Canada Energy Regulator

Régie de l’énergie du Canada

Canada’s Energy Future 2023

Canada

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Message from the Chief Executive Officer

I am proud to introduce the 2023 edition of Canada's Energy Future—our most ambitious report yet, and the Canada Energy Regulator's (CER) first long-term outlook modeling net-zero by 2050

As with past versions of Canada's Energy Future, EF2023 explores how possible energy futures might unfold for Canadians over the long term. In this analysis, we begin with the end goal in mind: net-zero greenhouse gas (GHG) emissions in 2050, and use our models to identify pathways to that point. This is a different approach compared to past versions of the report where we ran our models without restrictions, giving us insights into what a given premise meant for the future.

In this report we explore a key question about Canada's energy future: what could reaching net-zero emissions by 2050 look like? This report is not a prediction or a recommendation. It presents net-zero scenarios that can help Canadians and policy makers see what a net-zero world could look like, visualize the goal, and make informed decisions.

We know that modeling the pathways to net-zero is a big challenge. Canada's energy system is complex and diverse, and how we produce and use energy in net-zero world will be dramatically different than it is today. As you'll read in this report, there are some key components of this dramatically different world:

- Electricity becomes the cornerstone of the net-zero energy system. Devices that we use every day that use fossil fuels are replaced by technologies that use electricity. By 2050, technologies like electric vehicles and heat pumps become commonplace.
- Low-carbon fuels like hydrogen and biofuels enable the energy system's path to net-zero, while carbon capture, utilization, and storage (CCUS) helps to reduce emissions in many industries and the power generation sector.
- In a future with ambitious global climate action, global demand for fossil fuels falls steeply, reducing oil and natural gas prices and Canadian production of those commodities.

Uncertainty is inherent in all energy modeling exercises, including EF2023. And I am sure not everyone will agree with the assumptions we made, nor our findings. To address uncertainty about the future, we look at three scenarios in EF2023, two of which explore net-zero. We also introduce five additional "What if" cases that ask how changing some of our assumptions could impact Canada's pathway to net-zero. Our analysis is a means to understand what the future could look like under a certain premise and set of assumptions. Relying on just one scenario to understand the energy future implies too much certainty about what could happen.

It is important to state that the pathway to net-zero is broader than the technical and economic considerations that are the primary focus of EF2023. Policy choices, the regulatory landscape, Canada's journey towards Reconciliation, and societal preferences will each play a critical role in Canada's energy future. EF2023 is another step in the CER's net-zero modeling journey. We continue to learn and look forward to building on this report in the years to come.

The CER's energy information work is a key part of our mandate as an independent regulatory body. We do not develop government policies nor assess the appropriateness of such policies, and the assumptions, narrative, and results in EF2023 do not represent an official government position or policy direction. Canada's Energy Future contributes analysis and data to help inform Canada's energy dialogue for policy makers, the energy industry, and Canadians looking to make informed energy choices.

Additional CER work is underway to support Canada's emission reduction ambitions, beyond the energy information we provide to Canadians. For example, in collaboration with Natural Resources Canada, we are working to develop a regulatory framework for renewable energy projects and power lines in Canada's offshore areas, an activity within the CER's regulatory responsibility. We are also working to make sure we are ready to oversee the transportation of hydrogen by pipeline should such a facility be proposed within the CER's jurisdiction. In addition, we recently updated the GHG emissions and climate change information that companies need to provide the CER when they are seeking approval for a project.

Consultation and collaboration have always been key to the success of the Canada's Energy Future series. Our work is better when we hear the perspectives of others. Over the past 18 months we have sought advice and feedback from experts within the federal government, particularly Natural Resources Canada and Environment and Climate Change Canada. We also sought advice from some of the top energy system modeling experts outside of government, both in Canada and internationally. Finally, many experts responded to a technical discussion paper and survey on our preliminary approach. I would like to thank all of those who participated in these activities.

I would like to close by thanking the dedicated staff at the CER who contributed to EF2023. This report is the CER's latest contribution to the very important public dialogue on what the pathways to net-zero might look like. I am excited to share these scenarios with Canadians and look forward to the interesting discussions ahead as we navigate Canada's dynamic energy future.

Gitane De Silva,
Chief Executive Officer
Canada Energy Regulator

Executive Summary

Canada's Energy Future 2023: Energy Supply and Demand Projections to 2050 (EF2023) is the latest long-term energy outlook from the Canada Energy Regulator (CER).

The Canada's Energy Future series explores how possible energy futures might unfold for Canadians over the long term.

EF2023 focuses on the challenge of achieving net-zero greenhouse gas (GHG) emissions by 2050. We explore net-zero scenarios to help Canadians and policy makers see what a net-zero world could look like, visualize the goal, and make informed decisions. Our scenarios cover all energy commodities and all Canadian provinces and territories. We use economic and energy models to do this analysis.

The results in EF2023 are not predictions about the future, nor are they policy recommendations. Rather, they are the product of scenarios based on a specific premise and set of assumptions. Relying on just one scenario to understand the energy outlook implies too much certainty about what could happen in the future.

In EF2023 the end point of our analysis is predetermined: net-zero GHG emissions by 2050. We then explore the question, “what might a pathway to that end point look like?” Previous Canada’s Energy Future reports contained scenarios assessing how varying levels of future climate action might affect Canada’s energy future. In those reports, we did not limit the outcome of our scenarios based on a particular goal or target.

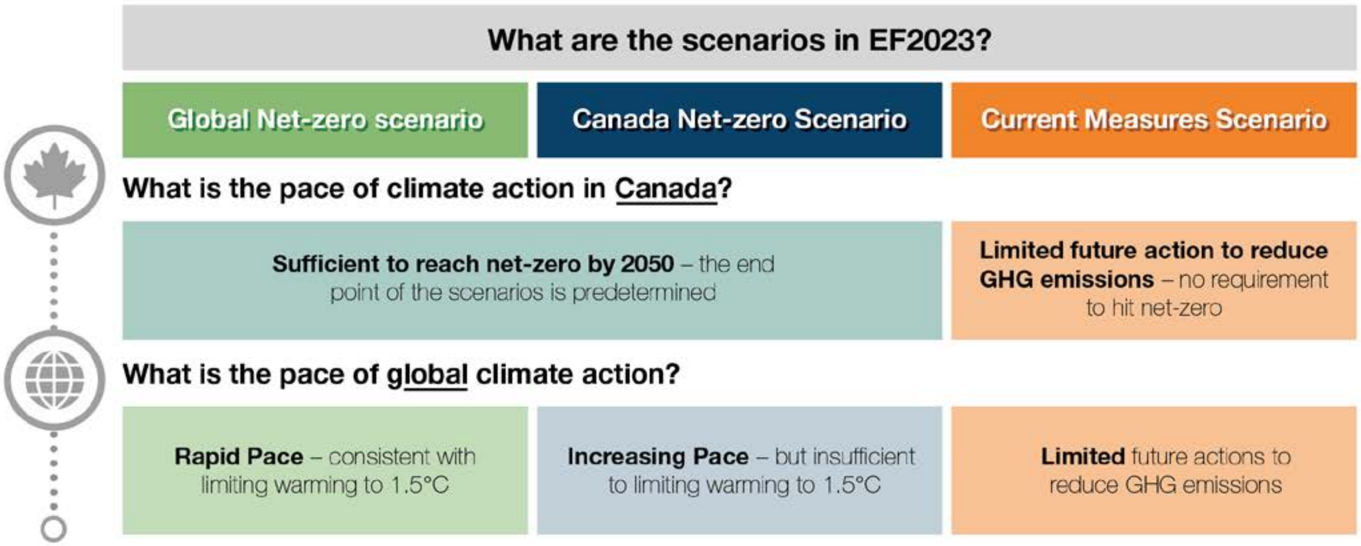
EF2023 contains three scenarios: Global Net-zero, Canada Net-zero, and Current Measures

In the Global Net-zero Scenario, we assume Canada achieves net-zero emissions by 2050. We also assume the rest of the world reduces emissions enough to limit global warming to 1.5 Celsius (°C). In the Canada Net-zero Scenario, Canada also achieves net-zero emissions by 2050, but the rest of the world moves more slowly to reduce GHG emissions.

The pace of action outside of Canada to reduce GHG emissions is the main difference between the net-zero scenarios in EF2023. As a trading nation, what happens globally affects Canada’s economy and energy system. EF2023 focuses on Canada, and we do not model global energy markets for the scenarios. Instead, international factors relevant to the Canadian energy outlook, such as global prices for crude oil and natural gas, and costs for many low-carbon technologies, are inputs into our models. For some of these inputs, we rely on scenarios from the International Energy Agency’s World Energy Outlook 2022.

The third scenario, the Current Measures Scenario, assumes limited action in Canada to reduce GHG emissions beyond measures in place today and does not require that Canada achieve net-zero emissions. In this scenario we also assume limited future global climate action. Figure ES.1 shows the three scenarios.

Figure ES.1:
Illustration of the scenarios in EF2023



Five "What if" cases explore uncertainties on the path to net-zero

In addition to the three main scenarios in EF2023, you will find five cases in this report that ask: "What if?" There are many uncertainties on the pathway to net-zero. These cases explore some of them by changing some key assumptions in EF2023 and showing what it could mean for Canada's pathway to net-zero.

- 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 electricity vehicle charging patterns result in higher peak electricity demand?

Key Findings

1 In our net-zero scenarios, the types of energy Canadians use changes dramatically, including using a lot more electricity.

The energy system in 2050 is very different than it is today in both of our net-zero scenarios. We project that electricity becomes the most important end-use energy source while the use of fossil fuels falls significantly.

As shown in Figure ES.2, electricity, hydrogen, and biofuels make up a much greater share of energy use. By 2050, we project that electricity makes up 41% of total end-use energy consumption in the Global Net-zero Scenario, and 39% in the Canada Net-zero Scenario, up from 17% in 2021.

Hydrogen and biofuels emerge as important alternatives when electricity may not be the best option to use, for example in heavy freight transportation, aviation, or certain industrial processes. By 2050, hydrogen makes up 12% of the energy mix and biofuels make up another 13% in the Global Net-zero Scenario.

With greater use of low and non-emitting energy sources, fossil fuel use drops by 65% from 2021 to 2050 in the Global Net-zero Scenario, and by 56% in the Canada Net-zero Scenario. Fossil fuels still play an important part in the energy system, with much of the fossil fuel in 2050 used at industrial facilities outfitted with carbon capture technology, or for non-energy use like asphalt, lubricants, and petrochemicals.

In both net-zero scenarios, electricity use more than doubles from 2021 to 2050, becoming the dominant energy source in the energy system. This is because many energy technologies we use today are steadily replaced with devices that do the same things but use electricity instead, like electric vehicles replacing vehicles with internal combustion engines and heat pumps replacing gas and oil furnaces. Many industries, like iron and steel and manufacturing, also switch to using more electricity. Finally, producing hydrogen and capturing carbon dioxide (CO_2) directly from the atmosphere further increase electricity use later in the projection period. In many instances, using electricity is much more efficient than using fossil fuels, and contributes to energy use decreasing by 22% from 2021 to 2050 in the Global Net-zero Scenario. Figure ES.3 shows electricity use by sector in the Global Net-zero Scenario.

While the types of fuels and technologies that shape our energy system change considerably over the next 27 years, we project little change to the energy services Canadians receive in both net-zero scenarios. Energy services are not the energy or technologies we use, but rather the things that energy enables us to do, like heat our homes, travel from place to place, or run equipment at a business. In 2050, Canadians continue to comfortably heat and cool their homes, get around how they prefer, and have their electricity needs met.

Figure ES.2:
End-use energy use, by fuel, all scenarios

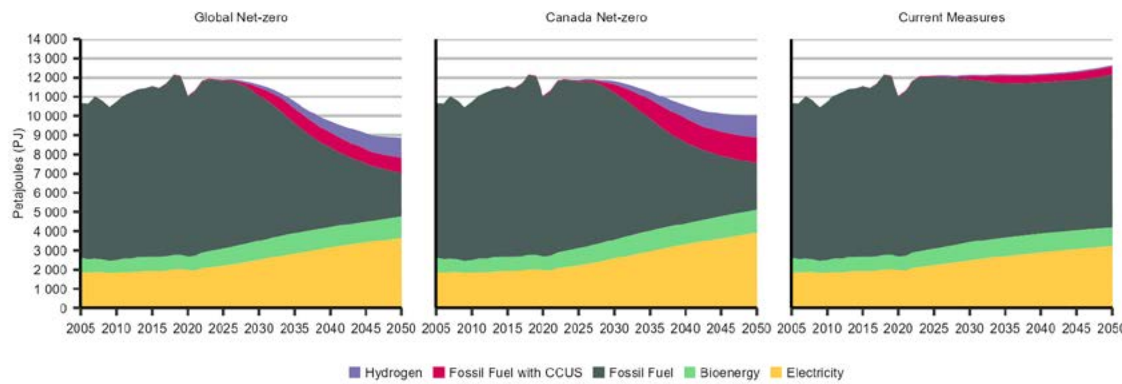
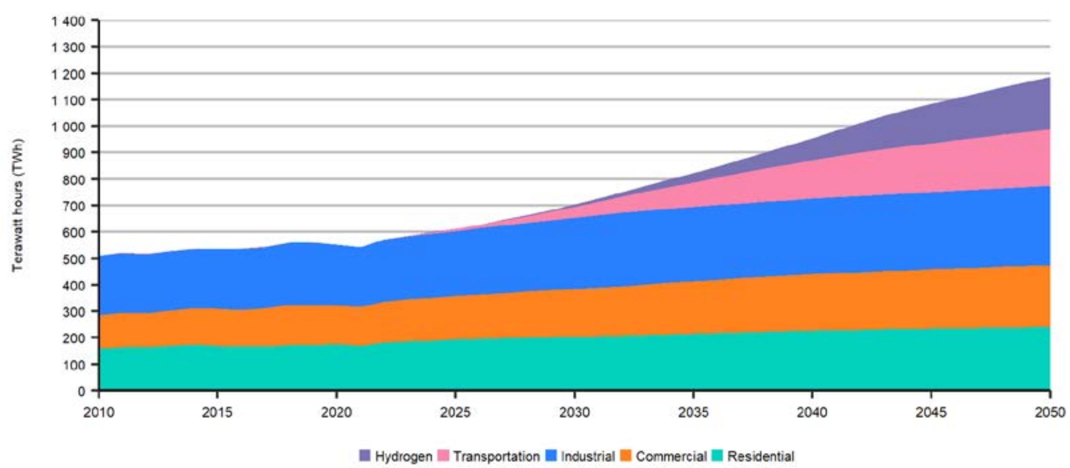


Figure ES.3:
Electricity use by sector, Global Net-zero Scenario



2 The electricity system, which decarbonizes by 2035 and achieves net-negative emissions thereafter, is the backbone of our net-zero scenarios.

In both net-zero scenarios, the electricity sector transforms to accommodate increasing electricity use while also rapidly decarbonizing electricity production. By 2050 in both net-zero scenarios, more than 99% of electricity is from non- or low-emission technologies. We project that wind, nuclear power, hydro, natural gas with CCUS, bioenergy with carbon capture and storage (BECCS), and solar make up most of the new generation growth over the projection period. Meanwhile, fossil fuel generation without CCUS declines swiftly in response to increasingly strong climate policies. The sector achieves net-zero emissions by 2035 and becomes net-negative thereafter, a result of using BECCS.

Canada's electricity system is regionally diverse, with the generation mix largely determined by the resources available in each province or territory. Many regions already have low-emitting electricity systems while others rely more on fossil fuels. This variation means that the transition of the electricity sector in each region is unique. Each region capitalizes on their own resources and technological expertise to drive the electricity sector towards net-zero.

As shown in Figure ES.4, among all technologies, wind contributes the greatest amount of new generation by 2050, increasing ninefold from current levels in the Global Net-zero Scenario. Wind increases it share of generation in most provinces, with significant growth in Alberta, Saskatchewan, British Columbia, and Ontario. Generation from hydroelectricity, currently the largest source of generation in Canada, increases by 26% from 2021 to 2050, largely in provinces that currently have significant hydroelectric resources already. Natural gas-fired generation with CCUS becomes a key source of power, particularly in Alberta and Saskatchewan, where it makes up 13% of generation in those provinces by 2050 in the Global Net-zero Scenario. Nuclear generation, in the form of small modular reactors (SMRs), increases significantly in the 2040 to 2050 period, with strong growth in Ontario and deployment in many other provinces. Solar generation increases steadily in both net-zero scenarios, making up 5% of total generation by 2050.

We project that the electricity sector reaches net-zero GHG emissions by 2035 in both net-zero scenarios and, after that, becomes net-negative due the use of BECCS. Negative emissions are achieved by burning biomass to generate power and then capturing and permanently storing the CO_2 which would otherwise be released naturally when the plants die. By 2050, net emissions from the power sector are -36 megatonnes (MT) in the Global Net-zero Scenario, as shown in Figure ES.5.

Figure ES.4:
Change in electricity generation from 2021 to 2050, by fuel, Global Net-zero Scenario

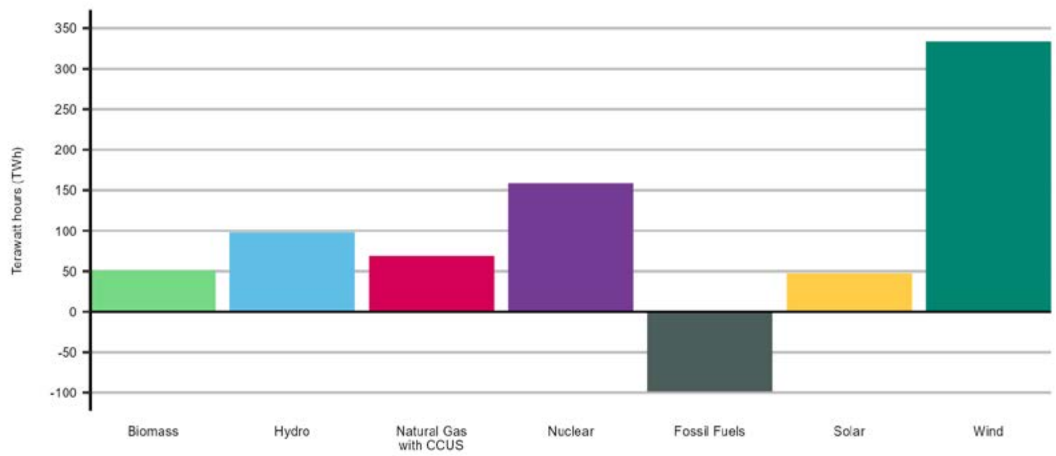
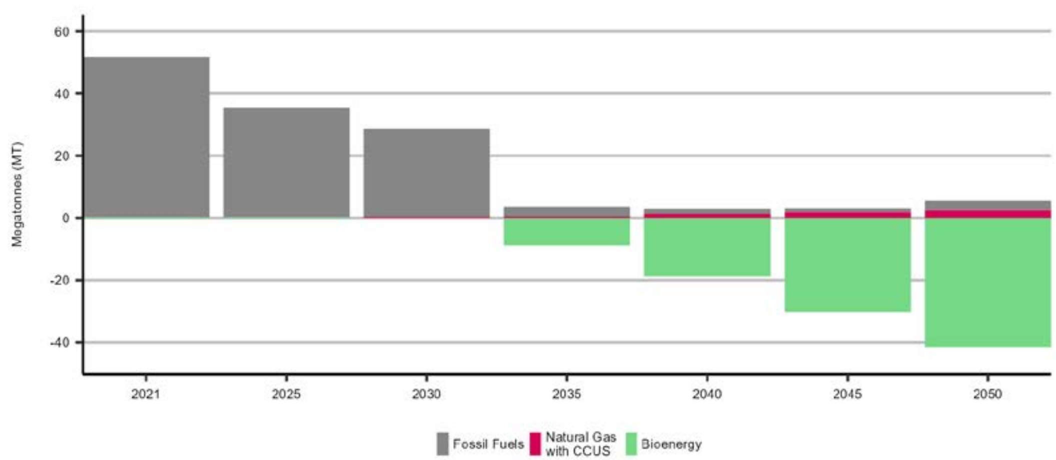


Figure ES.5:
GHG emissions from the electricity sector, by fuel, Global Net-zero Scenario



3 A portfolio of emerging technologies plays a key role in our net-zero scenarios, especially to address more difficult-to-reduce emissions.

For some energy uses, switching to electricity is not possible or less effective than other low- or non-emitting options. In both net-zero scenarios, a portfolio of options plays important supporting roles, including CCUS, hydrogen, negative emission technologies and nature-based solutions.

As shown in Figure ES.6, CCUS is used to capture CO_2 emissions from the electricity, heavy industry, and oil and gas sectors in both net-zero scenarios. By 2050, nearly 60 MT of CO_2 are captured from these sectors using CCUS in the Global Net-zero Scenario, which is about 9% of Canada's total GHG emissions in 2021. In the Canada Net-zero Scenario, almost 80 MT of CO_2 are captured by 2050, as there are more emissions to be captured from the greater amount of fuel used to produce oil and natural gas.

A robust hydrogen economy develops in both net-zero scenarios. Most hydrogen is used in heavy freight vehicles and in industries like chemicals, iron and steel, and petroleum refining. We project hydrogen use reaches over 8.5 MT by 2050 in the Global Net-zero Scenario, or 12% of total energy use. We also assume an additional 5 MT of hydrogen exports in the Global Net-zero Scenario. Combined, Canada produces nearly 14 MT of hydrogen by 2050 in the Global Net-zero scenario, and slightly more in the Canada Net-zero Scenario. We project hydrogen production from a variety of technologies including using natural gas as a feedstock along with CCUS, electrolysis using water and electricity, and biomass-based processes, as shown in Figure ES.7. Biomass-based hydrogen production, when coupled with CCUS, results in net-negative GHG emissions much like BECCS electricity generation.

Despite all sectors significantly reducing emissions, several sectors, like buildings, heavy industry and oil and gas still have positive GHG emissions by 2050 in both net-zero scenarios. Technologies like BECCS and direct air capture, as well as nature-based solutions, result in negative emissions by 2050 in both net-zero scenarios, allowing emissions to balance to zero. By 2050 in the Global Net-zero Scenario, we project -36 MT net-negative emissions from the electricity sector, -21 MT from hydrogen production using biomass with CCUS, and -46 MT from direct air capture technology. We also assume 50 MT of negative emissions from land use, land-use change and forestry (LULUCF).

Figure ES.6:
GHG emissions captured and permanently stored from fossil fuel combustion and industrial processes, by sector, Global and Canada Net-zero scenarios

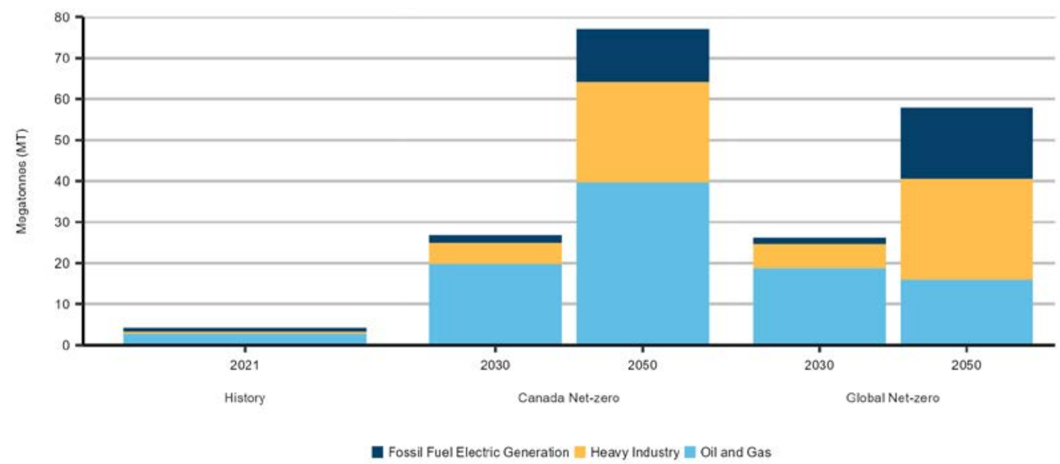
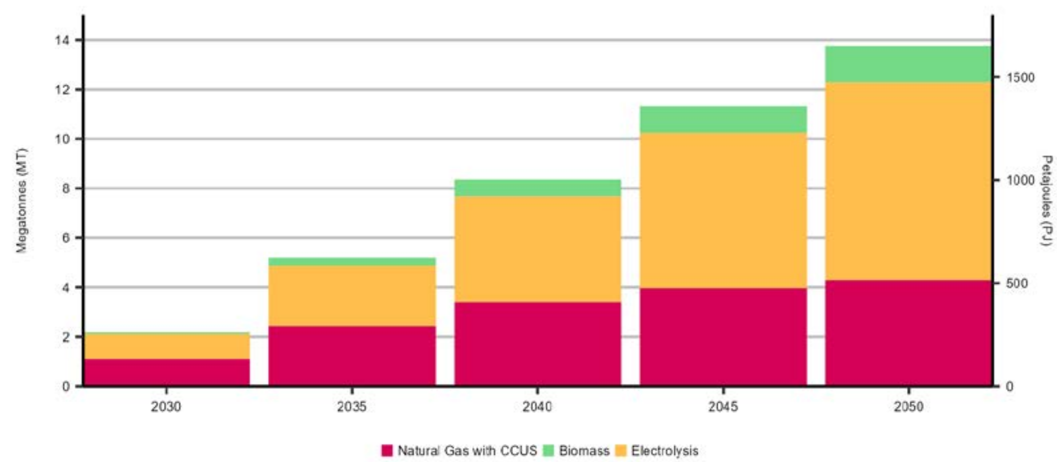


Figure ES.7:
Hydrogen production by technology, Global Net-zero Scenario



4 Canada's oil and natural gas industry significantly reduces its emissions in our net-zero scenarios and, while production declines, the pace of global climate action determines by how much.

