% estimate of the International Energy Agency (IEA).
- **Increased electricity generation will be needed to lower risk:** To reduce risk from overreliance on fossil fuels, CCUS, DAC and hydrogen, electricity generation will need to increase from the 39–41% of end-use energy supply in the CER net-zero scenarios. Increasing electricity's share of energy supply to 55%, as assumed in the IEA's net-zero roadmap, would be a more realistic target. This will require increased renewable generation and infrastructure compared to the CER net-zero scenarios.
- **Major improvements in forest management practices are required:** Existing forest management practices have seen Canada's forests become major net emitters. Tripling the sequestration capacity of Canada's forests, as assumed in CER's net-zero scenarios, will require major improvements in forest management practices.
- **Reducing energy demand must become a major priority:** Reducing energy consumption is the low-hanging fruit, as it eliminates the cost of new energy production and emissions reduction infrastructure. Prioritizing conservation, efficiency and behavioral change must become a major government policy priority.

Despite the formidable challenges ahead, Canada's path to net-zero is achievable with a clear, actionable plan that recognizes the scale of the undertaking and the limitations of potential solutions. This report underscores the need for a comprehensive strategy with practical, scalable solutions and a robust policy framework that will steer Canada toward a sustainable, net-zero future by 2050.

2. Introduction

Climate change is constantly in the news and many countries have pledged to reduce emissions to net-zero by 2050. However, collective progress towards this goal has been slow. There have been 28 United Nations' Conference of the Parties (COP) meetings on climate change (and several climate summits before that), yet global emissions have increased 58% since the first COP meeting was held in 1995.[1] In 2016, Canada signed the Paris Agreement with a pledge to cut emissions to 30% below 2005 levels by 2030, yet emissions were just 5% below 2016 levels in 2021.[2]

Reaching net-zero has become an urgent priority in the face of climate change. In 2021, Canada passed the Canadian Net-Zero Emissions Accountability Act[3] that committed Canada to reduce emissions to net-zero by 2050. This was followed in 2022 by the federal government's *2030 Emissions Reduction Plan,*[4] which increased the 2030 interim emissions reduction goal to 40–45% below 2005 levels by 2030.

Figure 1 illustrates Canada's emissions by economic sector through 2021 and its emissions reduction commitments through 2050. The rate of decrease in emissions from 2005 to 2021 has averaged 3.9 megatonnes per year (Mt/year). In order to achieve Canada's emissions reduction goals, the rate of decrease will have to accelerate several-fold. To meet the 40–45% reduction goal by 2030 this rate must increase 6.6–7.7 times over the 2022–2030 period, to declines of 26–30 Mt/year, followed by an increase of 5.2–5.6 times over the 2031–2050 period to meet the net-zero goal. This clearly indicates Canada's policies must be much more aggressive in order to achieve its legislated emissions reduction mandate.

In June 2023, the Canada Energy Regulator (CER), a departmental corporation and agent of the Crown established under the Canadian Energy Regulator Act, published its *Canada's Energy Future 2023* report[5] that examined three scenarios for future energy supply and demand in Canada through 2050. Two of these scenarios assumed net-zero emissions reduction would be achieved and the third assumed no further change to policies enacted as of March, 2023. Major reductions in oil and gas production and consumption will be required, even with assumptions of a rapid scaleup of carbon capture and storage and direct air capture technologies and an order of magnitude increase in renewable energy. Oil production in the two net-zero scenarios would decline 21–75% and gas production 37–68% from 2022 levels by 2050. This has profound implications for policy and investment decisions being made now.

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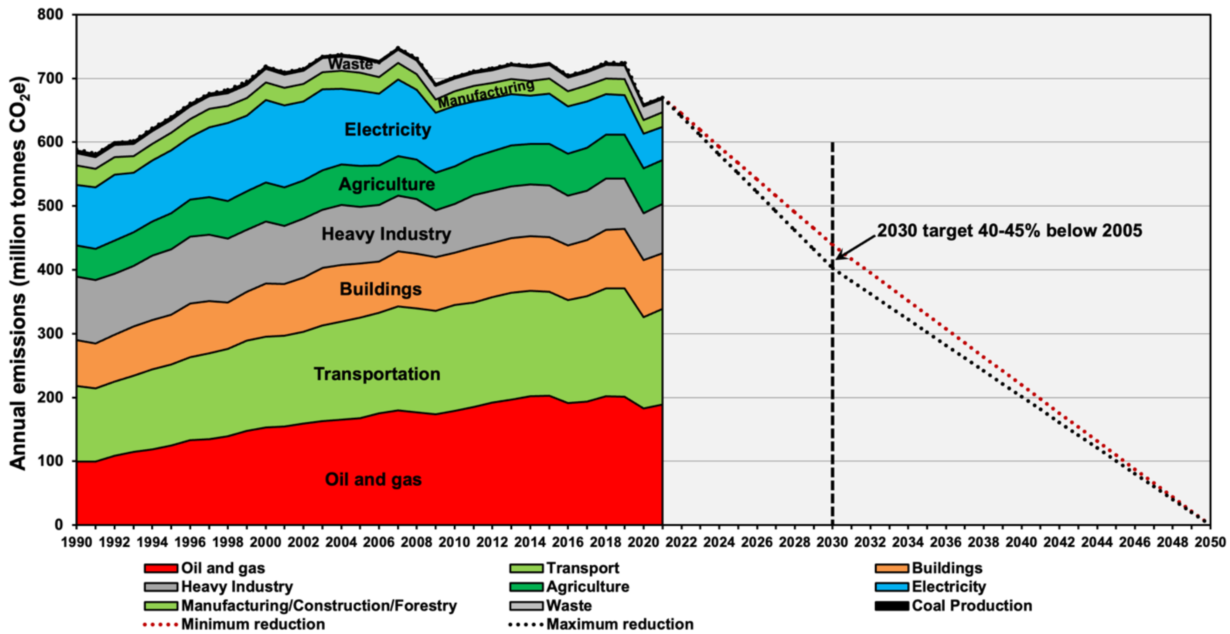
1. Global Carbon Budget with major processing by Our World in Data, "Annual CO_2 emissions – GCB" [dataset], December 12, 2023, https://ourworldindata.org/co2-emissions.
2. Environment and Climate Change Canada, *National Inventory Report 1990–2021: Greenhouse gas sources and sinks in Canada,* April 2023, https://publications.gc.ca/collections/collection_2023/eccc/En81-4-2021-3-eng.pdf.
3. Canadian Net-Zero Emissions Accountability Act, passed June 2021, https://laws-lois.justice.gc.ca/eng/acts/c-19.3/fulltext.html.
4. Environment and Climate Change Canada, *2030 Emissions Reduction Plan: Canada's Next Steps for Clean Air and a Strong Economy,* March 2022, https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf.
5. Canada Energy Regulator, *Canada's Energy Future 2023: Energy Supply and Demand Projections to 2050,* June 2023, https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2023/canada-energy-futures-2023.pdf.

Figure 1: Canada's emissions by economic sector through 2021 and its emissions reduction commitments through 2050.[6]

Emissions from land use, land use change and forestry are not included in Canada's official *National Inventory Report.*



Why has cutting emissions at the scale required proved to be so difficult? Are CER projections of pathways to meet Canada's emissions reduction commitments realistic? What are the major hurdles to reaching net-zero and what tradeoffs might Canada have to accept to get there? These are some of the questions this report endeavors to answer. The report is divided into three sections:

- A brief review of the cause, evolution and scale of the emissions problem in Canada and the world, including a discussion of energy production, revenue generated and emissions by province.
- An examination of CER's scenarios and assumptions and what they imply for future energy supply, demand and policy development.
- An evaluation of the assumptions made in the CER net-zero scenarios, including a comparison with the recently released net-zero roadmap from the IEA, and their implications for energy supply and the policies needed to maximize Canada's chances of meeting its net-zero mandate.

[6] Environment and Climate Change Canada, *National Inventory Report 1990–2021.*

3. Evolution of energy supply and the scale of the emissions problem

Although from the viewpoint of the average person alive today our present society based on continuous growth seems perfectly normal, the past two centuries represent an unparalleled period of growth and development of the human enterprise driven primarily by fossil fuels. Growth has brought prosperity to many, but has also resulted in unprecedented impacts from pollution, biodiversity loss (including what is sometimes referred to as the sixth mass extinction),[7] depletion of non-renewable resources and climate change.

The following section provides a brief overview of the development and scale of the emissions problem, both globally and in Canada, to provide an appreciation of the scale of the effort that will be required to reduce emissions in order to mitigate climate change.

3.1 World

It took 300,000 years from the first appearance of modern humans for population to reach one billion.[8] With the advent of abundant energy from fossil fuels, beginning with coal and then oil and gas, the human population has reached eight billion in a little over two centuries. Fossil fuel consumption has grown exponentially: half of the oil consumed by the human race has been burned in the past 27 years; half of the gas in the past 21 years; and half of the coal in the past 37 years.[9] As a result, 1.77 trillion tonnes of energy-related carbon dioxide emissions have been produced since 1750, half of which have been emitted in the past 30 years and 14% of which have been emitted since the landmark Paris Agreement of 2015.[10]
The explosive growth of the human enterprise is illustrated in Figure 2. Since 1800, annual energy consumption has increased 32 times, population has increased eight times, gross domestic product (GDP) has increased 114 times and anthropogenic carbon dioxide emissions have increased 1,321 times.[11]

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7 Yirka, B., "Anthropocene 'sixth mass extinction' event predicted to be worse than previously thought," May 24, 2023, Phsy Org, https://phys.org/news/2023-05-anthropocene-sixth-mass-extinction-event.html.

8 Handwerk, B., "An Evolutionary Timeline of Homo Sapiens," *Smithsonian Magazine,* February 2, 2021, https://www.smithsonianmag.com/science-nature/essential-timeline-understanding-evolution-homo-sapiens-180976807/.

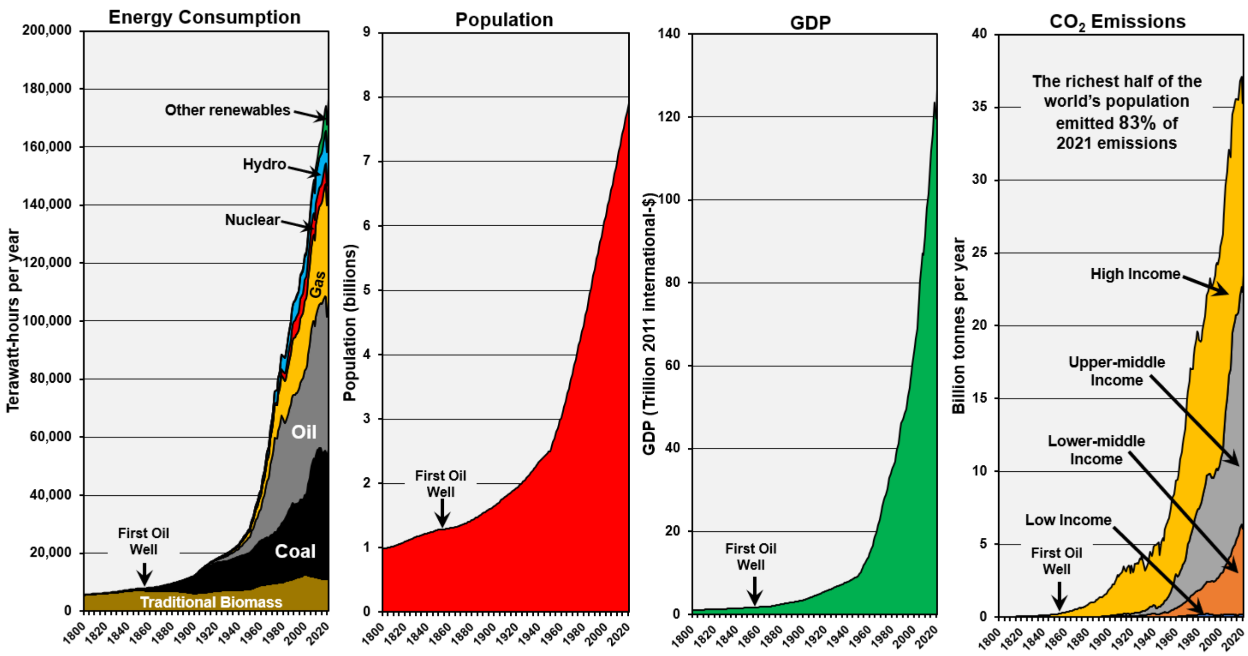
9 Compilation from various sources by Our World in Data retrieved September 3, 2023, https://ourworldindata.org/fossil-fuels.

10 Global Carbon Budget with major processing by Our World in Data, "Annual CO_2 emissions – GCB" [dataset].

11 Compilations from: Ritchie, H., and P. Rosado, "Energy Mix," January 2024 (revised), Our World in Data, https://ourworldindata.org/energy-mix; Ritchie, H. et al., "Data page: Population by world region," 2023, Our World in Data, https://ourworldindata.org/grapher/world-population-by-region-with-projections; Roser, M. et al., "Economic Growth," 2023, Our World in Data, https://ourworldindata.org/economic-growth; and Ritchie, H. and M. Roser, "CO_2 emissions," January 2024 (revised), Our World in Data, https://ourworldindata.org/co2-emissions (note that emissions from traditional biomass are not included as they are not anthropogenic).

Figure 2: Growth in global energy consumption since 1800 has allowed greatly accelerated growth in population, GDP and anthropogenic carbon dioxide emissions.[12]

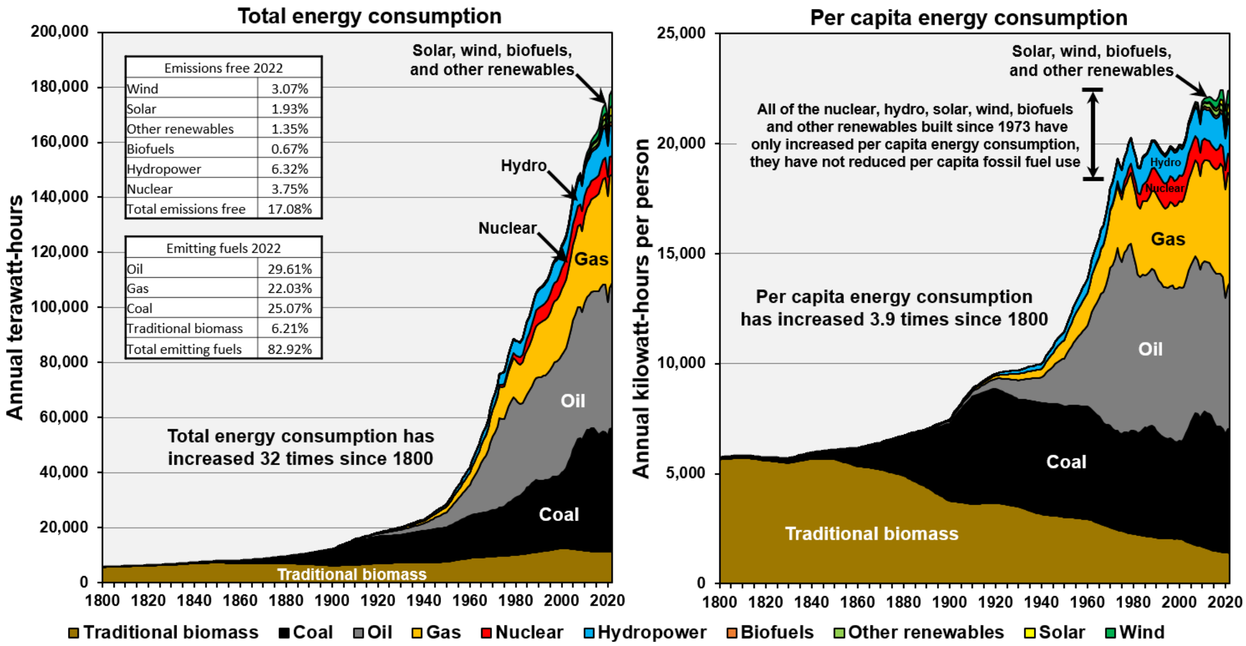
The beginning of the fossil fuel era is marked by the first oil well drilled in 1859, although small amounts of coal have been used in Europe since the 18th century. Figure data are current through year-end 2021.



Per capita energy consumption has also increased 3.9 times since 1800 due to the rapid growth in consumption of fossil fuels. Figure 3 illustrates total and per capita energy consumption from 1800 through 2022. After a period of rapid growth, per capita energy consumption of fossil fuels plateaued beginning in the early 1970s and most of the growth since then has been from hydro, nuclear and renewable sources. Of note, however, is that the growth of non-fossil fuel energy sources has not decreased per capita fossil fuel use—it has only served to increase overall energy consumption. In 2022 fossil fuels and biomass, both greenhouse gas-emitting sources, made up 82.9% of total energy consumption.

[12] Compilations from: Ritchie, H., and P. Rosado, "Energy Mix;" Ritchie, H. et al., "Data page: Population by world region"; Roser, M. et al., "Economic Growth"; Ritchie, H. and M. Roser, "CO_2 emissions," (note that emissions from traditional biomass are not included as they are not anthropogenic); and The World Bank, "Data for High income, Middle income, Low income," accessed November 2022, https://data.worldbank.org/?locations=XD-XP-XM.

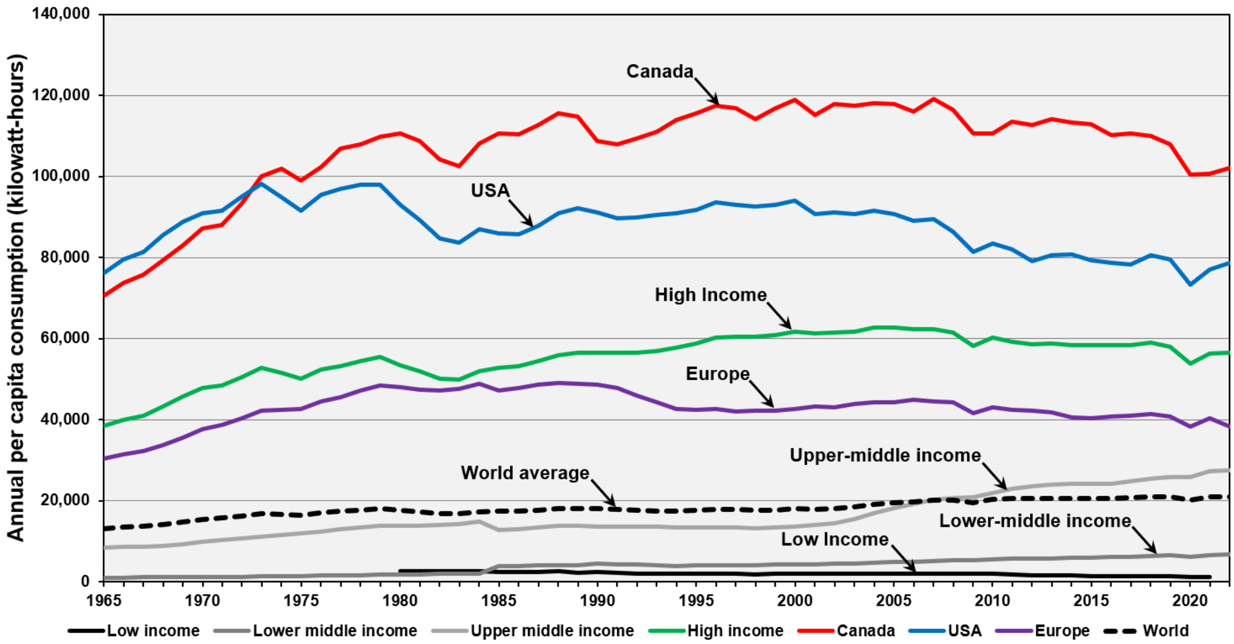
Figure 3: Total and per capita global energy consumption by source from 1800 to 2022.[13]
Energy from sources that produce electricity directly (hydro, nuclear, wind, solar) are illustrated using the "substitution method" (they are multiplied by 2.5 to account for 40% efficiency in converting fossil fuels to electricity).



There are great inequalities in energy consumption and resultant emissions between rich and poor countries. In 2022, Canadians had one of the highest per capita energy consumption levels in the world, at 4.9 times the world average and 2.8 times that of the average European. High-income countries (according to the World Bank classification) consumed 2.7 times the world average energy and 46 times low-income countries on a per capita basis. Per capita energy consumption over time is illustrated by income class and selected countries in Figure 4.

[13] Compilation from https://ourworldindata.org/energy-mix from: Appendix A of Vaclav S., *Energy Transitions: Global and National Perspectives,* 2nd edition (Santa Barbara: Praeger, 2017); and Energy Institute, *Statistical Review of World Energy*, 2023, https://www.energyinst.org/statistical-review/.

Figure 4: Per capita energy consumption by income class and selected countries from 1965 to 2022.
Canadians enjoy one of the highest per capita energy consumption levels in the world at 4.9 times the world average in 2022.[14]



Given that high-income countries have the highest per capita energy consumption and that 77% of the world's energy comes from fossil fuels, per capita emissions vary according to income. The richest half of the world's population produced 83% of global carbon dioxide emissions in 2021 and high-income countries, which account for 16% of world population, were responsible for 37% (Figure 2). High-income countries produced 35 times more emissions than low-income countries on a per capita basis in 2021, whereas Canadians and Americans produced four times the world per capita average and more than twice the per capita emissions of Europe. Table 1 summarizes the inequities in per capita carbon dioxide emissions by income class and for selected countries, as well as their relationship to the world average.

[14] Compilation based on energy data from Energy Institute, *Statistical Review of World Energy*, and United Nations population data in Ritchie, H., Rosado, P. and M. Roser, "Data Page: Primary energy consumption per capita," 2023, https://ourworldindata.org/grapher/per-capita-energy-use?tab=chart&country=Lower-middle-income+countries~High-income+countries~Low-income+countries~Upper-middle-income+countries.

Table 1: Per capita anthropogenic carbon dioxide emissions in 2021 for selected countries and World Bank income classes,[15] as well as their relationship to world average per capita emissions.
This does not include other greenhouse gases such as methane discussed below.

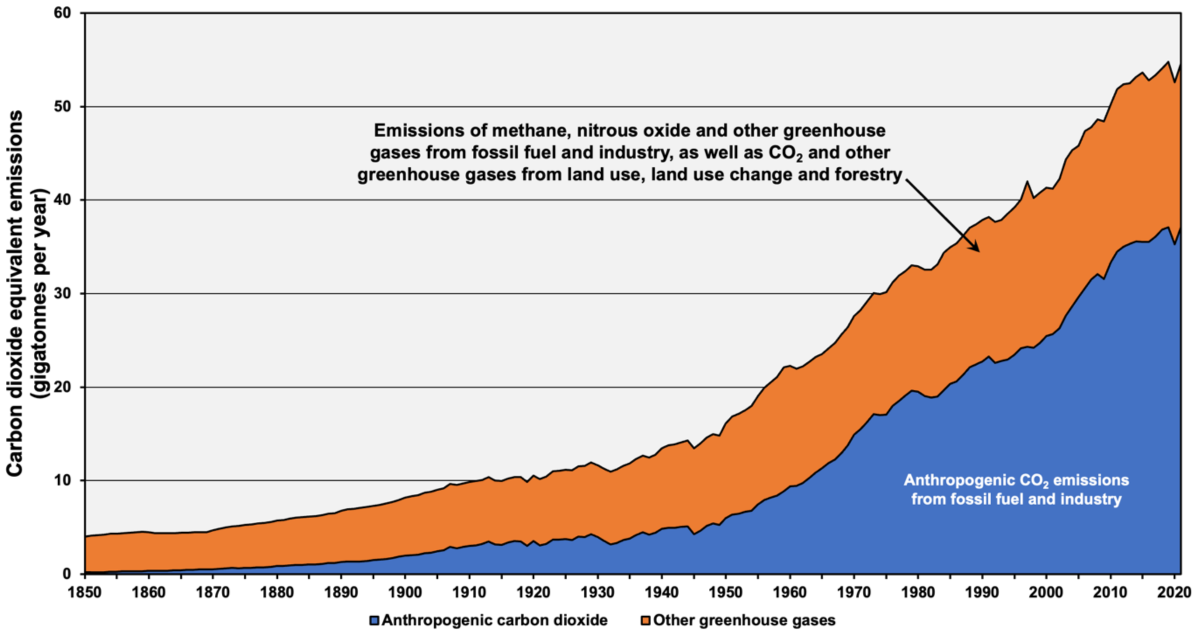
Country/income class	Tonnes/year	Relationship to world average (%)
United States	14.9	216.6%
Canada	14.3	204.7%
Europe	7.1	51.5%
World average	**4.7**	**0.0%**
India	1.9	-59.0%
Bangladesh	0.5	-88.4%
High-income	10.1	116.2%
Upper middle-income	6.7	42.1%
Lower middle-income	1.8	-60.6%
Low-income	0.3	-93.9%

In addition to anthropogenic carbon dioxide emissions produced from burning fossil fuels and industrial activities (primarily cement and steel production) illustrated in Figure 2 and Table 1, other greenhouse gases are produced from both fossil fuels and industry as well as other activities such as land use, land use change and forestry (LULUCF). Other greenhouse gases include methane, which is the most abundant, and nitrous oxide, both of which are much more potent greenhouse gases than carbon dioxide. Methane has a global warming potential (GWP) of 28 times that of carbon dioxide over 100 years and 81 times that of carbon dioxide over 20 years, whereas nitrous oxide is 273 times more potent than carbon dioxide on both 100- and 20-year time frames. Other non-carbon dioxide greenhouse gases include chlorofluorocarbons, hydrofluorocarbons and hydrofluorochlorocarbons, among others, that may have global warming potentials of several thousand times that of carbon dioxide but are present in extremely small quantities.[16] Figure 5 illustrates total global emissions using a global warming potential of 100 years for non-carbon dioxide gases. In 2021, anthropogenic carbon dioxide made up 68% of greenhouse gas emissions.