In both net-zero scenarios, GHG emissions from producing and processing oil and natural gas decrease approximately 90% by 2050 compared to 2021. We project that increasingly strong climate policies result in the adoption of CCUS, technological and process improvements to dramatically reduce methane emissions, efficiency improvements, and reliance on electricity where feasible. Ultimately, falling production in response to much lower crude oil and natural gas prices in the Global Net-zero Scenario is also a key driver of decreasing emissions.

In EF2023, the assumptions we make about the price of crude oil and natural gas have the largest impact on our projections for Canadian oil and gas production. Those prices are different in each scenario and are driven by the pace of global climate action in the future and the resulting amount of global demand for oil and natural gas.

In the Global Net-zero Scenario, we assume that global prices of oil and natural gas fall steeply in response to declining global demand for fossil fuels over the coming decades. In this scenario, we project that Canadian crude oil production falls to 1.2 million barrels per day (MMb/d) (194 thousand cubic metres per day ($10^3m^3/d$)) by 2050, 76% lower than in 2022 as shown in Figure ES.8. As shown in Figure ES.9, natural gas production falls by 68% over the same period, reaching 5.5 billion cubic feet per day (Bcf/d) (156 million cubic metres per day ($10^6m^3/d$)) by 2050.

In the Canada Net-zero Scenario, prices fall less than in the Global Net-zero Scenario, a result of less ambitious global climate action, which results in higher global demand for fossil fuels. We project that oil production falls to 3.9 MMb/d (623 10^3m^3/d) by 2050, 22% lower than in 2022, and natural gas production falls to 11.0 Bcf/d (310 10^6m^3/d), 37% lower than in 2022.

In the Current Measures Scenario, where prices are highest and future climate action is the least ambitious, crude oil and natural gas production are the highest, and so are emissions from the sector. Crude oil production reaches 6.1 MMb/d (964 10^3m^3/d) by 2050, 20% higher than in 2022. Production of natural gas grows to 21.5 Bcf/d (607 10^6m^3/d), a 24% increase over the projection period.

Figure ES.8:
Crude oil production, all scenarios

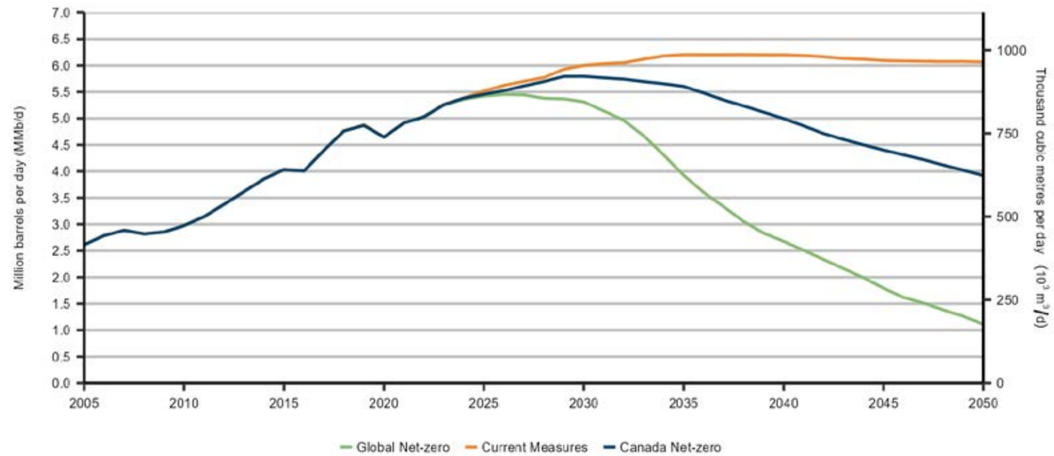
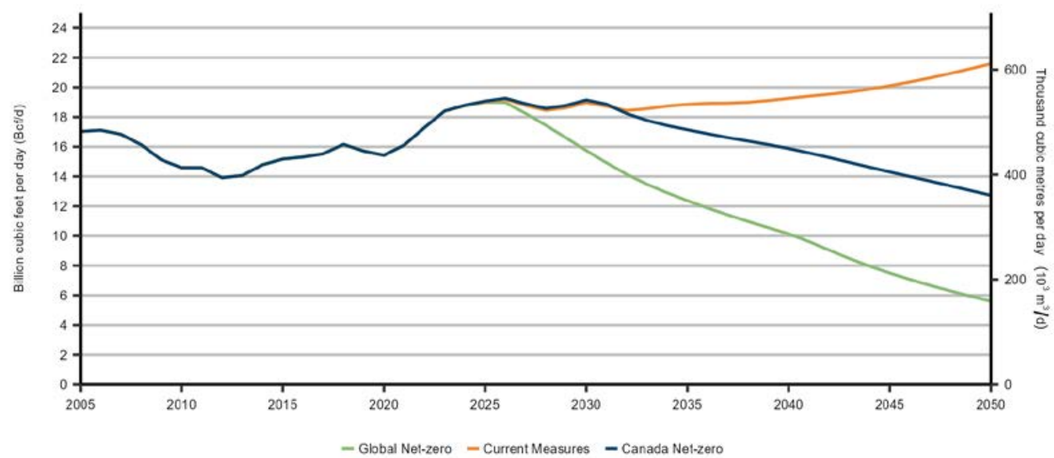


Figure ES.9:
Natural gas production, all scenarios



5 Reaching net-zero in our scenarios is driven by increasingly strong climate policies, in Canada and abroad.

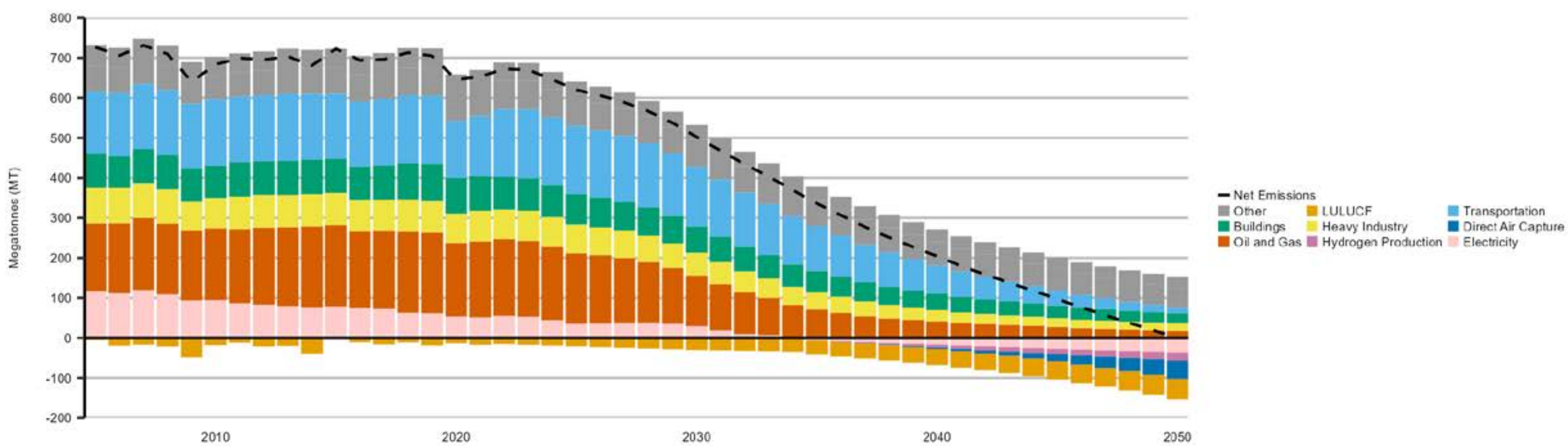
Both the Global and Canada Net-zero scenarios achieve net-zero GHG emissions by 2050, a pre-determined outcome given the nature of the analysis. Large emission reductions occur across the economy, with all sectors contributing to achieving net-zero. Figure ES.10 shows emissions by economic sector over the projection period in the Global Net-zero Scenario, with positive emissions from some sectors being offset by negative emissions in other sectors by 2050. The emission trends are similar in the Canada Net-zero Scenario.

Continued increases in the strength of climate policies in Canada is the key driver of emission reductions over the coming decades in both net-zero scenarios. Our modeling shows that the pace of climate action in Canada will need to continue to increase in the 2030 to 2050 period in order to achieve net-zero emissions by 2050.

This is in contrast to the Current Measures Scenario, where domestic climate action does not increase beyond those measures currently in place today. In that scenario, we project that GHG emissions are just 13% lower in 2050 than they were in 2021.

Action to reduce emissions globally also plays an important role in our projections and what the paths to net-zero look like in our scenarios. Depending on the scenario, we assume that climate policies around the world drive technological innovation and create markets for low-carbon technologies. This innovation and market development results in our assumption of lower costs and better performance for low emission technologies in the net-zero scenarios. In addition, global climate action also factors into our projections by influencing the prices and exports of energy we produce, which are key drivers of our scenarios.

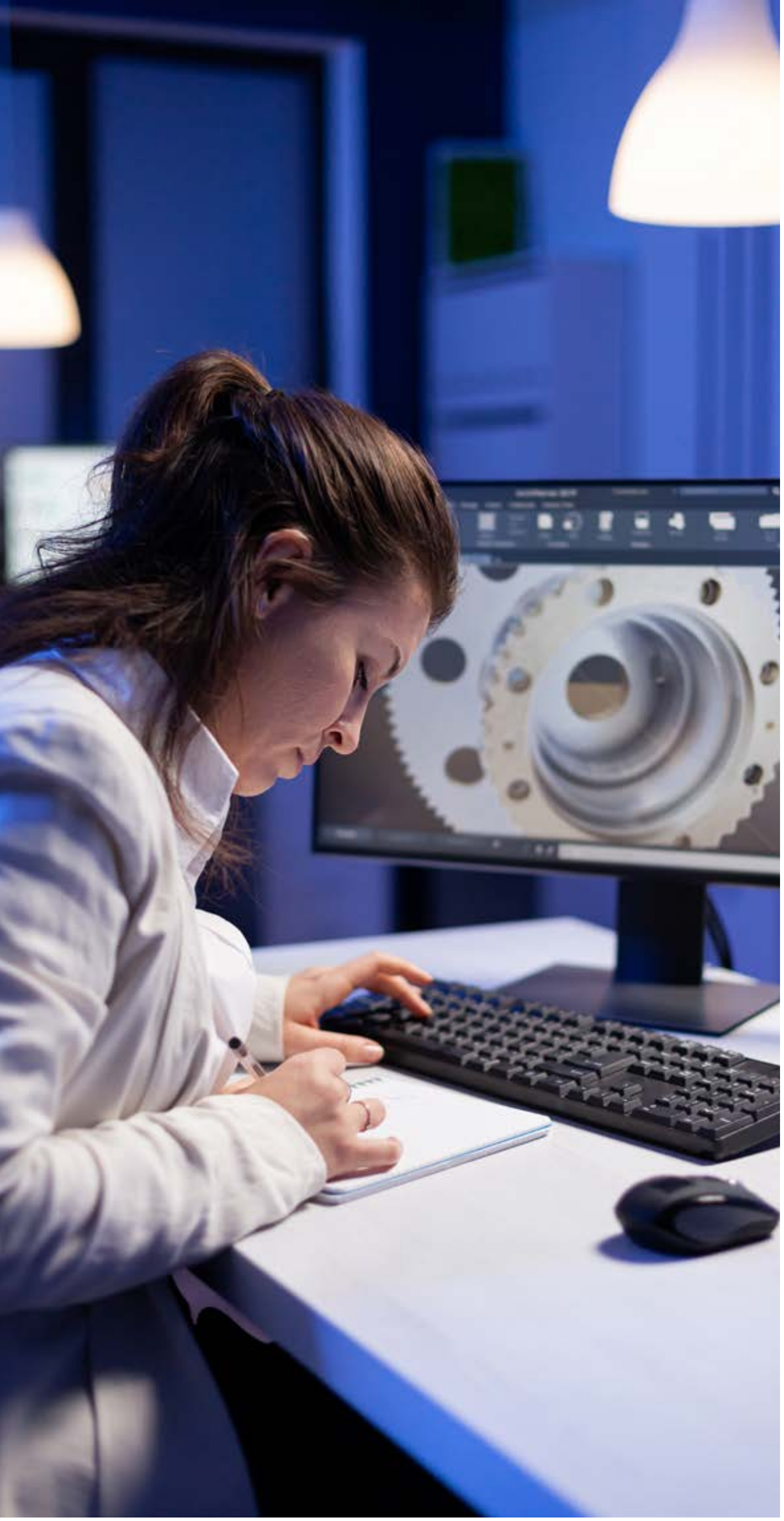
Figure ES.10:
GHG emissions by economic sector, Global Net-zero Scenario



Introduction

Canada's Energy Future 2023: Energy Supply and Demand Projections to 2050 (EF2023) is the latest long-term energy outlook from the Canada Energy Regulator (CER).

The Canada's Energy Future series explores how possible energy futures might unfold for Canadians over the long term. We use economic and energy models to explore how supply and demand for energy could evolve. EF2023 is the CER's first long-term outlook that models scenarios where Canada reaches net-zero greenhouse gas (GHG) emissions by 2050. To model net-zero, we begin with the end goal in mind—net-zero GHG emissions in 2050—and use our models to identify pathways to that point. This is a different approach compared to past versions of the report where we ran our models without restrictions, giving us insights into what a given premise meant for the future.



EF2023 includes three scenarios, two that reach net-zero by 2050

EF2023 contains three scenarios. Two of these scenarios explore pathways where Canada achieves net-zero emissions by 2050. In the Global Net-zero Scenario, we assume Canada achieves net-zero emissions by 2050. We also assume the rest of the world reduces emissions enough to limit global warming to 1.5 Celsius (°C). In the Canada Net-zero Scenario, Canada also achieves net-zero emissions by 2050 but the rest of the world moves more slowly to reduce GHG emissions. The third scenario, the Current Measures Scenario, assumes limited action to reduce GHG emissions beyond measures in place today. In this scenario, we do not require our modeling results achieve net-zero GHG emissions in Canada by 2050. We also assume limited future global climate action.

Five "What if" cases explore uncertainties on the path to net-zero

In addition to the three main scenarios in EF2023, you will find five cases in this report that ask: "What if?" There are many uncertainties on the pathway to net-zero. These cases explore some of them by changing some key assumptions in EF2023 and showing what it could mean for Canada's pathway to net-zero:

- 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 electricity vehicle charging patterns result in higher peak electricity demand?

We have been working to improve our analytical tools over the past several years to ensure we are up to the challenge of modeling net-zero. In late 2021, the Honourable Jonathan Wilkinson, Minister of Natural Resources and the Minister responsible for the CER, wrote a letter to the Chairperson of the CER's Board of Directors, Cassie Doyle. The letter requested that the CER undertake scenario analysis consistent with Canada achieving net-zero emissions[1] by 2050 as soon as possible. Minister Wilkinson requested that the analysis:

- Include fully modelled scenarios of supply and demand for all energy commodities in Canada.
- Be consistent with a global context in which the world achieves its Paris Accord goal of limiting warming to 1.5°C.
- Consider relevant uncertainties, including future trends in low-carbon technology and energy markets.

In her response, Chairperson Doyle welcomed the clarity provided by the Minister's letter and confirmed the next Canada's Energy Future report will include net-zero scenarios.

Consultation and collaboration have always been key to the Canada's Energy Future series. We sought advice and feedback from various experts throughout the process, with the goal of validating our approach, assumptions, and preliminary results to ensure EF2023 was technically robust and credible.

Federal departments, particularly Natural Resources Canada and Environment and Climate Change Canada, played an important role in supporting the EF2023 analysis. While the CER is ultimately accountable for the content of EF2023, both organizations supported our efforts by contributing substantial technical expertise to the analysis. This collaboration ensured we had the best possible information about the latest technologies and climate policy developments. The CER would like to thank both organizations for their steadfast support in this endeavor.

The *Canadian Energy Regulator Act* (CER Act) is the foundation for nearly all that we do. Our Strategic Plan aligns with the mandate set out in the CER Act and describes our mission as:

> Regulating federal infrastructure to ensure safe and efficient delivery of energy to Canada and the world, protecting the environment, recognizing, and respecting the rights of the Indigenous Peoples, and providing timely and relevant energy information and analysis.

The CER's Board of Directors sets the strategic direction of our organization. The Board of Directors supported the CER taking on the challenge of modeling net-zero and provided strategic direction for EF2023 throughout the exercise.

Core to the governance of our organization is a clear separation between the operational and adjudicative functions of the CER. The CER's energy information work, which includes EF2023, is separate from the adjudicative role of the Commission of the CER.

The Commission is responsible for making independent adjudicative decisions and recommendations pursuant to the CER Act and other legislation. The Commission considers each matter before it based on the evidence parties submit in a proceeding. If a party wishes to rely on material from EF2023 in a regulatory proceeding before the CER, it may submit the material, just as it may submit any public document. Under these circumstances, the submitting party in effect adopts the material and that party could be required to answer questions pertaining to the material.

1 The term "net-zero emissions" refers to a state where human-caused greenhouse gas (GHG) emissions are balanced by human-caused removals of GHGs from the atmosphere. GHG emissions include all gases that have heat-trapping potential including carbon dioxide, methane, nitrous oxide, and various other gases.

The Scope of EF2023

The projections in EF2023 are based primarily on economic and technical factors. This includes economic activity, relevant policies, technology performance and costs, energy costs, and the characteristics of various energy devices. Our models simulate the decision-making of households and businesses based on those factors, which differ in each of our scenarios.

The future of energy in Canada is, however, much broader than the economic and technical factors driving the projections in EF2023. Many of these are beyond the scope of our analysis. These include evolving societal preferences, regulatory frameworks and decisions, socioeconomic and affordability considerations, and the interaction between the energy transition and Canada's journey towards Reconciliation.

An example would be the choices our model makes regarding the type of power generating facilities that might be built to meet growing electricity demand in a given year. Our model simulates what technology is likely to be chosen based on the upfront costs of various options, future fuel costs, the impact on grid stability and any relevant policy considerations, such as carbon pricing.

Given our assumptions, the model might suggest that building a wind farm, for example, is the optimal outcome. However, the process to build such a facility would also depend on additional factors like the results of regulatory decision-making and societal viewpoints towards the project. We look at these factors in a general sense to assess if our projections are reasonable, but these factors are not easily accounted for within our energy models or study design, and largely fall outside the scope of EF2023.

Another aspect of Canada's energy future outside the scope of EF2023 is how climate change will impact the economy and energy system. Many of the impacts of climate change on Canada today are described in Canada's National Adaptation Strategy. These impacts include more frequent and intense weather events, such as floods and heat waves, and more gradual impacts such as permafrost thaw and coastal erosion. According to the United Nations International Panel on Climate Change, global surface temperatures are very likely to increase until at least 2050. This increase suggests that the impacts of climate change on the energy system and economy will increase over the projection period. Our models do not currently account for the wide range of climate impacts on the energy system and economy.

We also sought advice from some of the top experts outside of government, both in Canada and internationally. Conversations with experts from organizations like the International Energy Agency, Canadian Climate Institute, and Institut de l'énergie Trottier were instrumental to ensuring our approach was sound. We deeply appreciate their advice.

The CER would also like to thank the many experts who responded to a technical discussion paper and survey on our preliminary approach in the Spring of 2022. This early feedback on our project was important in setting the direction of our work. A summary of that engagement is on our website: Discussion Paper Results – A Summary of What we Heard.

We base the projections in EF2023 on several important assumptions, which we outline in the Scenarios and Assumptions chapter. The Results chapter describes our projections of the Canadian energy system to 2050 for each of the three scenarios. Finally, the Access and Explore Energy Futures Data chapter links to data, tools, and interactive data visualizations that offer further insight into EF2023.

Scenarios and Assumptions

This chapter describes the premise of the three scenarios in EF2023. We also describe the assumptions[2] of those scenarios.

Scenario premise

EF2023 analyzes three scenarios: the Global Net-zero Scenario, the Canada Net-zero Scenario, and the Current Measures Scenario. All three scenarios provide projections for all energy commodities and all Canadian provinces and territories. We developed these scenarios to explore questions that are relevant to the current Canadian energy dialogue, and to depict a range of potential outcomes for the future.

2 In the context of EF2023, assumptions are inputs to our energy and economic models. Assumptions are often made when a factor is necessary for the analysis but are not something that is explicitly modelled. Modellers often develop different sets of assumptions to generate different scenarios to understand how the energy future might look under different circumstances.

The premise of each scenario differs based on:

- The pace of climate action in Canada (including whether Canada must achieve net-zero emissions by 2050).
- The pace of climate action in the rest of the world.

Both the Global and Canada Net-zero scenarios share the premise that the future pace of climate action in Canada is consistent with Canada reaching net-zero[3] greenhouse gas (GHG) emissions in 2050. Simply put, a key outcome of these scenarios is predetermined: the level of GHG emissions in 2050. We then rely on our energy and economy models to project a pathway for the energy system that is consistent with this outcome.

In the Current Measures Scenario, there is no additional action to reduce GHGs beyond those in place today. In this scenario, we do not require our modeling results to achieve net-zero GHG emissions in Canada by 2050.

Global climate action affects Canada's energy system

While the pace of domestic climate action is a key part of our scenarios, the pace of action outside of Canada is also important. As a trading nation, what happens globally affects Canada's economy and energy system. EF2023 focuses on Canada, and we do not model global energy markets. Instead, international factors relevant to the Canadian energy outlook are assumptions, or inputs, that we put into our models. Examples include global prices for crude oil and natural gas, and costs for many low-carbon technologies.

While both net-zero scenarios share the same overall premise for achieving net-zero in Canada, they differ based on the pace of global climate action. The Global Net-zero Scenario is based on rapid global climate action: a pace consistent with the world achieving the Paris Agreement goal of limiting warming to 1.5°C, compared to pre-industrial levels. In the Canada Net-zero Scenario, the pace of global climate action increases, but not as quickly. Global action in the Current Measures Scenario is the slowest, with limited future global action beyond policies in place today.

3 Net-zero GHG emissions means that Canada's human-caused GHG emissions are balanced by human-caused removals of GHGs from the atmosphere.

The IEA's global outlook is our primary source for international assumptions

The primary source for international assumptions in the Global and Canada Net-zero scenarios is the International Energy Agency's (IEA) World Energy Outlook 2022 (WEO2022). Much like the CER's Canada's Energy Future report, the IEA's energy outlook contains multiple long-term scenarios.

Published in October 2022, WEO2022 provides robust and transparent projections. Relying on this analysis for the international perspective in EF2023 ensures our assumptions reflect recent international trends and events, including the impact of the Russian invasion of Ukraine on the global energy system.

While the IEA does model Canada, we do not rely on those results in EF2023. Rather we use the IEA's projections of key global variables (such as the global crude oil price) as assumptions in EF2023. We describe the specific assumptions we draw from the WEO2022 in the following section, Key Assumptions.

The Global Net-zero Scenario uses assumptions from the IEA's Net Zero Emissions by 2050 Scenario

In our Global Net-zero Scenario, we use the IEA's Net Zero Emissions by 2050 Scenario from WEO2022 as a source for many assumptions. This scenario is described by the IEA as "consistent with limiting the global temperature rise to 1.5°C without a temperature overshoot (with a 50% probability)." As a result, the scenario provides a good basis for ensuring our Global Net-zero Scenario reflects rapid global action to reduce GHG emissions.

Figure A.1:
Scenarios and assumptions

What are the scenarios in EF2023?

	Global Net-zero scenario	Canada Net-zero Scenario	Current Measures Scenario
What is the pace of climate action in Canada?	**Sufficient to reach net-zero by 2050** – the end point of the scenarios is predetermined		**Limited future action to reduce GHG emissions** – no requirement to hit net-zero
What is the pace of global climate action?	**Rapid Pace** – consistent with limiting warming to 1.5°C	**Increasing Pace** – but insufficient to limiting warming to 1.5°C	**Limited** future actions to reduce GHG emissions

What do does this mean for the assumptions in each scenario in EF2023?

	Global Net-zero scenario	Canada Net-zero Scenario	Current Measures Scenario
Domestic Climate Policies	Canadian climate policies increase in strength to achieve net-zero GHG emissions in Canada by 2050.		Only climate policies that are currently in place.
Technology	Adoption of low carbon technologies accelerates, which leads to cost deductions and efficiency improvements of technologies	Adoption of low carbon technologies accelerates. Costs fall and efficiency improves, but less so than in the Global Net-zero Scenario.	Limited global climate action reduces incentives to progress low-carbon technologies.
International Crude Oil Markets	Global climate action increases rapidly. Global crude oil demand, and crude oil prices, fall dramatically.	Global climate action increases, but less quickly. Global crude oil demand, and crude oil prices fall, but less than in the Global Net-zero Scenario.	Global climate action remains at current levels. Global crude oil demand and prices are the highest among the three scenarios.
International Natural Gas Markets	Global climate action increases rapidly. Global natural gas demand, and natural gas prices, fall, though less steeply than crude oil.	Global climate action increases, but less quickly. Global natural gas demand, and natural gas prices fall, but less than in the Global Net-zero Scenario.	Global climate action remains at current levels. Global natural gas demand and prices are the highest among the three scenarios.

The principles of the IEA's Net Zero Emissions by 2050 Scenario are summarized below:

- The uptake of all the available technologies and emissions reduction options is dictated by costs, technology maturity, policy preferences, and market and country conditions.
- All countries co-operate towards achieving net-zero emissions worldwide.
- An orderly transition across the energy sector, ensuring the security of fuel and electricity supplies at all times.

The Canada Net-zero Scenario uses the IEA's Announced Pledges Scenario for its international assumptions

The Announced Pledges Scenario includes all the climate commitments and longer-term targets made by governments around the world and assumes that they will be met in full and on time. It covers net-zero by 2050 targets from Canada, the United States, the European Union, and others. It also includes targets such as China's goal to achieve carbon neutrality before 2060, and India's goal to reach net-zero by 2070.

The IEA's Announced Pledges Scenario models increasing global climate action but is unlikely to limit the global temperature rise to 1.5°C. According to the IEA, the global GHG emissions resulting from this scenario would cause a temperature rise of around 1.7°C by 2100. The premise of the Canada net-zero Scenario is aligned with the Announced Pledges Scenario, with slower climate action outside of Canada than in the Global Net-zero Scenario.

The Current Measures Scenario uses other sources for international assumptions

The international assumptions of the Current Measures Scenario are not from the WEO2022. Instead, we review global scenario analysis produced by institutions, academia, industry, private forecasters, and other relevant energy analysis, to develop our own assumptions.

Figure A.1 summarizes, at a high-level, the premise of the CER's scenarios, and how they relate to the assumptions in EF2023. The following section, Key Assumptions, describes the assumptions in detail.

Different global scenarios modeling a net-zero world

For the Global Net-zero Scenario in EF2023, we rely on the IEA's Net Zero Emissions by 2050 Scenario as a source for international assumptions. We also rely on the IEA's Announced Pledges Scenario in our Canada Net-zero Scenario. The IEA is an autonomous inter-governmental organization within the Organisation for Economic Co-operation and Development framework. Canada is one of 31 full member countries of the IEA.

We chose this approach because the IEA's global energy outlooks are among the most authoritative analyses of the global energy system. The World Energy Outlook series is publicly available, transparent about its assumptions and modeling approach, and provides significant context to accompany the results. Nearly all of the variables we require for the international assumptions in our own modeling exercise, such as crude oil and natural gas prices and technology costs, are readily available.

Other global outlooks were considered for EF2023

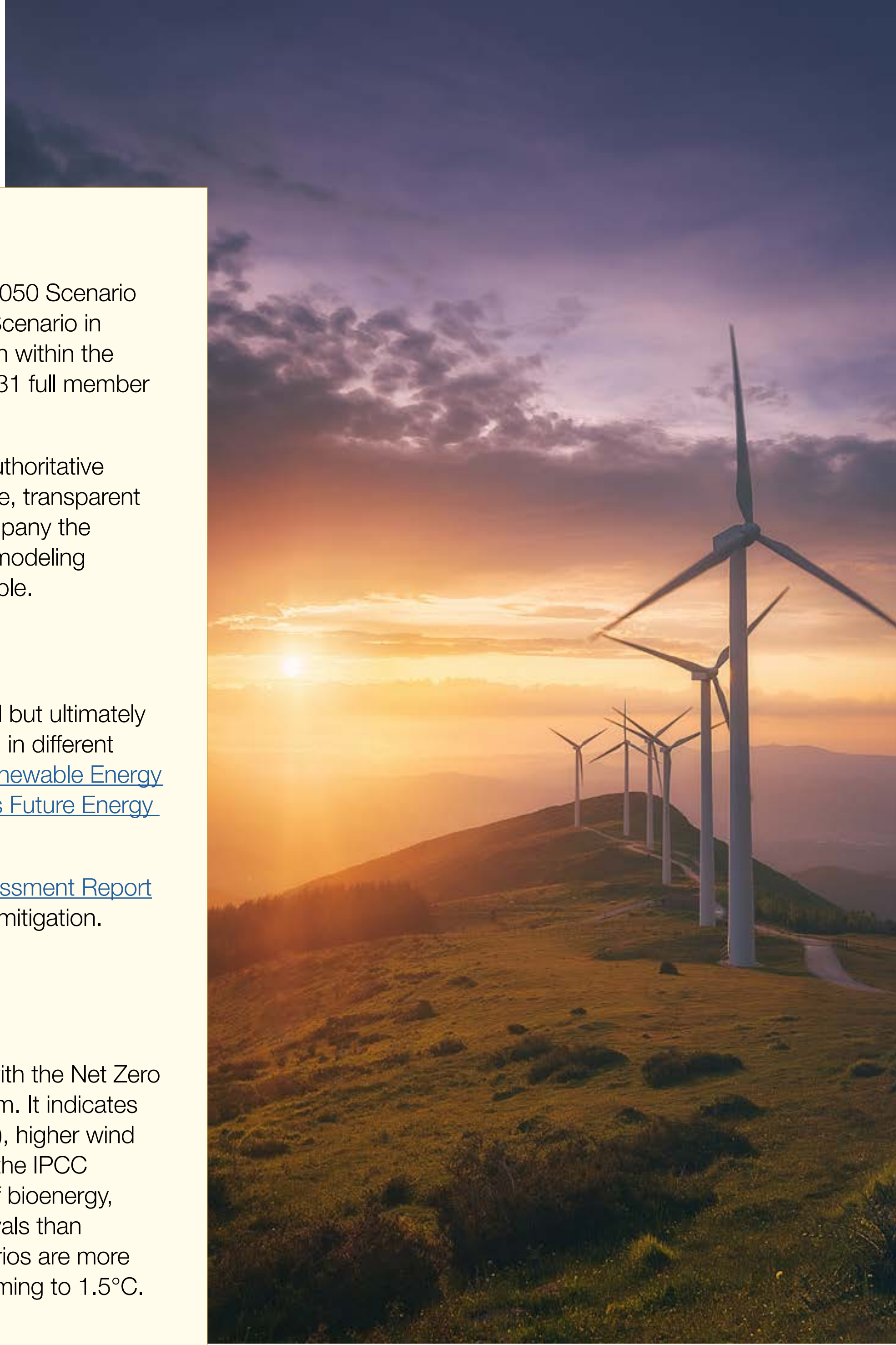
There are other energy outlooks that include global net-zero pathways that we considered but ultimately did not use in EF2023. Choosing a different global scenario to rely on would have resulted in different assumptions and outcomes in EF2023. Other global outlooks include the International Renewable Energy Agency World Energy Transitions Outlook, BP Energy Outlook, Shell Scenarios, and Platts Future Energy Outlooks.

In addition, as part of the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6), authors collected and assessed model-based scenarios related to climate change mitigation. The collection of these scenarios is referred to as the AR6 Scenarios Database[4].

The IEA's outlook compared to other global pathways to net-zero

WEO2022 provides a comparison between the 16 IPCC scenarios that are comparable with the Net Zero Emissions by 2050 Scenario outcome of net-zero emissions from the global energy system. It indicates that the IEA's scenario has lower total energy demand (due to efficiency and electrification), higher wind and solar electricity generation, and higher hydrogen consumption compared to many of the IPCC scenarios. It also shows that the Net Zero Emissions by 2050 Scenario has lower levels of bioenergy, carbon capture, utilization, and storage (CCUS), and energy-related carbon dioxide removals than most of the IPCC scenarios. This does not indicate that the IEA, IPCC or any other scenarios are more reasonable but rather that there is a range of global pathways consistent with limiting warming to 1.5°C.

4 The database, and a scenario explorer tool is hosted by the International Institute for Applied Systems Analysis.



In addition to the three main scenarios in EF2023, you will find five cases in this report that ask: “What if?” There are many uncertainties on the pathway to net-zero. These cases explore some of them by changing key assumptions in EF2023 and showing what it could mean for Canada’s pathway to net-zero:

- 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 DAC technology matures more quickly and is less costly?
- What if CCUS technology does not mature as quickly and is more costly?
- What if electricity vehicle charging patterns result in higher peak electricity demand?

We chose these questions based on the magnitude of the impact these factors could have on the pathway to net-zero, and the level of uncertainty about their future.

Why do we do scenario analysis?

EF2023, and most previous versions of the report, contain multiple scenarios. Scenario analysis is common in most long-term energy outlooks.

We do scenario analysis to explore uncertainties facing the future of the energy system. The results in EF2023 are not predictions about the future. Rather, they are the product of scenarios based on a premise and a certain set of assumptions. Relying on just one scenario to understand the energy outlook implies too much certainty about what could happen in the future.

The scenarios in EF2023 explore uncertainty about the future pace of climate action in Canada and around the world. Past versions of the report explored this and other areas of uncertainty using scenarios. Past scenarios focused on energy infrastructure developments, energy prices, economic growth, and technological progress.

While scenarios provide a range of potential outcomes for the future, they are also useful to compare against one another. The similarities and differences across the scenarios often provide more useful insights than a single scenario in isolation.

Key assumptions

Domestic climate policy

Domestic climate policies include laws, regulations, and programs put in place by governments with the goal of reducing GHG emissions. Such policies can affect the trajectory of Canada's energy system. We make assumptions about the climate policies we model in each scenario in EF2023. This section outlines some of the key policies we include. Additional details are available in Appendix 1: Domestic Climate Policy Assumptions.

Domestic climate policies in the Current Measures Scenario

Federal, provincial, and territorial climate policies that are currently in place are the basis of the Current Measures Scenario. A policy is "in place" if it was enacted prior to March 2023. We do not include announced policies that are not yet implemented in the Current Measures Scenario.

The *Canadian Net-Zero Emissions Accountability Act* (CNZEAA) enshrines in legislation the Government of Canada's commitment to achieve net-zero GHG emissions by 2050. The CNZEAA does not contain mechanisms that directly influence the energy system like a more typical climate policy might, rather it provides a framework of accountability and transparency to deliver on Canada's climate commitments. The Current Measures Scenario does not model the CNZEAA.

* All dollar figures throughout the report are in Canadian dollars unless stated otherwise.

Carbon pricing in EF2023

Pricing carbon pollution is a key existing climate policy in Canada. Canada's carbon pricing approach allows provinces and territories to choose their own system to price carbon pollution, or to rely on the federal pricing system. The federal pricing system is comprised of two parts, a regulatory charge on fossil fuels like gasoline and natural gas, called the fuel charge, and a performance-based system for industries, called the Output-Based Pricing System. Provinces and territories that develop their own systems must meet minimum national stringency criteria set by the federal government to ensure consistency and fairness. In all instances, mechanisms for allocating proceeds from carbon pricing continue as outlined by provinces or territories in their own systems, or as defined in the federal system. All revenue from the federal carbon pricing system is returned to the provinces and territories where they are collected.

In all three scenarios, we assume that existing provincial and territorial carbon pricing systems remain in place. Prices in all jurisdictions increase from current levels by $15 per tonne of carbon dioxide equivalent (CO_2e) per year to reach $170 per tonne by 2030. We describe our assumptions about how we model the cost of carbon between 2030 and 2050 later in this section.

Carbon pricing and mitigating economic competitiveness risks

How we apply carbon pricing to large industrial emitters differs between scenarios. This difference ensures consistency with each scenario premise. A key difference between all three scenarios is the level of future climate action outside of Canada. This can influence the design of carbon pricing systems. When some countries are not moving as quickly as Canada to reduce GHG emissions, there is a risk that some industries in those countries have an economic advantage over competitors in Canada. There is also a risk some industrial facilities may move from Canada to another country to avoid paying a price on carbon pollution; this migration is often called carbon leakage.

The federal and provincial carbon pricing systems have mechanisms to mitigate these risks. Under the federal system, this mechanism is referred to as the Output-Based Pricing System. This performance-based system is designed to create a financial incentive for industries to reduce emissions but also reduce the risk of carbon leakage and adverse competitiveness impacts due to domestic carbon pricing. Industry-specific benchmarks (output-based standards) are used to determine the amount of carbon price owed. Instead of paying the fuel charge on fuels that they use, facilities must provide compensation for emissions above an emissions limit, calculated by multiplying relevant output-based standards and the quantity of product produced.

We assume that in the Global Net-zero Scenario, the Output-Based Pricing System, and provincial mechanisms to mitigate the risks of competitiveness impacts and carbon leakage, phase out completely by 2050. In the Canada Net-zero Scenario, slower global action implies that competitiveness could still be a concern. As a result, we assume these mechanisms remain in place but the benchmarks for determining the emission limits decline steadily over the projection period. In the Current Measures Scenario, these emission limits remain at their current levels over the projection period.

Domestic climate policies in the Global and Canada Net-zero scenarios

The Global and Canada Net-zero scenarios include all in-place federal, provincial, and territorial climate policies. Both net-zero scenarios also include all announced but not-yet-implemented policies, to the extent possible. We applied the following criteria to determine whether an announced policy was included in our analysis:

- The policy was announced prior to March 2023.
- Sufficient details exist to model the policy.

The federal government made several key climate policy announcements that it is working to implement, including:

- Clean Electricity Regulations – regulations to reduce GHG emissions from the generation of electricity to help work towards a net-zero electricity supply by 2035.
- Oil and Gas Emissions Cap – regulations to reduce GHG emissions from the oil and gas sector at a pace and scale necessary to achieve Canada's 2030 and 2050 climate targets.
- Light-duty Zero Emission Vehicle (ZEV) Sales Mandate – a mandatory 100% zero-emission vehicle sales target by 2035, including interim targets of at least 20% by 2026 and at least 60% by 2030.
- A 75% reduction in oil and gas sector methane emissions relative to 2012 levels by 2030 – regulations and other measures needed to achieve at least a 75% reduction in methane emissions from the oil and gas sector from 2012 levels by 2030.
- Investment Tax Credit for Clean Hydrogen – a tax credit to support investments in clean hydrogen production

These and other announced but not-yet-implemented policies are modeled in both net-zero scenarios. Final details of some of these policies were not available at the time of analysis. We include these policies by relying on assumptions about those policies as necessary.

In some cases, we strengthen existing and announced policies beyond what is specified in a policy or regulation. For example, the Clean Fuel Regulations require the emission intensity of certain fuels for sale in Canada to decline by a specific rate until 2030. We continue emission intensity reductions as if the policy continued to increase in strength beyond 2030.

Finally, to ensure the Global and Canada Net-zero scenarios achieve net-zero by 2050, we rely on some hypothetical policies in the 2030 to 2050 period. The following section, Modeling Net-zero and Future Climate Policy Assumptions describes this approach.

Table A.1 describes the key policy assumptions in EF2023. Further details on these and other policies is available in Appendix 1: Domestic Climate Policy Assumptions.

> Assumptions regarding future policies in EF2023 are meant to be illustrative and represent a stylized future policy environment. Our assumptions are not policy recommendations for governments. In developing future policies, governments will consider economic, social, legal, jurisdictional (both within and outside of Canada), and other factors.

Table A.1:
Overview of domestic climate policy assumptions

Policies currently in place These policies are the basis of the Current Measures Scenario and are also included in the Global and Canada Net-zero scenarios.	
Policy	**Description**
Carbon pricing	Current provincial and territorial pricing systems, as well as the federal carbon pricing backstop.
Methane regulations	Federal and provincial regulations applying to methane, including federal regulations for the upstream oil and gas sector aimed at reducing emissions by 40% from 2012 levels by 2025.
Investment tax credit for carbon capture, utilization, and storage	A federal investment tax credit for CCUS projects that permanently store captured carbon dioxide (CO_2) in geological storage or in concrete.
Investment tax credit for clean technologies	A federal investment tax credit for electricity generation systems, stationary electricity storage systems, low-carbon heat equipment, and industrial zero-emission vehicles and related infrastructure.
Clean fuel regulations	A performance-based supply standard requiring suppliers of gasoline and diesel to reduce the lifecycle carbon intensity of their fuels.
Coal phase-out	Traditional coal-fired generation is phased out of electricity generation by 2030.
Energy efficiency regulations	Current federal and provincial regulations on energy efficiency for appliances, heating and cooling equipment, building codes, and vehicles.
Zero-emissions vehicle subsidies	Current federal and provincial subsidies on zero-emission vehicles.
Renewable fuels	Current provincial and federal regulations for blending biodiesel, ethanol, hydrogenation-derived renewable diesel, and renewable natural gas.
Announced policies that are not yet implemented These policies are included in the Global and Canada Net-zero scenarios but not the Current Measures Scenario.	
Policy	**Description**
Clean electricity regulations	Federal regulations to reduce GHG emissions from the generation of electricity to help work towards a net-zero electricity supply by 2035.
Zero-emission vehicle mandate	A federal zero-emission vehicle (ZEV) mandate is introduced in 2025, rising to 100% of new light duty vehicle sales by 2035 in the provinces. New heavy duty vehicle sales rise to 100% ZEV where feasible by 2040.
National net-zero emissions building strategy	Increase energy efficiency of new and existing buildings out to 2050.
Oil and gas emissions cap	Regulations to reduce GHG emissions from the oil and gas sector at a pace and scale necessary to achieve Canada's 2030 and 2050 climate targets.
Methane regulations	Methane emissions from the upstream oil and gas sector are reduced by 40% by 2025 from 2012 levels and 75% by 2030.
Carbon pricing	See the following section, "Modeling net-zero and Future Climate Policy Assumptions."

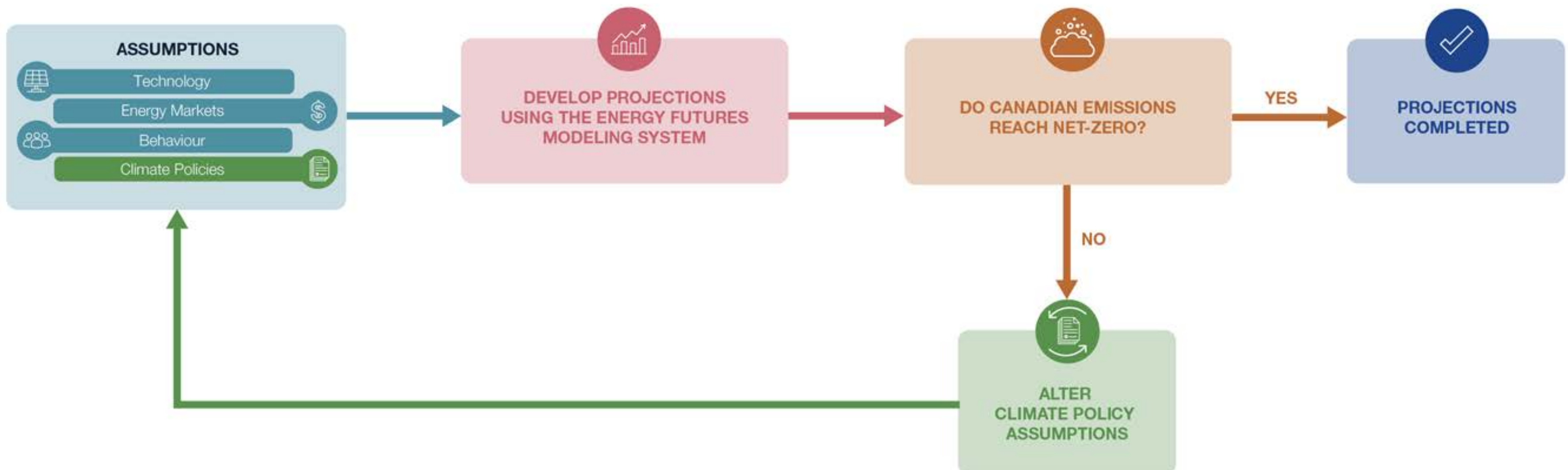
Modeling net-zero and future climate policy assumptions

A requirement of the Global and Canada Net-zero scenarios is that Canada reaches net-zero GHG emissions by 2050. **In the net-zero scenarios in EF2023, we begin with the end goal in mind: net-zero GHG emissions in 2050, and use our models to identify a pathway to that point**. This is a different approach compared to past versions of this report. Previously, we ran our models without restrictions, giving us insights into what a given premise and set of assumptions meant for the future.

To reach net-zero, we take an iterative approach

This approach[5] begins with running the Energy Futures Modeling System with an initial set of assumptions. Once complete, we look at the resulting GHG emissions in 2050. If our projections do not result in net-zero emissions by 2050, we alter our hypothetical future climate policy assumptions and re-run our models. With each additional model run, we alter the policy assumptions, resulting in higher or lower GHG emissions. We repeat this process until the outcome of the model is consistent with net-zero GHG emissions by 2050. Other assumptions, such as those on technologies, international markets, and behaviour, remain constant. Figure A.2 shows this process.

Figure A.2:
Simplified iterative approach to modeling net-zero in the Global and Canada Net-zero scenarios



5 Another approach to modeling net-zero pathways is referred to as optimization. This approach uses models to compute an optimal pathway to a pre-determined outcome (such as net-zero emissions by 2050). Canadian Energy Outlook 2021 published by the Institut de l'énergie Trottier is an example of modeling Canada's energy system using optimization techniques.

The main driver of our models reaching a net-zero emissions outcome is what we refer to as the “aggregate cost of carbon.” The aggregate cost of carbon represents the hypothetical suite of policies, regulations, and programs, that we assume in the 2030 to 2050 period. In practical terms, to implement this in the Energy Futures Modeling System, we rely on a hypothetical economy-wide carbon price to represent the aggregate cost of carbon. This choice is solely for technical modeling purposes. It is likely that future climate policy in Canada, like it is today, will be a diverse mix of tools to reduce emissions. **Our assumptions are not policy recommendations for governments. In addition, these assumptions are not an estimate of what future carbon prices are necessary to achieve net-zero, but instead a modeling technique we use to explore potential net-zero outcomes**.

The aggregate cost of carbon resulting from the iterative process shown in Figure A.2 increases steadily from $0 per tonne of carbon dioxide equivalent (CO_2e) in 2030 to 2022$330 per tonne of CO_2e in 2050 in inflation adjusted terms in the Global Net-zero Scenario, and to 2022$380 per tonne of CO_2e in the Canada Net-zero Scenario. In both net-zero scenarios, this is in addition to the federal backstop carbon price of $170 per tonne of CO_2e in 2030 to 2050 (or 2022$95 per tonne of CO_2e in inflation-adjusted terms by 2050), as well as all in-place federal, provincial, and territorial climate policies and the announced but not-yet-implemented policies that we model in our analysis.

Technology

To model Canada's energy system, we make assumptions about a wide variety of technologies that use or produce energy. These range from well-established technologies (like refrigerators, furnaces, and wind turbines) to those under development or not yet widely used (like heat pumps, small modular reactors (SMRs), and DAC processes). We make assumptions about the current and future costs, performance, and efficiency of technologies.