[15] Ritchie, H., Rosado, P. and M. Roser, "Data page: Per capita CO_2 emissions," 2023, Our World in Data, https://ourworldindata.org/grapher/co-emissions-per-capita?tab=chart.

[16] United Nations Intergovernmental Panel on Climate Change (IPCC), *Sixth Assessment Report (AR6)*, Chapter 7 supplementary material, 2023, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_07_Supplementary_Material.pdf.

Figure 5: Total world greenhouse gas emissions.
Anthropogenic carbon dioxide emissions are those from fossil fuel combustion and industrial activities (primarily cement and steel production). Other greenhouse gases include methane, nitrous oxide and other less abundant gases (which are shown here at a GWP of 100 years in accordance with protocols of the UN Framework Convention on Climate Change) as well as emissions from land use, land use change and forestry.[17]



3.2 Canada

The evolution of the economic and energy system in Canada has, like most of the rest of the world, undergone an explosive transformation in the past two centuries. In 1800, nearly 90% of Canada's energy was provided by firewood, with the balance from human and animal muscle and a small amount of coal. Coal use increased throughout the 19th century and became the dominate energy source in the early 20th century before being overtaken by oil and gas in the mid-20th century. Electricity produced by burning fossil fuels, nuclear, hydro and renewable sources grew to about 20% of end-use energy consumption by the end of the 20th century. Figure 6 illustrates the evolution of the Canadian energy system from 1800 to 2010. Since 1800, Canada's population has grown 134 times, from approximately 300,000 to 40 million, and energy consumption has grown by 269 times.[18]

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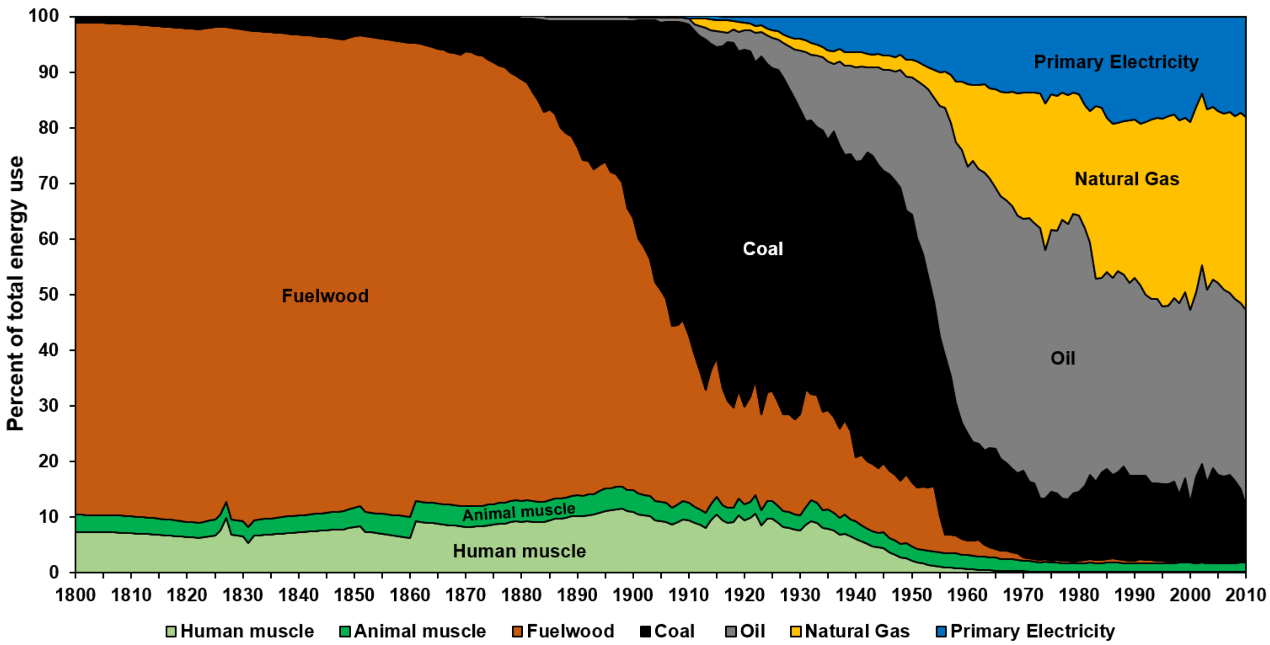
[17] Global Carbon Budget with major processing by Our World in Data, "Annual CO_2 emissions including land-use change – GCB" [dataset], Global Carbon Project, "Global Carbon Budget" [original data], accessed September 2023, https://ourworldindata.org/explorers/co2.

[18] Unger, R.W. and J. Thistle, *Energy Consumption in Canada in the 19th and 20th Centuries. A Statistical Outline,* (Naples: CNR, 2013), ctd. in Harvard University Center for History and Economics, "Energy History," Total energy consumption in Canada, 1800-2010, accessed May 2022, https://histecon.fas.harvard.edu/energyhistory/energydata.html. End-use energy consumption in 2022 from Canada Energy Regulator, *Canada's Energy Future 2023*.

Figure 6: Energy consumption by source in Canada from 1800 to 2010.[19]
Primary electricity includes hydropower, nuclear power, wind, photo-voltaics, tidal, wave, solar thermal and geothermal (i.e., it does not include natural gas and coal used to generate electricity).



Greenhouse gas emissions accompanying this explosive growth in energy consumption are illustrated in Figure 7. Anthropogenic carbon dioxide emissions from fossil fuel combustion and industry made up 70% of greenhouse gas emissions in Canada in 2021. Emissions from forestry are not included in Canada's National Inventory, hence the official tally of emissions illustrated in Figure 1 is lower than shown in Figure 7. Forestry emissions have been highly variable in the past two decades and Canada's forests, which had long been a major carbon sink, have become significant emitters since 2001, as will be discussed in a following section.

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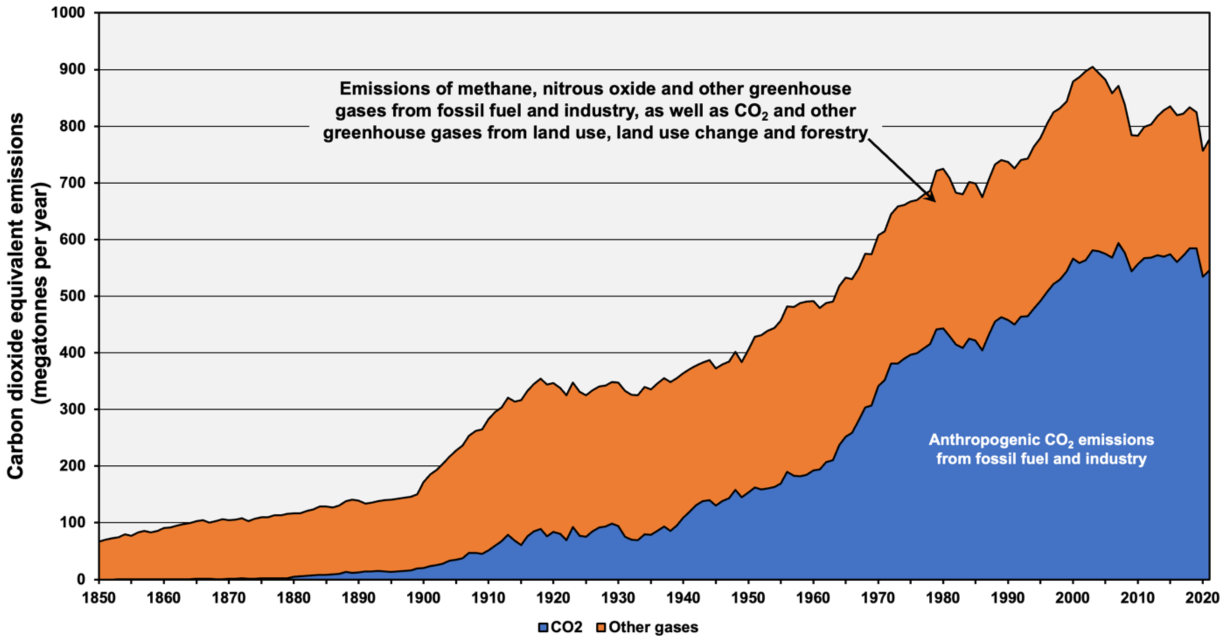
[19] Harvard University Center for History and Economics, *Energy Consumption in Canada*.

Figure 7: Total Canadian greenhouse gas emissions.
Anthropogenic carbon dioxide emissions are those from fossil fuel combustion and industrial activities (primarily cement and steel production). Other greenhouse gases include methane, nitrous oxide and other less abundant gases (which are shown here at a GWP of 100 years in accordance with protocols of the UN Framework Convention on Climate Change) as well as emissions from land use, land use change and forestry.[20]



3.2.1 ENERGY PRODUCTION, EXPORTS AND REVENUE

Canada's production of energy grew 46-fold over the 1900—2022 period to meet growing demand, first from coal and then from oil and gas, as illustrated in Figure 8. Energy production from large hydro and nuclear began in the mid-20th century followed by growth from other renewable energy sources such as wind, solar and biofuels. Much of the energy produced from fossil fuels was exported towards the end of this period, although prior to 1980 Canada imported significant amounts of fossil fuels.

In 2022, 90.8% of primary energy production came from fossil fuels: 54% from oil, 31% from natural gas and 6% from coal. Hydro, nuclear and non-hydro renewables such as wind, solar and biofuels accounted for just 9%. However, because they produce electricity directly unlike fossil fuels, which have an electric conversion efficiency of about 40%, these sources make up a much larger share of end-use energy consumption.

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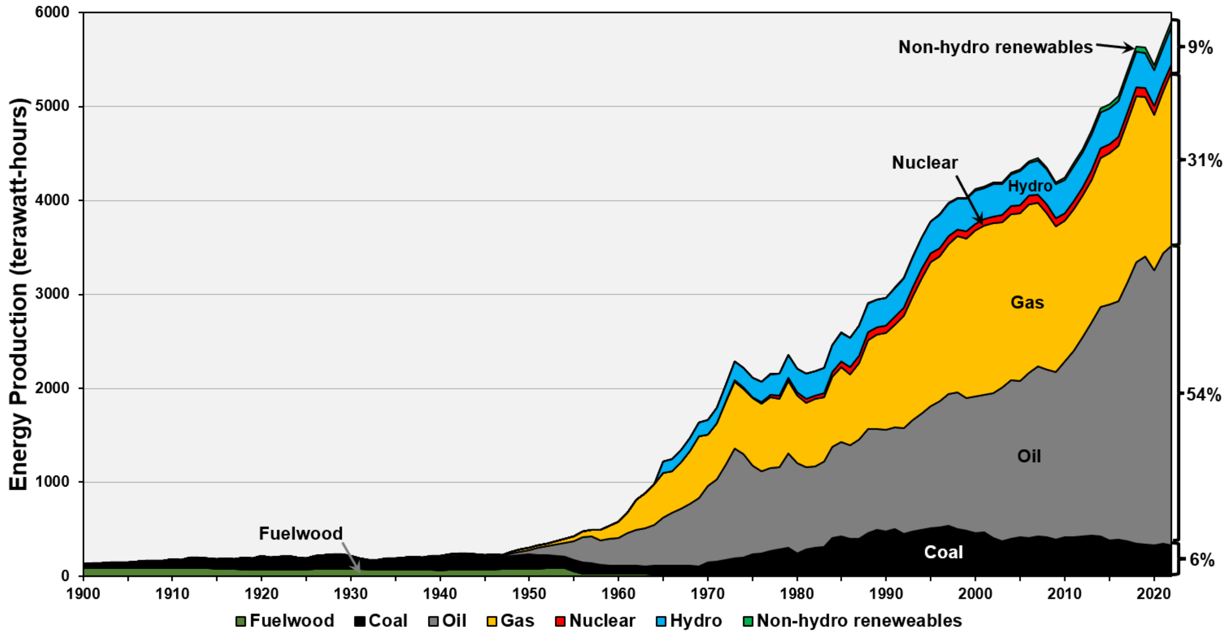
[20] Global Carbon Budget with major processing by Our World in Data, "Annual CO_2 emissions including land-use change – GCB" [dataset], Global Carbon Project, "Global Carbon Budget" [original data].

Figure 8: Primary energy production by fuel in Canada from 1900 to 2022.[21]

Energy production grew 46-fold over the 1900–2022 period with fossil fuels making up 91% of production in 2022.



Over half of the fossil fuels produced in 2022 were exported: oil to the U.S. and international markets; gas primarily to the U.S.; and coal to markets in Asia. Prior to 1983, Canada was a significant importer of both oil and coal, however, development of the oil sands in Alberta, metallurgical coal mines in B.C., and low permeability oil and gas reservoirs, has allowed production to grow rapidly since. Figure 9 illustrates fossil fuel production, consumption, imports and exports over the past 57 years. Investments in additional export capacity with the completion of the Trans Mountain pipeline in 2024 and Phase 1 of LNG Canada in 2025 suggest exports will continue to grow in the future.

[21] Compilation by Ritchie, H. et al., "Data on Energy," Our World in Data, retrieved August 2023, https://github.com/owid/energy-data. See reference 19 above for fuelwood.

Figure 9: Fossil fuel production, consumption, imports and exports in Canada since 1965.[22]
Imports and exports are shown on a "net" basis by subtracting consumption from production. Due to distance and lack of infrastructure, oil and gas are still imported into eastern Canada from the U.S. and offshore and offset by exports from western Canada, hence they don't appear in this figure.

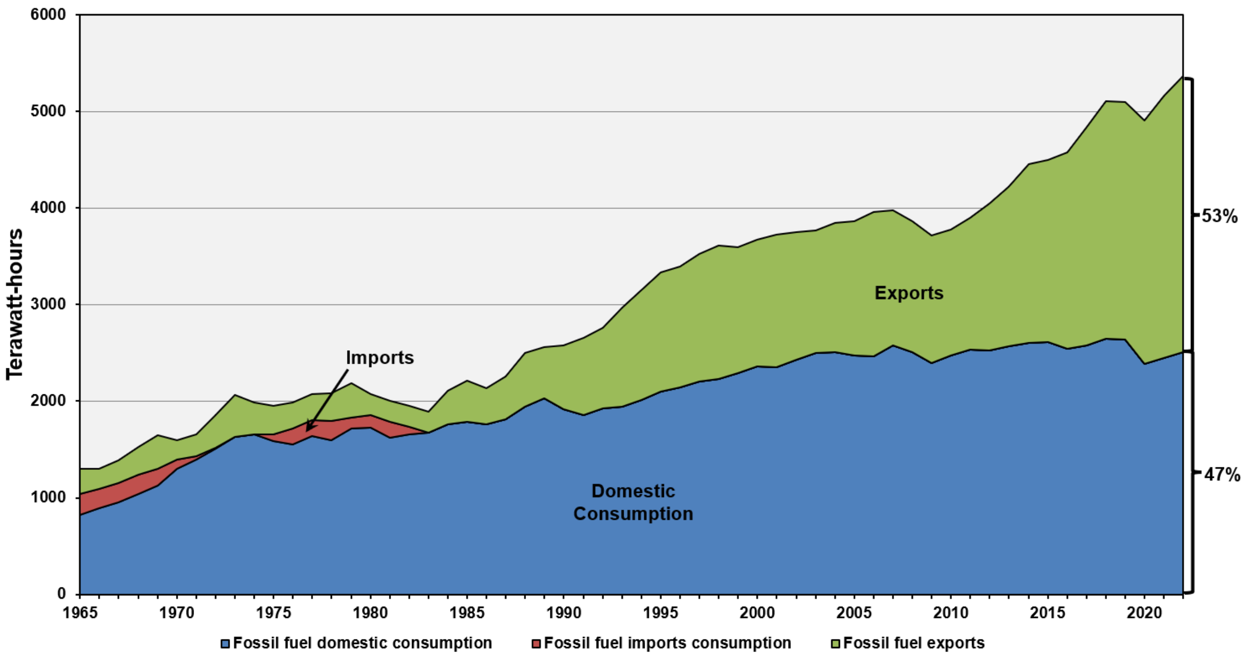


Figure 10 illustrates production, consumption, imports and exports by fossil fuel commodity. Oil is by far Canada's most important fossil fuel in terms of volume and exports. Oil production has nearly tripled since the early 1980s and 63% of production was exported in 2022, mainly to the U.S. The U.S. is home to more than half of the world's complex refinery capacity capable of optimizing the production of diverse products from the heavy oil that is Canada's primary export, although some Canadian oil is sent to international markets through the existing Trans Mountain pipeline and via U.S. pipelines to the Gulf Coast.

Natural gas production has also tripled from the late 1960s, but in terms of energy content is only a little over half that of oil. Thirty-four per cent of Canada's natural gas production was exported via pipeline to the U.S. in 2022. The governments of Canada and B.C. have approved four LNG export terminals in B.C. that would require a 25% increase in Canadian gas production should they all be built. The first of these terminals, Phase 1 of LNG Canada in Kitimat, is set to be operational in 2025, along with the controversial Coastal Gas Link pipeline, which will supply its gas.

Coal production peaked in Canada in 1998 and declined sharply beginning in 2014 with the phase-out of much of the thermal coal electricity generation in Alberta. Thermal coal consumption for electricity generation has remained constant in Saskatchewan as has metallurgical coal production for export in B.C. A small amount of thermal coal is also produced in eastern Canada. Even at peak production, coal in Canada was dwarfed by oil and gas in terms of energy content.

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22 Energy Institute, *Statistical Review of World Energy*.

Figure 10: Oil, gas and coal production, consumption, imports and exports in Canada since 1965.[23]
Imports and exports are shown on a "net" basis by subtracting consumption from production.

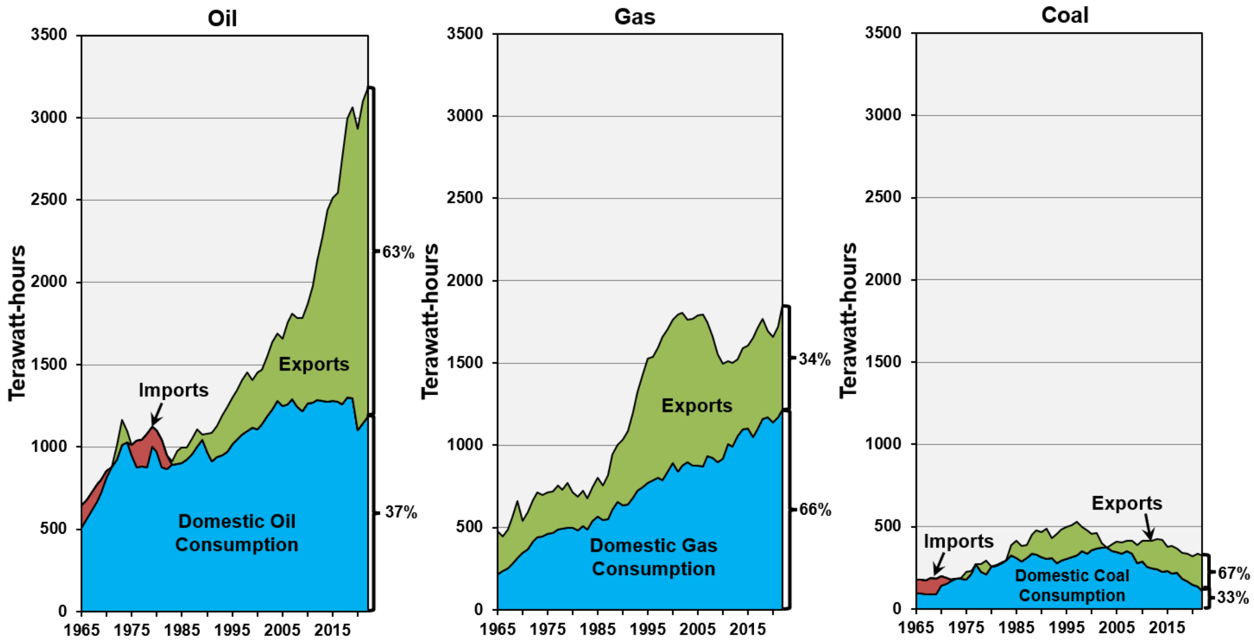

Figure 11 illustrates the proportion of Canada's fossil fuel consumption and exports made up of oil, gas and coal. Although oil has dominated fossil fuel consumption for most of the 1965–2022 period, it is now equaled by natural gas which has increased to replace the phase-out of coal for electricity generation in Ontario and Alberta. Oil and gas now make up 96% of domestic fossil fuel consumption as the coal phase-out continues.

In terms of fossil fuel exports, oil is by far the most important commodity, accounting for 70% of exports. Most natural gas production is used domestically as it is largely landlocked, although 22% of production was exported to the United States in 2022. The completion of the LNG Canada export terminal in British Columbia in 2025, and government aspirations for additional terminals, will allow export growth to international markets. Most coal production in Canada is now metallurgical grade for steel-making that is exported to Asia from mines in B.C. and Alberta, although thermal coal for electricity generation is also produced in Alberta, Saskatchewan and Nova Scotia. Canada imports coal, primarily for steel-making, in eastern Canada. In 2021, Canada exported 32 million tonnes of coal and imported six million tonnes.[24]

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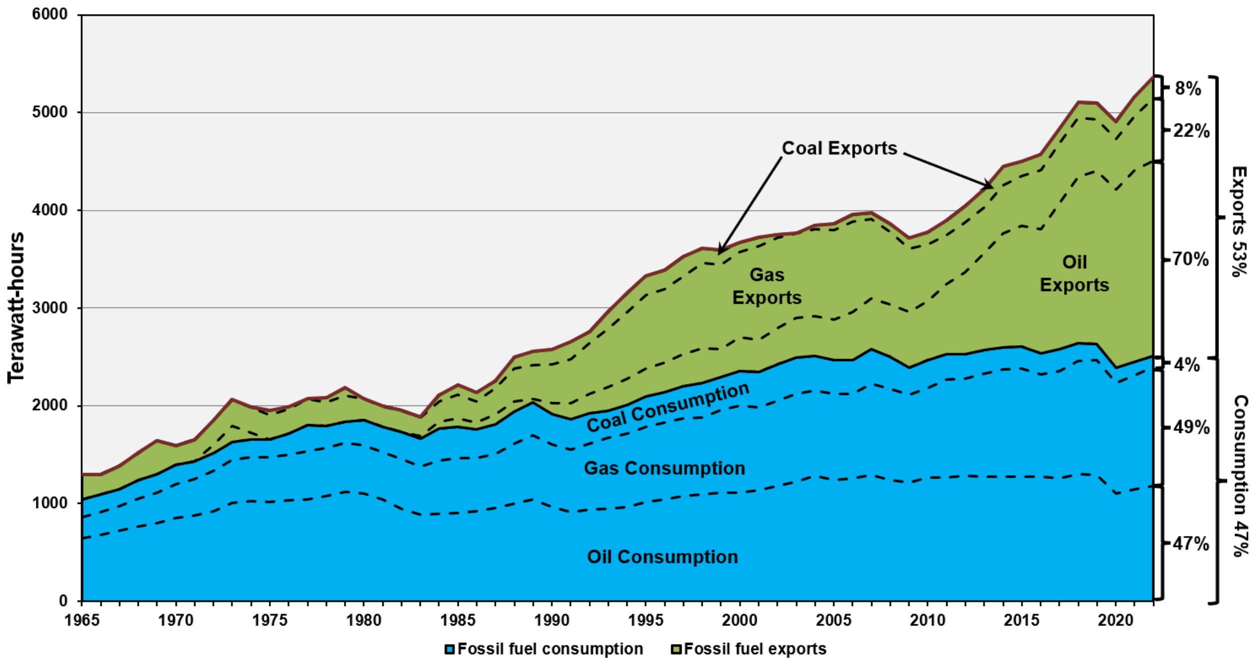
[23] Energy Institute, *Statistical Review of World Energy*.

[24] Natural Resources Canada, "Coal Facts," 2023, https://natural-resources.canada.ca/our-natural-resources/minerals-mining/mining-data-statistics-and-analysis/minerals-metals-facts/coal-facts/20071.

Figure 11: Canada's fossil fuel production, consumption and exports illustrating the proportion of oil, gas and coal consumed and exported.[25]

Exports are shown on a "net" basis by subtracting consumption from production.



Under the Constitution of Canada and the Natural Resources Act,[26] the provinces have jurisdiction over energy resources as well as revenues from their production. Given that fossil fuels are concentrated in only a few provinces, and that the production of fossil fuels generates substantial emissions, these jurisdictional issues have created conflicts between provincial and national priorities over emissions reduction.

Figure 12 illustrates oil, gas and coal production by province. As of year-end 2022, Alberta controlled the largest share of Canada's fossil fuel production by far, with 83% of oil, 61% of gas and 21% of coal production. Saskatchewan was second, with 9%, 2% and 22% of oil, gas and coal production, respectively, and British Columbia was third with 2%, 37% and 58% of oil, gas and coal production, respectively. Newfoundland and Labrador is also a significant oil producer from offshore Atlantic oilfields, with 5% of Canada's production.

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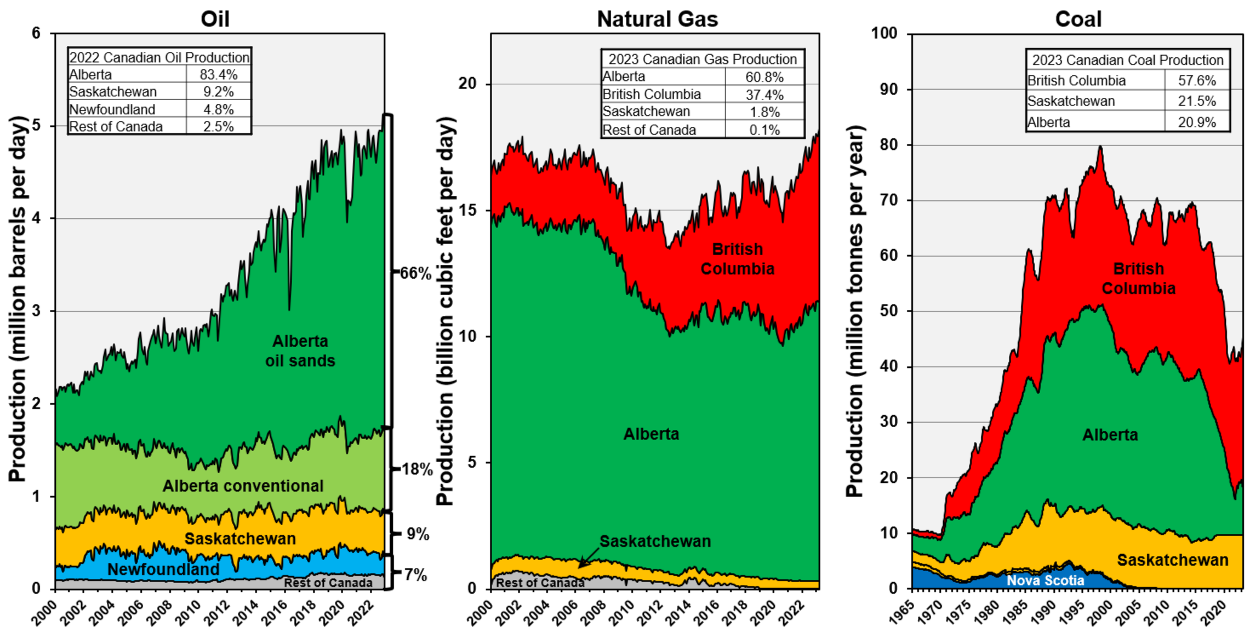
[25] Energy Institute, *Statistical Review of World Energy*.

[26] Wikipedia, "Energy policy of Canada," retrieved September 19, 2023, https://en.wikipedia.org/wiki/Energy_policy_of_Canada.

Figure 12: Production of fossil fuels by province.[27]

The percentages of Canadian oil, gas and coal production by province in mid-2023 is also indicated.



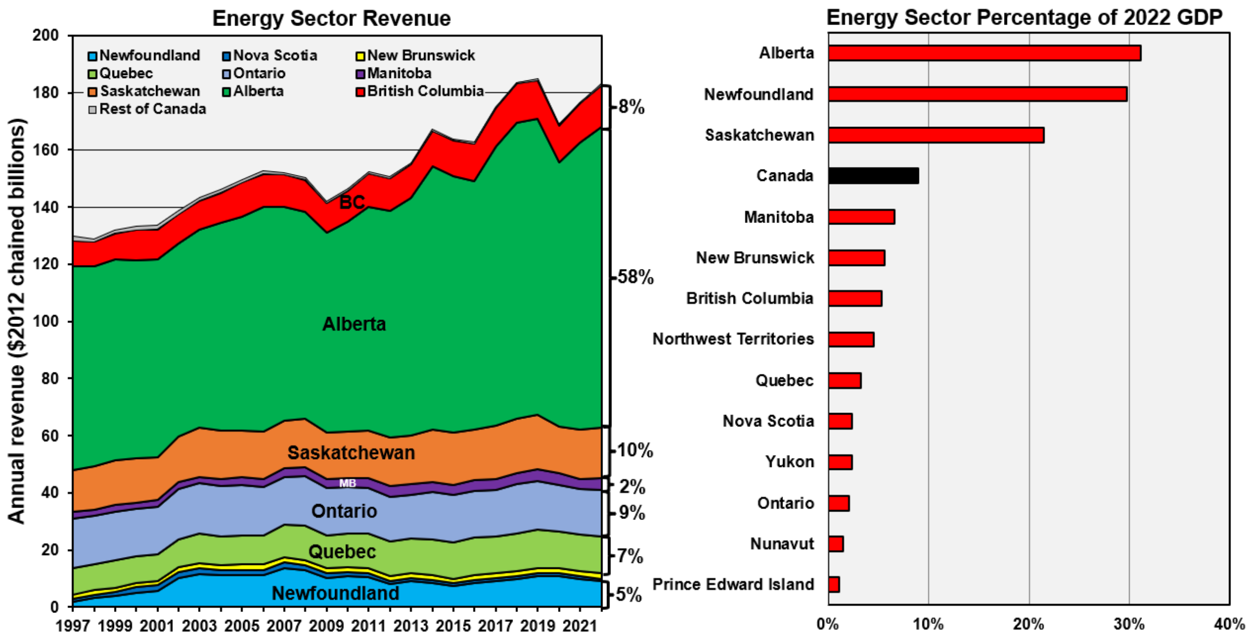
The contribution of the energy sector to provincial economies and Canada's overall GDP is illustrated in Figure 13. Although total revenue from the energy sector has grown 41% from 1997 to 2022, its proportional contribution to Canada's GDP has declined slightly, from 11% to 8.9%, over this period.[28] Alberta, Newfoundland and Labrador and Saskatchewan were the most reliant on the energy sector in 2022, at 31.1%, 29.8% and 21.4% of total GDP, respectively. Alberta's oil production has doubled since 2010 and the GDP contribution of its energy sector has increased 44%, thanks almost exclusively to the expansion of the oil sands, one of the most emissions-intensive sources of oil in the world. Similarly, British Columbia's energy sector GDP has increased 34% since 2010 as its natural gas production doubled, largely through development of the very large Montney play made possible by the advent of high-volume hydraulic fracturing (fracking).

[27] Oil production from Canada Energy Regulator, "Estimated Production of Canadian Crude Oil and Equivalent," https://www.cer-rec.gc.ca/en/data-analysis/energy-commodities/crude-oil-petroleum-products/statistics/estimated-production-canadian-crude-oil-equivalent.html; marketable natural gas production from Canada Energy Regulator, "Marketable Natural Gas Production in Canada," https://www.cer-rec.gc.ca/en/data-analysis/energy-commodities/natural-gas/statistics/marketable-natural-gas-production-in-canada.html; and coal production from Statistics Canada tables 2510004601 and 2510004801. Retrieved September 2023.

[28] Statistics Canada, "Gross domestic product (GDP) at basic prices, by industry, provinces and territories," Table 36-10-0402-01, November 8, 2023, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610040201.

Figure 13: GDP of the energy sector by province from 1997 to 2022 and the contribution of the energy sector to total provincial GDP in 2022.[29]

Also shown is the proportion of Canada's total energy sector GDP contributed by each province in 2022.



A recent report has found that Canada is poised to be the world's second-largest developer of new oil and gas extraction to 2050.[30] Further expansion of oil and gas production is likely, at least in the medium term, given projects currently under development. British Columbia's gas production will continue to grow with the commissioning of LNG Canada's export terminal, currently under construction in Kitimat and slated to be completed in 2025, as well as potential development of Phase 2 of LNG Canada and three other LNG projects that have received environmental approval and a fourth that is undergoing review. In Alberta, the federally funded Trans Mountain expansion project will come on line in 2024 providing an additional 590,000 barrels per day of pipeline capacity for expanded oil sands production and export. These expansions will lock in emissions for the next several decades.

3.2.2 ENERGY CONSUMPTION AND EMISSIONS

Fossil fuel production has more than doubled since 1990, which has made upstream production, refining and transportation of oil and gas the largest source of Canada's emissions. Annual emissions from the oil and gas sector have grown from 100 to 189 megatonnes per year since 1990 and made up 28% of Canada's emissions in 2021, the most recent year for which data are available.[31] Figure 14 illustrates emissions by economic sector over the 1990-to-2021 period.

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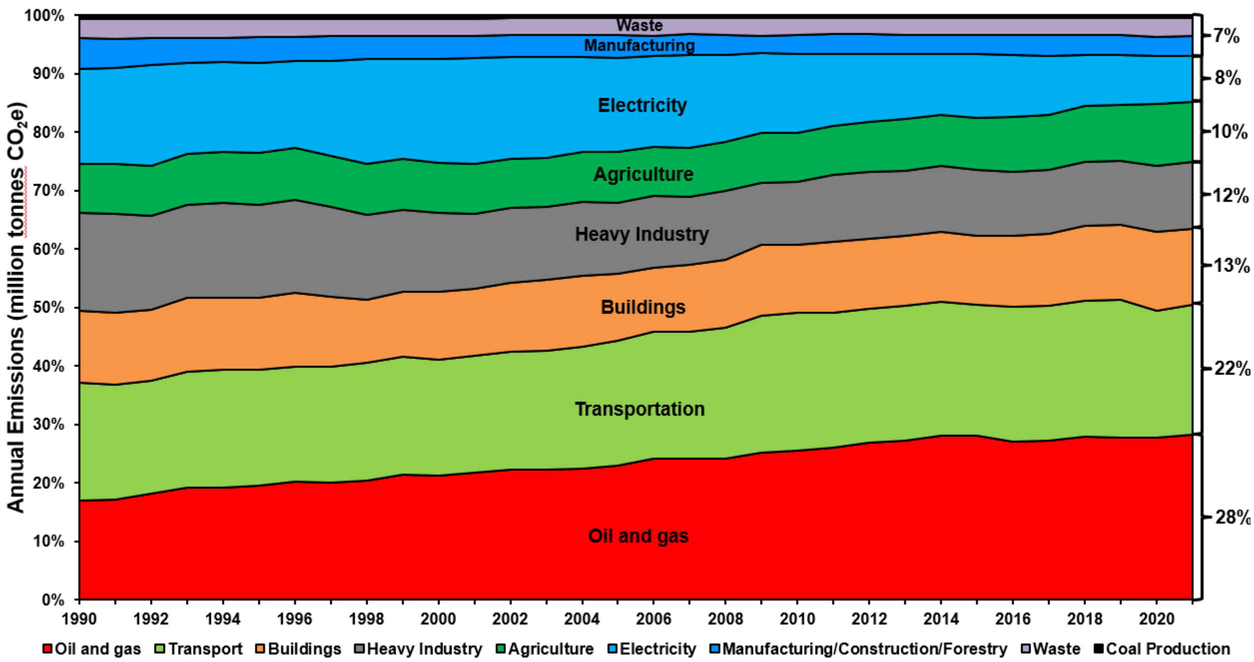
29 Statistics Canada, "Gross domestic product (GDP) at basic prices, by industry, provinces and territories."

30 Ioualalen R. and K. Trout, *Planet wreckers: How countries' oil and gas extraction plans risk locking in climate chaos,* September 2023, Oil Change International, https://priceofoil.org/2023/09/12/planet-wreckers-how-20-countries-oil-and-gas-extraction-plans-risk-locking-in-climate-chaos/.

31 Environment and Climate Change Canada, *National Inventory Report 1990–2021.*

Figure 14: Change in composition of Canada's emissions by economic sector from 1990-2021.[32]
The proportion of emissions from upstream oil and gas production, refining and distribution has increased from 17% to 28% over the period as a result of the doubling of production.



Progress through 2021 in emissions reduction since the 2005 base year for Canada's emissions reduction commitments and since the signing of the Paris Agreement in 2016 are summarized by economic sector in Table 2. Although there has been progress in most economic sectors (with the exception of oil and gas, buildings and agriculture), the rate of emissions reduction must increase radically if Canada is to have any hope of meeting its emissions reduction commitments.

Table 2: Emissions reduction by economic sector since the 2005 base year for Canada's emissions reduction commitments and since the signing of the Paris Agreement in 2016.[33]

Economic sector	Share in 2021	Change in emissions	
		Since 2005	Since 2016
Oil and gas	28.2%	12.5%	-1.0%
Transport	22.4%	-4.5%	-7.4%
Buildings	13.0%	2.4%	2.4%
Heavy industry	11.5%	-13.5%	-1.3%
Agriculture	10.3%	7.8%	4.5%
Electricity	7.7%	-55.9%	-29.7%
Manufacturing/construction/forestry	3.4%	-17.9%	-4.2%
Waste	3.1%	-4.5%	0.0%
Coal production	0.4%	0.0%	0.0%
Overall	100.0%	-8.5%	-5.0%

32 Environment and Climate Change Canada, *National Inventory Report 1990–2021*.

33 Environment and Climate Change Canada, *National Inventory Report 1990–2021*.

Canada's overall reduction of 8.5% since 2005 amounts to 3.9 megatonnes per year. This rate must be increased 6.6–7.7 times over the 2022–2030 period in order to meet Canada's 2030 emissions reduction goal. In the event that the 2030 goal is achieved, emissions reductions would need to be 5.2–5.6 times the 2005–2021 rate over the 2031–2050 period in order to achieve Canada's net-zero emissions commitment. Table 3 summarizes the emissions reductions and rate accelerations required.

Table 3: Emissions reductions achieved from 2005 to 2021 and reductions needed to meet Canada's emissions reduction commitments.[34]

The rate of emissions reduction must increase 6.6–7.6 times from 2005–2021 levels through 2022–2030 in order to meet Canada's 2030 emissions reduction goals and, if the 2030 goals are met, from 5.2–5.6 times from 2031–2050 in order to meet Canada's 2050 net-zero goal.

Time period	% below 2005 levels	Reduction per year (Mt)	Total reduction (Mt)	Rate acceleration required
2005–2021	8.5%	3.9	62	-
2022–2030	40–45%	25.6–29.7	231–267	6.6–7.6 times
2031–2050	100%	20.1–22	403–439	5.2–5.6 times

A recently released estimate of Canada's 2022 emissions indicates that Table 3 likely understates how much Canada's emissions reduction rates must increase in order to meet the 2030 goal. The Canadian Climate Institute's early estimate shows Canada's emissions have grown by 2.1% or 15 Mt from 2021 to 2022.[35] This puts Canada's emissions only 6.4% below 2005 levels, and that the average emissions reduction between 2005 and 2022 was just 2.8 Mt per year. This means emissions reductions would have to increase to 30.7–35.3 Mt per year in order to meet Canada's 2030 reduction goal, which is 11–12.7 times higher than the 2005–2022 average rate (Table 4).

Table 4: Emissions reductions required to meet Canada's commitment given the preliminary 2022 emissions estimate of the Canada Climate Institute.[36]

Time period	% below 2005 levels	Reduction per year (Mt)	Total reduction (Mt)	Rate acceleration required
2005–2022	6.4%	2.8	47	-
2023–2030	40–45%	30.7–35.3	245–282	11–12.7 times
2031–2050	100%	20.1–22	403–439	7–7.6 times

Total and per capita emissions by province are illustrated in Figure 15. Alberta and Saskatchewan, with just 15% of Canada's population, produced 48% of Canada's emissions in 2021 owing to the concentration of oil and gas production in these provinces. Per capita emissions within Alberta and Saskatchewan are three times the Canadian average, whereas Newfoundland and Labrador, which relies on oil production for a significant proportion of its economy, has much lower per capita emissions as it produces conventional light oil, not the much more emissions-intensive heavy oil and oil sands produced in Alberta and Saskatchewan.

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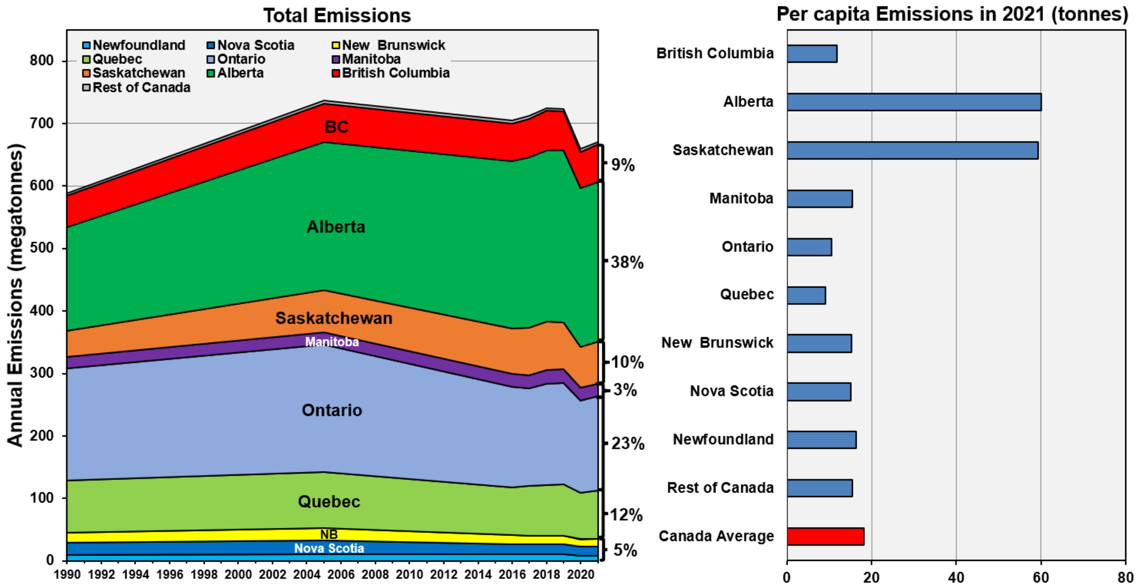
34 Environment and Climate Change Canada, *National Inventory Report 1990–2021.*

35 Canadian Climate Institute, "Early Estimate of National Emissions," September 28, 2023, https://440megatonnes.ca/early-estimate-of-national-emissions/?utm_source=newsletter&utm_medium=email&utm_campaign=440nsept27nee.

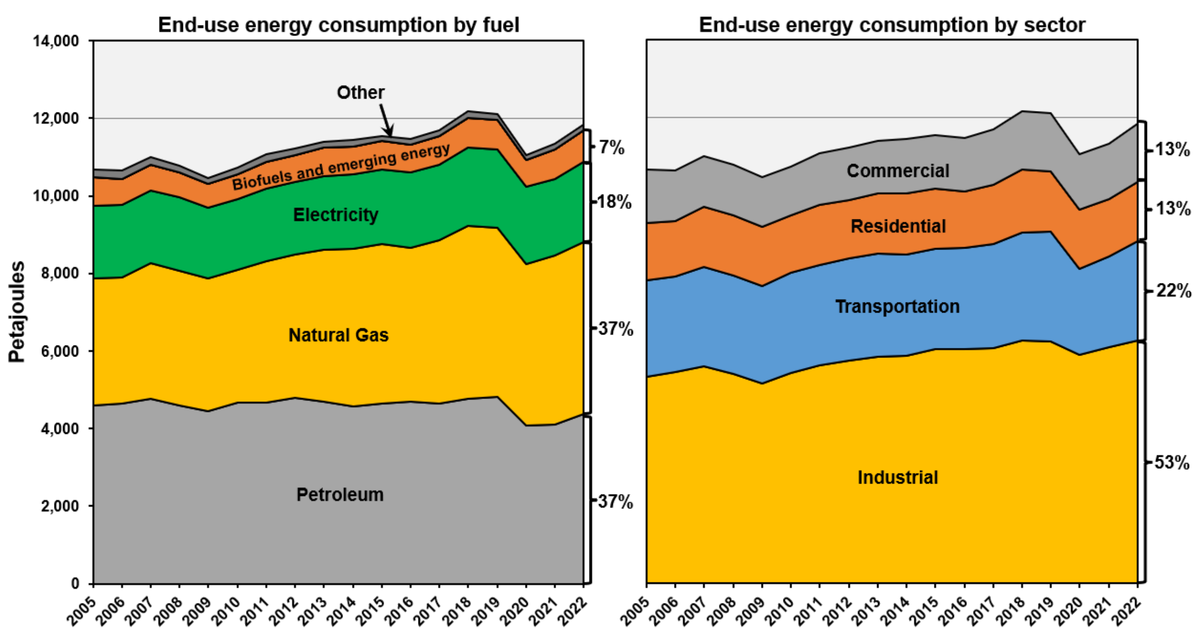
36 Canadian Climate Institute, "Early Estimate of National Emissions."

Figure 15: Total emissions over 1990-2021 and per capita emissions in 2021 by province.[37]



End-use energy consumption by fuel source and CER economic sector is illustrated in Figure 16. End-use energy is the final energy used at the point of consumption after conversion losses such as from fossil fuels to electricity. Fossil fuels, not including those used to generate electricity, amounted to 74% of total end-use consumption in 2022. Electricity, which is often looked upon as a replacement for fossil fuels to reduce emissions, made up just 17.6% of end-use consumption in 2022.

Figure 16: Canada's end-use energy consumption by fuel source and CER economic sector.[38]



[37] Environment and Climate Change Canada, *National Inventory Report 1990–2021*. Population data from Statistics Canada, Table 981000101, February 9, 2022, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=9810000101.

[38] Canada Energy Regulator, *Canada's Energy Future 2023*.

Although all sectors of the Canadian economy rely on fossil fuels for the majority of end-use energy supply, ranging from 54% for the residential sector to 93.6% for the transportation sector (see Table 5),[39] Canada is fortunate in that its electricity grid has relatively low emissions. In 2022, 81.3% of Canada's electricity was generated by emissions-free sources including hydro (59.4%), wind (7.8%), solar (1.2%) and nuclear (12.8%), with fossil fuels making up 17% (0.2% oil, 4.2% coal and 12.5% gas) and biofuel/geothermal the remaining 1.7%. Given that emissions-free electricity makes up only 14.3% of end-use energy consumption (ranging from 0.2% in the transportation sector to 35% in the residential sector), electrification provides a key pathway for reducing emissions.