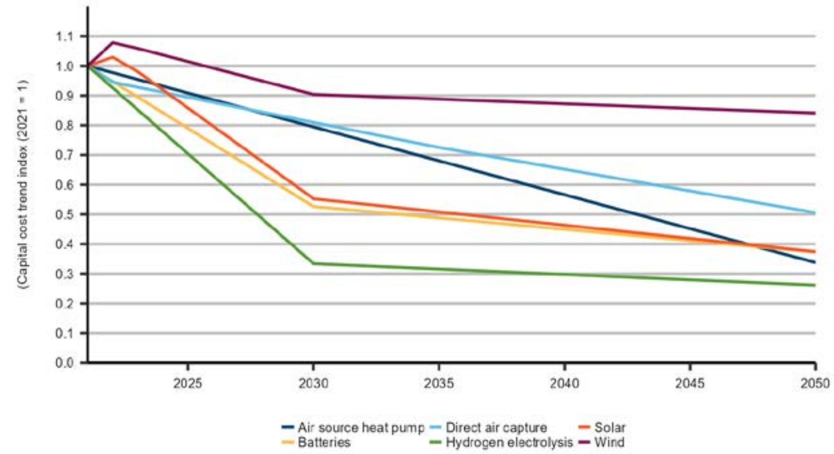
Energy technology development and the pace of climate action are related

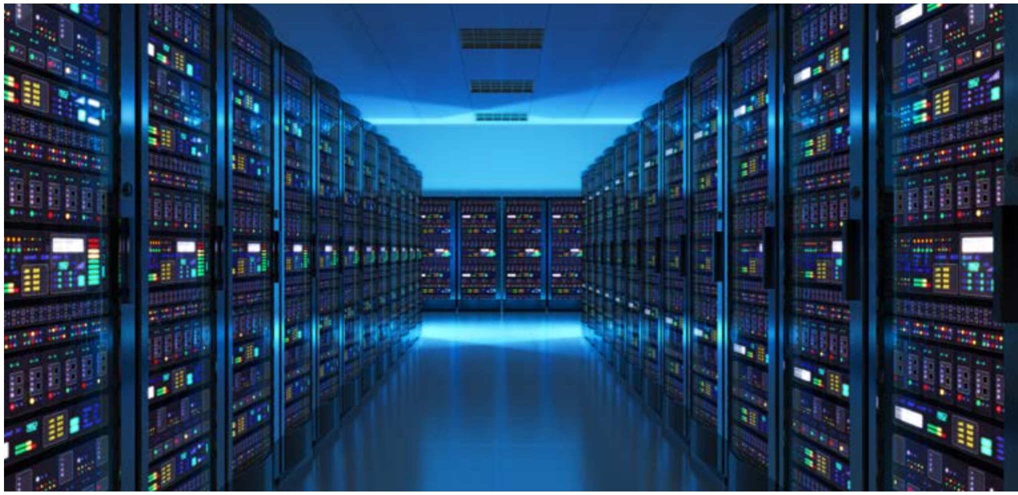
Climate policies drive technological innovation and create markets for low-carbon technologies. This innovation and market development can result in lower costs and better performance. The difference in global climate action in our three scenarios means we make different assumptions about technology in each scenario.

The Global and Canada Net-zero scenarios assume continued technological progress, including commercialization of many emerging technologies that can support a net-zero future. Both scenarios rely on the IEA's scenarios for many of the technology assumptions, where clean energy technologies generally get progressively less costly over time. The pace of this cost decline varies by scenario. In the IEA's analysis, the more households and businesses use a technology, the more its cost tends to decline. This means that technology costs decline the most in the Global Net-zero Scenario because it draws its technology assumptions from the IEA's Net Zero Emissions by 2050 Scenario, which is the most ambitious scenario in WEO2022. The cost declines in the Canada Net-zero Scenario are somewhat slower, as that scenario relies on the IEA's Announced Pledges Scenario, which has somewhat slower global climate action. The Current Measures Scenario has the slowest pace of technological development.

Figure A.3 provides an example of the cost declines for some of the technologies in the Global Net-zero Scenario.

Figure A.3:
Capital cost trends for select technologies, Global Net-zero Scenario





Critical minerals are key to low-carbon energy deployment

All assumptions in EF2023 have a degree of uncertainty associated with them. How much different technologies eventually cost will likely differ from what we assume in this report. A key factor affecting many low-carbon technologies is the cost of inputs to manufacture those technologies, including critical minerals. In its WEO2022 report, the IEA notes that the increasing use and importance of critical minerals could become a bottleneck for clean energy deployment. For more information on the impact of critical minerals on the Canadian energy outlook, see the text box: "Critical Minerals and the Energy Transition" in EF2021, or the CER's Market Snapshot "Critical Minerals are Key to the Global Energy Transition".

Table A.2 describes many of the technology assumptions in EF2023 in all three scenarios. Further details on these and other technologies is available in Appendix 2: Technology Assumptions.

Table A.2:
Overview of technology assumptions[a]

Technology	Global Net-zero	Canada Net-zero	Current Measures
CCUS	Capture costs are different by industry and range from \$45-200/tCO_2 by 2030 and \$30-160/tCO_2 from 2030-2050.	Capture costs are different by industry and range from \$45-200/tCO_2 by 2030 and \$ 30-160/tCO_2 from 2030-2050.	Capture costs are different by industry and range from \$45-200/tCO_2 through the projection period.
Battery-electric passenger vehicles	Cost declines 30% by 2030 and 38% by 2050.	Cost declines 28% by 2030 and 36% by 2050.	Cost declines 26% by 2030 and 33% by 2050.
Medium and heavy-duty freight vehicles	Battery-electric and fuel cell truck costs fall steadily, approaching parity with diesel vehicles in 2035-2050 period.	Battery-electric and fuel cell truck costs fall steadily, approaching parity with diesel vehicles in 2035-2050 period.	Battery-electric and fuel cell truck costs remain near current levels.
Heat pumps	Cost declines 15% by 2030 and 40% by 2050.	Cost declines 13% by 2030 and 34% by 2050.	Cost declines 7% by 2030 and 20% by 2050.
Wind electricity	Capital cost declines 13% by 2030 and 17% by 2050.	Capital cost declines 10% by 2030 and 16% by 2050.	Capital cost declines 9% by 2030 and 15% by 2050.
Solar electricity	Capital cost declines 44% by 2030 and 60% by 2050.	Capital cost declines 44% by 2030 and 60% by 2050.	Capital cost declines 40% by 2030 and 57% by 2050.
Direct Air Capture (DAC)	Capture cost declines to \$330/tCO_2 by 2035 and \$230/tCO_2 by 2050.	Capture cost declines to \$350/tCO_2 by 2035 and \$250/tCO_2 by 2050.	Capture cost remains at \$400-450/tCO_2 over projection period.
Hydrogen electrolyzer	Capital cost declines 80% by 2030 and 84% by 2050.	Capital cost declines 74% by 2030 and 82% by 2050.	Capital cost declines 62% by 2030 and 70% by 2050.

[a] Cost reductions are relative to 2021, and dollar figures are adjusted for inflation.

Crude oil and natural gas markets

Global crude oil and natural gas prices are a key driver of the Canadian energy system and are determined by supply and demand factors beyond Canada's borders. The CER does not model international energy markets. Instead, we rely on other sources of information, including the analysis of others, to develop assumptions on factors like crude oil and natural gas prices. As we describe later in this section, we rely on IEA's WEO2022 projections for key inputs in both of our net-zero scenarios.

Global crude oil prices were volatile over the past few years

After averaging around US$60 per barrel (bbl) from 2017 to 2019, the annual average price for Brent crude oil fell to US$42/bbl in 2020. This price decreased largely because the COVID-19 pandemic reduced business activity, commuting, shipping, and travel, reducing global demand for oil-based products like gasoline, diesel, and jet fuel. Beginning in 2021, prices began to steadily increase, as consumption of these products rebounded when many countries eased pandemic restrictions. Meanwhile, oil producers were slow to increase investment from 2020 levels, meaning there was less new oil production to supply growing demand. Price increases accelerated in early 2022 when Russia invaded Ukraine and countries around the world sanctioned Russia's energy exports, increasing demand for non-Russian oil. The price for Brent crude oil rose above US$100/bbl for several months in 2022 before declining to closer to US$80/bbl late in the year.

North American natural gas prices followed similar trends to crude oil

From 2017 to 2019, the Henry Hub natural gas price was stable around US$3.00 per million British thermal units (MMBtu). With the onset of the COVID-19 pandemic, the price fell, averaging just over US$2.00/MMBtu in 2020. Like crude oil, natural gas prices increased through 2021 and 2022, at first because many countries eased pandemic restrictions and then because natural gas producers were slow to ramp up investment levels as demand increased. Then Russia invaded Ukraine, increasing demand for non-Russian natural gas around the world, especially liquefied natural gas (LNG) from markets like the United States. Henry Hub natural gas prices averaged US$8.81/MMBtu in August 2022, the highest monthly average since July 2008. By the end of 2022, natural gas prices decreased to less than US$6.00/MMBtu. In the first three months of 2023, gas prices continued to fall, trading closer to US$2.00/MMBtu in March.

International crude oil and natural gas prices

We rely on the IEA's WEO2022 for the global oil and natural gas price assumptions in the two net-zero scenarios in EF2023. The IEA's Net Zero Emissions by 2050 Scenario is the source of price assumptions for our Global Net-zero Scenario. The IEA projects crude oil prices to decrease to 2021US$35/bbl in inflation-adjusted terms by 2030 and 2021US$24/bbl in 2050. In the IEA's scenario, global crude oil consumption falls from 94.5 million barrels per day (MMb/d) (15.0 10^3m^3/d) in 2021, to 75.3 MMb/d (12.0 10^3m^3/d) in 2030 and 22.8 MMb/d (3.6 10^3m^3/d) in 2050. Much of this drop is because of the electrification of transportation; all global passenger vehicle sales are electric vehicles by 2035 in the IEA's Net Zero Emissions by 2050 Scenario. By 2050, three quarters of remaining global crude oil use is for products like petrochemical feedstock, lubricants, and asphalt, where the oil is not combusted.

In the Net Zero Emissions by 2050 Scenario, the IEA projects that North American natural gas prices fall from 2021US$6.60/MMBtu in 2021 to 2021US$2.00/MMBtu in 2030 and 2021US$1.80/MMBtu in 2050, in inflation-adjusted terms. Global demand for natural gas in this scenario falls by 20% from 2021 to 2030, and by over 70% by 2050. The steepest reductions in the global use of natural gas occurs in electricity generation and heating of buildings. Producing low-carbon hydrogen from natural gas makes up half of the remaining consumption in 2050.

The IEA's WEO2022 Announced Pledges Scenario is the source of global price assumptions for our Canada Net-zero Scenario. In the Announced Pledges Scenario, the drop in fossil fuel consumption is not as dramatic as in the Net Zero Emissions by 2050 Scenario. Global crude oil consumption declines 40% from 2021 to 2050, and natural gas falls 37% over the same period. As a result, the price of crude oil decreases to 2021US$64/bbl in 2030 and 2021US$60/bbl in 2050 in inflation-adjusted terms in the IEA's Announced Pledges Scenario. The price of natural gas decreases to 2021US$3.70/MMBtu in 2030 and 2021US$2.60/MMBtu in 2050.

EF2023 uses IEA price projections to model crude oil and natural gas production

While we rely on the IEA's crude oil and natural price projections, we do not use the IEA's projected production of Canadian crude oil and natural gas. Instead, we use the IEA's prices (adjusted to reflect local Canadian prices) in our models to project crude oil and natural gas production (which we describe in the following chapter, "Results").

We base our global price assumptions in the Current Measures Scenario on a review of price projections by various other organizations. In this scenario, we assume the Brent crude oil price is 2021US$75/bbl by 2030 and stays at that level through the projection period. We assume the Henry Hub natural gas price reaches 2021US$3.75/MMBtu in 2030, after which the price increases slowly, reaching 2021US$4.40/MMBtu in 2050.

Figures A.4 and A.5 show the prices we assume for crude oil and natural gas for all three scenarios in EF2023. For the Global and Canada Net-zero scenarios, we adjust the IEA's WEO2022 prices to align with key global price benchmarks used in the Canada's Energy Future series: Brent, the primary global benchmark price for crude oil, and Henry Hub, a key North American benchmark price for natural gas. We also interpolate annual prices from IEA's projections, which are only available for the years 2030 and 2050.

Domestic crude oil and natural gas prices

While international prices are a key driver of Canadian crude oil prices (like Western Canada Select (WCS) for heavy crude oil), local factors are also important in determining the prices Canadian crude oil producers receive. The difference, or "differential," in prices between local markets and international prices depends on many things, such as whether pipelines have enough capacity to ship all exports, issues in downstream markets, and quality differences between different types of crude oil (like the chemical and compositional differences between light, sweet crude oil, and heavy, sour crude oil).

In all three scenarios, the difference between West Texas Intermediate (WTI), a key North American crude benchmark, is US$2.50/bbl lower, in inflation-adjusted terms, than Brent over the entire projection period. We also assume that the difference between WTI and WCS remains at its historical level over the projection period at US$12.50/bbl in the Current Measures and Canada Net-zero scenarios. In the Global Net-zero Scenario, this differential begins to narrow slightly starting in 2035, reaching US$10/bbl in 2050. We alter the differential in this scenario to account for continued demand of heavier refined products, like asphalt.

Figure A.4:
Brent crude oil price assumptions, all scenarios

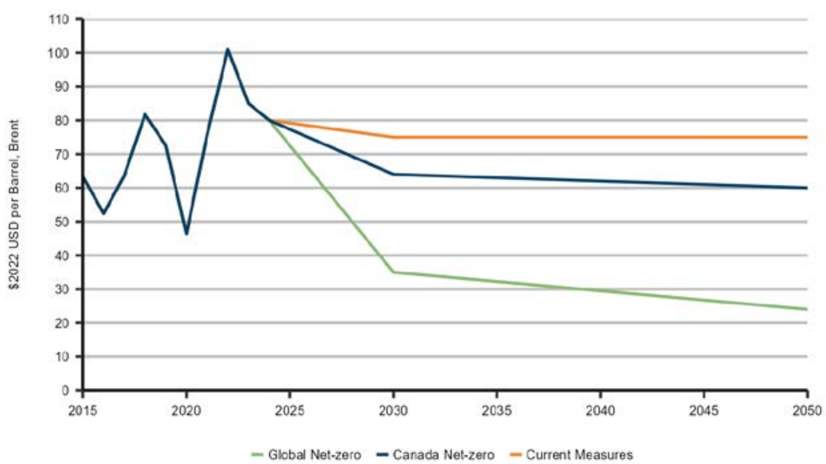


Figure A.5:
Henry Hub natural gas price assumptions, all scenarios

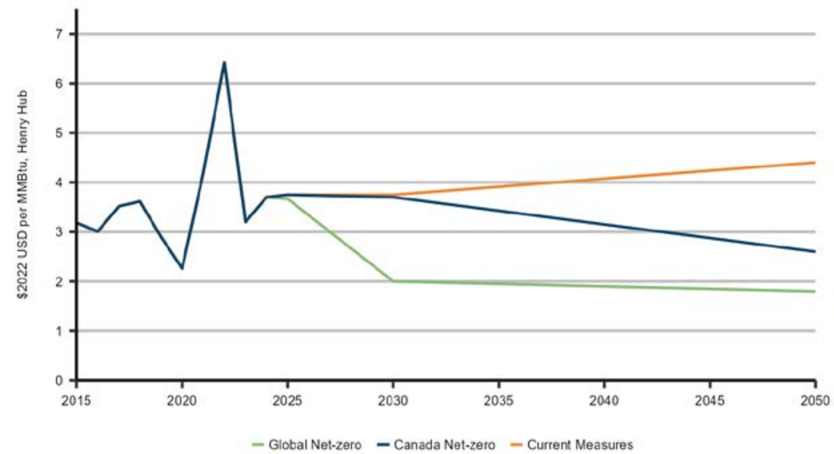
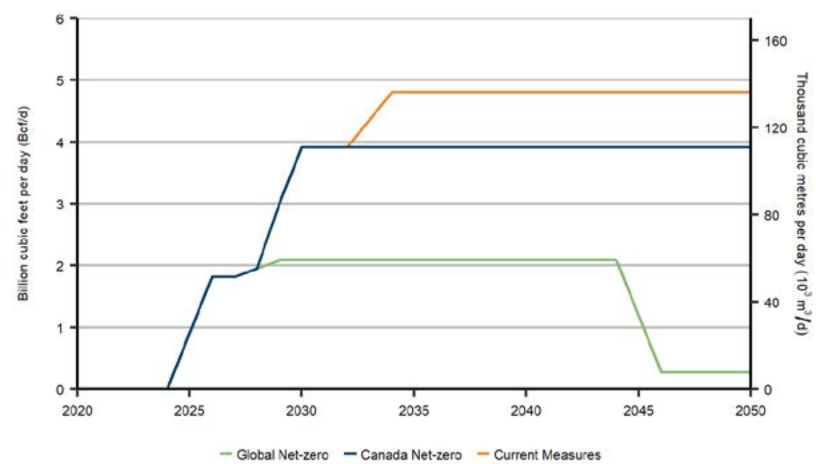


Figure A.6:
Canadian LNG export volume assumptions, all scenarios



Liquefied natural gas

We make assumptions about the amount of natural gas that Canada exports as LNG in all three scenarios (Figure A.6). Unlike many other industries, we do not use a model to project future LNG production. This is because the sector consists of a few large potential projects, each with their own unique circumstances. Instead, we rely on Asian natural gas prices in the WEO2022 to assess the economic viability of Canadian LNG exports, from which we develop our assumptions.

We assume LNG production is the lowest in the Global Net-zero Scenario

In the Global Net-zero Scenario, we assume exports of LNG from the first phase of the LNG Canada project begin in 2025 and ramp up to 1.7 billion cubic feet per day (Bcf/d) 49.0 $10^6m^3/d$) in 2026. This is the volume of natural gas that would be exported, accounting for natural gas used for fuel at the LNG facility. We also assume the Woodfibre LNG project begins production in 2028 and increases to full capacity of just below 0.3 Bcf/d (8.5 $10^6m^3/d$) in 2029. Total exports in the Global Net-zero Scenario reach 2 Bcf/d (56.6 $10^6m^3/d$) in 2029 and remain at that level until 2044. In 2045, LNG production begins to fall in response to much lower global LNG demand, reaching 0.3 Bcf/d (8.5 $10^6m^3/d$) by 2046 and staying at that level to 2050.

LNG exports increase to 2030 and then level off in the Canada Net-zero Scenario

In addition to the LNG exports in the Global Net-zero Scenario, we assume the Canada Net-zero Scenario also includes the second phase of the LNG Canada project beginning in 2029. Total LNG exports reach 3.8 Bcf/d (108.2 $10^6m^3/d$) in in 2030 and continue at that level throughout the projection period. We assume higher LNG exports in the Canada Net-zero Scenario because of higher natural gas prices and global LNG trade in the IEA's Announced Pledges Scenario.

LNG exports are the highest in the Current Measures Scenario

LNG Exports reach 4.6 Bcf/d (131.4 $10^6m^3/d$) in 2034 and staying at that level to 2050 in the Current Measures Scenario. In all three scenarios, we assume all LNG exports originate from Canada's west coast. Future LNG development is uncertain and could be significantly different than implied by these assumptions.

Implications of Russia's invasion of Ukraine

In early 2022, Russia, a major exporter of oil and natural gas to world energy markets, invaded Ukraine. Nations around the world condemned the invasion and responded by sanctioning Russian energy exports. For example, much of Europe, which relied heavily on Russian natural gas, restricted imports. In addition, transportation of Russian natural gas to Europe was severely curtailed when the Nord Stream pipeline – two offshore pipelines that connect Russia to Germany – reduced flows in July 2022, and then was shut down entirely in September 2022 because of sabotage. These events resulted in an immediate surge in global demand for non-Russian oil and natural gas that could last for several years.

European countries have also responded by accelerating plans to shift to less reliance on oil and natural gas. This acceleration includes new policies to speed up the adoption of electric vehicles, enable bigger and quicker buildouts of renewable energy, delay the retirement of some nuclear power plants, and increase energy efficiency. These are in addition to accelerating climate policy action around the world. In the WEO2022, the IEA projects that policies in place around the world today could cause fossil fuel demand to peak in the mid-2020s and then decline.

These developments result in additional uncertainty in modeling Canada's energy system. Canada is major exporter of oil and natural gas, and the global market is undergoing significant changes. For a detailed discussion of how these events could impact the global energy outlook, please see "The global energy crisis" in the IEA's WEO2022.

Non-energy and land use, land-use change and forestry emissions (LULUCF)

The analysis in EF2023 focuses on energy production, processing, transportation, and consumption in Canada, which currently represents approximately 80% of Canada's GHG emissions (mostly from fossil fuel combustion).

To depict a net-zero outcome for Canada, however, our analysis requires projections for all GHG emission sources and sinks. There are several human-caused GHG emission sources and sinks not directly linked to the energy system. While we do model non-energy emissions from industrial processes and product use, we do not model other non-energy GHG emissions in Canada. As a result, we make assumptions about them in our scenarios. Table A.3 describes the non-energy emissions we do not model, and the assumptions we make in our scenarios.

Table A.3:
Non-energy emission assumptions, all scenarios

Emissions source	Description[6]	Assumption
Agriculture	Emissions related to the production of crops and livestock (excludes on-farm fuel use). Agriculture emissions were 54 MT in 2021.	Our projections of agricultural sector output were the primary driver of the agriculture emission assumptions. Some potential emissions reductions from adoption of innovative agriculture practices are included in the net-zero scenarios. Current Measures Scenario: 55 MT in 2030 and 59 MT by 2050 Global and Canada Net-zero scenarios: 51 MT in 2030 and 41 MT by 2050
Waste	Emissions from the treatment and disposal of solid and liquid wastes, and waste incineration. Waste emissions were 21 MT in 2021.	Our projections of the number of households were the primary driver of the waste emission assumptions. We account for the proposed regulations on landfill methane in the assumptions of the net-zero scenarios. Current Measures Scenario: 22 MT in 2030 and 23 MT by 2050 Global and Canada Net-zero scenarios: 13 MT in 2030 and 11 MT by 2050
Land use, land-use change and forestry (LULUCF)	Net emissions associated with Canada's managed lands, such as forests and cropland. Land use, land-use change and forestry emissions were negative 17 MT in 2021.	Our assumptions for land use, land-use change and forestry emissions are based on a review of various studies and projections of others, such as recent studies by Environment and Climate Change Canada, Canadian Climate Institute, and Institut de l'énergie Trottier. Current Measures Scenario: -13 MT in 2030 and beyond Global and Canada Net-zero scenarios: -30 MT in 2030 and -50 MT by 2050

6 A full description of the types of non-energy emissions is available in Canada's National Greenhouse Gas Inventory Report.

Results

This chapter presents results of the EF2023 projections. These projections are not a prediction, but instead illustrate possible futures based on the scenarios and assumptions described in the previous chapter.

Many factors and uncertainties will influence future trends. Key uncertainties are discussed in each section of this chapter.

The data supporting this discussion, including full data tables for all three scenarios, is available in the "Access and Explore Energy Futures Data" chapter.

* All dollar figures throughout the report are in Canadian dollars unless stated otherwise.

Greenhouse gas (GHG) emissions

In December 2015, most countries in the world, including Canada, adopted the Paris Agreement. The overarching goal of the agreement is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels." These efforts are because the United Nation's Intergovernmental Panel on Climate Change indicates that crossing the 1.5°C threshold risks far more severe climate change impacts, including more frequent and severe droughts, heatwaves and rainfall. Fundamental to achieving the goal of the agreement is dramatically reducing global GHG emissions.

Canada's long-term climate goal is reaching net-zero GHG emissions by 2050.[7] Given that reaching net-zero emissions by 2050 is the central focus of both our net-zero scenarios in EF2023, GHG emission trends are vital to our analysis. Around 80% of Canada's total emissions are related to the production and consumption of energy, so the GHG emission and energy supply and demand projections in EF2023 are tightly linked.

Canada's GHG emission profile

From 2000 to 2019, Canada's GHG emissions have fluctuated between just below 700 megatonnes (MT) to around 750 MT. In 2020, emissions fell 8% from 2019 levels. Much of this decrease was a result of lower energy use in response to actions to reduce the spread of COVID-19, such as travel restrictions and closing businesses. The decrease in emissions from 2019 to 2020 is the largest drop in emissions recorded over the period for which data is available (1990 to 2021).

In 2021, emissions were 653 MT, or a 1.2% increase from 2020 levels, but 7.3% lower than in 2019. Figure R.1 shows Canada's GHG emissions in 2021,[8] categorized by economic sector.[9]

Of the sectors in Figure R.1, GHG emissions fell in electricity (-56%), heavy industry (-13%), transportation (-4%), and waste and others (-10%) from 2005 to 2021. GHG emissions increased in oil and gas (+13%), buildings (+2%), and agriculture (+8%) over that same period. Consistent with the past 30 years, about 80% of GHG emissions in 2021 were related to the production and consumption of energy, mostly from the combustion of fossil fuels. The remaining 20% of emissions are from other activities such as agriculture, waste management, and certain industrial processes.

Canada's GHG emission profile varies significantly among the provinces and territories, as shown in Figure R.2.

Detailed data and a more thorough description of Canada's GHG emission profile can be found in Canada's National Greenhouse Gas Inventory Report, published by Environment and Climate Change Canada (ECCC).

7 The Canadian Net-Zero Emissions Accountability Act

8 2021 emissions data, along with some historical revisions to 1990-2020 data, was released by Environment and Climate Change Canada in April 2023 in the 2023 National Inventory Report. The modeling in EF2023 is based on emissions data from the 2022 National Inventory Report, which includes GHG emission data up to 2020. Total emissions shown in EF2023 include Land Use, Land-Use Change and Forestry (LULUCF), which are often negative.

9 Canada reports GHG emissions different formats, including by economic sector. These different categorizations simply allocate GHG emissions into different groupings; there is no difference in the overall magnitude of Canadian emissions estimates. The economic sectors allocate emissions to the sector from which they originate.

Figure R.1:
GHG emissions by economic sector, 2021

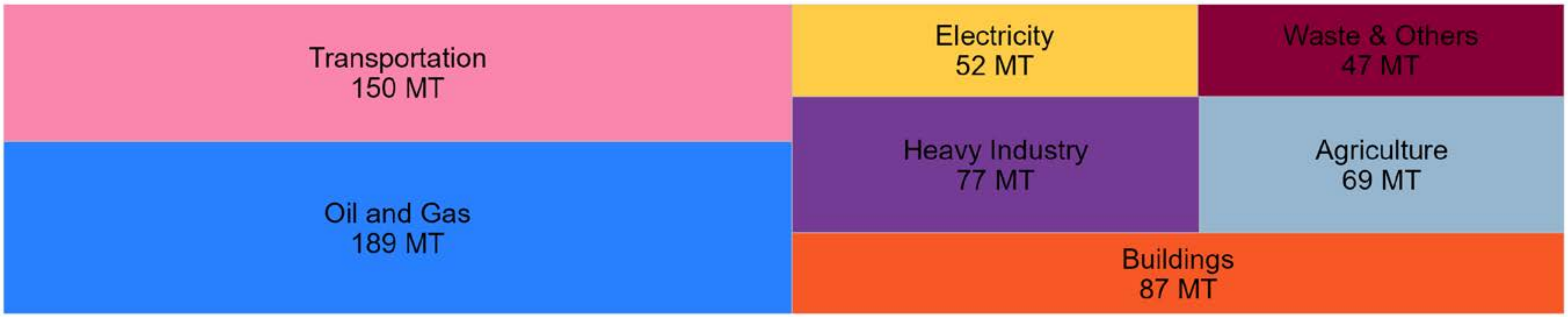
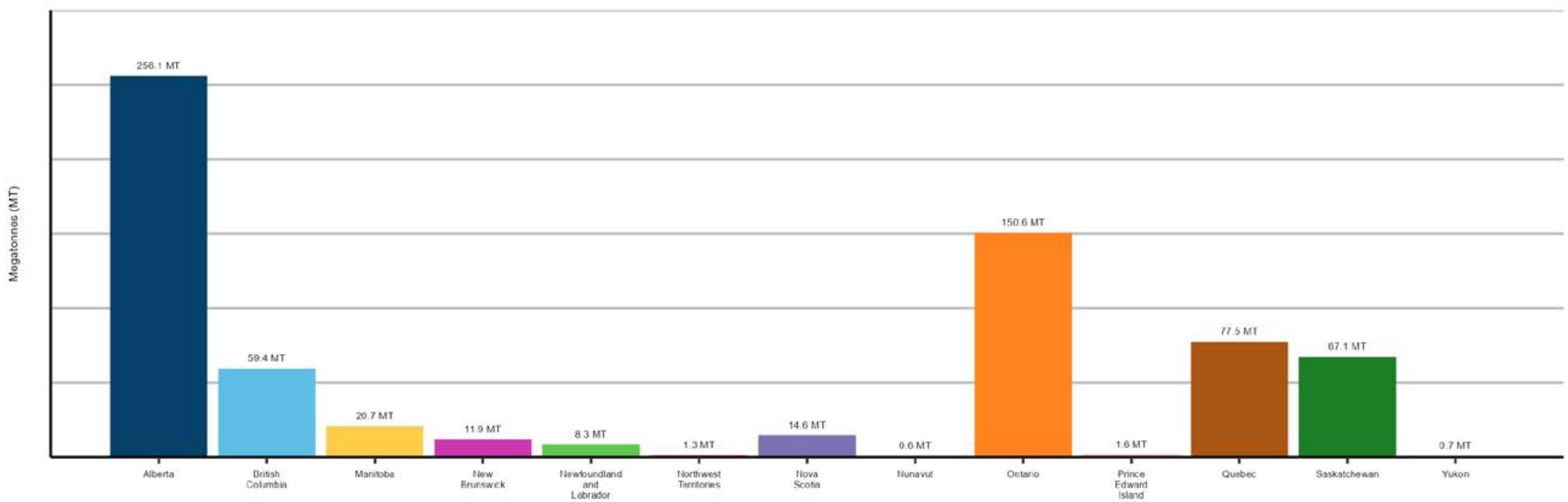


Figure R.2:
GHG emissions by province and territory, 2021



GHG emission projections

This section provides an overview of our projections of GHG emissions in all three scenarios. The sections that follow explore the energy and GHG emissions trends for the individual segments of the energy system.

Net economy-wide GHG emissions fall to zero by 2050 in the Global and Canada Net-zero scenarios, which is a pre-determined outcome due to the nature of the analysis. Total emission trends are similar in the two scenarios given they share similar climate policy assumptions. In the Current Measures Scenario, we project emissions to be 566 MT by 2050, 13% lower than 2021 levels. This projection of GHG emissions in the Current Measures Scenario only includes policies currently in place during the analysis and does not reflect recently announced policies that are in development. Figure R.3 shows total net emissions in all three scenarios and figure R.4 shows emissions by economic sector in the Global Net-zero Scenario.

Figure R.3:
Total GHG emissions, all scenarios

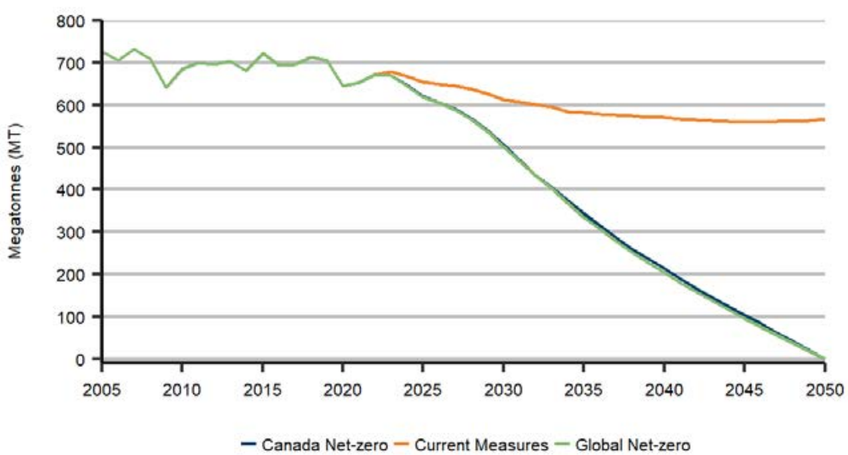
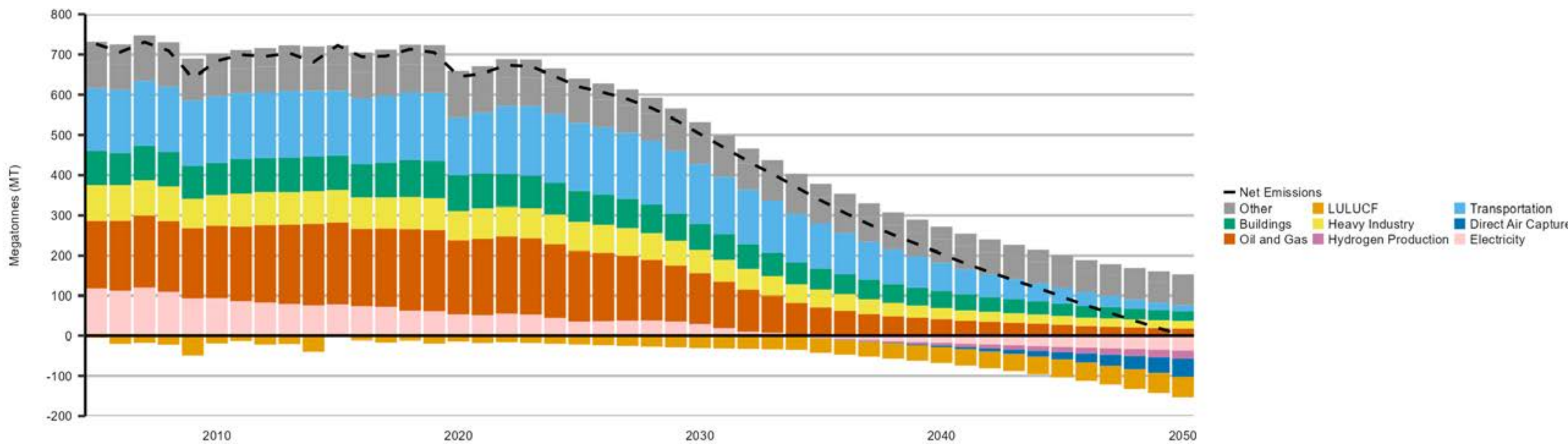


Figure R.4:
GHG emissions by economic sector, Global Net-zero Scenario



Which GHG emissions are included in EF2023

Parties to the United Nations Framework Convention on Climate Change (UNFCCC) estimate and report their historical GHG emissions according to guidelines developed by the UNFCCC. This report is referred to as a country's National Inventory Report (NIR). The UNFCC's guidelines for calculating GHG emissions aim to make reporting by countries transparent, consistent, comparable, complete, and accurate. ECCC is responsible for preparing and submitting Canada's national GHG inventory to the UNFCCC.

Each country's NIR covers emissions (and removals) of GHGs, including carbon dioxide, methane, nitrous oxide, and various other gases that have heat-trapping potential. GHG emissions are calculated as those that occur within a country. For example, if country A produces and exports natural gas to country B, any GHG emissions resulting from producing that natural gas (such as the GHG emissions from facilities that process raw natural gas) are attributed to country A, while emissions related to the combustion of that natural gas are attributed to country B.

The historical GHG emissions that we report in EF2023 align with Canada's NIR. The latest historical emissions data available is from 2021. The GHG emission projections in EF2023 are estimates resulting from the Energy Futures Modeling System, relying on inputs based on the scenario premise and assumptions we describe in the previous chapter. In various publications, such as the Emission Reduction Plan and Biennial Report to the UNFCCC, ECCC produces the official analysis of Canada's current emissions outlook and performance against its climate commitments.

In both net-zero scenarios, all sectors have much lower emissions by 2050, compared to 2021 levels. Table R.1 shows the GHG emissions in each sector in 2050, and briefly describes the transformations that occur in each sector.

Table R.1:
Change in emissions from 2021 to 2050 by economic sector, and key outcomes, Global and Canada Net-zero scenarios

Sector	2021	2050		Key outcomes – Net-zero scenarios
		Global Net-zero	Canada Net-zero	
Total	653 MT	0 MT	0 MT	• Domestic and global climate policy assumptions drive most of the emission reductions in both net-zero scenarios, which grow in strength over the projection period.
Buildings	87 MT	25 MT	25 MT	• Heat pumps steadily replace natural gas and heating oil furnaces. • Improved efficiency of buildings, reducing overall space heating needs.
Heavy industry	77 MT	19 MT	19 MT	• Innovative industry-specific technologies to reduce energy and process GHG emissions. • Application of carbon capture, utilization, and storage (CCUS) in industries like chemicals and fertilizers, cement, and iron and steel. • Some switching to low- or non-emitting fuels like electricity, hydrogen, and biofuels.
Transport	150 MT	15 MT	14 MT	• Electric vehicles become the primary mode of on-road passenger transportation. • Freight shipping by truck, train, and ship is increasingly fueled by electricity, hydrogen, or biofuels. • Aviation emissions are reduced using a mix of bioenergy and hydrogen-based aviation fuel.
Electricity	52 MT	-36 MT	-35 MT	• Electricity use doubles over the projection period in both net-zero scenarios. • Rapid growth in low- and non-emitting generation sources, led by wind, natural gas with CCUS, bioenergy with CCUS, and nuclear, accompanied by steady growth in solar and hydro. • The electricity system decarbonizes and becomes net-negative by 2035 with the deployment of bioenergy with CCUS generation facilities.
Oil and gas	189 MT	17 MT	32 MT	• Declines in crude oil and natural gas production in the Global Net-zero Scenario, mostly driven by falling international demand and prices. Production declines more slowly in the Canada Net-zero Scenario. • Adoption of CCUS, especially in the oil sands. • Rapid uptake of processes and technologies to significantly reduce methane emissions from conventional oil and natural gas production and processing activities.

Sector	2021	2050		Key outcomes – Net-zero scenarios
		Global Net-zero	Canada Net-zero	
Low-emitting hydrogen production	0 MT	-21 MT	-25 MT	• To meet growing hydrogen demand from domestic and international markets, hydrogen production grows significantly. • Low or non-emitting hydrogen is produced from electricity, natural gas, and biomass. • Coupled with CCUS, production of hydrogen using biomass results in net-negative emissions from the sector.
Direct air capture (DAC)	0 MT	-46 MT	-55 MT	• DAC technology is deployed later in the projection period, offsetting particularly difficult-to-reduce GHG emissions from other sectors.
Agriculture	69 MT	50 MT	49 MT	• We assume GHG emissions from agriculture decline somewhat with the adoption of innovative agricultural practices.
Waste and others (coal production, light manufacturing, construction, and forest resources)	47 MT	26 MT	26 MT	• We assume emissions from waste decline, in part due to proposed regulations that aim to reduce landfill methane emissions.
Land Use, Land-Use Change and Forestry (LULUCF)	-17 MT	-50 MT	-50 MT	• We assume LULUCF emissions are net-negative in 2050, based on a review of various studies and projections by other organizations.

Energy demand

This section first discusses secondary[10] (or “end-use”) energy demand[11] projections by reviewing energy use by sector of the economy and their associated GHG emissions. We then describe the primary energy demand[12] projections. End-use demand includes consumption of energy, including electricity and hydrogen, but not the energy used to produce electricity and hydrogen.

We make projections about energy demand by simulating the energy choices of households and businesses, including the energy technologies and fuels they use. Economic activity, population growth, technology characteristics, energy prices, and climate policies all influence the model’s outcomes.

Our energy demand projections also rely on projections about the need for energy services. Energy services are not the energy or technologies we use, but rather the things that energy enables us to do, like heat our homes, travel from place to place, or run equipment at a business. This includes projections of the output from various industries, the number of homes and businesses requiring heating and cooling, and the number of kilometres that passengers and goods move. The eventual level of energy services required may be different than in our scenarios, which would impact our projections of energy use.

In all three scenarios, energy use increases in the near term

We estimate Canadian end-use energy demand increased 4% in 2022, largely a result of increasing industrial and oil and gas activity, as well as a return to near pre-pandemic transportation levels. We project that demand growth continues in 2023 and 2024, but at a slower pace.

In the long term, energy use falls in both net-zero scenarios

While we project continuing economic and population growth, end-use demand declines by 22% from 2021 to 2050 in the Global Net-zero Scenario and 12% in the Canada Net-zero Scenario. As we describe in the following sections, this decline is largely due to switching to different technologies and fuels, more efficient use of energy, and lower activity levels in some sectors. In particular, switching from fossil fuels to electricity can reduce overall energy demand significantly because electric devices often use energy more efficiently. For example, 30% or less of the energy in gasoline is used to propel vehicles with much of the remainder being lost to heat. In an electric vehicle (EV), much more of the energy stored in the vehicle’s battery is converted to movement. The combined impact of these changes reduces Canada’s energy intensity. The energy intensity of the economy, often measured as energy use per $ of real gross domestic product, declines by 2.2% per year in the Global Net-zero Scenario, and 1.7% per year in the Canada Net-zero Scenario. Energy intensity has typically fallen about 1% per year on average in recent decades.

In the Current Measures Scenario, energy use is relatively stable

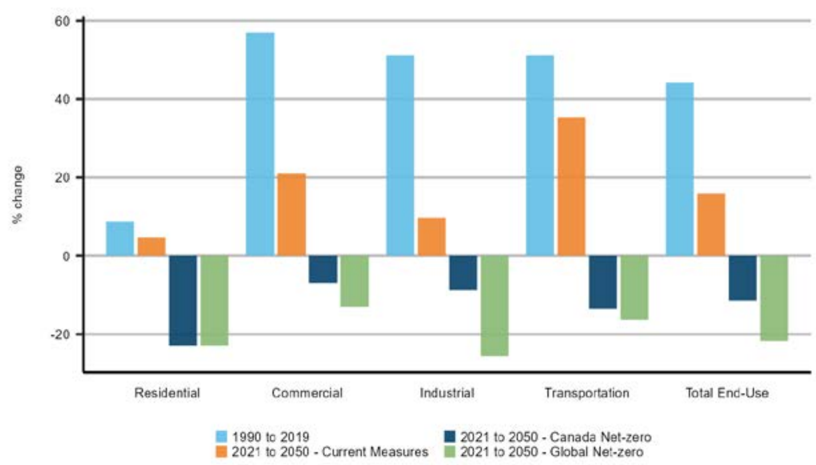
In the Current Measures Scenario, energy use is relatively stable until 2040. After 2040, energy use begins slowly increasing again. This increase is because climate policies do not strengthen beyond 2030, but the economy and population continue to grow, increasing energy use. Figure R.5 shows the changes in end-use energy demand in each scenario.

10 Energy used by final consumers for residential, agricultural, commercial, industrial and transportation purposes. It excludes the energy used to generate electricity, which is included under primary demand.

11 That energy is accounted for in primary energy demand. Historical energy demand data is sourced primarily from Statistics Canada’s Report on Energy Supply and Demand in Canada. This data is supplemented with additional details from ECCC, Natural Resources Canada, and various provincial data sources.

12 Primary demand is the total energy used in Canada, including energy to produce electricity and hydrogen.

Figure R.5:
Change in end-use energy demand by sector, 2021 to 2050, all scenarios



In all scenarios, households and businesses continue to receive the energy services much like they do today, like being able to reliably heat their homes or travel from place to place. As described in the following sections, we project considerable changes to the types of fuels and technologies that power the energy system in the future, but little change to the energy services Canadians receive.

KEY TRENDS
Energy demand

- Rapid adoption of devices that use electricity, like EVs and heat pumps in the net-zero scenarios.
- In both net-zero scenarios, clean fuels such as hydrogen and bioenergy, along with CCUS, play an increasing role in areas that are harder to electrify.
- Energy efficiency improves steadily over the projection period.

Residential and commercial

The residential sector made up 13% of Canada's end-use energy demand, and 6% of its GHG emissions in 2021. The commercial sector, which includes buildings like offices, restaurants, and schools, made up 11% of Canada's end-use energy demand, and 7% of its GHG emissions in 2021. Most energy use in both sectors is electricity and natural gas, and in some regions refined petroleum products (RPPs) and biomass are also key fuels. When combined, GHG emissions in both sectors are referred to as the "buildings sector" for the purposes of GHG emission reporting. GHGs in the buildings sector are primarily the result of burning natural gas and fuel oil for heating buildings and water.

In the Global and Canada Net-zero scenarios, we project that energy use patterns change considerably in both sectors. The electrification of space and water heating, along with rapid improvements in the efficiency of buildings, are core to this sector's transformation.

In the Global Net-zero Scenario, we project that building shell efficiency (or how well buildings resist losing heated or cooled air to the outside environment) of the entire residential building stock improves by 50% from 2021 to 2050. In the commercial sector, this improvement is slightly slower at 43%. Efficiency gains are driven by energy retrofits of existing buildings and increasingly strict building codes for new buildings, with all new homes built to a "net-zero-ready" standard by 2030. Efficiency improvements are similar in the Canada Net-zero Scenario. These efficiency improvements are important because residential and commercial floorspace both grow around 50% over the projection period as new houses and buildings are built. In the Current Measures Scenario, less ambitious policy measures result in slower improvements in efficiency.

Fuel-switching is necessary to achieve net-zero

In both net-zero scenarios, efficiency improvements support achieving net-zero, but switching existing fossil fuel heating devices to non-emitting options is necessary to achieve net-zero emissions. In many regions, heating needs are currently met with natural gas or heating oil furnaces. Due to our assumptions about climate policies and technology cost reductions, electric heat pumps steadily become the device of choice when households and businesses replace their furnaces. Heat pumps also grow in regions that currently rely heavily on electric baseboard heating. Because heat pumps are very energy efficient, switching from baseboard heating to heat pumps helps limit electric demand growth in the building sector. Currently, heat pumps are gaining popularity in some regions in Canada but are used sparingly in many regions. More information about the characteristics of heat pumps is in the text box "Spotlight on Heat Pumps." Importantly, our projections are based on parameters about the willingness of households and businesses to adopt new technologies like heat pumps. However, societal preferences change over time, which could change the adoption rates of heat pumps, or any of the other technologies we discuss in this chapter.

Heat pump use increases in both net-zero scenarios, but some gas and oil furnaces remain

In both net-zero scenarios, heat pumps provide about 50% of residential space heating needs by 2050, up from 6% in 2021, as shown in Figure R.6. This is similar in the commercial sector as heat pumps provide around half of space heating needs by 2050. While heat pumps dominate new heating technology installations by the mid-2030s, the rate of change in the residential and commercial sectors tends to be slow as most households and businesses usually replace devices near the end of their useful lives. As a result, we project that some natural gas and heating oil furnaces remain in 2050 in both net-zero scenarios. Efficiency improvements and blending fossil fuels with low-carbon fuels such as hydrogen and renewable natural gas helps reduce the emissions from these buildings. By 2050, approximately 13% of the energy used in gas-fired residential and commercial space and water heating is renewable natural gas, and 7% hydrogen.

Spotlight on heat pumps

Electric heat pumps are a key technology for building decarbonization in our net-zero scenarios. Heat pumps have been used globally for decades and most Canadians already have technologies that operate under the same principles in their homes: refrigerators and air conditioners. Heat pumps work by moving heat from one space (a source) to another (a sink). The two most common sources for heat pumps are the outside air and the ground. Electricity is used to transfer heat from the air or ground to a sink, either the indoor air or water of a building. This process can be reversed so that the building acts as a source and the air or ground acts as a sink, cooling the building instead of heating it. Therefore, heat pumps can be used year-round in Canada to regulate indoor temperatures.

Since heat pumps move heat instead of generating it, they can achieve efficiencies far beyond those of conventional heating methods like a natural gas furnace. Heat pumps currently on the market can achieve efficiencies of 300-550% depending on the temperature of the source and the size of the heat pump.

Air-source heat pumps are lower cost and cheaper to install than ground-source heat pumps and subsequently makeup most of the installed heat pumps across Canada, both now and in our scenarios. However, as the outside air temperature decreases, air source heat pumps become less efficient. Currently, cold climate air-source heat pumps can still achieve efficiencies of 180% at -15°C and still function well up to -25°C. Below this temperature, however, they have difficulty supplying enough heat to a home. As temperatures decrease, homes lose heat more quickly and more energy is required to extract heat from the air.

Canadians that live in climates that drop below -25°C and wish to install heat pumps have two options to heat their homes even on the coldest of days. First, when installing a heat pump, they can leave their current heating system as a backup or install a new backup at the same time. This backup can be any conventional technology used to heat a home, such as a natural gas furnace or electric resistance heating. Secondly, Canadians can choose to invest in a ground-source heat pump instead. Even in the coldest climates in Canada, the ground retains significantly more heat than the air and therefore can efficiently provide heat all winter.

Further information on heat pumps including functionality, technical specifications, and installation is available from Natural Resources Canada's Heating and Cooling With a Heat Pump.