Table 5: Canada end-use energy consumption in 2022 by CER economic sector and energy source.[40]

2022 end-use energy consumption by sector				
End-use sector	% fossil fuel	% biofuels	% emissions free electricity	Other
Residential	54.0%	11.1%	35.0%	0.0%
Commercial	69.0%	0.8%	30.2%	0.0%
Industrial	78.3%	8.1%	11.3%	2.2%
Transportation	93.6%	6.2%	0.2%	0.0%
Total end-use	77.4%	7.2%	14.3%	1.2%

Figure 17 illustrates end-use energy consumption with electricity disaggregated into its component sources. Fossil fuels make up 77.4% of Canada's total end-use energy consumption including fossil fuels that are used to generate electricity. Emissions-free energy sources make up only 14.3% of Canada's end-use energy supply in 2022. Biofuels and other sources including geothermal energy make up the remaining 8.3% (geothermal provides very little energy in Canada at present). Although emissions from burning biofuels and biomass are not included in official tallies of emissions as biomass grows back removing the emissions from its combustion, the time lag between combustion and emissions removal may be years or decades, and for this reason are not included as "non-emitting" in Figure 17.[41]

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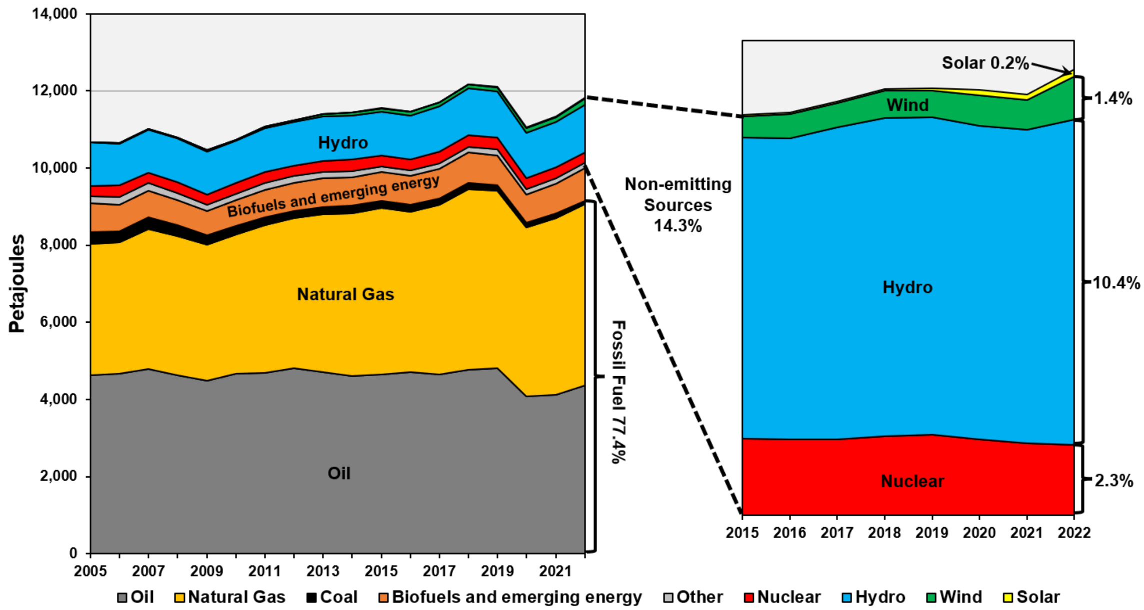
[39] Canada Energy Regulator, *Canada's Energy Future 2023.*

[40] Canada Energy Regulator, *Canada's Energy Future 2023.*

[41] U.S. Energy Information Administration "Biofuels explained: biofuels and the environment," April 13, 2022, https://www.eia.gov/energyexplained/biofuels/biofuels-and-the-environment.php.

Figure 17: Canada's end-use energy consumption with electricity disaggregated into component fuel sources.[42]

Fossil fuels, including those used to generate electricity, made up 77.4% of Canada's end-use energy consumption in 2022.



Recent growth rates of the non-emitting energy sources illustrated in Figure 17 are given in Table 6. Hydro generation, which is by far the largest source of non-emitting energy, has been relatively flat over the past five years and although there is significant potential in Canada, new hydro projects require long time frames and are likely to face significant public opposition. Recent hydro projects at Muskrat Falls in Labrador and Site C in British Columbia have both faced massive cost overruns. The second-largest source of non-emitting energy—nuclear power—has been declining over the past five years and similarly requires long time frames for development, although there is hope for lower costs and faster construction times with the development of small, modular reactors (SMRs), which so far have had very little deployment. Wind and solar have grown at annual rates of 43% and 13%, respectively, over the past five years, and have much shorter construction times than either hydro or nuclear, although they currently contribute a combined total of only 1.6% of end-use energy.

Table 6: Growth rates of non-emitting energy sources in Canada over the most recent 2-, 5- and 10-year periods and the proportion of end-use energy contributed by each source in 2022.[43]

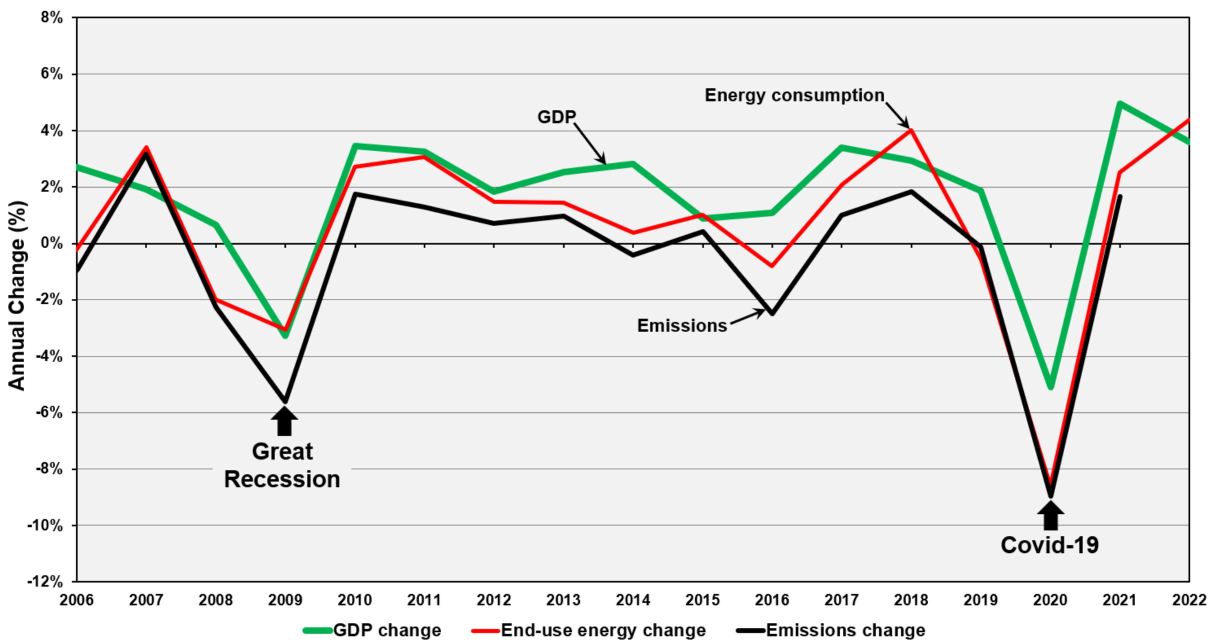
	Growth rate			
Non-emitting energy source	10 years	5 years	2 years	End-use energy contribution in 2022 (%)
Nuclear	0.0%	-1.5%	-4.0%	2.25%
Hydro	0.9%	0.9%	2.0%	10.44%
Wind	15.5%	12.7%	20.4%	1.38%
Solar	32.3%	43.0%	18.2%	0.22%

[42] Canada Energy Regulator, *Canada's Energy Future 2023.*

[43] Canada Energy Regulator, *Canada's Energy Future 2023.*

In the past, given the strong correlation between energy consumption and GDP, significant emissions reductions have occurred mainly during economic recessions in Canada. Figure 18 illustrates growth in energy consumption, GDP and emissions over the 2006–2021 period. Significant emissions reductions occurred only during the Great Recession of 2008–2009 and during the economic downturn as a result of the Covid-19 pandemic in 2020.

Figure 18: Annual change in GDP, energy consumption and emissions in Canada, 2006–2022.[44]



[44] GDP from Statistics Canada, "Gross domestic product (GDP) at basic prices, by industry, monthly, growth rates," Table 36-10-0434-02, accessed September 19, 2023, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610043402; energy consumption from Canada Energy Regulator, *Canada's Energy Future 2023*; emissions from Environment and Climate Change Canada, *National Inventory Report 1990–2021*.

4. Canada Energy Regulator scenarios for net-zero emissions

In June, 2023, the Canada Energy Regulator (CER) published *Canada's Energy Future 2023* (EF2023), which marked the first time CER had developed scenarios to determine what achieving net-zero emissions by 2050 might involve. CER was careful to note that its scenarios were not predictions or recommendations and that they did not represent an official government position or policy direction. Nonetheless, the CER net-zero scenarios—which are based on an economic analysis of current and announced government policies, technical factors and the most comprehensive knowledge base of Canadian energy data available—provide an important starting point for understanding what a transition to net-zero emissions might require.

In EF2023, CER developed the following three scenarios, two of which reach the government-mandated net-zero goal in 2050:

- Global net-zero scenario: Canada reaches net-zero in 2050 along with the rest of the world. Provincial and federal policies in place and announced but not yet implemented as of March 2023, are considered.
- Canada net-zero scenario: Canada reaches net-zero in 2050 but the rest of the world does not. Provincial and federal policies in place and announced but not yet implemented as of March 2023, are considered.
- Current measures scenario: Canada does not reach net-zero. Only policies in place prior to March 2023, are considered.

Over the 2030 to 2050 period in the two net-zero scenarios, CER also relied on hypothetical policies that were expressed as the aggregate cost of carbon defined by its iterative modelling process. The aggregate cost of carbon was assumed to increase steadily, from $0 per tonne of carbon dioxide equivalent (CO_2e) in 2030 to $285 per tonne of CO_2e in 2050 in the global net-zero scenario, and to $335 per tonne of CO_2e in the Canada net-zero scenario (note that in Appendix 2 this aggregate cost of carbon differs from the main text and is reported as $330 and $380 in 2050, respectively).[45] In both net-zero scenarios this is in addition to the federal backstop carbon price of $140 per tonne of CO_2e in 2030 (all prices are in constant 2022 dollars).

In addition to these three scenarios, CER also considered the potential effects of five "what-if" cases:

- What if the technologies to enable wide-scale adoption of hydrogen are more or less costly?
- What if small modular reactor (SMR) technology matures less quickly and is more costly?
- What if direct air capture (DAC) technology matures more quickly and is less costly?
- What if carbon capture, utilization and storage (CCUS) technology does not mature as quickly and is more costly?
- What if electric vehicle charging patterns result in higher peak electricity demand?

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[45] See Chapter 2 and appendix 1 in Canada Energy Regulator, *Canada's Energy Future 2023.* Note that the aggregate cost of carbon in Appendix 1 differs from the text on page 31 cited above and states "Global Net-zero Scenario: Starting at $0/t CO_2e (carbon dioxide equivalent) in 2030 and rising to $330 in 2050. Canada Net-zero Scenario: Starting at $0/t CO_2e in 2030 and rising to $380 in 2050."

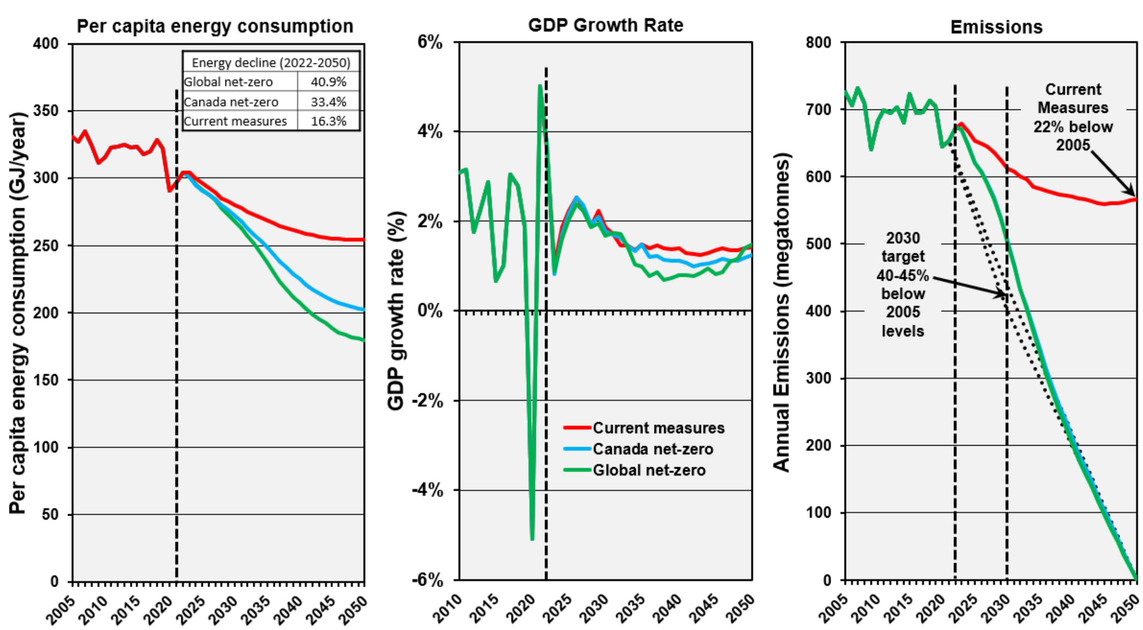
Of the three scenarios, the global net-zero scenario is of most interest as it models the outcome of least harm to the world and Canadians and is therefore the primary focus of the following discussion. The Canada net-zero scenario assumes that oil and gas prices will remain higher and that Canada could generate revenue by producing and exporting additional oil and gas, even though doing so would make the climate worse for the world and Canadians. The current measures scenario would mean a disastrous outcome for Canada and the world but has no chance of occurring if announced government policies are implemented.

The following discussion first reviews the outputs of the modelled scenarios and their implications for needed policy change, and then evaluates key assumptions that appear overly optimistic and the implications should they fail to be achieved.

4.1 Macro-indicators and outputs

Some of the overall outputs from the CER scenario modelling are illustrated in Figure 19. Canada's population is projected to grow by 27% between 2022 and 2050 in all three scenarios, whereas total end-use energy consumption is projected to decline 15–25% in the two net-zero scenarios and grow by 7% in the current measures scenario. This means that per capita energy consumption would decline by 33–41% in the two net-zero scenarios and by 16% in the current measures scenario. The economy is projected to grow modestly in all three scenarios with an annual increase in GDP of 1–2.4% per year over the 2022–2050 period. Emissions are projected to be 31% below 2005 levels by 2030 in the two net-zero scenarios, meaning that Canada would miss its legislated 2030 goal of 40–45% below 2005 levels. Emissions in the current measures scenario are projected to decline 16% from 2005 levels by 2030 and 22% by 2050.

Figure 19: Per capita end-use energy consumption, GDP and emissions by scenario from the CER modelling.[46]
Per capita energy consumption declines 33–41% from 2022 levels in the two net-zero scenarios and 16% in the current measures scenario and annual GDP growth ranges between 1–2.4% over the 2022–2050 period in all three scenarios. Canada's 2030 emissions reduction goal of 40–45% below 2005 levels is not met in either net-zero scenario and the current measures scenario achieves only a 22% reduction by 2050.



46 Canada Energy Regulator, *Canada's Energy Future 2023.* See Data Appendix.

4.2 End-use energy demand

End-use energy demand is final energy consumption at the point-of-use after conversion losses such as the 50–60% loss when coal or gas is converted to electricity. End-use energy demand by source and CER scenario is summarized in Table 7 and illustrated in Figure 20. Major trends in end-use energy demand in the two net-zero scenarios over the 2021–2050 period include:

- An 86–99% increase in electricity supply for electrification of transport, buildings and other sectors. Electricity grows from 17.4% of energy supply in 2021 to 39–41% in 2050.
- A 47–55% growth in biofuels and emerging energy. Biofuels and emerging energy grow from 6.7% of energy supply to 11–12%.
- A 2,939–3,236 times increase in the use of hydrogen as a fuel in the transportation and other sectors. Hydrogen grows from almost nothing to 11–12% of energy supply. Hydrogen at present is mainly used as a feedstock in emissions-intensive industrial sectors such as oil refining, ammonia production, methanol production and steel production.[47]
- A 61–62% decline in oil consumption and a 50–66% decline in natural gas consumption as these fuels are replaced with electricity, biofuels and hydrogen. Fossil fuels decline from 75% of energy supply to 35–38%.

Table 7: End-use energy demand by energy source and scenario as a share of total energy supply in 2021 and 2050 and the percentage change in supply over the 2021–2050 period.[48]
Also shown is the total energy supply in 2021 and 2050 by scenario and its change over the 2021–2050 period.

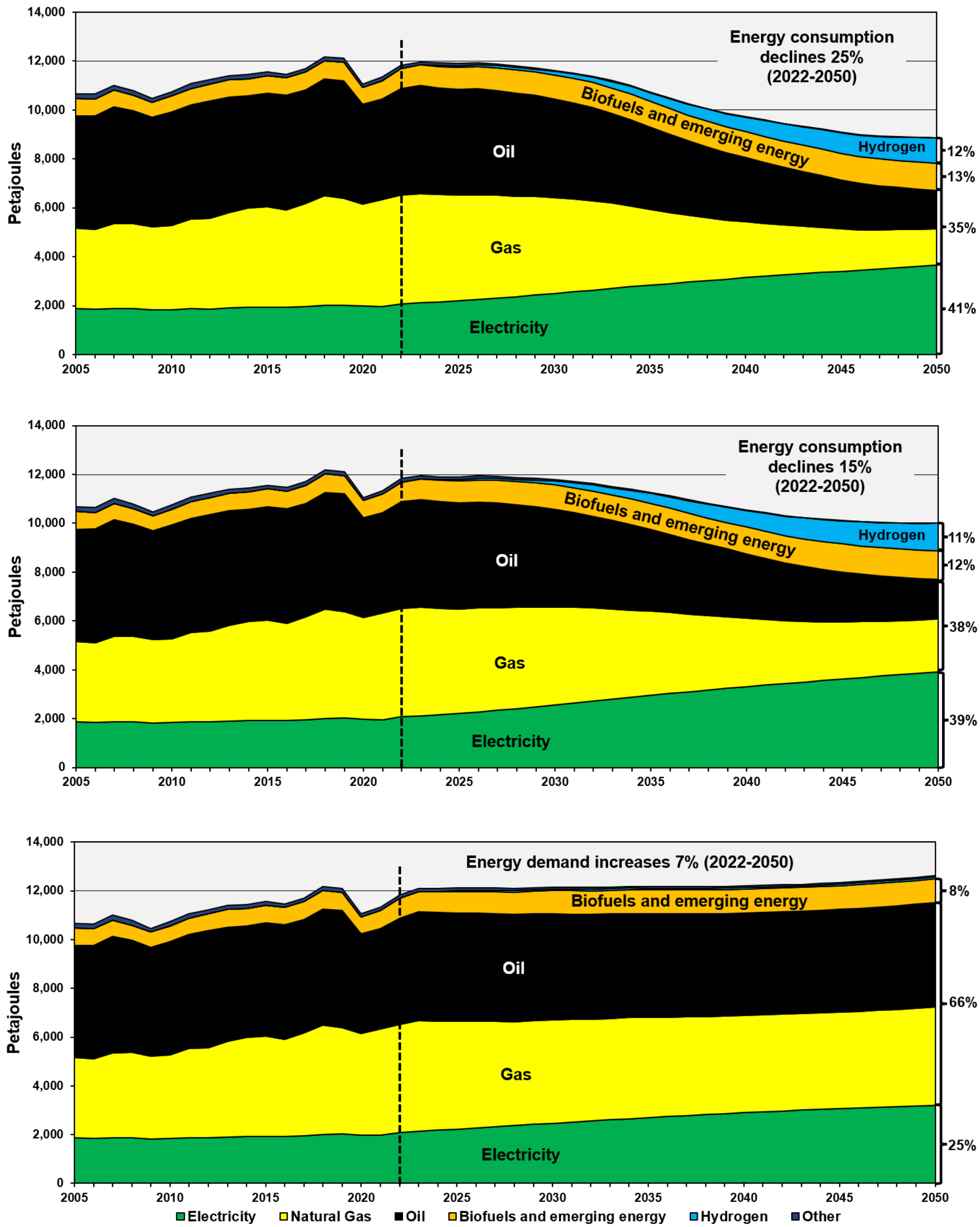
Energy source	2021 share	Global net-zero		Canada net-zero		Current measures	
		2050	Change	2050	Change	2050	Change
Electricity	17.4%	41.2%	85.7%	39.1%	99.2%	25.4%	63.3%
Natural Gas	38.4%	16.9%	-65.6%	21.7%	-50.2%	31.8%	-7.8%
Oil	36.3%	17.6%	-62.0%	16.0%	-61.0%	34.0%	4.4%
Biofuels & emerging energy	6.7%	12.5%	46.5%	11.8%	55.4%	7.7%	28.5%
Hydrogen	0.0%	11.6%	293889%	11.3%	323594%	0.6%	20520%
Other	1.2%	0.1%	-91.4%	0.1%	-89.4%	0.5%	-56.0%
Total energy (PJ)	11,336	8,868	-25.1%	10024	-15.3%	12631	6.7%

[47] Natural Resources Canada, "Using hydrogen in Canada," September 19, 2023, https://natural-resources.canada.ca/our-natural-resources/energy-sources-distribution/clean-fuels/using-hydrogen-canada/23149/.

[48] Canada Energy Regulator, *Canada's Energy Future 2023.*

Figure 20: End-use energy demand by source in CER scenarios.[49]

Global net-zero scenario; centre: Canada net-zero scenario; bottom: current measures scenario.



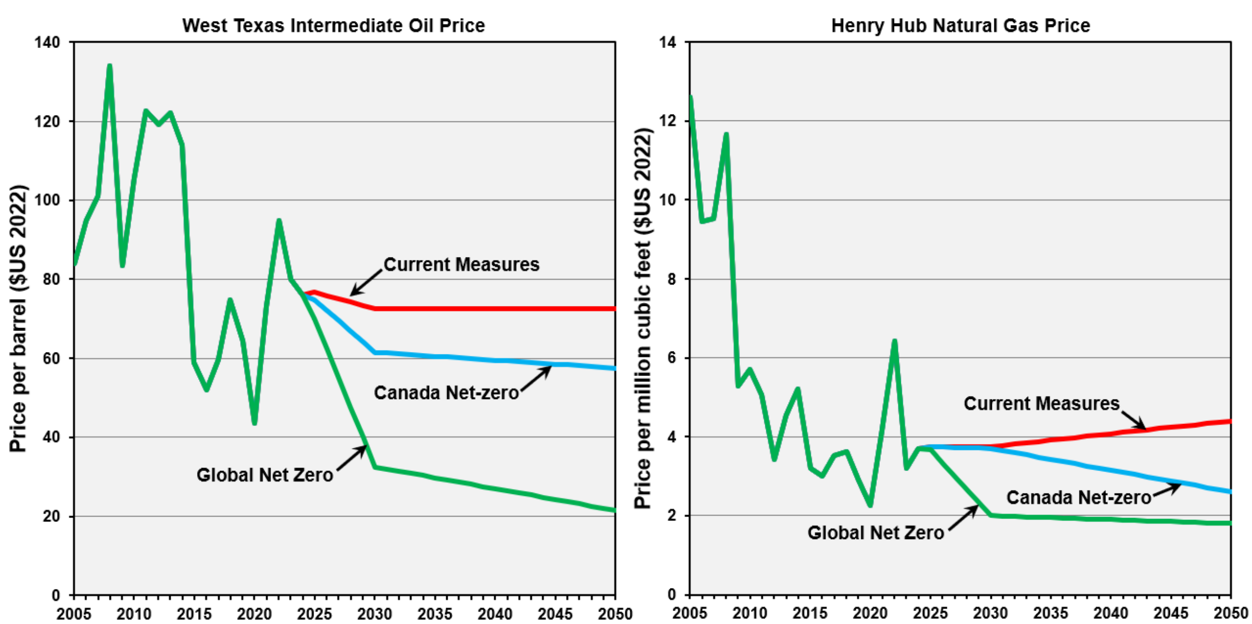
49 Canada Energy Regulator, *Canada's Energy Future 2023.*

4.3 Oil and natural gas production

As noted above, Canada is a major producer and exporter of oil and gas. The energy sector made up 8.9% of Canada's GDP in 2022, and in Alberta, Newfoundland and Labrador and Saskatchewan the energy sector accounted for 31.1%, 29.8% and 21.4% of GDP, respectively. Production of oil and gas is projected by CER to decline sharply in the two net-zero scenarios, resulting in a major decrease in revenue from these sources.