Figure R.6:
Residential space heating by technology, Global Net-zero Scenario

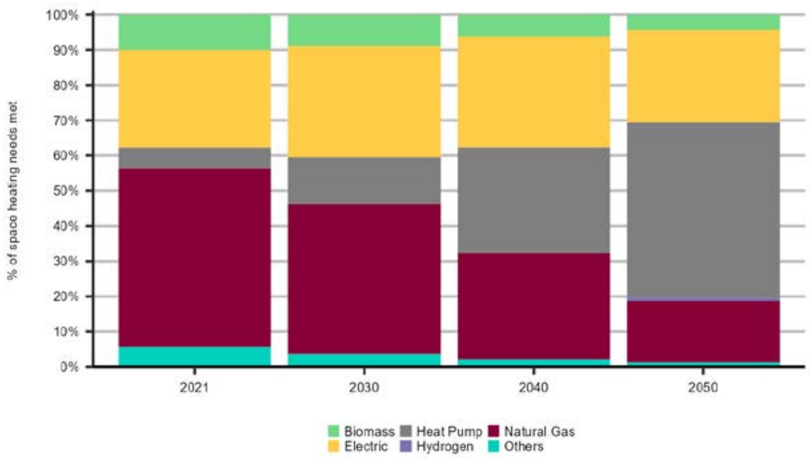
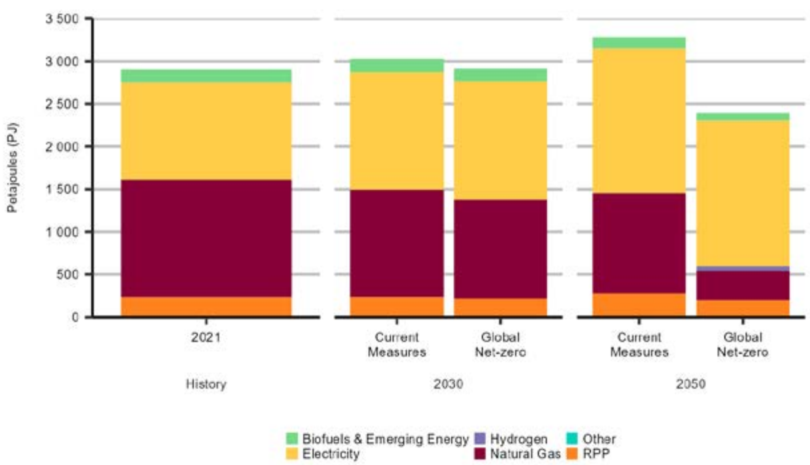


Figure R.7:
Combined residential and commercial buildings energy use by fuel, Global Net-zero and Current Measures scenarios



Total energy use in the residential sector declines by 22% from 2021 to 2050 in the Global Net-zero and Canada Net-zero scenarios. While overall demand decreases, electricity use grows at 1.2% per year over the projection period, largely because of steady growth of electric heating with heat pumps. As more homes switch to heat pumps and electric hot water heating, demand for natural gas falls steadily. In the Global Net-zero Scenario, residential natural gas demand is 72% lower in 2050 compared to 2021, and 73% lower in the Canada Net-zero Scenario. Energy use from at-home charging of EVs is accounted for in the transportation sector, which we describe later in this chapter.

In the Current Measures Scenario, the residential and commercial sectors show steady improvements in efficiency plus some switching to electricity-based heating. However, the pace of change is much slower than in the net-zero scenarios. Natural gas demand in these sectors declines by 18% from 2021 to 2050, while electricity use also increases at a pace similar to the past two decades. Figure R.7 shows total electricity and natural gas demand in the Global Net-zero and Current Measures scenarios.

Residential and commercial GHG emissions

GHG emissions from residential and commercial buildings follow the energy demand trends we describe above. GHG emissions from the buildings sector track closely to the volume of natural gas and heating oil used. In the Global Net-zero Scenario, GHG emissions in the buildings sector fall from 87 MT in 2021 to 25 MT in 2050, a 71% decrease, with very similar reductions in the Canada Net-zero Scenario. In both net-zero scenarios, emissions from the buildings sector remain positive in 2050, but Canada overall achieves net-zero due to negative emissions occurring in other sectors. In the Current Measures Scenario, emissions decline more slowly in the buildings sector, reaching 64 MT in 2050, a 27% decline.

Industrial

The industrial sector accounted for 54% of Canada's end-use energy demand in 2021, making it the largest in terms of energy use. The industrial sector is diverse, with several sub-sectors, including oil and natural gas, and various heavy industries like cement, pulp and paper, and iron and steel. The sector is also diverse in terms of energy use, with natural gas making up the largest share of fuel use at 49% in 2021, followed by RPPs (28%), electricity (14%), and biofuels (8%). The main use of energy in the industrial sector is to produce heat, which is used in different industrial processes. Energy commodities such as RPPs and natural gas liquids are also used as non-energy feedstock in sectors such as chemicals and fertilizer production.

Industrial GHG emissions are mainly from oil and gas and heavy industry

In 2021, the oil and natural gas sector emitted 189 MT, 29% of Canada's total emissions. Heavy industry made up 12% of total emissions in 2021, or 77 MT.

This section focuses mostly on the energy use and GHG emission trends in heavy industry. We describe the trends for the oil and natural gas sector in the "Oil and natural gas production" section.

In both net-zero scenarios, new technology, CCUS, and fuel switching are key changes in heavy industry

In the Global and Canada Net-zero scenarios, the changes that occur in the sector to reduce GHG emissions is varied due to unique processes specific to each industrial subsector. However, the primary factors driving change are technological innovation, the application of CCUS technology, and fuel switching. In heavy industry, there are two major emissions sources: emissions from the combustion of fossil fuels to create high temperature heat and process emissions that occur from chemical or physical reactions in the production process itself.

Lower costs and stronger climate policies drive new technology deployment

New industrial technologies are adopted in the net-zero scenarios as they become more widely available at lower costs, and as producers look for options to respond to strengthening climate policies. For example, in the aluminum production sector, the use of inert anodes becomes an increasingly economic choice. Compared to carbon anodes, the benefit of inert anodes is that carbon dioxide (CO_2) is no longer released as a byproduct of the aluminum smelting process.

Another example of technology innovation occurs in the iron and steel industry. Most new steel produced in Canada occurs by reacting iron ore with coal, which creates both combustion and process emissions. In both net-zero scenarios, iron and steel producers use a mix of technologies that rely on electricity, natural gas with CCUS, and hydrogen to decarbonize the industry. Steel can also be recycled using 100% electricity and producers increasingly use this pathway where scrap steel is available.

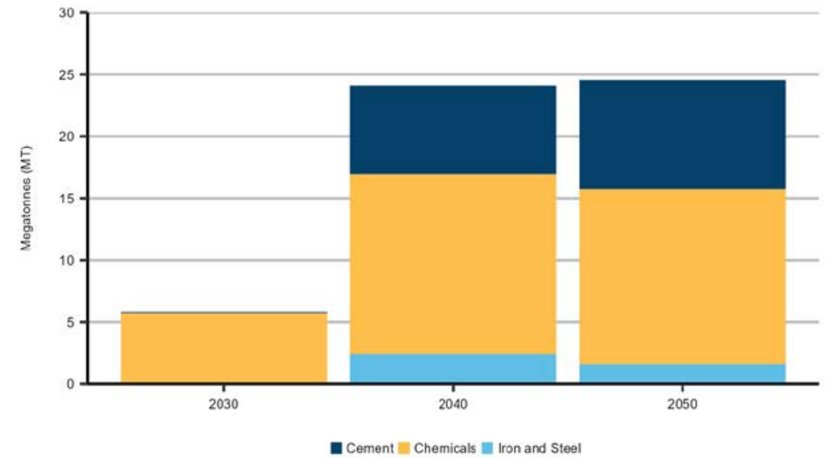
CCUS becomes an important decarbonization option in the industrial sector

CCUS becomes an important decarbonization option where a production process requires high-temperature heat and/or has significant process related emissions. CCUS is a suite of technologies that capture CO_2 from facilities to either store it in geological formations underground or use in other processes, like permanent mineralization in concrete. Instead of being permanently stored, there are also other potential uses for captured carbon, such as producing synthetic fuels.

In heavy industry, several sectors increasingly use CCUS over the projection period in both net-zero scenarios, as shown in Figure R.8. We project the heavy industry sector captures a total of 6 MT of GHG emissions in 2030, increasing to 24 MT by 2040 in the Global Net-zero Scenario, after which CCUS in the sector is relatively stable. This excludes the carbon captured in the electricity and oil and gas sectors, which we describe later in this chapter. In the Canada Net-zero Scenario, CCUS plays a similar role in heavy industry.

Figure R.8:

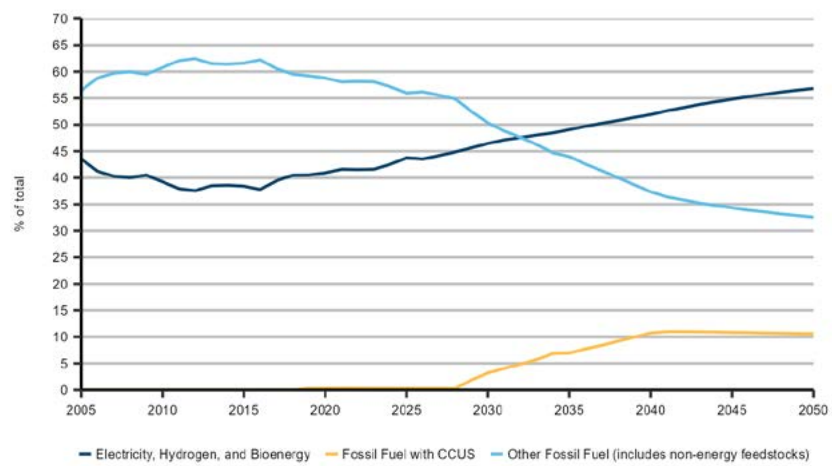
GHG emissions captured using CCUS in heavy industry, Global Net-zero Scenario



Fuel-switching is an important trend in both net-zero scenarios

Various climate policies change the relative cost of fuels and industries respond by switching to low- or non-emitting energy sources when feasible. As shown in Figure R.9, the share of low- or no-carbon energy sources grows steadily over the projection period. The use of low-carbon hydrogen as a share of total heavy industrial energy demand increases from less than 1% in 2021 to 6% in 2050 in the Global Net-zero Scenario, and similar in the Canada Net-zero Scenario. Other energy sources, such as electricity, biomass, biofuels, and renewable natural gas, increase their share in both net-zero scenarios. These low- or no-carbon energy sources offset energy from fossil fuels, whose combined share of the heavy industrial sector's energy use falls from around 60% of energy use in 2021 to 32% in 2050.

Figure R.9:
Share of energy type in the industrial sector, excluding the oil and natural gas sector, Global Net-zero Scenario



Energy use changes are much slower in the Current Measures Scenario

In the Current Measures Scenario, energy use in the industrial sector undergoes some change, such as efficiency improvements and some limited applications of CCUS. However, the pace of change is much slower than in both net-zero scenarios. This is because of our assumptions about climate policies and technology costs in this scenario give less incentive for industries to change their energy use patterns.

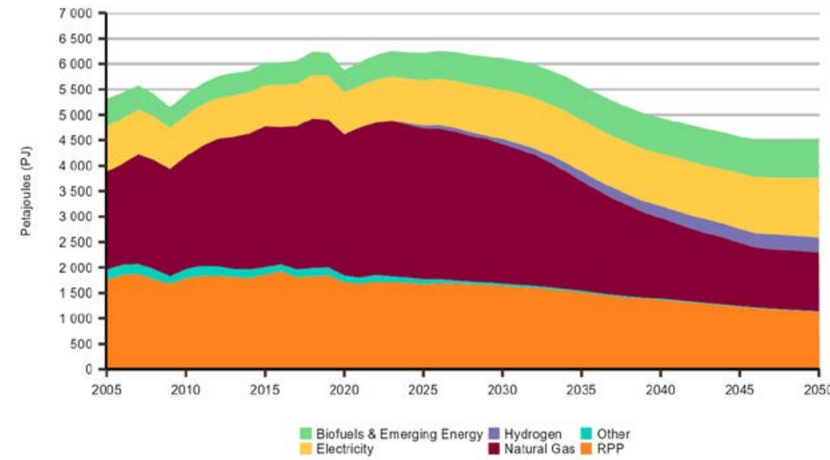
Total industrial energy use increases less than 10% in both net-zero scenarios

We project total energy use in the heavy industry sector to be relatively flat in both net-zero scenarios, increasing less than 10% from 2021 to 2050, compared to nearly 20% in the Current Measures Scenario. New technologies and energy efficiency improvements reduce energy use in the sector.

In the Global Net-zero Scenario, total energy use in the entire industrial sector, including energy use in oil and gas, light industry, and for direct air capture processes, declines by 27% to 2050. Declining energy use for oil and natural gas production drives this trend and is partly offset by the emergence of direct air capture (DAC) facilities later in the projection period, which use large amounts of electricity and natural gas. In the Canada Net-zero Scenario, oil and natural gas production are higher and total industrial energy use is higher than the Global Net-zero Scenario, but still declines by 10% by 2050. In the Current Measures Scenario, total industrial energy use grows steadily, although somewhat slower than over the past two decades.

Figure R.10 shows total industrial demand by fuel in the Global Net-zero Scenario. By 2050, the share of electricity, clean fuels such as bioenergy and hydrogen, and fossil fuels with CCUS more than triples from current levels.

Figure R.10:
Total industrial energy use by fuel, Global Net-zero Scenario



Industrial GHG emissions

The key trends we describe in the previous section, technological innovation, CCUS, and fuel switching, result in steadily decreasing GHG emissions from the heavy industry sector in both net-zero scenarios. In both net-zero scenarios, emissions decline by nearly 75% from 2021 levels. This implies that heavy industry GHG emissions are positive in 2050, although Canada still achieves net-zero due to negative emissions occurring in other sectors. Emissions fall by 15% in the Current Measures Scenario.

DAC facilities, which we consider to be a part of the broader industrial sector, result in net-negative emissions by 2050 in both net-zero scenarios. Emissions from the oil and gas sector drop significantly in both net-zero scenarios. We describe our energy use and GHG emission results for both of these sectors later in this chapter.

Transportation

The transportation sector accounted for 21% of Canada's end-use energy demand in 2021. This demand includes energy used to transport people and goods using a variety of modes, including on-road vehicles, rail, airplanes, and boats. Almost all energy use in this sector is RPPs derived from crude oil. Gasoline, the primary fuel for on-road passenger vehicles, made up 53% of total transportation demand in 2021. In the freight sector, diesel is the most common fuel, making up 32% of total transportation demand in 2021. Aviation fuel, biofuels, and heavy fuel oil made up much of the remaining energy use in 2021. Electricity is a small but growing portion of energy demand in the transportation sector.

The transportation sector's GHG emissions in 2021 were 150 MT, or nearly a quarter of Canada's total emissions. Emissions from the sector have declined by 4% since 2005. Transporting passengers accounted for 57% of GHG emissions in the transportation sector, with freight making up 33% and the remaining emissions coming from off-road vehicles.

Passenger transportation

In both our net-zero scenarios, the primary change in the passenger transportation sector is the movement towards electric passenger vehicles and away from internal combustion engine (ICE) vehicles. Emissions from ICE vehicles remaining on the road also decline.

The use of EVs increases substantially in all scenarios

EV sales, including plug-in hybrid-electric vehicles (PHEVs), made up over 8% of all vehicles sales in Canada in 2022, up from 2% in 2018. We project this trend to accelerate in the Global and Canada Net-zero scenarios, with nearly all passenger vehicle sales being EVs by 2035. However, the total stock of vehicles on the road changes more slowly, as vehicles can stay on the road for 15 or more years. Though sales of new ICE vehicles are nearly zero by 2035, there are some older vehicles on the road by 2050 in both net-zero scenarios. In the Current Measures Scenario, EV sales grow at a slower rate than in the net-zero scenarios but still become a competitive choice for consumers, making up 50% of all vehicle sales by 2035, and 75% in 2050. Figure R.11 shows the share of EV sales and passenger vehicles on the road that are EVs in the Global Net-zero Scenario.

The electrification of the passenger vehicle fleet is driven by the policies we assume in the net-zero scenarios. The federal mandatory zero-emission vehicle sales targets and similar policies in British Columbia (BC) and Quebec, federal and provincial EV incentives, and increasing carbon pricing all increase the availability and cost-effectiveness of EVs compared to ICE vehicles. In addition, we assume the costs of batteries, which are major component of the cost of EVs, decline over the projection period.

Emissions from the remaining ICE vehicles decrease significantly

While EVs gain an increasing market share over the projection period, emissions from ICE vehicles also decline in all three scenarios. Policies, including Canada's light-duty vehicle GHG emissions standards and Clean Fuel Regulations, result in lower overall emissions per kilometre travelled by ICE vehicles. This includes greater blending of biofuels into the liquid fuel supply and better fuel efficiency of new ICE vehicles. Combined with wide-scale adoption of EVs, the emissions per kilometre travelled by passenger vehicles fall by around 95% in both the Global and Canada Net-zero scenarios from 2021 to 2050. In addition to the switch to EVs, public transportation continues to play a key role in moving people. Transit is increasingly powered by electricity and bioenergy in the net-zero scenarios.

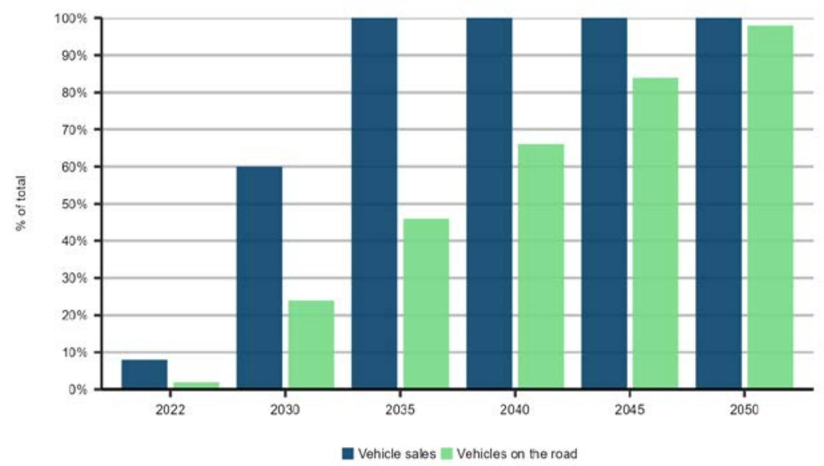
Air travel emissions reduce due to aircraft efficiency improvements and use of clean fuels

In all three scenarios, demand for aviation fuel recovers to pre-pandemic levels by 2023. In the Global Net-zero Scenario, we project energy use for passenger aviation remains relatively stable after 2023 as newer, more efficient aircraft help to improve fuel efficiency of air travel, and the trends are similar in the Canada Net-zero Scenario. In the net-zero scenarios the main source of GHG emissions reductions in the sector are through increased use of biofuels and hydrogen-based fuels.

Passenger transportation energy use declines across all scenarios

Led by large-scale adoption of EVs, we project total energy use in the passenger transportation sector to decline by 43% from 2021 to 2050 in the Global Net-zero Scenario and similar levels in the Canada Net-zero Scenario. This drop in energy use is largely due to EVs being far more energy-efficient compared to ICE vehicles[13]. By 2050, electricity makes up nearly 50% of the energy use in the passenger transportation sector in both net-zero scenarios, up from below 1% in 2021. Low-carbon aviation fuel, conventional jet fuel, gasoline, and ethanol make up much of the remaining fuel mix in 2050. In the Current Measures Scenario, passenger transportation energy use declines slowly after rebounding to pre-pandemic levels in 2023. Increasing number of EVs and improving efficiency of ICE vehicles are reasons for this decline.

Figure R.11:
EVs as a share of total vehicle sales and vehicles on the road, Global Net-zero Scenario



13 CER Market Snapshot: Battery electric vehicles are far more fuel efficient than vehicles with internal combustion engines

Freight transportation

In both net-zero scenarios, we project a few key shifts in the energy use and technologies used to transport goods. Electric trucks and vans increase significantly in some segments of the freight sector but in the heavy freight sector we project that other options are viable, including increasing use of hydrogen fuel cell technology. Biofuels also become an economically attractive fuel in the net-zero scenarios, providing a low-carbon fuel that can be used in existing diesel engines, or blended with fossil fuel-derived diesel to reduce the emission intensity of that fuel.

Light-duty freight vehicles are typically used to move smaller loads over relatively short distances. In both net-zero scenarios, electric trucks and vans gradually become the most economic choice of vehicle to serve this purpose. Nearly all light-duty freight vehicle sales are electric by 2040 in both net-zero scenarios.

Hydrogen-based vehicle use grows significantly in the heavy freight sector in the net-zero scenarios.

For heavier freight, electric-powered vehicles take a share of the market in our net-zero scenarios, as do other technologies. A robust hydrogen supply develops in both net-zero scenarios, in part due the demand for hydrogen to use in trucks, rail locomotives, and marine vessels equipped with fuel cell technology. Fuel cells convert hydrogen to electricity, which then drives electric motors. Compared to batteries, compressed hydrogen paired with fuel cells is more energy-dense, which is beneficial when moving heavy goods over long distances. The use of hydrogen in the freight sector grows from nearly 0.5 MT in 2030 to almost 5 MT in 2050 in the Global Net-zero Scenario, with slightly more in the Canada Net-zero Scenario. Electricity demand for freight transportation reaches over 90 terawatt-hours (TWh) by 2050 in the Global Net-zero Scenario. Given the relatively high efficiency of EVs, this represents a large portion of freight activity. Unlike the passenger sector, where electrification of personal vehicles has significant momentum, the relative mix of technologies in the freight sector is more uncertain. Depending how technologies and markets evolve, we may see more or less hydrogen, electricity, or other clean fuels in the future. We explore this uncertainty further in the “What if” case for hydrogen supply and demand, located in the hydrogen results section.

Renewable diesel use grows to 35% of the diesel fuel supply by 2050 in the Global Net-zero Scenario

We also project steady growth of biofuel use in the freight sector. The most common biofuels used today are ethanol and biodiesel. These biofuels are often blended into petroleum-based fuels for use in ICE vehicles. However, the rate at which these fuels can be blended into the petroleum-based fuel stream is limited, usually anywhere from 5 to 20% depending on the characteristics of the engine. In the Global and Canada Net-zero scenarios, renewable diesel, often referred to as hydrogenation-derived renewable diesel, emerges as the leading biofuel over the projection period. Renewable diesel is chemically equivalent to diesel derived from fossil fuels. This means it is a "drop-in" biofuel and can be used as a direct replacement for petroleum-based diesel or blended at a much higher ratio than biodiesel. Renewable diesel can be derived from many different processes, allowing a diverse set of biomass feedstocks to be used. By 2030, in the Global Net-zero Scenario, we project renewable diesel's share of the diesel fuel supply to reach 7%, then grow to 35% by 2050.

In the Current Measures Scenario, the freight sector gradually becomes more efficient, with improvements mostly focused on engine efficiency and aerodynamics. We also project much lower uptake of electric and hydrogen fuel cell vehicles, and less use of biofuels.

Freight energy use decreases in the net-zero scenarios, and increases in the Current Measures Scenario

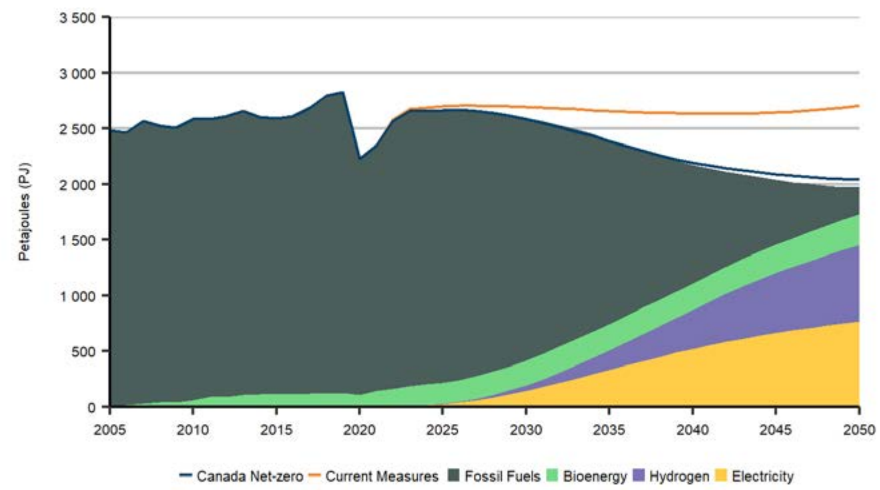
Total energy use in the freight transportation sector increases in the near term as shipping volumes recover to pre-pandemic levels. In the longer term, demand trends downward in both net-zero scenarios. This decrease is primarily due to growth of electric and hydrogen fuel cell freight vehicles, both of which are more energy efficient compared to ICE vehicles. This effect is partially offset by steadily growing demand for freight transportation services. In the Current Measures Scenario, energy use in the freight sector increases by 25% over the projection period.

Figure R.12 shows end-use demand by fuel in the transportation sector, including passenger, freight and off-road energy use in the Global Net-zero Scenario, and total end-use demand in the other two scenarios.

Transportation GHG emissions

Emissions from the transportation sector decline steeply in both net-zero scenarios while staying relatively flat in the Current Measures Scenario. We project that GHG emissions in the Global Net-zero Scenario fall by 90% from 2021 to 2050, and to a similar level in the Canada Net-zero Scenario. In both net-zero scenarios, these reductions are driven by our assumptions about policies like the federal mandatory zero-emission vehicle sales targets and steadily increasing economy-wide carbon pricing. Declining costs of certain technologies such as batteries in EVs and hydrogen vehicles also factor into our projections. While Canada achieves net-zero by 2050 in our net-zero scenarios, some emissions from the transportation sector remain in 2050, mainly in the aviation and freight sectors. In the Current Measures Scenario, emissions fall steadily after 2025, with continued emission reductions in the passenger sector offsetting growing emissions in the freight sector.