The CER net-zero scenarios also project a major decline in oil and gas prices as the world shifts from fossil fuels to other energy sources, which would render much of Canada's oil and gas production uneconomic. Oil sands projects, which are emissions-intensive and produce two-thirds of Canada's oil, would be particularly affected by higher prices. Although prices are projected to decline in both net-zero scenarios, CER projects much higher prices and production in its Canada net-zero scenario than its global net-zero scenario as the rest of the world would still be dependent on oil and gas for a major portion of energy consumption. Figure 21 illustrates CER's price projections in the three CER scenarios.

Figure 21: Oil and natural gas price assumptions by CER scenario for the West Texas Intermediate (WTI) oil and Henry Hub natural gas benchmarks, respectively.[50]



4.3.1 OIL

Oil production by type and CER scenario is summarized in Table 8 and illustrated in Figure 22. Major trends in oil production by type in the net-zero scenarios over the 2021–2050 period include:

- An overall production decline of 21–75%.
- A 53% decline to a 21% growth in conventional light oil production. Light oil is generally the least emissions-intensive oil to produce and refine and commands a premium price.

[50] Canada Energy Regulator, *Canada's Energy Future 2023.*

- A 18–74% decline in conventional heavy oil production. Heavy oil is more emissions-intensive to produce and commands a lower price than light oil.
- A 19–44% decline in field condensate and pentanes plus production. These hydrocarbon liquids are separated from natural gas in the field and at gas processing plants.
- A 31–79% decline in mined bitumen production from the oil sands. Mined bitumen is the least emissions-intensive oil produced from the oil sands and made up 32% of all Canadian production in 2021.
- A 29–93% decline in in situ bitumen production from the oil sands. In situ bitumen is the most emissions-intensive oil produced from the oil sands and made up 34% of all Canadian production in 2021.
- A 46–74% decline in upgraded bitumen production. Upgrading converts bitumen, mainly from mining, into light, sweet conventional crude oil.

Table 8: Change in oil production by type and scenario over 2022-2050 and the proportion of total Canadian production made up by each oil type in 2021 and 2050.[51]

		Production change 2022–2050			Proportion in 2050		
Oil type	Proportion in 2021	Global net-zero	Canada net-zero	Current measures	Global net-zero	Canada net-zero	Current measures
Total	100%	-75.0%	-20.7%	21.7%	100%	100%	100%
Conventional light	13.6%	-52.8%	21.0%	53.7%	25.7%	20.8%	17.3%
Conventional heavy	10.6%	-74.2%	-17.8%	6.2%	10.8%	10.8%	9.1%
Pentanes plus	2.8%	-41.0%	-27.4%	27.2%	7.3%	2.8%	3.2%
Field condensate	7.2%	-43.5%	-19.4%	77.7%	20.2%	9.1%	13.0%
Mined bitumen	32.3%	-78.7%	-31.1%	0.1%	26.8%	27.3%	25.9%
In situ bitumen	33.6%	-93.0%	-28.7%	18.1%	9.2%	29.2%	31.5%
(Upgraded bitumen)	23.2%	-73.7%	-45.5%	-0.8%	24.3%	15.8%	18.8%

CER projects that existing pipeline and structural rail capacity will be sufficient in all three scenarios through 2050, even with projected production growth in the near term.[52] The steep production decline after 2030 in the global net-zero scenario would progressively idle capacity rendering 86% unused by 2050. In the other two scenarios production decline begins after 2035 rendering 16–36% of capacity unused by 2050.

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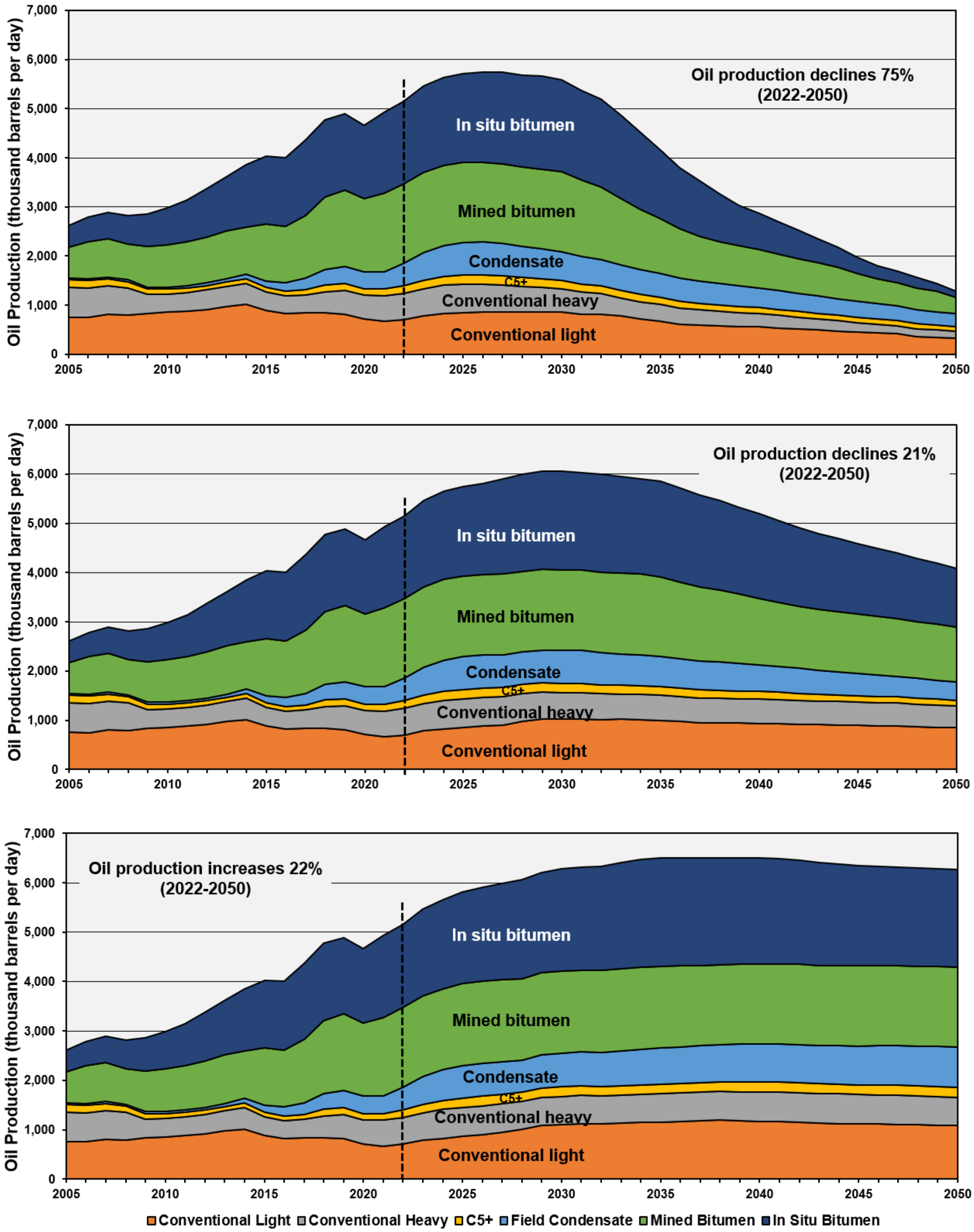
[51] Canada Energy Regulator, *Canada's Energy Future 2023.*

[52] Canada Energy Regulator, *Canada's Energy Future 2023.* See pages 90–91.

Figure 22: Oil production by type in CER scenarios.

Top: global net-zero scenario; centre: Canada net-zero scenario; bottom: current measures scenario. Oil production declines 21–75% over the 2022–2050 period in the two net-zero scenarios and increases 22% in the current measures scenario.



4.3.2 NATURAL GAS

Natural gas production by type and CER scenario is summarized in Table 9 and illustrated in Figure 23. Major trends in natural gas production by type in the net-zero scenarios over the 2021–2050 period include:

- An overall decline in natural gas production of 37–68%.
- An 85–87% decline in non-associated gas production. Non-associated gas is gas not produced in association with crude oil. It is termed “conventional” in Figure 23 and has been in decline for many years.
- A 34–66% decline in tight gas production that, in 2022, made up 66% of Canada’s gas production. Tight gas and shale gas are both from impermeable host rocks that were inaccessible before the widespread application of horizontal drilling and high-volume hydraulic fracturing (fracking) that began in the late 1990s. Tight gas will provide the source for most of BC’s planned LNG exports and BC tight gas production is projected by CER to grow from 34% of Canadian production in 2022 to 47–53% of Canadian production by 2050.
- Shale gas is projected to decline 47–71% and made up just 4% of 2022 Canadian production.
- Solution gas, produced in conjunction with crude oil, is projected to decline 3–61%. The 3% decline reflects the CER projection of a 21% growth in light oil production in the Canada net-zero scenario, the production of which would also yield solution gas.
- Coalbed methane, once thought to be a major source of new gas supply, is projected to decline 93% from 3% of 2021 Canadian production.

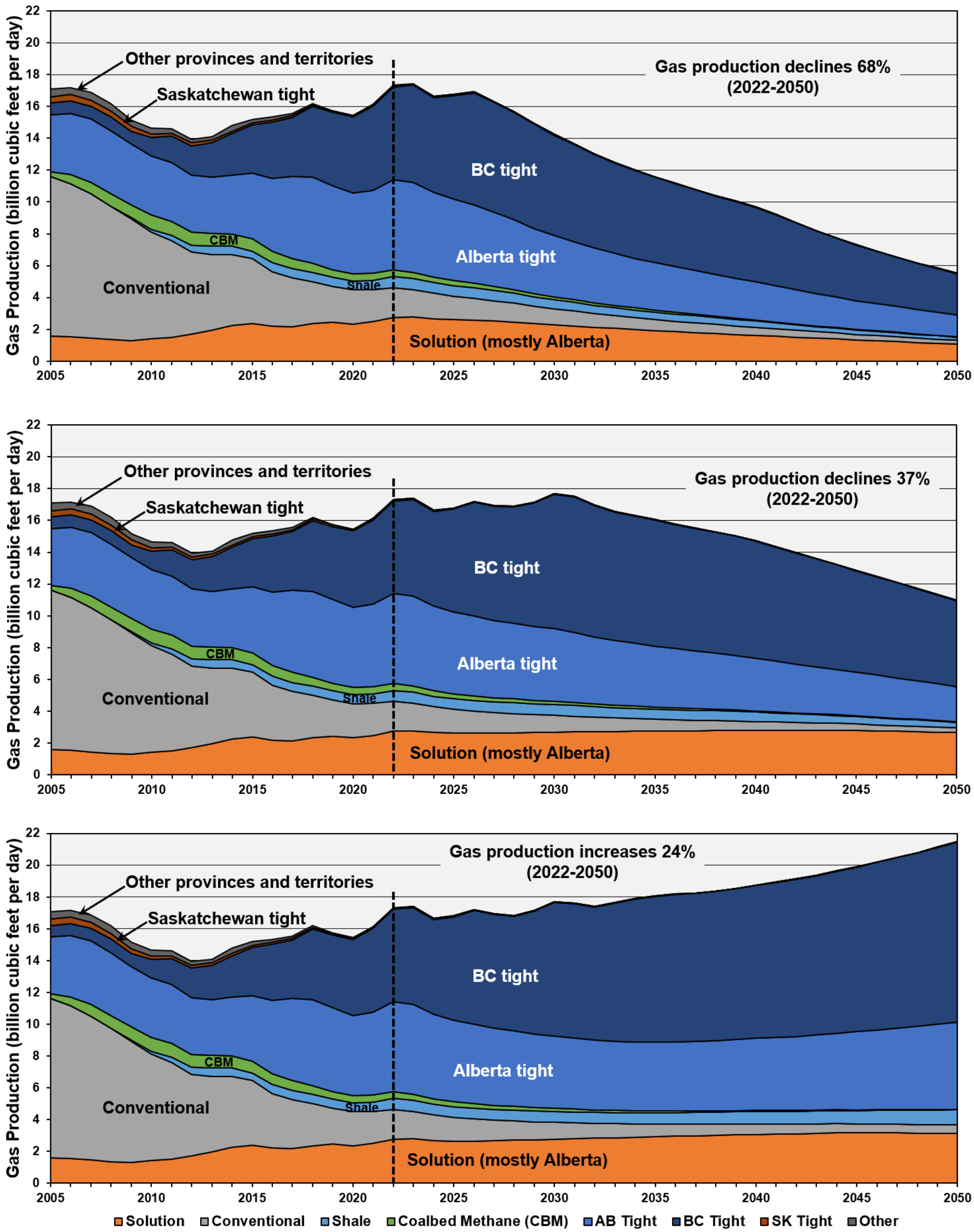
Table 9: Change in natural gas production by type and scenario over the 2022-2050 period and the proportion of total Canadian gas production made up by each natural gas type in 2021 and 2050.[53]

		Production change 2022–2050			Proportion in 2050		
Natural gas type	Proportion in 2021	Global net-zero	Canada net-zero	Current measures	Global net-zero	Canada net-zero	Current measures
Total	100%	-68.1%	-36.6%	24.0%	100%	100%	100%
Solution	15.4%	-60.7%	-3.3%	13.8%	19.6%	24.2%	14.6%
Non-associated	12.5%	-87.2%	-85.1%	-71.8%	4.3%	2.6%	2.5%
Tight	65.6%	-65.6%	-34.0%	45.6%	72.1%	69.6%	78.4%
Shale	3.5%	-70.6%	-47.1%	39.7%	3.6%	3.3%	4.4%
Coalbed methane	2.9%	-93.0%	-93.0%	-93.0%	0.5%	0%	0%

[53] Canada Energy Regulator, *Canada’s Energy Future 2023.*

Figure 23: Natural gas production by type in CER scenarios.

Top: global net-zero scenario; centre: Canada net-zero scenario; bottom: current measures scenario. Gas production declines 37–68% over the 2022–2050 period in the two net-zero scenarios and increases 24% in the current measures scenario.

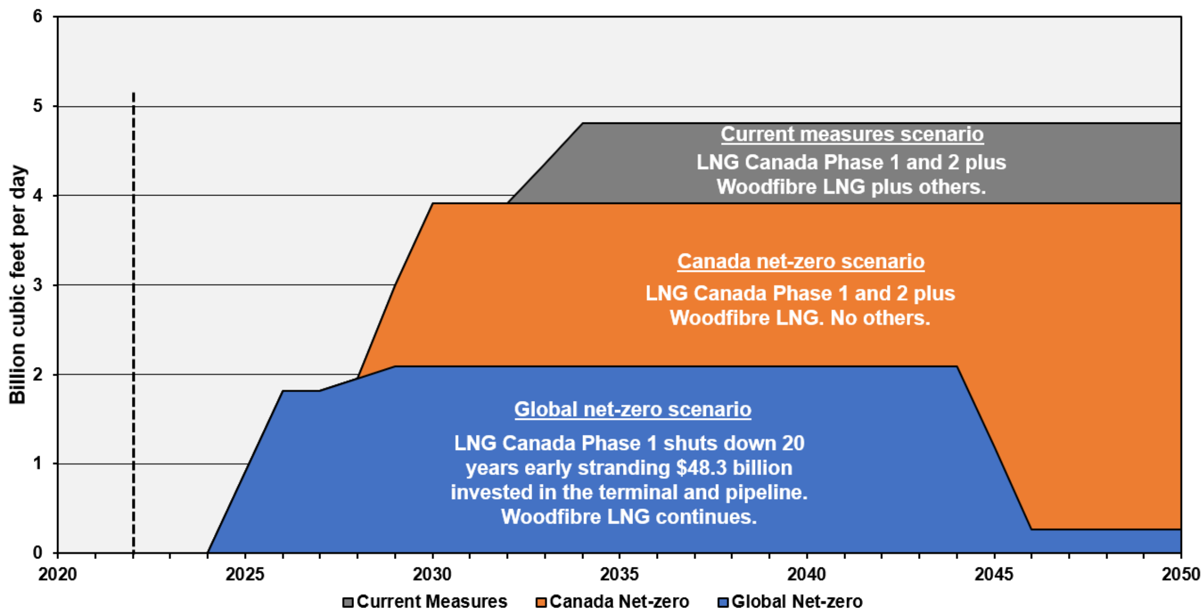


4.3.2.1 LNG exports

The CER net-zero scenarios have important implications for British Columbia's LNG exports. There are four LNG terminals that could be completed in the next few years and a fifth is undergoing an environmental assessment. The largest of these, LNG Canada Phase 1, is under construction in Kitimat slated for completion in 2025, and construction of Woodfibre LNG in Squamish is slated to begin in late 2023.

Figure 24 illustrates LNG exports in the three CER scenarios. In the global net-zero scenario, which is the most credible in terms of achieving net-zero, the LNG Canada terminal under-construction in Kitimat must be shut down in 2045, 20 years before its design lifespan, stranding the $48.3 billion[54] spent on the terminal and the Coastal Gas Link pipeline built to supply it. In the less credible Canada net-zero scenario in which the world does not achieve net-zero, there is sufficient supply for LNG Canada Phases 1 and 2 as well as Woodfibre LNG but no others. Only in the current measures scenario, in which Canada does nothing further to control emissions, is there additional gas available for the approved Cedar LNG and the currently under review Ksi Lisims LNG projects.

Figure 24: Natural gas volumes available for LNG export in the three CER scenarios and implications for planned expansion (see text).[55]



[54] Jang, B., "Estimated cost of Coastal GasLink pipeline surges to $14.5-billion," February 1, 2023, *The Globe and Mail*, https://www.theglobeandmail.com/business/article-coastal-gaslink-pipeline-cost/.

[55] Canada Energy Regulator, *Canada's Energy Future 2023*. See Figure A-6, page 36.

4.4 Electricity capacity

Electricity generation capacity (generation capacity at 100% utilization) is projected by CER to grow 107–124% in its net-zero scenarios through the addition of wind, solar, biomass, nuclear and gas generating infrastructure over the 2022–2050 period. Electricity generation is projected to grow 99–111% over the same period.

Electricity generation capacity in 2021 is summarized by type in Table 10. The projected change over the 2021–2050 period and the proportion of each generation type in 2050 is summarized in Table 11. Figure 25 illustrates the evolution of existing and projected electricity capacity over the 2005–2050 period. Major trends in electricity generation capacity in the net-zero scenarios over the 2021–2050 period include:

- A 590–700% increase in wind and a 755–941% increase in solar generating capacity. Wind and solar would amount to 31–33% and 9–11% of total generation capacity in 2050, respectively.
- A 257–407% increase in biomass/geothermal generating capacity. There is virtually no geothermal generating capacity in Canada at present although there is potential for development. Biomass/geothermal generating capacity is projected to amount to 3–4% of generating capacity in 2050.
- A 172–182% increase in nuclear generating capacity. This is projected to come entirely from small, modular reactors (SMRs) that are an emerging technology with just three SMRs in operation worldwide.[56] Nuclear is projected to grow to 11% of generation capacity in 2050.
- A 102–105% increase in natural gas to 11% of total generating capacity. Natural gas is a readily dispatchable source of electricity that can compensate for intermittency in variable sources like wind and solar.
- A 51% decline in oil to 1% of total generating capacity in 2050.
- A complete phase-out of coal generating capacity by 2030.

Table 10: Canada electricity generation capacity by infrastructure type in 2021.[57]

Electricity capacity	Capacity in 2021 (MW)	% of 2021 capacity
Hydro/wave/tidal	83,067	55.7%
Wind	13,878	9.3%
Biomass/geothermal	2,542	1.7%
Solar	3,351	2.2%
Uranium	13,085	8.8%
Coal & coke	6,546	4.4%
Natural gas	22,978	15.4%
Oil	3,661	2.5%
Total	**149,108**	

[56] International Energy Agency, "Global number of small modular reactor projects by status of development," June 30, 2022, https://www.iea.org/data-and-statistics/charts/global-number-of-small-modular-reactor-projects-by-status-of-development-2022.

[57] Canada Energy Regulator, *Canada's Energy Future 2023.* See electricity capacity in Data Appendix.

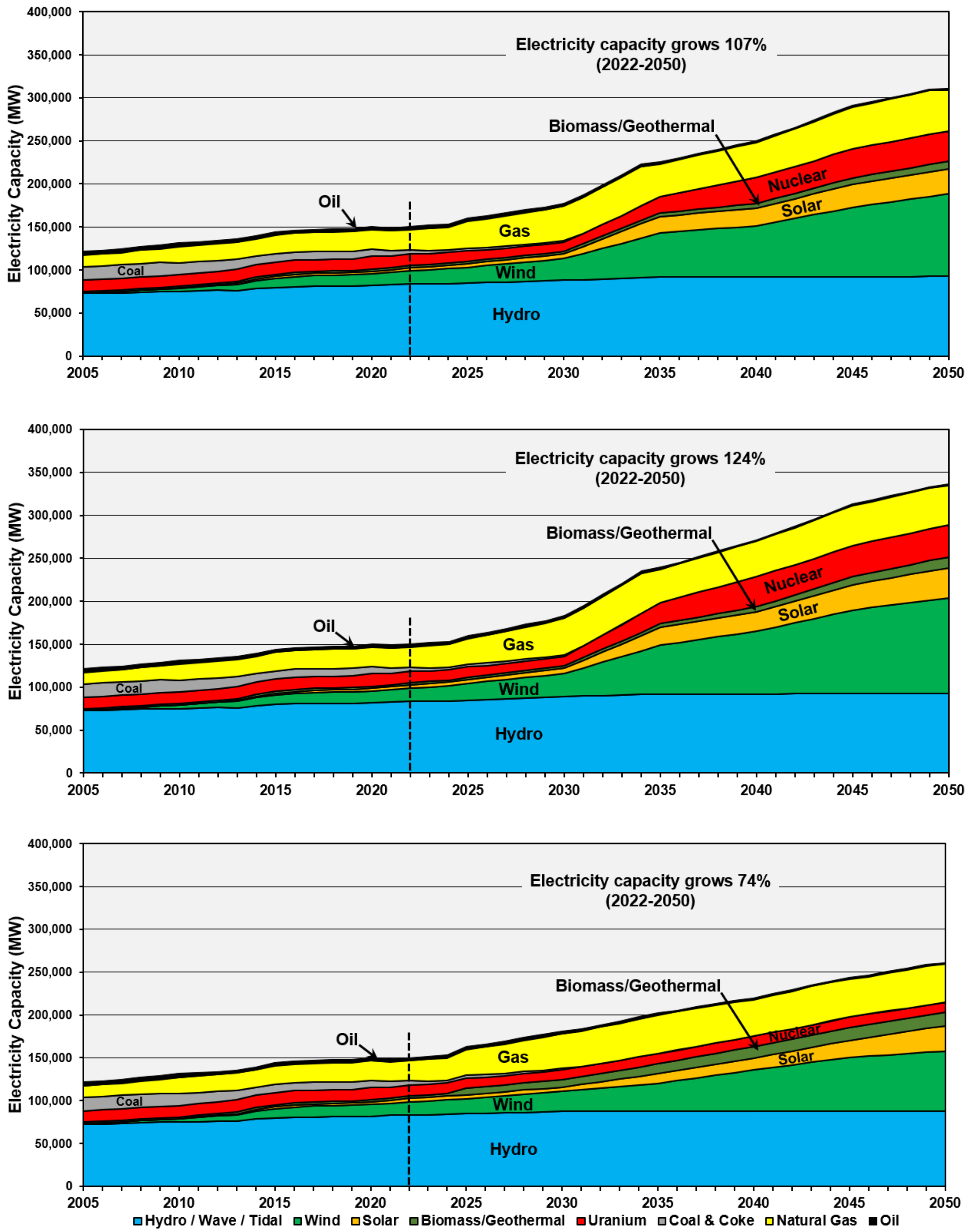
Table 11: Projected change in electricity generation capacity by infrastructure type and CER scenario over the 2021–2050 period and the proportion of each infrastructure type in 2050.[58]

	Global net-zero		Canada net-zero		Current measures	
Electricity capacity source	% change 2021–2050	% of 2050 capacity	% change 2021–2050	% of 2050 capacity	% change 2021–2050	% of 2050 capacity
Hydro/wave/tidal	12%	30%	12%	28%	6%	34%
Wind	590%	31%	700%	33%	405%	27%
Biomass/geothermal	257%	3%	407%	4%	513%	6%
Solar	755%	9%	941%	10%	786%	11%
Nuclear	172%	11%	182%	11%	-9%	5%
Coal & coke	-100%	0%	-100%	0%	-98%	0%
Natural gas	105%	15%	102%	14%	93%	17%
Oil	-51%	1%	-51%	1%	-50%	1%

58 Canada Energy Regulator, *Canada's Energy Future 2023.*

Figure 25: Electricity generating capacity by type in CER scenarios.

Top: Global net-zero scenario; centre: Canada net-zero scenario; bottom: current measures scenario. Electricity capacity increases 107–124% over the 2022–2050 period in the two net-zero scenarios and increases 74% in the current measures scenario.

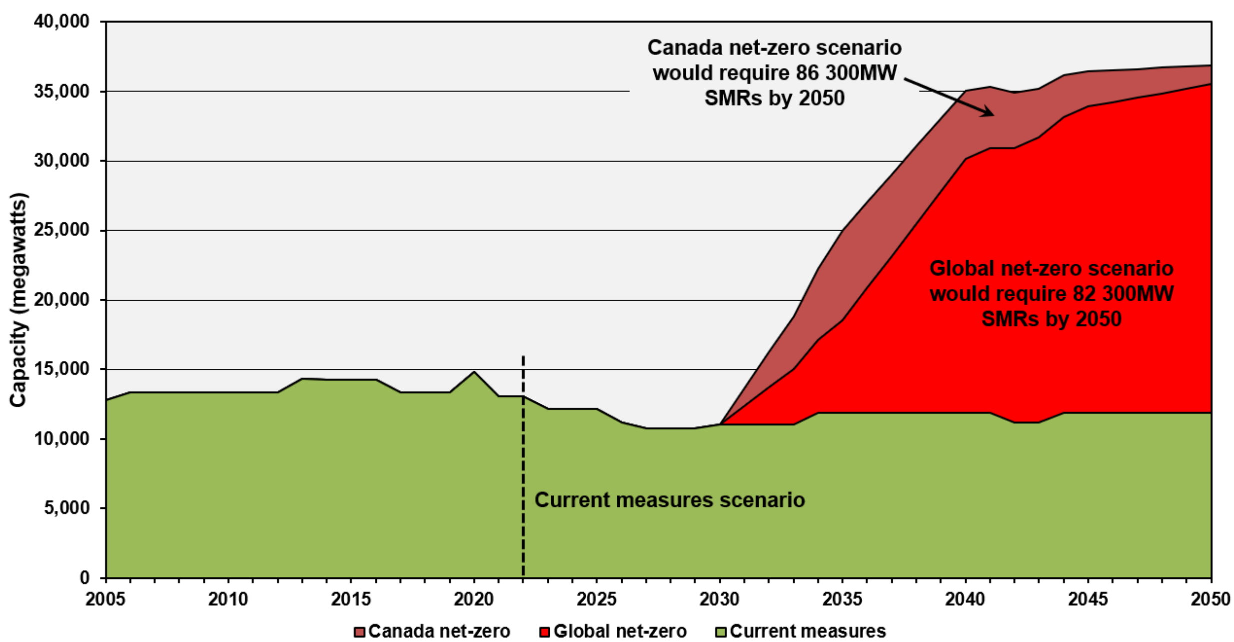


4.4.1 SMALL MODULAR REACTORS

Of the projections in CER's net-zero electricity generating capacity scenarios, the growth rates and total capacity of small, modular, nuclear reactors (SMRs) are perhaps the most questionable. SMRs are generally defined as advanced reactors with a capacity of 300 megawatts (MW) or less. Their modularity means they can be prefabricated using a common design, resulting in cost savings, and then transported to an installation site.[59] Globally, there are three SMRs operating, three under construction, 26 in basic and detailed design and 39 in conceptual design.[60] There is one SMR under construction in Canada, which has a 2028 completion date, and three more planned for completion between 2034 and 2036.[61]

Including expected nuclear retirements by 2030, the two CER net-zero scenarios would require building 64–80, 300 MW, SMRs by 2040 and have 82–86, 300 MW, SMRs operating by 2050.[62] Figure 26 illustrates nuclear capacity requirements in the three CER scenarios. An assessment by M.V. Ramana and S. O'Donnell pointed out that CER's estimated construction costs of SMRs may be far too low and the construction lead times underestimated. This would mean that, unless costs and construction times can be significantly lowered through the modularity envisaged for SMRs, it is highly unlikely that the number of SMRs needed could be built in the time frames required by the CER projections.[63]

Figure 26: Nuclear capacity projections by CER scenario and estimated number of 300 MW SMRs that would be required to meet them.[64]



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[59] Liou, J., "What are Small Modular Reactors (SMRs)?" September 13, 2023, International Atomic Energy Agency, https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs.

[60] International Energy Agency, "Global number of small modular reactor projects by status of development."

[61] Shakil, I., "Ontario plans more nuclear reactors to meet rising electricity demand," July 7, 2023, Reuters, https://www.reuters.com/business/energy/ontario-plans-more-nuclear-reactors-meet-rising-electricity-demand-2023-07-07/.

[62] Canada Energy Regulator, *Canada's Energy Future 2023.*

[63] Ramana, M.V. and S. O'donnell, "Wishful thinking about nuclear energy won't get us to net zero," July 3, 2023, *The Hill Times,* https://www.hilltimes.com/story/2023/07/03/wishful-thinking-about-nuclear-energy-wont-get-us-to-net-zero/391721/.

[64] Canada Energy Regulator, *Canada's Energy Future 2023.*

4.5 Electricity generation

Electricity generation from the current mix of infrastructure is summarized in Table 12. Non-emitting sources made up 82.6% of total generation in 2021. Table 13 summarizes the projected change in generation by CER scenario and the proportion of generation from each source in 2050. Figure 27 illustrates the evolution of existing and projected electricity generation over the 2005–2050 period.

Major trends in electricity generation in the net-zero scenarios over the 2021–2050 period include:

- A 926–1081% increase in wind and 893–1095% increase in solar generation. Wind and solar would amount to 29–31% and 5% of total generation in 2050, respectively.
- A 540–660% increase in biomass/geothermal generation. Biomass/geothermal generation is projected to amount to 5% of total generation in 2050.
- A 182–188% increase in nuclear generation. Nuclear is projected to grow to 18–19% of total generation by 2050.
- A 16% reduction to a 5% growth in natural gas generation, to 5–6% of total generation in 2050. Natural gas is a readily dispatchable source of electricity that can compensate for intermittency in variable sources like wind and solar.
- A 47–53% decline in oil generation to 0.5–0.7% of total generation in 2050.
- A complete phase-out of coal generating capacity by 2030.

Table 12: Electricity generation by source in 2021.[65]
Non-emitting sources made up 82.6% of total generation in 2021.

Electricity generation source	Generation in 2021 (GWh)	% of total 2021 generation
Hydro/wave/tidal	378,131	60.4%
Wind	35,996	5.8%
Biomass/geothermal	9,462	1.5%
Solar	6,249	1.0%
Nuclear	86,895	13.9%
Coal & coke	32,642	5.2%
Natural gas	74,449	11.9%
Oil	1,898	0.3%
Total	**625,721**	**100%**

[65] Canada Energy Regulator, *Canada's Energy Future 2023.* See electricity generation in Data Appendix.

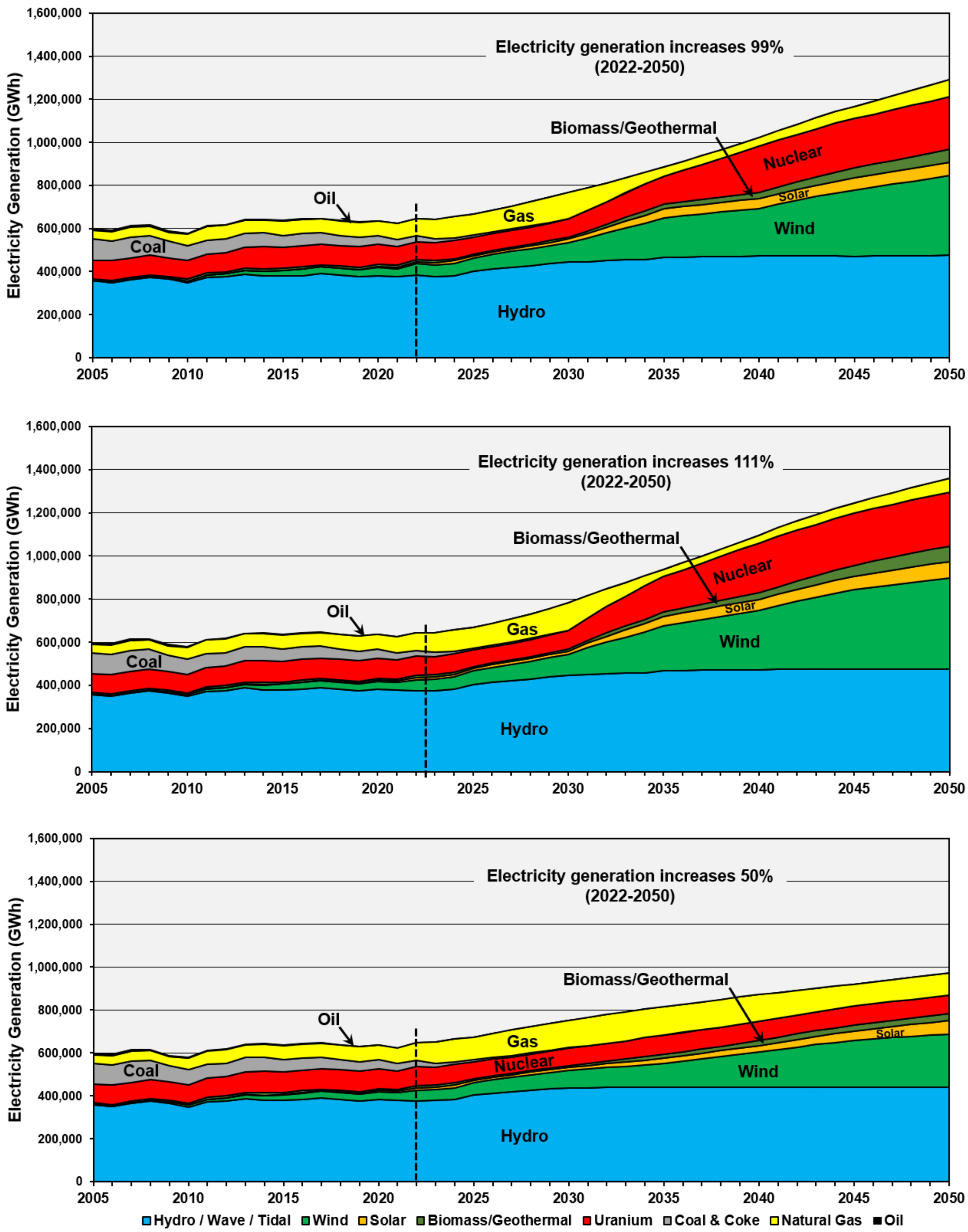
Table 13: Projected change in electricity generation by infrastructure type and CER scenario over the 2021–2050 period and the proportion of each infrastructure type in 2050.[66]

	Global net-zero		Canada net-zero		Current measures	
Electricity generation source	% change 2021–2050	% of 2050 generation	% change 2021–2050	% of 2050 generation	% change 2021–2050	% of 2050 generation
Hydro/wave/tidal	26%	37%	25%	17%	16%	23%
Wind	926%	29%	1081%	31%	588%	25%
Biomass/geothermal	540%	5%	660%	5%	230%	3%
Solar	893%	5%	1095%	5%	908%	6%
Nuclear	182%	19%	188%	18%	1%	9%
Coal & coke	-100%	0%	-100%	0%	-98%	0%
Natural gas	5%	6%	-16%	5%	37%	11%
Oil	-54%	0.07%	-47%	0.07%	-76%	0.05%

[66] Canada Energy Regulator, *Canada's Energy Future 2023.*

Figure 27: Electricity generation by type in CER scenarios.

Top: Global net-zero scenario; centre: Canada net-zero scenario; bottom: current measures scenario. Electricity generation increases 99–111% over the 2022–2050 period in the two net-zero scenarios and increases 50% in the current measures scenario.



Capacity factor refers to the amount of electricity a generation source would generate if it ran at its rated capacity 100% of the time compared to the amount of electricity it actually generates. For generation infrastructure like natural gas, oil, nuclear or biomass, the capacity factor can be controlled by the amount of fuel burned. Hydro can similarly be controlled by the amount of water released to the turbines from a reservoir. Intermittent sources like solar and wind are inherently unpredictable, as they are dependent on weather, day/night and seasonal cycles. Whereas nuclear typically runs as base load with a capacity factor of 80–90%, and natural gas, oil, biomass and hydro can be turned on and off as needed, emissions-free sources such as wind and solar need to be paired either with electricity storage, such as pumped hydro or batteries, or an easily dispatchable source of electricity, such as natural gas, to fill in gaps when wind or solar are not available.

Figure 28 illustrates the capacity factor projections for wind, solar and biomass by CER scenario. Wind, which typically has a capacity factor of about 35% in an area with a good wind resource,[67] is projected by CER to increase to a capacity factor of 41–43% on average by 2050. This may be possible with improvements in turbine design, but will require deployment in areas with a high-quality wind resource that are often distant from population centres, requiring new transmission lines.

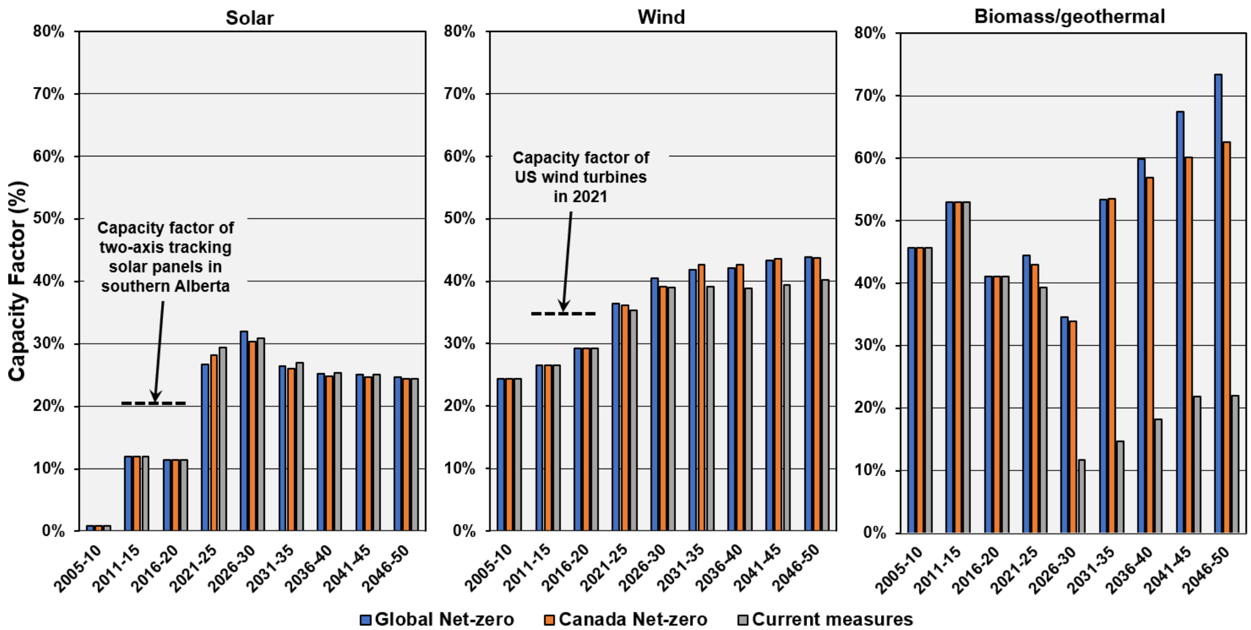
More than 95% of utility-scale solar projects in 2022 were installed in Alberta, which is home to some of Canada's highest quality solar resources.[68] The capacity factor of solar in southern Alberta is about 21% (assuming two-axis tracking panels),[69] which is significantly below the 24–32% assumed by CER for all solar projects in Canada in its scenario projections, which suggests CER's projections may be too optimistic.
The capacity factor for biomass is projected in CER's two net-zero scenarios to grow from the current 41% to 62–73% by 2050. This, coupled with a 257–407% increase in biomass generating capacity, means a 540–660% increase in biomass consumption for electricity generation.

67 Wiser, R. et al., *Land-Based Wind Market Report: 2022 Edition,* 2022, U.S. Department of Energy, https://www.energy.gov/sites/default/files/2022-08/land_based_wind_market_report_2202.pdf.

68 Canada Renewable Energy Association, "Canada added 1.8 GW of wind and solar in 2022," January 31, 2023, news release, https://renewablesassociation.ca/news-release-canada-added-1-8-gw-of-wind-and-solar-in-2022/.

69 Renewables.ninja, based on 2019 weather records assuming two-axis tracking solar panels, accessed October 15, 2023, https://www.renewables.ninja/.

Figure 28: Capacity factor projections for solar, wind and biomass/geothermal generation sources in CER scenarios.[70,71,72,73]



4.6 Emissions

Emission reductions in the CER projections are achieved through greater efficiency in energy use, through replacement of fossil fuels with hydrogen, biomass and electricity from renewable sources, and through carbon capture, utilization and storage (CCUS) and direct air capture (DAC) emissions reduction technologies. Canada is projected to miss its legislated 2030 emissions reduction target of 40–45% below 2005 levels in all three scenarios. The two net-zero scenarios are projected to be 31% below 2005 levels and the current measures scenario 16% below 2005 levels by 2030. Emissions by economic sector over the 2005–2050 period are illustrated by CER scenario in Figure 29.

Negative emissions are critical in both of CER's net-zero scenarios to offset emissions from the combustion of fossil fuels and biomass. Since biomass is considered emissions-neutral, because emissions from its combustion are removed when it eventually grows back, biomass emissions captured and stored using CCUS are considered negative emissions that offset other emissions sources. Negative emissions are also projected to come from land use, restoration of the sequestration capacity of Canada's forests and from DAC. Negative emissions in CER's net-zero scenarios, which total 153–166 megatonnes by 2050, are illustrated in Figure 30.

70 Canada Energy Regulator, *Canada's Energy Future 2023.*

71 Canada Energy Regulator, *Canada's Energy Future 2023.* See electricity generation in Data Appendix.

72 Wiser, R. et al., *Land-Based Wind Market Report.*

73 Renewables.ninja.

Figure 29: Emissions by sector in CER scenarios.

Top: Global net-zero scenario; centre: Canada net-zero scenario; bottom: current measures scenario. Emissions in the net-zero scenarios are 31% below 2005 levels in 2030, missing Canada's 40–45% target, and are 22% below 2005 levels by 2050 in the current measures scenario.

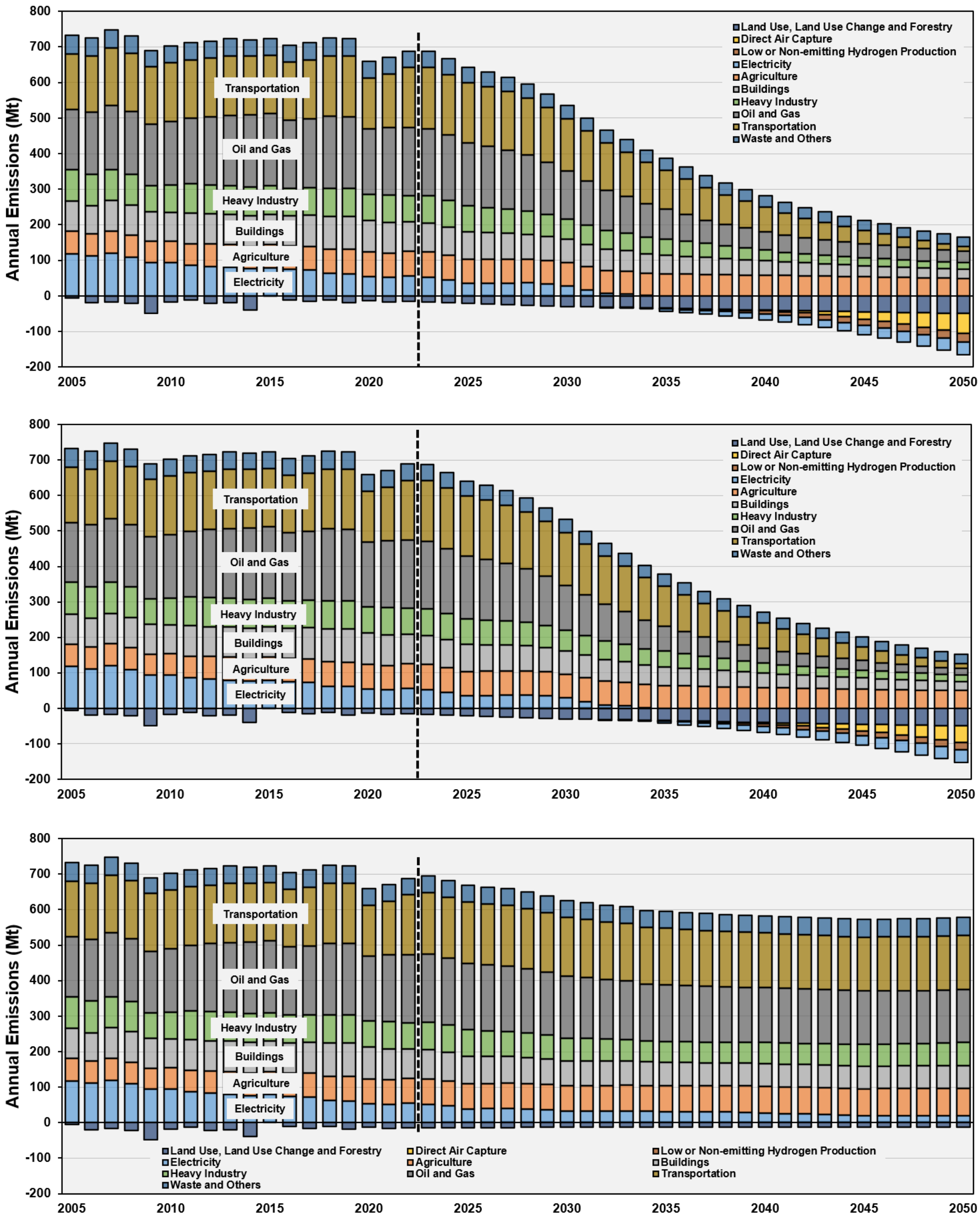
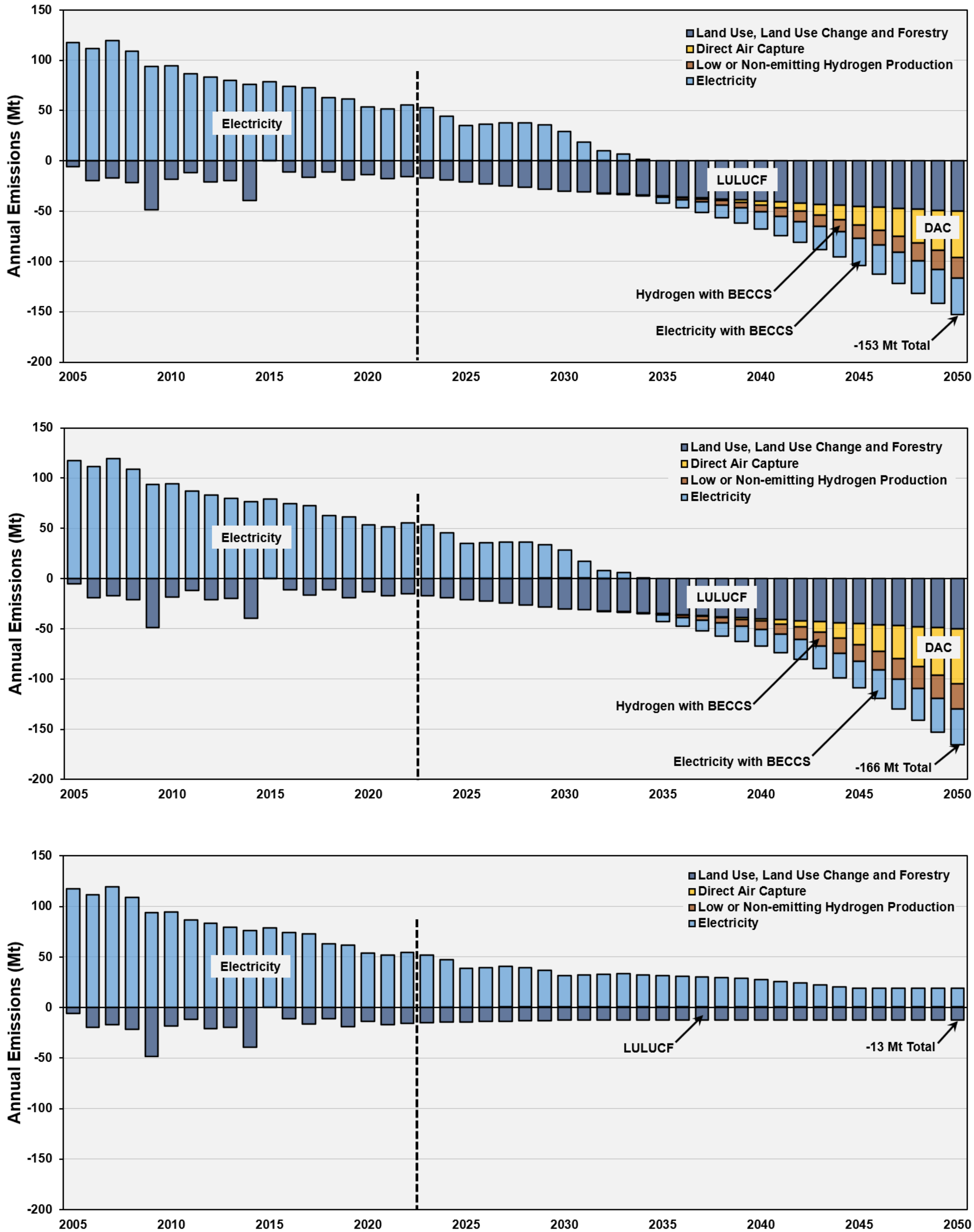


Figure 30: Negative emissions by sector in CER scenarios.