Figure R.12:
Transportation sector end-use demand by fuel, Global Net-zero Scenario



Primary energy demand

In this analysis, primary demand is the total amount of energy used in Canada. Primary demand is calculated by adding the energy used to generate electricity[14] and hydrogen to total end-use demand, and then subtracting the end-use demand for electricity and hydrogen. Primary demand is higher than end-use demand due to factors such as heat loss in thermal electric generation, and the energy required for the hydrogen production process.

In both net-zero scenarios, total primary demand falls, largely a result of declining fossil fuel use

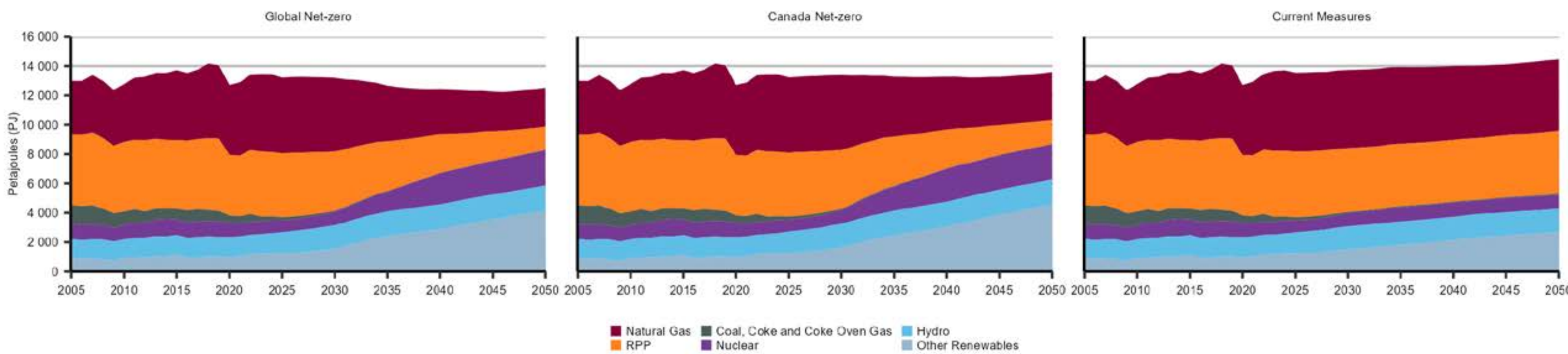
Coal use continues its current declining trend, largely due to the phase out of coal-fired power generation. Demand for RPPs falls, largely due to much greater use of electricity in the transportation sector. One source of crude oil demand that is relatively stable over the projection period is for non-energy products such as asphalt, lubricants, and petrochemical feedstocks.

Natural gas demand declines in both net-zero scenarios, and increases in the Current Measures scenario

Natural gas demand falls due to electrification of home heating, less natural gas use in the upstream oil and natural gas sectors, and efficiency improvements in the residential and industrial sectors. The decrease in natural gas demand is less than for coal and RPPs, as we project that natural gas becomes increasingly used in the power generation sector when coupled with CCUS, and as a feedstock for hydrogen production. In the Current Measures Scenario, primary energy demand is relatively flat until 2040, before increasing in the last decade of the projection period. Figure R.13 shows primary demand by fuel for all three scenarios.

14 Including fossil fuels, nuclear, and renewable energy. See Figure R.25 for a breakdown of these demands.

Figure R.13:
Primary energy demand by fuel, all scenarios



KEY UNCERTAINTIES

Energy demand

Energy use drivers: The need for energy in each sector is driven by our projections of activity in that sector, like economic output of various industries or population growth. Different outcomes for any of the energy use drivers could impact the long-term energy outlook.

Technology: We make assumptions about the costs of various energy technologies in the future. Costs that are different than we assume will change the decision-making of energy users and the energy use projections in our scenarios. We explore some of these uncertainties in the “What if” cases throughout this report.

Behavioural change: Energy users’ decision-making changes as societal preferences change over time. For example, preferences could evolve towards more or less dense cities, more remote work, or bigger or smaller homes, all of which can influence energy use projections.

Electricity

Canada's electricity system is currently among the lowest emitting in the world, with 81% of the sector's generation coming from low- or non-emitting sources. This is largely due to Canada's hydroelectric generation resources, which supplied over 61% of Canada's electricity in 2021. Nuclear generation and, increasingly, wind and solar, also contribute to Canada's high proportion of non-emitting power generation.

To develop the electricity production projections in EF2023, we rely on a model that simulates the operations and the investment decisions of the electricity sector, while also ensuring reliability of the system. The model builds new generation, storage and transmission infrastructure based on minimizing the total system costs throughout the projection period. We also incorporate our assumptions about policies and the costs and operational characteristics of various generation technologies. Factors beyond these can impact the development of a wide array of energy projects, including electricity projects. Examples include concerns about air quality, safety, noise, competing land-uses, or visual impacts. Societal preferences and how they may evolve in the future, are largely beyond the scope of our analysis but have potential to impact the projections for any of the electricity generation technologies we describe in this section.

Canada's electricity system is regionally diverse

The generation mix in each province and territory is largely determined by the resources it has available. Quebec, Manitoba, Newfoundland and Labrador, Yukon, and BC have significant amounts of hydro generation, whereas Alberta, Saskatchewan, and remote and northern communities rely more on fossil fuel generation. Ontario and New Brunswick both have diverse electricity mixes, including nuclear. This regional diversity means that the emission reduction pathways in our net-zero scenarios are unique to each region's specific circumstances.

The electricity sector has exhibited the greatest reduction in emissions among Canada's major sectors, cutting emissions by more than half from 2005 to 2021. Many provinces reduced emissions from this sector during that time, with the biggest reductions from Ontario and Alberta. Ontario phased out coal-fired generation by 2015 and Alberta is likely to do so by the end of 2023. In total, the electricity sector accounted for 8% of Canada's emissions in 2021.

Electricity use increases while emissions decrease in the net-zero scenarios

In the Global and Canada Net-zero scenarios, electricity becomes the cornerstone of Canada's energy system. In both scenarios we project the amount of electricity generated and consumed in Canada in 2050 more than doubles from current levels. While the need for electricity grows, we project the electricity system also reduces emissions to net-zero by 2035 in both scenarios. This reduction in emissions is led by growth in wind, nuclear, hydroelectric, and natural gas-fired generation with CCUS, and the phase out of coal-fired electricity generation. After 2035, GHG emissions from the electricity sector become net-negative, meaning the sector removes more emissions than it emits through deployment of bioenergy coupled with CCUS technology (BECCS).

KEY TRENDS
Electricity

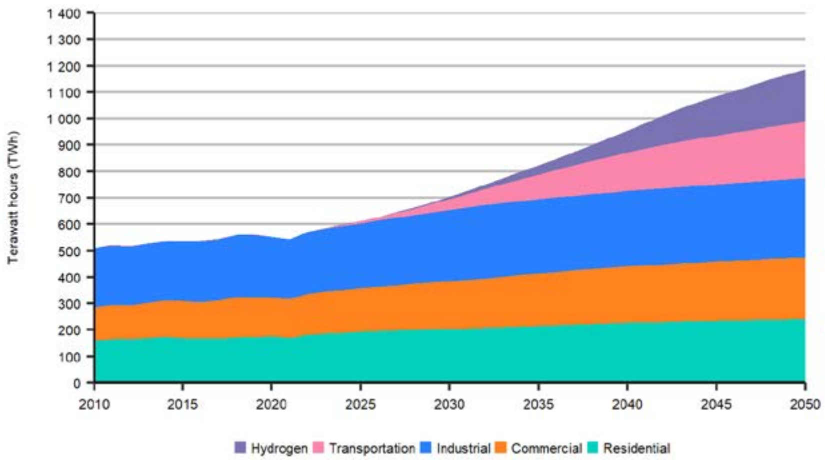
- Electricity use more than doubles over the projection period in both net-zero scenarios.
- We project the most growth in wind generation in all scenarios, including the Current Measures Scenario, despite less ambitious climate policies and more modest technology cost improvements.
- The electricity system decarbonizes and becomes net-negative by 2035 with the deployment of BECCS generation facilities.

Electricity use

As described in the "Energy demand" section of this chapter, we project that electricity demand grows significantly in all end-use sectors in both net-zero scenarios. This growth is driven by wide-scale adoption of EVs and heat pumps, and electrification of some industrial activities. In addition, as we describe in more detail in the "Hydrogen" section of this chapter, hydrogen production becomes a significant source of new electricity demand in the future. Finally, we project construction of direct air capture (DAC) facilities, which become another new source of electricity demand later in the projection period. We describe the role of DAC in the "Negative emissions" section later in this chapter.

Figure R.14 shows electricity demand by sector in the Global Net-zero Scenario. Overall, we project electricity demand to grow 120% from 2021 to 2050 in the Global Net-zero Scenario, and 135% in the Canada Net-zero Scenario. In both scenarios, the annual rate of demand growth is almost triple that of the 1995 to 2019 period. In the Current Measures Scenario, electricity demand grows more slowly than in the net-zero scenarios, increasing by 62% over the projection period.

Figure R.14:
Electricity use by sector, Global Net-zero Scenario



Our electricity projections are also influenced by changes in day-to-day and seasonal electricity use patterns. As new uses of electricity emerge, the annual peak in electricity demand in a system will likely change. This change will influence how electricity systems evolve as utilities and system operators need to reliably meet the annual peak in electricity demand, which might occur for only an hour or two in a year.

In both net-zero scenarios, the annual hourly peak of electricity demand grows in all regions

This increase is because of growing electricity use overall, but also growing use of devices that increase electricity use more during a certain period during the day or in a particular season. For example, EVs typically draw relatively large amounts of electricity over a short period when owners plug them in. Similarly, greater use of heat pumps means that overall electricity demand is more sensitive to weather than it is now.

What if electricity vehicle charging patterns result in higher peak electricity demand?

Sales of EVs in Canada have quickly increased in recent years, reaching over 8% of total vehicle sales in 2022. While ICE vehicles rely on RPPs like gasoline and diesel as their source of energy, EVs are powered by electricity stored in large batteries, which drive electric motors, propelling the vehicle. EV batteries are charged using the same electricity grid we use to power other aspects of our daily lives.

EVs need more electricity than most other household devices

Most currently available EVs consume about 3,000 to 6,000 kilowatt-hours (kWh) in a year based on 20,000 km of driving. A new refrigerator uses about 500 kWh per year. Currently, most EV charging occurs through a charger installed in a garage or at a dedicated public charging station. Most EV charging occurs at a fairly high rate of power transfer in order to charge batteries quickly. Most home chargers can charge a depleted battery in 4 to 12 hours. Many public EV charging stations are much quicker than home chargers.

EV owners tend to plug their vehicles into chargers when they arrive home. For many drivers, this is often in the late afternoon when they return from work. Residential electricity demand is often already high during these hours, including higher use of stoves and electronics. It is also often the hottest part of the day in the summer, meaning more air conditioning units may be running. If charging patterns are not managed as the share of EVs grows, EV charging could contribute to much higher electricity use during peak times. The level of peak electricity demand throughout the day and over the year affects how electricity systems develop. Utilities and system operators need to continually meet the electricity needs of users, but also have sufficient capacity to meet annual peak electricity demand, which might be for only a few hours in a year.

How EV charging patterns affect peak electricity demand largely depends on how much utilities and grid operators can more evenly spread charging out across the hours of the day. Charging patterns can be influenced through market mechanisms, such as offering consumers lower electricity prices during certain hours of the day when demand is lower. Most home chargers can be controlled by consumers or grid operators to delay charging to lower demand hours.

"What if" EV charging during peak hours is not managed?

In the Global Net-zero Scenario, we assume that a combination of price signals, technologies, and behavioural changes result in charging that is more evenly spread across the hours of the day. In this "What if" analysis, we explore how uncoordinated EV charging might impact the electricity system and ultimately the total amount of electricity generating capacity required. This analysis, the Uncoordinated Charging Case, models an outcome where more drivers charge their EVs during peak hours.

Peak electricity demand in each province and territory increases throughout the projection period in the Global Net-zero Scenario as total electricity demand increases and electricity use patterns change. For example, peak electricity demand in Ontario was 22.2 gigawatts (GW) in 2021. In the Global Net-zero Scenario, peak demand is 177% higher by 2050, reaching 61 GW. This increase in peak demand is similar in magnitude in many other provinces and territories.

However, while total electricity use is identical in both cases, peak demands by 2050 in most provinces and territories in the Uncoordinated Charging Case are between 1 and 5% higher than in the Global Net-zero Scenario. Despite this higher peak in demand, the overall impact on system-wide needs for new capacity is relatively small, as we project some changes to the generation mix compared to the Global Net-zero Scenario, as well as changes to the operations of the electricity system.

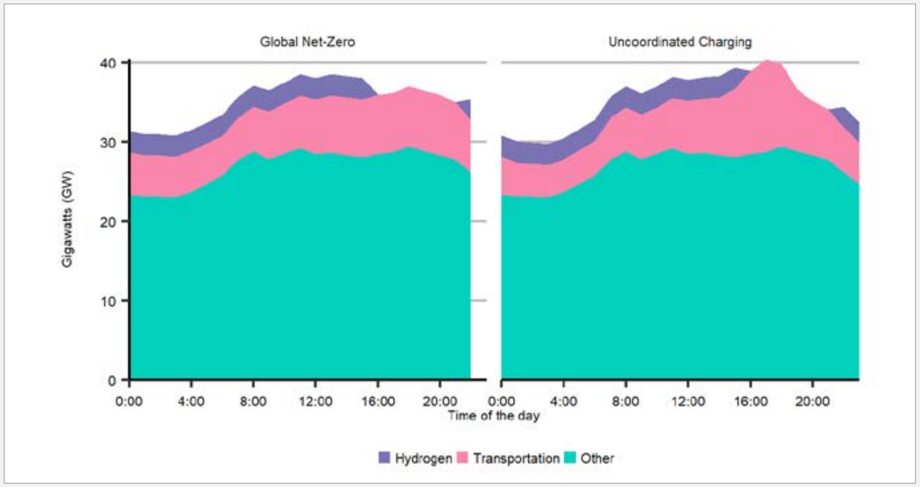
Energy systems become more flexible, potentially accounting for uncoordinated charging

Figure R.15 shows an example winter day in 2050, showing hourly electricity demand in BC with coordinated and uncoordinated EV charging. The emergence of hydrogen as a new source of electricity demand requires building more electricity generation capacity. However, hydrogen production is a flexible source of electricity demand. During periods of high demand, hydrogen production using electricity can be reduced to accommodate the needs of the electricity system. That flexibility allows the electricity systems in several regions to accommodate the higher peak demand in the Uncoordinated Charging Case without significant additional investment in generating capacity.

We project that many provinces utilize this flexibility in both the Global Net-zero Scenario and Uncoordinated Charging Case to offset peak periods of demand. Without this demand flexibility, the difference in peak demand in the two scenarios would have been higher, requiring more investment in new generation in the Uncoordinated Charging Case.

Figure R.15:

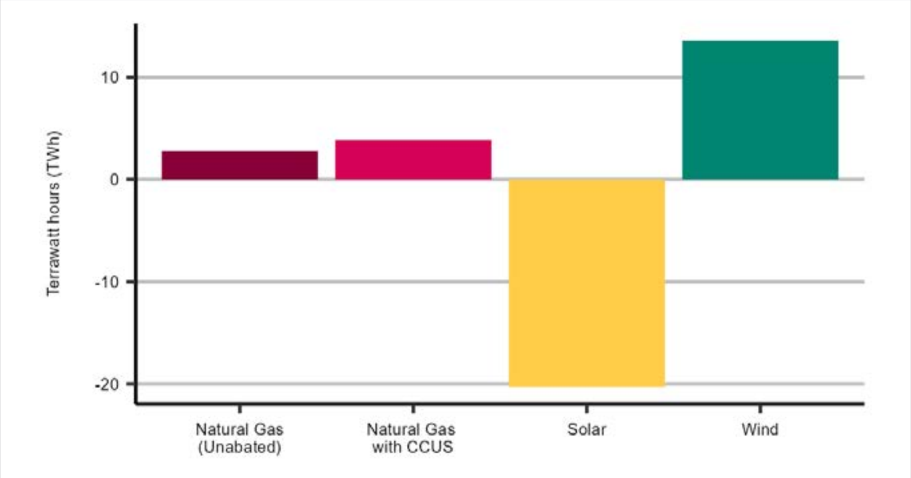
Example daily hourly electricity demand in British Columbia by use, winter of 2050, Global Net-zero Scenario and Uncoordinated Charging Case



Wind generation increases while solar decreases in the Uncoordinated Charging Case

As shown in Figure R.16, compared to the Global Net-zero Scenario, we project more wind and less solar generation in the Uncoordinated Charging Case. In this case, electricity use is higher during the early evening and lower during the day. Because solar generates more during the day than in the evening, solar generation is less valuable in the Uncoordinated Charging Case relative to the Global Net-zero Scenario and less solar generation is built. Conversely, wind tends to blow more during the evening period, so becomes a more valuable asset to the electricity system in the Uncoordinated Charging Case. By 2050, wind generation is 4% higher in the Uncoordinated Charging Case compared to the Global Net-zero Scenario, while solar generation is 32% lower.

Figure R.16:
Difference in generation between the Global Net-zero Scenario and the Uncoordinated Charging Case in 2050, by select fuel



Natural gas without CCUS is used more often in the Uncoordinated Charging Case

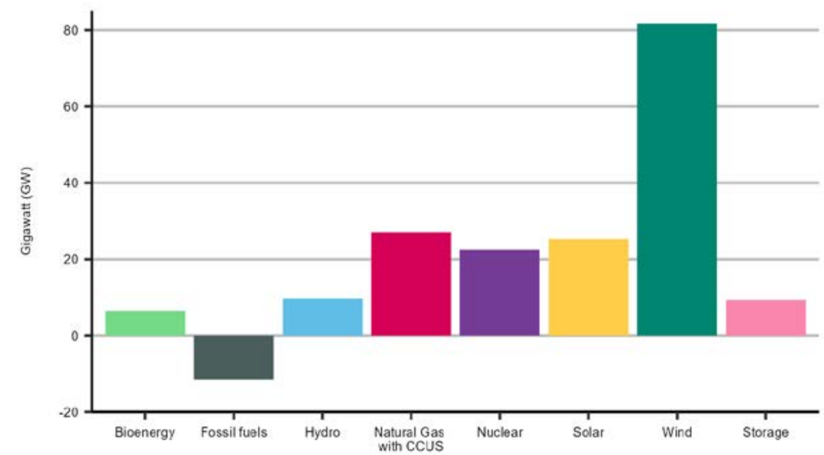
Finally, in some provinces, we project higher generation from natural gas with and without CCUS. To accommodate the highest peaks in generation throughout the year, some provinces have natural gas-generating facilities without CCUS that are utilized very rarely in the Global Net-zero Scenario. In the Uncoordinated Charging Case these assets are utilized more often in order to meet higher and more frequent peaks in electricity demand. As a result of more frequent natural gas use, there are slightly higher GHG emissions from the electricity sector in the Uncoordinated Charging Case.

Greater use of EVs, along with greater electricity use across the energy system, would likely require investments in local distribution system infrastructure to ensure sufficient capacity to deliver electricity during high demand periods. This need for additional infrastructure could be increased by uncoordinated EV charging, but this is beyond the scope of this analysis. The analysis in EF2023, and in this "What if," focuses on the bulk power system and does not model local electricity distribution systems.

Electricity production

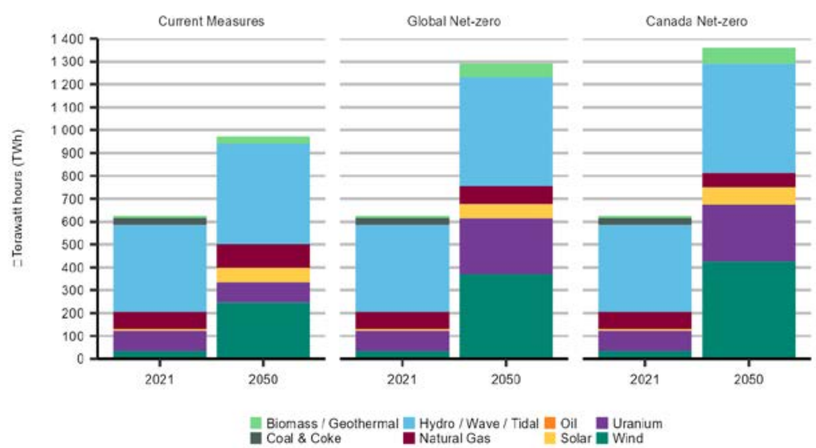
To meet rapidly growing electricity demand while also decarbonizing electricity production, we project significant changes to Canada's electricity system in both net-zero scenarios. Our assumptions about policies like carbon pricing and the proposed Clean Electricity Regulations mean that almost all electricity-generating facilities built over the projection period are low- or non-emitting, or even net-negative in terms of GHG emissions. Given the diversity of Canada's electricity system today, there is considerable variety in how each region's electricity system evolves in our net-zero scenarios. Technologies deployed include wind, solar, hydro, nuclear, fossil fuel with CCUS, and BECCS. Meanwhile, power generation from coal and natural gas not equipped with CCUS drops quickly over the first decade of the projection and is near zero after 2035. Figure R.17 shows the difference in capacity, by fuel, from 2021 to 2050 in the Global Net-zero Scenario.

Figure R.17:
Change in electricity capacity from 2021 to 2050, by fuel, Global Net-zero Scenario



We project that electricity production grows more slowly in the Current Measures Scenario when compared to the net-zero scenarios. There are also fewer policies aimed at reducing the sector's GHG emissions. Still, while not as dramatic as in the net-zero scenarios, in-place policies, along with our assumptions of modest technology cost improvements, result in strong growth in low-emitting generation sources. Figure R.18 shows electricity generation by fuel in each scenario.

Figure R.18:
Electricity generation by fuel, all scenarios



Wind and solar

In all three of the scenarios in EF2023, we project substantial growth of wind generation and steady growth of solar. Our modeling suggests that the low capital and operating costs of both resources make them among the most attractive options for utilities and power producers to increase electricity generation to meet growing demand while also reducing GHG emissions.

Onshore wind generation increases significantly in all scenarios

Electricity generation from onshore wind increases the most among all generation technologies considered in our analysis. We project that wind generation grows ninefold in both the Global and Canada Net-zero scenarios, making up over a quarter of all electricity produced in Canada by 2050. In the Current Measures Scenario, wind generation does not grow as quickly as in the net-zero scenarios, but still increases substantially from current levels, and seven times higher by 2050.

Onshore wind generation grows the most in Alberta, Saskatchewan, and Ontario. This is in part due to strong wind resources in these provinces. In addition, wind generation often matches periods of high electricity demand in these regions, making the energy it generates particularly valuable. For example, in Alberta, it is often windier during the winter, coinciding with periods when demand from electric heat pumps is also high.

Offshore wind grows in both net-zero scenarios

This technology currently not deployed in Canada, but increasingly used in Europe and Asia. Grid-connected offshore generation reaches 23 TWh by 2050. All of that generation comes from offshore wind facilities[15] built off the coast of Nova Scotia. As we discuss in the hydrogen section, additional offshore wind capacity is built off the coast of Nova Scotia and Newfoundland & Labrador and is directly connected to hydrogen electrolysis facilities aiming to export hydrogen to international markets.

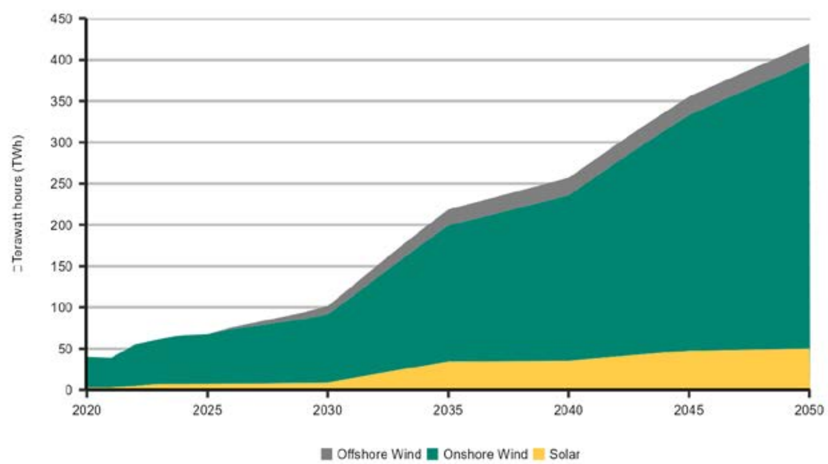
15 The CER is the federal regulator responsible for exploration, construction, operation, and decommissioning activities related to renewable energy projects and power lines in Canada's offshore areas. Any inclusion of offshore wind in our projections has no bearing on any regulatory proceeding before the CER related to the development of offshore renewable energy.