Top: global net-zero scenario; centre Canada net-zero scenario; bottom: current measures scenario. BECCS = bioenergy with carbon capture and storage.



4.6.1 CARBON CAPTURE AND STORAGE

Although CCUS has been in development for several decades, it is currently capturing just 45 Mt, or 0.12%, of annual global carbon dioxide emissions. In its net-zero roadmap report the International Energy Agency (IEA) notes:[74]

> *The history of CCUS has largely been one of underperformance. Although the recent surge of announced projects for CCUS and hydrogen is encouraging, the majority have yet to reach final investment decision and need further policy support to boost demand and facilitate new enabling infrastructure.*

Over the past six years the world added an average of 2.3 Mt per year of CCUS capacity.[75] The IEA notes that if the average lead time for CCUS projects can be shortened from six to four years, "reaching 1 Gt CO_2/year of global capture capacity by 2030 in line with the NZE Scenario would require on average 160 Mt CO_2/year of capture capacity and 140 Mt CO_2/year of storage capacity to start the planning stage each year between 2023 and 2026."[76] Table 14 summarizes the CCUS and DAC capacity required in the IEA's net-zero roadmap scenario and the rate of additions needed to meet them. Three to eight times current world capacity would need to be added each year in order to meet IEA's net-zero requirements (with the highest additions in the 2041–2050 period).

Table 14: Carbon capture required globally from point sources and the atmosphere using CCUS and DAC over the 2022–050 period in the IEA global net-zero scenario.[77]
Also shown are the average annual rates of addition needed to meet these requirements.

	Annual capacity (Mt/year)				Annual rate of additions (Mt/year)		
Milestones	2022	2030	2040	2050	2022–2030	2031–2040	2041–2050
Total CO_2 captured (Mt CO_2)	**45**	**1,024**	**2,421**	**6,040**	**122**	**140**	**362**
CO_2 capture from fossil fuels and industrial processes	44	759	1,712	3,736	89	119	253
Power	1	188	568	811	23	48	30
Industry	4	247	769	2,152	30	65	173
Merchant hydrogen	0	161	285	756	20	16	59
Other fuel transformation	38	163	90	17	16	-9	-9
CO_2 capture from bioenergy	1	185	506	1,263	23	40	95
Power	0	44	204	438	6	20	29
Industry	0	23	77	232	3	7	19
Biofuels production	1	114	213	474	14	12	33
Other fuel transformation	0	5	13	121	1	1	14
Direct air capture	0	80	203	1,041	10	15	105
Total CO_2 removed (Mt CO_2)	**1**	**234**	**632**	**1,710**	**29**	**50**	**135**

[74] Fernández, A. et al., *Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach,* 2023, p. 15, International Energy Agency, https://iea.blob.core.windows.net/assets/d0ba63c5-9d93-4457-be03-da0f1405a5dd/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf.

[75] Zapantis, A. et al., *Global Status of CCS 2022,* 2022, Global CCS Institute, https://www.globalccsinstitute.com/resources/global-status-of-ccs-2022/.

[76] Fernández, A. et al., *Net Zero Roadmap*, p. 133.

[77] Fernández, A. et al., *Net Zero Roadmap,* p. 102.

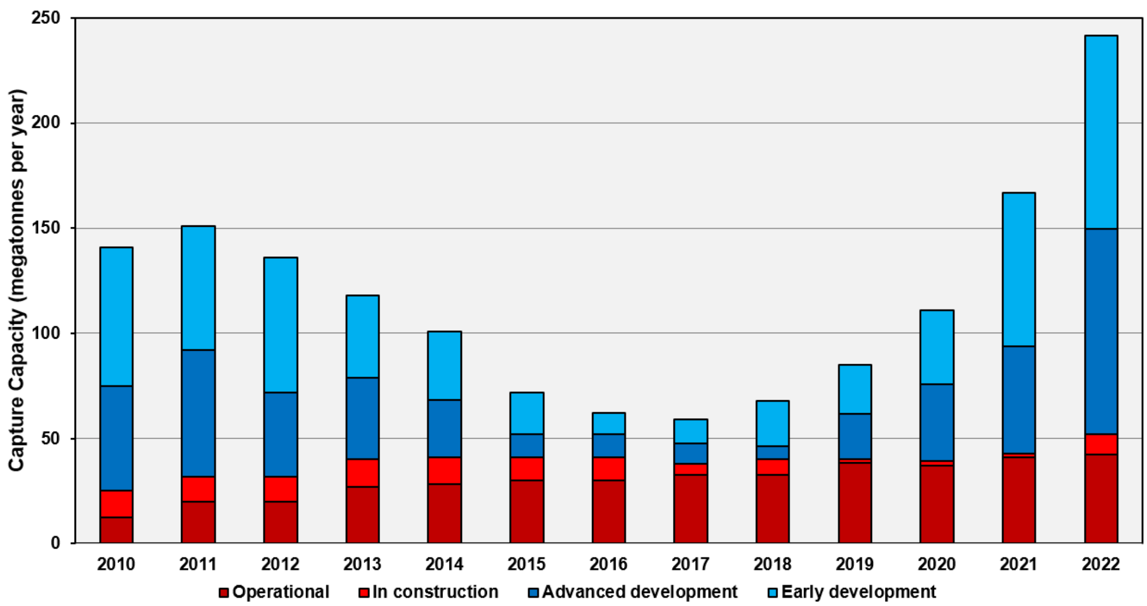
The development of world CCUS capacity over the 2010–2022 period is illustrated in Figure 31. Although there have been times when large numbers of CCUS projects have been in "advanced development" and "early development" stages, few of these projects have actually been built. In late 2023, there were many CCUS projects in the planning stage, however, the EIA notes:[78]

> *If all projects in the pipeline were realised, CO_2 capture capacity would expand more than eight-fold, rising from about 45 Mt today to reach nearly 400 Mt per year in 2030, and CO_2 storage capacity would increase to comparable levels (see Chapter 3). However, so far only about 5% of announced projects have reached the final investment decision stage.*

And even if all these projects came to fruition, they would only meet 40% of the capacity needed by 2030 to meet the IEA's net-zero roadmap requirement.

Figure 31: World development of CCUS capacity over the 2010-2022 period.[79]

Despite large numbers of projects in advanced- and early-development stages, growth in actual CCUS capacity has been slow. World CCUS capacity needs to grow 17-fold by 2030 to meet the IEA's net-zero roadmap requirements.



Canada has been a leader in the application of carbon capture, utilization and storage with 4.24 Mt of emissions sequestered in 2021.[80] Development began in Canada in 2008, with planning for CCUS at the coal-fired Boundary Dam generating station in Saskatchewan that was completed in 2014, followed by the Quest project in 2015, the Alberta Carbon Trunk Line (ACTL) in 2020 and other projects.[81] Figure 31 illustrates the current and projected CCUS capacity by economic sector and scenario needed to meet the CER projections.

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78 Fernández, A. et al., *Net Zero Roadmap*, p. 39.

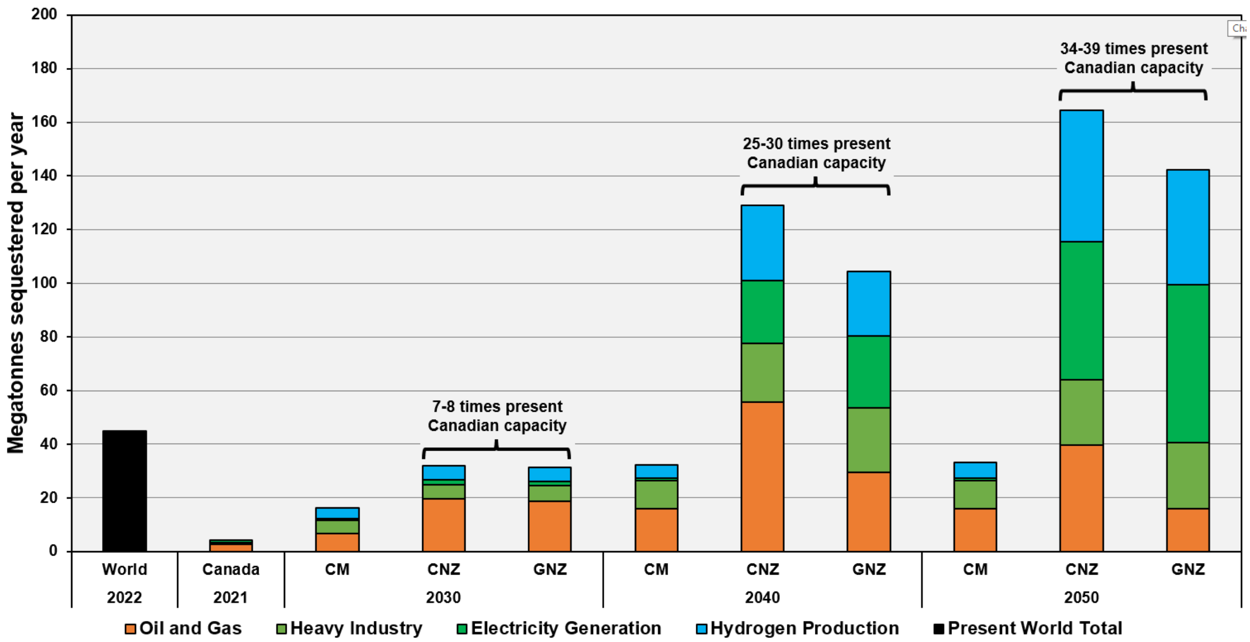
79 Zapantis, A. et al., *Global Status of CCS 2022*.

80 Canada Energy Regulator, *Canada's Energy Future 2023,* Data Supplement, 2023, https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2023-data-supplement/.

81 Ihejirika, N., *The Role of CCUS in Accelerating Canada's Transition to Net-Zero,* September 2021, Oxford Institute for Energy Studies, https://www.oxfordenergy.org/wpcms/wp-content/uploads/2021/09/The-Role-of-CCUS-in-Accelerating-Canadas-Transition-to-Net-Zero.pdf.

The CER net-zero scenarios require a 7–8 times expansion of capacity by 2030, a 25–30 times expansion by 2040 and a 34–39 times expansion by 2050. This would require annual capacity additions of 3.4–3.5 Mt per year between 2023 and 2030, 7.7–9.9 Mt per year between 2031 and 2040, and 8–8.8 Mt per year between 2041 and 2050. Overall, meeting the 2050 CCUS requirements in CER's net-zero scenarios would mean adding 1.5–1.8 times Canada's total current CCUS capacity every year from now until 2050.

Figure 32: CCUS sequestration capacity projected by CER in the current measures (CM), Canada net-zero (CNZ) and global net-zero (GNZ) scenarios by year.
Also shown are Canada's and the world's total sequestration capacity in 2021 and 2022, respectively.



Canada's Carbon Management Strategy, which calls for "CO_2 sequestration nearly quadrupling to at least 16 Mt per year by 2030," was released in September 2023.[82] Unfortunately, 16 Mt per year of sequestration capacity by 2030 is nowhere near enough, given that CER's net-zero scenarios require 31–32 Mt by 2030. If only 16 Mt of sequestration capacity is built, Canada will miss its 2030 emissions by an additional 15–16 Mt per year (29% below 2005 levels compared to the 40–45% target), and require an accelerated CCUS building rate in later years to meet its 2050 net-zero target.

A significant factor in the slow growth of CCUS capacity has been the low price of carbon, and much of the carbon dioxide captured to date has been used for enhanced oil recovery to make a business case. The price of carbon would have to increase substantially to incentivize the massive increase of carbon capture required in the CER and IEA net-zero scenarios. The aggregate cost of carbon assumed in CER's net-zero scenarios, which rises to \$330–\$380 per tonne in 2050 on top of the 2030 \$140 per tonne carbon price backstop, gives some idea of how high the carbon price may have to go.[83] This compares to the 2023 carbon tax in Canada of \$65 per tonne.

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82 Natural Resources Canada, *Canada's Carbon Management Strategy,* Appendix A, September 2023, https://natural-resources.canada.ca/climate-change/canadas-green-future/capturing-the-opportunity-carbon-management-strategy-for-canada/canadas-carbon-management-strategy/25337.

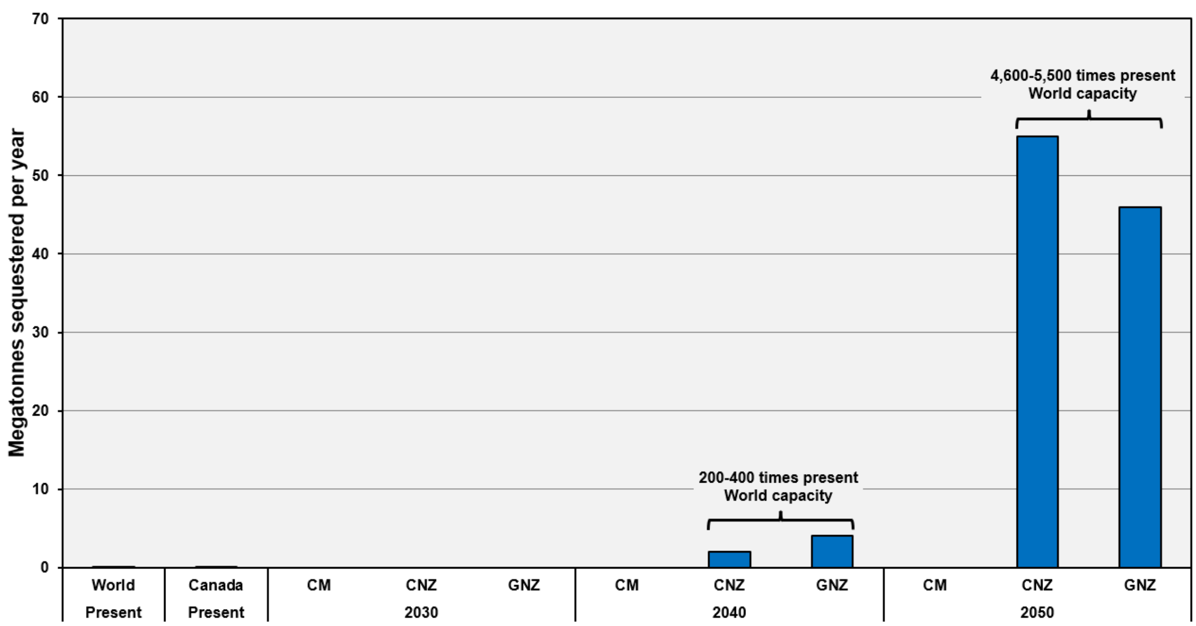
83 Canada Energy Regulator, *Canada's Energy Future 2023.* See Appendix 1. Prices are in 2022 Canadian dollars.

4.6.2 DIRECT AIR CAPTURE

Direct air capture (DAC) of carbon dioxide is in its very early stages, with a combined capture capacity of about 10,000 tonnes of carbon dioxide per year from 27 plants around the world.[84] The largest operational DAC plant, which has a capture capacity of 4,000 tonnes per year, is in Iceland.[85] DAC is costly, with current capture and storage costs estimated at more than US$1,000 per tonne, however, capture costs are dependent on the technology used and are projected to fall with scale. Cost estimates at the million tonne per year scale are projected to range between $250 and $1,500 per tonne.[86] There is currently a plant with 0.5 Mt per year capacity under construction in Texas[87] and the U.S. has announced $3.5 billion for four DAC hubs, each capable of removing one Mt per year, to be constructed over the next 10 years.[88]

As with CCUS, DAC requires immense scaling in order to meet the projected capacity needed. By 2050, DAC in Canada must scale to 4,600–5,500 times current world capacity to meet the CER net-zero scenario requirements illustrated in Figure 33. This will require significant cost reductions and favourable policy to incentivize development.

Figure 33: DAC capacity projected by CER in the current measures (CM), Canada net-zero (CNZ) and global net-zero (GNZ) scenarios by year.
Massive scaling is needed to meet the CER projections, which will require significant cost reductions and a favourable policy environment to incentivize development.



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84 Budinis, S., "Tracking Direct Air Capture," July 11, 2023, International Energy Agency, https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage/direct-air-capture.

85 Envirotec, "World's largest direct air capture and storage plant opens in Iceland," September 2021, https://envirotecmagazine.com/2021/09/09/worlds-largest-direct-air-capture-and-storage-plant-for-co2-opens-in-iceland/.

86 Young, J. et al., "The cost of direct air capture and storage can be reduced via strategic deployment but is unlikely to fall below stated cost targets," July 21, 2023, *One Earth* 6, no. 7, pp. 899–917, https://www.sciencedirect.com/science/article/pii/S2590332223003007?ref=pdf_download&fr=RR-2&rr=8189b2de9bc808a9.

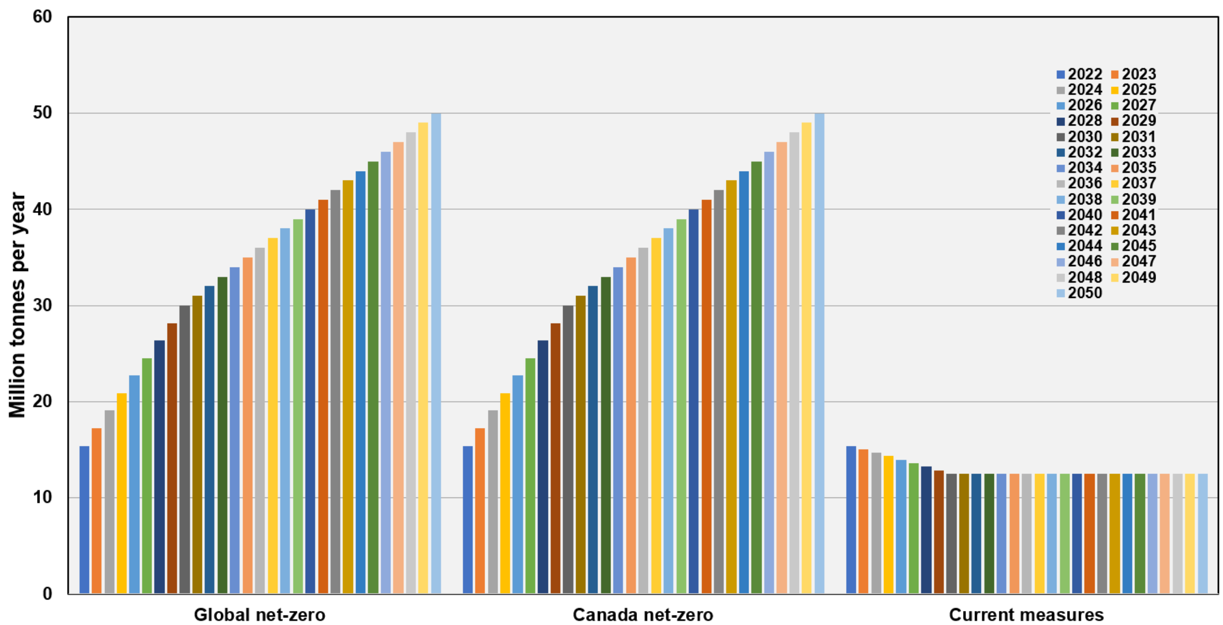
87 Milman, O., "The world's biggest carbon capture facility is being built in Texas. Will it work?," September 12, 2023, *The Guardian,* https://www.theguardian.com/environment/2023/sep/12/carbon-capture-texas-worlds-biggest-will-it-work.

88 Service, R. F., "U.S. unveils plans for large facilities to capture carbon directly from air," August 11, 2023, *Science,* https://www.science.org/content/article/us-unveils-plans-for-large-facilities-to-capture-carbon-directly-from-air.

4.6.3 LAND USE, LAND USE CHANGE AND FORESTRY

CER also projects a significant increase in negative emissions from land use, land use change and forestry (LULUCF) in its net-zero scenarios. Sequestration of emissions from LULUCF is projected to increase from 15 to 50 Mt per year by 2050 as illustrated in Figure 34. CER also projects that the use of biomass/geothermal energy for electricity generation will grow 540–660% over the 2021–2050 period, which would put additional pressure on forests (there is no significant geothermal generation at present and most of this growth would likely come from forest biomass).

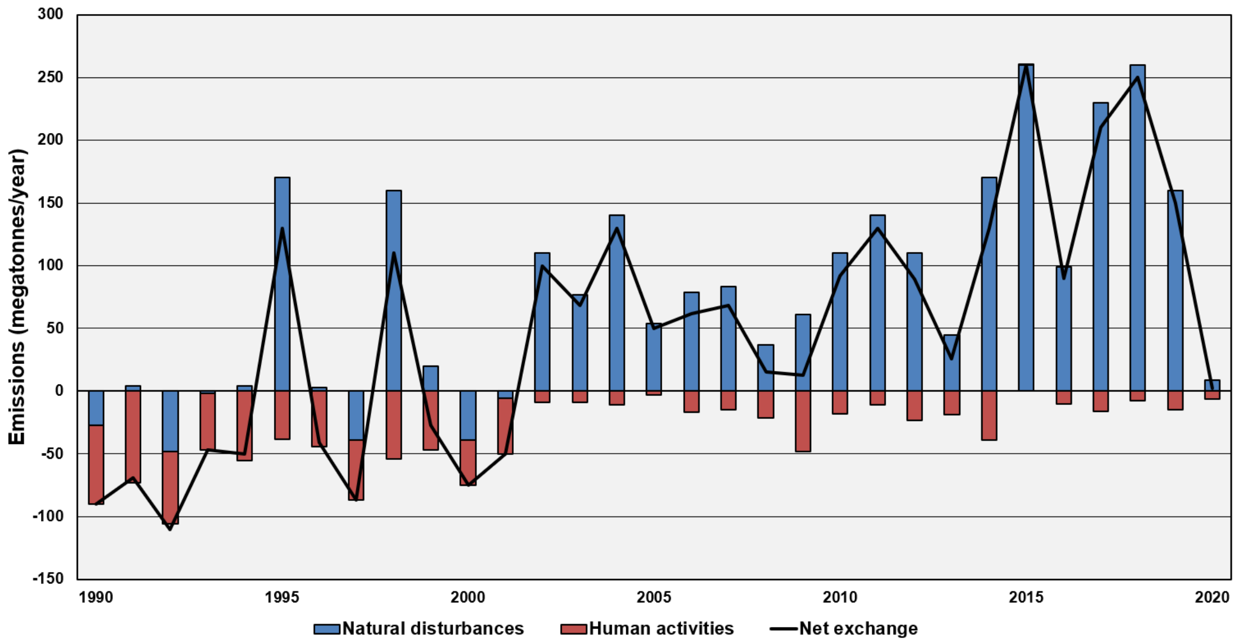
Figure 34: Projected negative emissions from LULUCF in the CER scenarios.
The three-fold growth in negative emissions in the net-zero scenarios over 2022–2050 is projected to occur despite a several-fold increase in the use of biomass for electricity generation (see text).



In fact, LULUCF is now a significant source of emissions due to increasing wildfires resulting from climate change and forest management practices, and has not sequestered carbon on a net basis since 2001. Figure 35 illustrates net emissions from LULUCF over the 1990–2020 period. Although, by convention, emissions from natural disturbances such as forest fires and wood product decomposition are not counted in national emissions inventories, they are a significant source of emissions. In 2023, emissions from Canada's forests due to wildfires far exceeded the emissions actually counted in Canada's official inventory.[89]

[89] Cecco, L., "Wildfires turn Canada's vast forests from carbon sink into super-emitter," September 22, 2023, *The Guardian,* https://www.theguardian.com/world/2023/sep/22/canada-wildfires-forests-carbon-emissions.

Figure 35: Emissions from LULUCF in Canada over the 1990–2020 period.
There have been no negative emissions from LULUCF since 2001.[90]



[90] Environment and Climate Change Canada, *Land-based greenhouse gas emissions and removals: Canadian Environmental Sustainability Indicators*, 2022, https://www.canada.ca/content/dam/eccc/documents/pdf/cesindicators/land-based-ghg-emissions-and-removals/2022/Land-based-GHG-emissions-removals.pdf.

5. Discussion and implications

To summarize, the requirements of CER's scenarios imply that massive changes are needed in Canada's energy system. End-use energy demand must be reduced by 33–41% on a per capita basis and by 15–25% on an overall basis. To reach net-zero by 2050 in CER's net-zero scenarios:

- Oil production must be cut 21–75%.
- Gas production must be cut 37–68%.
- Wind and solar generation must increase 10–12 times.
- Biomass/geothermal generation must increase 6–7 times.
- Nuclear generation must nearly triple.
- Carbon capture, utilization and storage must increase 34–39 times.
- Direct air capture must increase by 4,600-5,500 times current world capacity.

To facilitate these changes in the energy system while maintaining economic growth, CER made the following, arguably optimistic, assumptions about future cost reductions in its net-zero scenarios: [91]

- CCUS costs for industry will decline from \$45–200/tCO_2 in 2030 to \$30–160/tCO_2 in 2050.
- CCUS costs for oil and gas production will decline from \$45–125/tCO_2 in 2030 to \$30–90/tCO_2 in 2050.
- Direct air capture costs will decline from \$330–350/tCO_2 in 2030 to \$230–250/tCO_2 in 2050.
- Small modular nuclear reactor capital costs will decline 30% from \$9,262/kW in 2020 to \$8,348/ kW by 2030 and \$6,519/kW in 2050.
- Wind electricity capital costs will decline 7–8% by 2030 and 12–14% by 2050.
- Solar electricity capital costs will decline 40–44% by 2030 and 58–62% by 2050.
- Battery storage capital costs will decline 43–57% by 2030 and 58–75% by 2050.
- Natural gas combined cycle with CCUS capital costs will decline 18–29% by 2030 and 32–44% by 2050.
- Battery electric passenger vehicle costs will decline 28–30% by 2030 and 36–38% by 2050.
- Medium- and heavy-duty battery electric truck capital costs will decline 65% to parity with Class 8 diesel trucks in the 2035–2050 period.[92]
- Medium- and heavy-duty hydrogen fueled truck capital costs will decline 40% to parity with Class 8 diesel trucks in the 2035–2050 period.[68]
- Hydrogen electrolyzer capital costs will decline 74–80% by 2030 and 82–84% by 2050.
- Hydrogen from natural gas with CCUS capital costs will decline 25% by 2030 and 40% by 2050.

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91 Canada Energy Regulator, *Canada's Energy Future 2023.* See Appendix 2: Technology Assumptions.

92 Current cost of battery-electric and hydrogen fuel-cell trucks taken from U.S. Department of Energy cited in "Fletcher, N., "DOE Outlines Higher Upfront Costs for Green Heavy Trucks," March 1, 2023, *Transport Topics,* https://www.ttnews.com/articles/doe-outlines-higher-upfront-costs-green-heavy-trucks.

- Hydrogen from biomass capital costs will decline 18% by 2030 and 25% by 2050.
- Heat pump costs will decline 13–15% by 2030 and 34–40% by 2050.

In addition to these cost assumptions, CER assumed that the price of carbon would need to increase much more than the currently legislated increase of the carbon tax to \$170/tCO_2e in 2030 (\$140 in 2022 dollars). In its net-zero scenarios CER added an aggregate cost of carbon, defined as "a hypothetical suite of policies, regulations, and programs," which started at \$0/tCO_2e in 2030 rising to \$330–380/tCO2e by 2050 to the backstop carbon price.

Clearly, there are a lot of optimistic assumptions in the CER scenarios that have to go right if Canada is to meet its net-zero obligations. As for CER's assumptions of declining costs, the IEA notes that "costs have started to increase rather than decrease in the last two years for some clean technologies such as solar PV and batteries, reflecting inflationary pressure and, in particular, surging costs for critical minerals."[93] Critical mineral supply needs to be scaled up several times to meet forecast global requirements of an energy transition. Supply issues with critical minerals have been the subject of several recent reports.[94,95]

Perhaps the weakest link in the CER scenarios is their excessive reliance on CCUS and negative emissions from DAC. These assumptions are necessary to offset the relatively high reliance on fossil fuels, particularly in the Canada net-zero scenario. The IEA notes in its net-zero roadmap:[96]

> *However, so far, the history of CCUS has largely been one of unmet expectations. Progress has been slow and deployment relatively flat for years. The current level of annual CO_2 capture of 45 Mt represents only 0.1% of total annual energy sector emissions. This lack of progress has led to progressive downward revisions in the role of CCUS in climate mitigation scenarios, including the 2023 NZE Scenario.*

Another arguably overly ambitious goal in the CER net-zero scenarios is the growth of hydrogen from essentially nothing to 11–12% of end-use energy demand by 2050. The IEA notes in its net-zero roadmap:[97]

> *Today hydrogen production is more of a climate problem than a climate solution. Demand for hydrogen is rising, reaching 95 Mt in 2022, but most of it is met by emissions-intensive supply, resulting in more than 0.9 Gt of direct CO_2 emissions in 2022. Production of low emissions hydrogen from water electrolysis or from fossil fuels with high levels of CO_2 capture and storage amounted to less than 1 Mt in 2022.*

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[93] Fernández, A. et al., *Net Zero Roadmap*, p. 49.

[94] International Renewable Energy Agency, *Geopolitics of the energy transition: Critical Materials,* 2023, https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Jul/IRENA_Geopolitics_energy_transition_critical_materials_2023.pdf?rev=420aeb58d2e745d79f1b564ea89ef9f8.

[95] International Energy Agency, "Critical Minerals: The role of critical minerals in clean energy transitions," 2023, https://www.iea.org/topics/critical-minerals.

[96] Fernández, A. et al., *Net Zero Roadmap*, p. 132.

[97] Fernández, A. et al., *Net Zero Roadmap*, p. 136.

Hydrogen is also very energy intensive to produce. If used for energy storage, the round-trip efficiency from power to hydrogen back to power is 18–46%.[98] If "green" hydrogen is made using electricity from renewable sources, 54–82% of the input energy will be lost compared to using the electricity directly.

A comparison of end-use energy demand by sector in the IEA's net-zero roadmap with the CER net-zero scenarios is illustrated in Figure 36. The total decline in end-use energy demand by 2050 is similar in the IEA and CER global net-zero scenarios at 25–26%, however it is considerably less in the CER Canada net-zero scenario at 15%. More reduction in energy demand occurs in early years in the IEA scenario compared to the CER scenarios.

Figure 36: Proportion of end-use energy demand supplied by energy type in the IEA net-zero roadmap and CER net-zero scenarios over the 2022–2050 period.

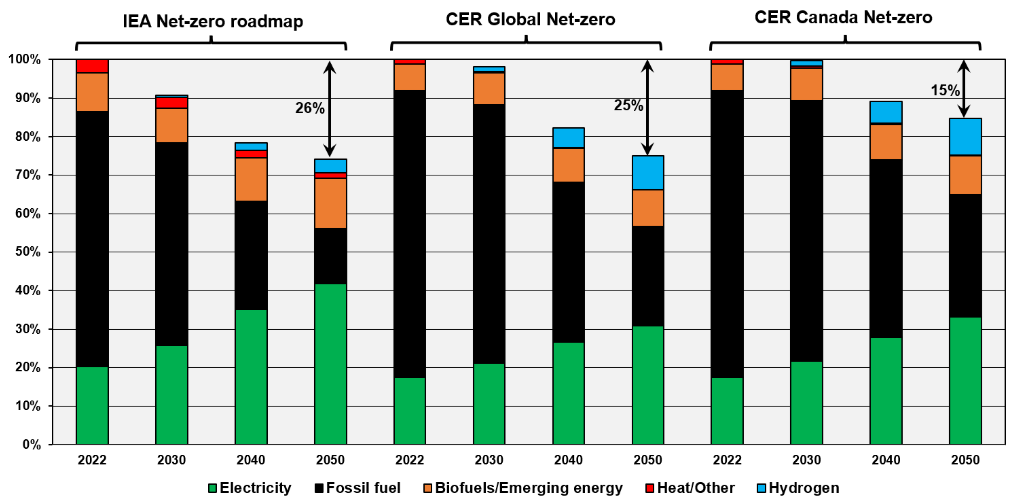

Table 15 compares end-use energy demand by energy type in the IEA and CER net-zero scenarios. Compared to the CER scenarios, end-use energy demand in 2050 in the IEA net-zero roadmap has:

- A much larger proportion of electricity at 56% compared to 39–41% in the CER scenarios.
- A much lower proportion of fossil fuels at 19% compared to 35–38% in the CER scenarios.
- A much lower proportion of hydrogen at 5% compared to 11–12% in the CER scenarios.
- A higher proportion of biofuels/emerging energy compared at 18% compared to 12–13% in the CER scenarios.

[98] DiChristopher, T., "Hydrogen technology faces efficiency disadvantage in power storage race," June 24, 2021, S&P Global Market Intelligence, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/hydrogen-technology-faces-efficiency-disadvantage-in-power-storage-race-65162028.

Table 15: Percentage of end-use energy demand supplied by energy type in the IEA net-zero roadmap and CER net-zero scenarios over the 2022–2050 period.
IEA NZE = IEA net-zero roadmap scenario; GNZ = CER global net-zero scenario; CNZ = CER Canada net-zero scenario.

Year	Scenario	Electricity	Fossil fuel	Biofuels/ emerging energy	Hydrogen	Heat/other
2022	IEA NZE	20.3%	66.2%	10.0%	0.0%	3.4%
	GNZ	17.6%	74.4%	6.9%	0.0%	1.2%
	CNZ	17.6%	74.4%	6.9%	0.0%	1.2%
2030	IEA NZE	28.5%	57.9%	10.1%	0.5%	3.0%
	GNZ	21.5%	68.3%	8.5%	1.3%	0.3%
	CNZ	21.8%	67.9%	8.4%	1.3%	0.6%
2040	IEA NZE	44.9%	35.9%	14.3%	2.3%	2.6%
	GNZ	32.3%	50.5%	10.9%	6.1%	0.2%
	CNZ	31.4%	51.5%	10.4%	6.5%	0.3%
2050	IEA NZE	56.3%	19.4%	17.5%	4.9%	1.8%
	GNZ	41.2%	34.5%	12.5%	11.6%	0.1%
	CNZ	39.1%	37.7%	11.8%	11.3%	0.1%

The implications of CER's net-zero scenarios for the change required in Canada's energy and emissions management policies and this review of assumptions made and areas of weakness that need improvement suggest:

1. Canada's emissions reduction policies must be greatly strengthened. CER's current measures scenario shows that policies as of March 2023, would result in only a 16% reduction in emissions from 2022 levels by 2050. The U.S. Energy Information Administration is even more pessimistic in its International Energy Outlook released in October 2023, in which its reference case for Canada's current policies would result in emissions that are 14% higher in 2050 than in 2022.[99]

2. The high proportion of fossil fuels projected by CER in 2050 end-use energy demand would require a massive buildout of carbon capture and storage to offset emissions and greatly increase the risk that net-zero will not be achieved. CER's net-zero scenarios assume that fossil fuels will make up more than one-third of final energy consumption in 2050, which is double that of the IEA's net-zero roadmap. To compensate for this, CER has assumed a 33–38 times scaleup of CCUS capacity to offset emissions from fossil fuels and biomass combustion along with a massive scaleup of DAC capacity. Given the slow growth in CCUS capacity in the past and the very early development stage of DAC, this is a very risky strategy. Reducing end-use demand from fossil fuels in 2050 by half, to the proportion assumed in the IEA's net-zero roadmap, would greatly reduce the risk of CCUS and DAC not being able to be scaled to meet requirements.

3. Maintaining high levels of fossil fuel production in 2050 for export greatly increases the risk that net-zero will not be achieved. Fossil fuel production accounted for 28% of Canada's emissions in 2021, the latest year for which data are available, making it Canada's largest source of emissions. CER's Canada net-zero scenario calls for oil production to fall just 21% by 2050 in order to preserve a large export

[99] U.S. Energy Information Administration, "International Energy Outlook," data appendices, October 11, 2023, https://www.eia.gov/outlooks/ieo/.

industry. This scenario also assumes that gas production in 2050 will be at 63% of current levels, allowing for a near doubling of LNG export capacity and construction of new LNG export terminals that typically have a lifespan of 40 years. Attempting to preserve high levels of fossil fuel production for export greatly increases the risk that net-zero will not be achieved given the massive scaleup of CCUS and DAC required to offset emissions.

4. The proportion of hydrogen in end-use energy demand in 2050 may be unrealistically high in CER's net-zero scenarios. Hydrogen provides an alternative for hard-to-electrify sectors in industry and transport, however, the use of hydrogen as an energy storage medium is in its infancy and its current production for the chemical industry is very energy- and emissions-intensive. Producing hydrogen from renewable electricity costs 54–82% of the energy in the electricity used. Although there is no question that hydrogen will be needed, scaling back the proportion of hydrogen in end-use energy demand in 2050, from essentially nothing to 11–12% as projected in the CER net-zero scenarios, to 5%, as projected in the IEA net-zero roadmap, would be more realistic.

5. The proportion of electricity in final end-use energy demand in 2050 will need to be significantly higher if the risks introduced by assumptions of massive scaleup of CCUS and DAC in CER's net-zero scenarios are to be minimized, as well as to compensate for lowering fossil fuels and hydrogen in end-use energy demand. Electricity use lowers end-use energy demand while providing the same amount of useful energy owing to the high efficiency of electric motors and heat pumps.[100] Although the 39–41% share of electricity in end-use energy demand represents a doubling from current levels, it will need to be significantly higher if fossil fuel and hydrogen demand in the CER net-zero scenarios are reduced as discussed above. The IEA net-zero roadmap's level of 55% electricity in 2050 end-use energy demand may be more realistic. This would require expanding renewable generation capacity by more than in CER's net-zero scenarios, along with expansion of associated storage and transmission infrastructure.

6. Given the impact of climate change on the carbon sequestration capacity of Canada's forests, major improvements are required in forest management policies. Canada's forests have become major sources of emissions in the past two decades, reversing their long-standing ability to sequester substantial amounts of carbon dioxide. Although much of this reversal can be attributed to climate change, a large part is due to forest management practices that have resulted in clear-cutting a major proportion of Canada's marketable timber and replanting with monocrops of more combustible species.[101] Record wildfires in 2023 resulted in three times the amount of emissions from forests as in the total emissions recorded for Canada's official inventory.[102] Tripling sequestration from Canada's forests and other lands, as assumed in CER's net-zero scenarios, would require a major improvement in Canada's forest management practices.

7. A fundamental focus of government energy supply and emissions management policies must be on maximizing efficiency and reducing energy consumption so that investments in new energy infrastructure can be optimized. Reducing energy demand through conservation, efficiency and behavioral change will reduce the need for costly energy production infrastructure as well as infrastructure to capture emissions and should be at the forefront of government policy incentives.

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[100] Pahud, K. et al., *Beyond Primary Energy: The energy transition needs a new lens,* July 2023, https://assets-global.website-files.com/62b9fb2aad2275b3dcfe568b/64a6e7c8bf3662ad7a43a57f_Rapport_Efficacite%CC%81_Energe%CC%81tique_V3.pdf.

[101] Haupt, F. et al., *Off Track and Falling Behind: Tracking progress on 2030 forest goals,* October 2023, Forest Declaration Assessment, https://forestdeclaration.org/wp-content/uploads/2023/10/2023ForestDeclarationAssessment3.pdf. See in particular "Canada country case study" on page 33.

[102] Cecco, L., "Wildfires."

Investments in efficiency and alternatives that reduce energy consumption will be paid back through lower costs to manage the emissions problem and a higher probability of reaching net-zero. Maximizing reduction of energy consumption should become a major focus of government policy in the quest to meet net-zero commitments.

6. Conclusions

Fossil fuels have powered an unprecedented expansion of the human enterprise over the past two centuries. Energy consumption has increased 32-fold as the population grew from one to eight billion. The average person on earth consumes four times as much energy as in 1800, when the world was powered primarily by burning biomass. The growth in energy consumption has been exponential, such that half of all fossil fuels consumed by the human race have been consumed in the last 29 years. Fossil fuels make up 77% of energy consumption today, and most of the remaining sources of energy rely on fossil fuels for mining the material used to build them (and fuel them in the case of nuclear), as well as for manufacturing and maintenance. The energy wealth from fossil fuels is unequally distributed: high-income countries, with 16% of the world's population, consumed 42% of the world's energy in 2021, whereas low-income countries, with 9% of the world's population, consumed just 0.5%. The average high-income person consumes 46 times as much energy as the average low-income person.

Emissions from the combustion of fossil fuels have also grown exponentially, resulting in the global warming crisis of today. Despite being recognized as a global warming problem since at least the 1960s, emissions have continued to grow. Half of all anthropogenic emissions created by the human race have been emitted in the last 30 years.

Growth in emissions has been highly correlated with economic growth and growth in energy consumption. Although there has been some decoupling of emissions from economic growth, particularly in high-income countries where most of the renewable energy has been added, emissions continue to rise in the world as a whole.[103] To reach net-zero, the Canadian economy has to completely decouple from emissions.

Canada is highly dependent on fossil fuels for both domestic energy supply and revenue from oil, gas and coal production. In 2022, fossil fuels supplied 77.4% of Canada's end-use energy demand and Canada exported production of 63% of its oil, 34% of its gas and 67% of its coal. The energy sector made up 8.9% of Canada's overall GDP in 2022, but accounted for 21% of Saskatchewan, 30% of Newfoundland and Labrador and 31% of Alberta GDP. On a per capita basis, Canadians consume 4.9 times as much energy as the world average and emit three times world average emissions. Although Canada's electricity supply is more than 80% emissions-free due to generation from hydro, nuclear, wind and solar, electricity made up only 17.6% of end-use energy demand in 2022.

The net-zero scenarios presented by CER in its *Canada Energy Futures 2023* report represent an important first step in evaluating what it will take to meet Canada's net-zero mandate. This review of the implications and weaknesses of CER's net-zero scenarios concludes:

- Canada's existing policies must be greatly strengthened to have any hope of reaching net-zero. With policies in place as of March 2023, Canada's emissions would only be 16% below 2022 levels by 2050.
- The relatively large proportion of fossil fuels in 2050 end-use energy demand assumed by CER would require a 33–38 times scaleup of CCUS capacity as well as a several thousand times scaleup of DAC capacity. This is a very high-risk strategy given the early stage of DAC development and the cost and uncertainties of scaling CCUS that much by 2050, given its slow growth over the past decade. Reducing end-use demand from fossil fuels in 2050 by half, to the proportion assumed in the IEA's net-zero

[103] Ritchie, H., "Many countries have decoupled economic growth from CO_2 emissions, even if we take offshored production into account," December 1, 2021, Our World in Data, https://ourworldindata.org/co2-gdp-decoupling.

roadmap, would greatly reduce the risk of CCUS and DAC not being able to be scaled to meet requirements.

- Maintaining high levels of fossil fuel production in 2050 for export is unrealistic. Building new oil and gas infrastructure, such as LNG export terminals with 40-year lifespans allowed in CER's Canada net-zero scenario, along with the additional CCUS and DAC capacity required to offset emissions from producing oil and gas for export, would greatly increase the risk that Canada's net-zero commitment will not be achieved.
- The proportion of hydrogen in end-use energy demand in CER's net-zero scenarios in 2050 may be unrealistically high. Hydrogen provides an alternative for hard-to-electrify sectors in industry and transport. However, the use of hydrogen as an energy storage medium is in its infancy and its current production for the chemical industry is very energy- and emissions-intensive. Although there is no question that hydrogen will be needed, scaling back the proportion of hydrogen in end-use energy demand in 2050, from essentially nothing to 11–12% as projected in the CER net-zero scenarios, to 5%, as projected in the IEA net-zero roadmap, would be more realistic.
- The proportion of electricity in final end-use energy demand in 2050 will need to be significantly higher if the risks introduced by assumptions of massive scaleup of CCUS and DAC in CER's scenarios are to be minimized, as well as to compensate for lowering fossil fuels and hydrogen in end-use energy demand. Electricity use lowers end-use energy demand while providing the same level of useful energy owing to the high efficiency of electric motors and heat pumps. Increasing the proportion of electricity in 2050 end-use demand from 39–41%, as assumed in the CER scenarios, to 55%, as assumed in the IEA net-zero roadmap, would significantly increase the probability of achieving net-zero. This would necessitate expansion of renewable generation capacity beyond that assumed by CER along with expansion of associated storage and transmission infrastructure.
- Tripling sequestration from Canada's forests and other lands, as required in CER's net-zero scenarios, will necessitate major improvements of Canada's forest management practices. Canada's forests have become major net emitters since 2001 due to climate change and to poor forest management practices that have seen large portions of Canada's marketable timber clearcut and replaced with more combustible monocrops.
- Maximizing reduction of energy demand through conservation, efficiency and behavioral change will reduce the need for costly energy production infrastructure, as well as infrastructure to capture emissions, and should be at the forefront of government policy incentives. Investments in efficiency and alternatives that reduce energy consumption will be paid back in lower costs to manage the emissions problem and a higher probability of reaching net-zero. Maximizing reduction of energy consumption should become a major focus of government policy in the quest to meet net-zero commitments.
- Canada faces daunting challenges in meeting its net-zero commitments. These are not insurmountable but must be clearly understood and faced head-on with policies and incentives commensurate with the scale of the problem.

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