Solar generation grows steadily in all three scenarios

Like wind, solar generation becomes one of the most economic choices for utilities and power producers in most regions. In the Global Net-zero Scenario, utility-scale solar generation becomes an important aspect of the electricity system in many provinces, with total Canadian generation growing from 2.5 TWh of generation in 2021 to 50 TWh in 2050. By 2050, solar generation makes up around 5% of total electricity generation in both the Global and Canada Net-zero scenarios. In the Current Measures Scenario, solar generation grows at a similar rate as in the net-zero scenarios.

We also project steady growth of distributed solar generation installed primarily on rooftops of residential and commercial buildings. The growth is driven by declining costs and supporting policies such as net-zero building policies and voluntary actions by companies to reduce their environmental footprint. Total installed rooftop capacity reaches 8.2 GW by 2050, meeting 2.5% of residential and commercial electricity demand in the Global Net-zero Scenario. Figure R.19 shows generation from wind and solar in the Global Net-zero Scenario.

Figure R.19:
Generation from onshore wind, offshore wind, and solar, Global Net-zero Scenario

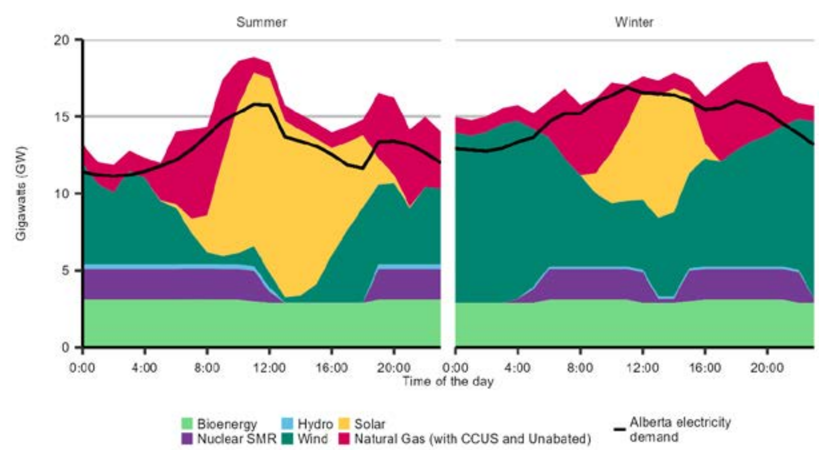


Matching electricity supply and demand

Compared to most power generation technologies, wind and solar are unique in that their power output is tied to weather patterns, specifically wind speeds and sunlight. Other generating technologies, like hydroelectric or fossil fuel-based generation, can usually adjust their output, although different resources can adjust more quickly and cost effectively than others. This adjustment is important, because electricity systems must constantly balance electricity production and consumption in real time.

Electricity consumption can vary significantly over a day and from season to season in response to factors like the patterns of daily life and weather conditions. Wind and solar become important sources of bulk power in all our scenarios but adjustable sources of power remain critical to balancing electricity systems. Our modeling takes this necessity into account, ensuring the electricity needs of users are met, and regional electricity demand and supply are in balance on an hourly basis. Figure R.20 shows our projections of hourly electricity demand and generation on two typical days in Alberta in the summer and the winter of 2050.

Figure R.20:
Example hourly electricity supply and demand in Alberta for a day in summer and winter, 2050, Global Net-zero Scenario



Hydroelectricity

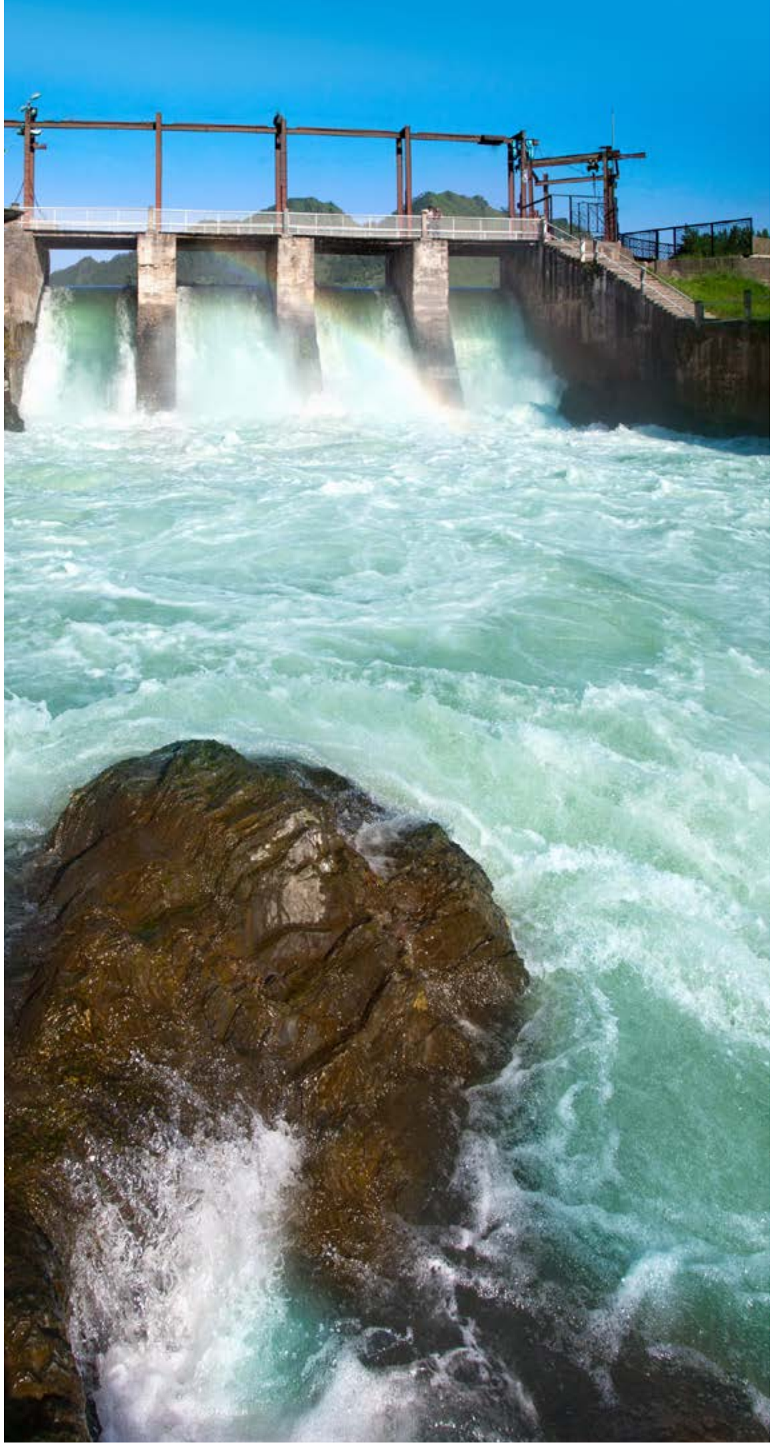
Hydroelectricity is currently the core of many provincial electricity systems, making up 90% or more of generation in Newfoundland and Labrador, Manitoba, Quebec, and BC. Hydroelectric generation is emission-free, and most facilities can vary power generation to help grids balance electricity supply and demand.

Hydroelectric generation grows steadily and at a similar rate in all three scenarios

Hydroelectric generation increases around 26% from 2021 to 2050 in each scenario. Total hydroelectric generation as a share of total Canadian generation falls from 61% in 2021 to 38% in 2050 in the Global Net-zero Scenario, as other generation sources increase more quickly. Our projections of hydroelectric power include the Site C project in BC, which is currently under construction. Our technology cost assumptions indicate that building a new hydroelectric facility is relatively expensive compared to many other options.

Most growth in hydroelectric power occurs in provinces with existing hydroelectric facilities

The geography of those regions presents more opportunities for additional hydroelectric projects or expansions. In both net-zero scenarios, hydroelectric generating capacity increases the most in Quebec (+11% from 2021 to 2050) and Manitoba (+40%). Most hydroelectricity growth comes from projects that are currently under construction and projected new developments. The remainder comes from upgrades to existing hydroelectricity units.

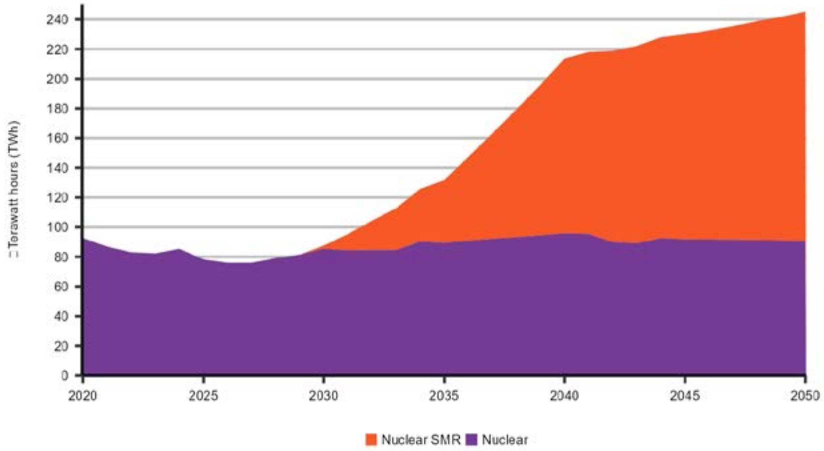


Nuclear

Nuclear power is a key component of Ontario and New Brunswick's electricity systems. Nationally, nuclear power generation made up 14% of total electricity generation in 2021.

In all three scenarios, we project nuclear generation to vary over time as some of the large nuclear facilities are refurbished, meaning the units are modernized to extend their usable life. We assume Ontario's nuclear fleet is refurbished as per the schedule laid out by the Ontario Independent System Operator in its 2022 Annual Planning Outlook.

Figure R.21:
Nuclear generation by technology, Global Net-zero Scenario



Small modular reactors (SMRs) increase significantly in both net-zero scenarios

In all three scenarios, we do not project any new large-scale nuclear facilities are built over the projection period, as other generation technologies more cost-effectively meet growing electricity demand given our assumptions. However, in both net-zero scenarios, we project considerable growth for small modular reactors (SMRs), particularly in the 2035 to 2050 period. Along with renewable technologies, these nuclear SMR units play a pivotal role in Canada's electricity system in the net-zero scenarios. By 2050, generation from SMRs make up 12% of total electricity generation by 2050 in both net-zero scenarios, with large additions in Ontario, Alberta, and BC. In the Current Measures Scenario, nuclear generation remains close to current levels through much of the projection period, with very limited growth in SMRs. Figure R.21 shows nuclear generation over the projection period in the Global Net-zero Scenario.

What if small modular reactor (SMR) technology matures less quickly and is more costly?

Canada has a long history with nuclear power, with three large-scale power facilities operating in Ontario, and one in New Brunswick. About 14%, or 82 TWh, of Canada's electricity came from nuclear power in 2021. Recently, some governments, utilities, and power producers have focused on SMRs as a potential way to meet future electricity demand growth with a carbon-free generation option. In 2020, the Government of Canada released its SMR Action Plan, and in 2022 the governments of Ontario, Saskatchewan, New Brunswick, and Alberta released A Strategic Plan for the Deployment of SMRs. In the fall of 2022, Ontario Power Generation began site preparation activities and applied to the Canada Canadian Nuclear Safety Commission for a license to construct an SMR at the existing Darlington nuclear site.

SMRs are an emerging class of nuclear reactors that are smaller than conventional nuclear power plants in terms of size and power output. The modular aspect of SMRs means many components of a facility are factory-built, shortening plant construction times. SMRs can be used to generate electricity and to produce steam for some industrial applications such as in-situ oil sands operations.

SMR building costs fall and generation increases in the Global Net-zero Scenario

In EF2023, our electricity sector analysis relies on assumptions about the costs of various technologies. The electricity model then projects the future electricity generating mix based on the demand for electricity and the costs and characteristics of a wide range of options to generate electricity. In the Global Net-zero Scenario, we assume the capital cost of building and connecting a new SMR to the grid is 2022$9,180 per installed kilowatt (kW) of capacity in 2030, falling to 2022$7,080/kW in 2050.

Given these assumptions, and the costs and characteristics of other generating facilities, we project nuclear power generation to more than double from current levels by 2050 in the Global Net-zero Scenario. All of that growth is from SMRs, which are almost all built in the post-2035 period. About 52% of this growth occurs in Ontario, where the nuclear industry is already well-established, along with notable additions of SMRs in Quebec, BC, and Alberta.

Low SMR Case: "What if" SMR building costs remain high?

As SMRs are an emerging technology, there is considerable uncertainty as to how much the technology will ultimately cost, especially 25 years or more in the future. To explore this uncertainty, we modeled the Low SMR Case, where we assume higher capital costs for SMRs than in the Global Net-zero Scenario. In the Low SMR Case, we assume that the capital cost of building a new SMR is 2022$10,170/kW in 2030, falling to 2022$9,173/kW in 2050.

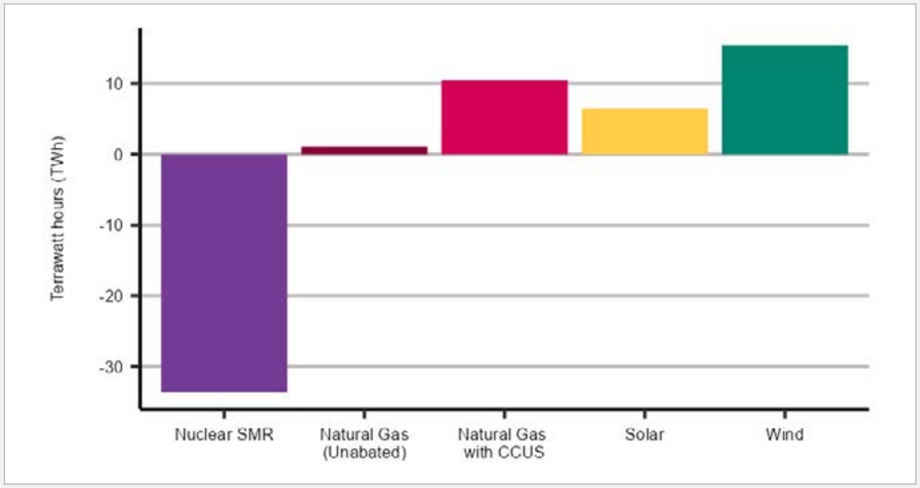
The results of this analysis suggest that higher costs for SMRs translates into less investment in SMRs and greater deployment of a variety of other generating technologies. Generation from SMRs is 34% lower in the Low SMR Case than in the Global Net-zero Scenario. The share of generation from SMRs by 2050 in the Low SMR Case is 9% of total generation in Canada, compared to 12% in the Global Net-zero Scenario.

Other types of electricity generation increase in the Low SMR Case

Lower use of SMRs to meet electricity demand affects the broader electricity mix. Compared to the Global Net-zero Scenario, the installed capacity and generation of almost all other forms of generation increase in the Low SMR Case, with the largest increases in wind and natural gas with CCUS, as shown in Figure R.22. In the Global Net-zero Scenario, SMRs played a role in supporting the electricity system as a flexible source of electricity production. In the Low SMR Case, more of this flexible generation comes from natural gas with CCUS.

Figure R.22

Difference in generation between the Global Net-zero Scenario and the Low SMR Case in 2050, by select fuel



Given the emerging nature of SMRs, there is uncertainty in the role they will play in achieving net-zero emissions by 2050. This “What if” analysis shows that lower use of SMRs results in an increased capacity and generation from a diverse mix of technologies. However, the overall GHG emissions from Canada's electricity sector in the Low SMR Case still remain close to the Global Net-Zero Scenario.

Fossil fuels

All provinces and territories have some fossil fuels in their electricity generation mix, and in 2021, 18% of all electricity generated in Canada came from facilities powered by fossil fuels, including coal, natural gas, and RPPs. The majority of generation in Nova Scotia, Alberta, Saskatchewan, Nunavut, and the Northwest Territories was fossil fuel based.

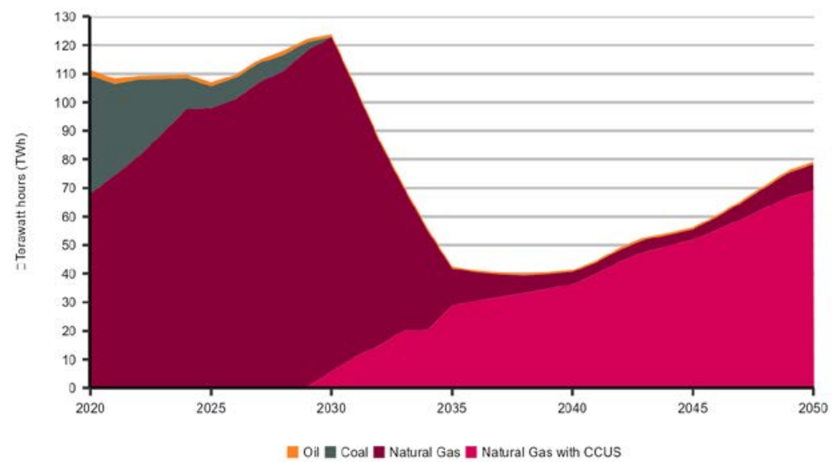
Unabated fossil fuels remain only for emergencies in the net-zero scenarios

In both net-zero scenarios, we project that generation from coal is completely phased out by 2030. This phase-out, along with steady growth in electricity use, means natural gas-fired electricity generation increases early in our projections. We also project unabated fossil fuel generation, meaning no CCUS is used to capture emissions, is nearly zero after 2030. Our assumptions about policies and costs of other technologies mean low- and non-emitting power sources are the most cost-effective option for generating electricity. Some unabated generation facilities remain online throughout the projection period, providing an option for emergency generation if required. The share of unabated fossil fuel generation falls from 18% in 2021 to 2% by 2035, and further decline to less than 1% of generation in 2050. An exception is the Territories and other remote and northern regions, where many communities rely solely on diesel-fired generation.

Natural gas with CCUS is a flexible power source in the net-zero scenarios

While unabated fossil fuel generation is largely phased-out in the net-zero scenarios, natural gas-fired generation combined with CCUS becomes an important part of the generation mix in some regions. Natural gas with CCUS is first deployed in 2030 and grows steadily throughout the projection period, reaching 69 TWh by 2050. While more expensive compared to wind and solar per unit of electricity generated, natural gas with CCUS is a flexible source of power, meaning it plays an important role in balancing electricity systems, particularly those that do not have many other flexible options. Most additions of natural gas with CCUS are in Alberta, Saskatchewan, and Ontario. Figure R.23 shows fossil fuel generation by fuel in the Global Net-zero Scenario.

Figure R.23:
Fossil fuel generation by fuel, Global Net-zero Scenario



In the Current Measures Scenario, unabated natural gas-fired generation increases steadily. Natural gas-fired generation grows by 38% from 2021 to 2050, making up 11% of total generation at the end of the projection period. We do not project any natural gas generating units with CCUS in the Current Measures Scenario.

Biomass

In 2021, just over 2% of Canada's electricity is generated from biomass, much of which is in BC. Biomass and biofuel combustion releases CO_2 that was originally captured and stored in plant matter. Plants release this stored CO_2 when they die naturally. As a result, we consider biomass and bioenergy a low-carbon source of energy when well managed. In both net-zero scenarios, bioenergy with carbon capture and storage (BECCS), becomes a key technology that supports decarbonization of the electricity sector and Canada as a whole. Generating electricity using BECSS can result in negative GHG emissions by permanently storing carbon that would otherwise be temporarily stored in plants. As a result, BECCS generation serves a dual purpose in the energy system, providing electricity to the grid and offering a source of negative emissions. We assume those negative emissions can then be sold to other power producers or industries outside of the power sector aiming to offset their GHG emissions.

Negative emissions from BECCS plays an important role in both net-zero scenarios

In the Global Net-zero Scenario, BECCS generation begins in 2035 and grows to reach 51 TWh in 2050, or 4% of total generation. The negative emissions resulting from BECCS are 9 MT in 2035, and 41 MT by 2050 in both net-zero scenarios. We discuss total GHG emissions from the electricity sector later in this section.

In both net-zero scenarios, bioenergy plays an increasingly important role, in electricity as well as in the entire energy system. However, the annual availability of sustainable biomass feedstocks is limited by biological constraints and competition with other economic sectors like forestry and agriculture. An analysis of available biomass resources and our projections of its usage within Canada's energy system shows that the bioenergy used for electricity generation is well within the total resource supply.

Hydrogen

Hydrogen can be used to generate non-emitting electricity. The hydrogen is combusted to turn a turbine, much like a natural gas-fired facility. Currently there is no hydrogen-powered electricity generation in Canada.

In the Global Net-zero Scenario, we do not project any hydrogen use in the power sector as other generating technologies meet the power system's needs at a lower cost. However, in the Canada Net-zero Scenario, we project a small amount of hydrogen-fueled electricity generation in Alberta late in the projection period. The higher cost of carbon pollution in that scenario makes hydrogen an attractive power generation option in Alberta during peak demand periods. In addition, electricity demand is higher in Alberta in the Canada Net-zero Scenario compared to the Global Net-zero Scenario due to higher oil and natural gas production, increasing electricity demand. Hydrogen generation in Alberta reaches 1.4 TWh, or just less than 1% of total Albertan generation in 2050.

Storage

Storage of electricity, either directly in batteries or other forms like compressed air or pumped hydro storage, can help balance electricity supply and demand. It allows electricity to be stored during times of high production or low use, and then be used when production is low, or use is high. Storage provides a source of complimentary electricity to renewable power sources like wind and solar. Currently, a number of provinces have grid-connected battery storage systems including about 90 MW in Alberta and 50 MW in Ontario.

In both net-zero scenarios, we project growth in battery storage, while other forms of storage are not built. By 2030, we project 1.5 GW of battery storage in the Global Net-zero Scenario, reaching 9 GW by 2050. There is no battery storage built in the Current Measures Scenario.

In EF2023, our electricity modeling focuses primarily on electricity supply and demand. As a result, the incentive to build battery storage facilities is based on storing inexpensive power and then discharging it later at a higher price. Batteries can also provide other functions that support the electricity system, like short-term reliability services. The potential for additional revenue from these services could increase the attractiveness of battery storage beyond what we model in EF2023. In addition, hydrogen production using electricity is an important source of flexible demand in our net-zero scenarios. This source of flexibility provides similar grid-balancing functionality as other storage options. Lower hydrogen production using electricity would mean there is more need for grid-balancing options and could result in greater need for battery and other storage options.

Trade and transmission

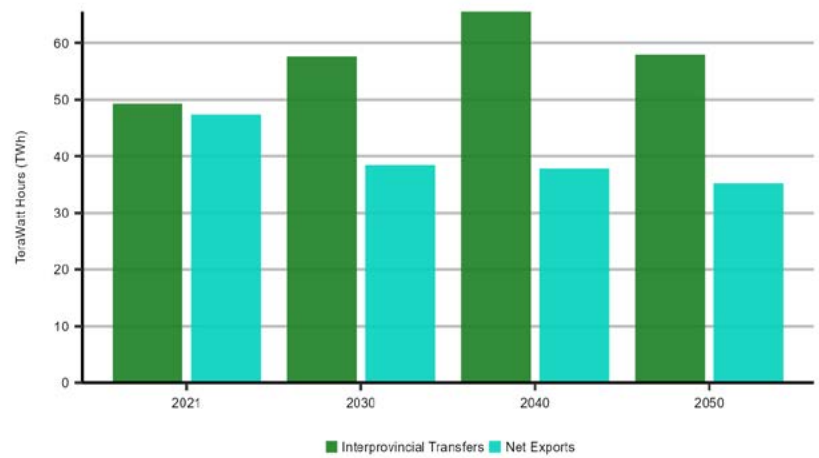
Canada is a net exporter of electricity to the U.S., and electricity is also traded between provinces, mainly in eastern Canada. In 2021, Canada exported 60 TWh of electricity and imported 13 TWh. The total aggregated interprovincial electricity flows in 2021 was 47 TWh.

In both net-zero scenarios, net exports of electricity to the U.S. fall modestly from current levels

This decline is in response to growing Canadian electricity demand. Meanwhile, we project the aggregate interprovincial trade increases by about 16% in 2050 compared to 2021 levels, facilitated by some additional transmission capacity between provinces. By connecting the electricity grids of different regions, grid operators can take advantage of regional differences in electricity mixes, available variable renewable energy, and periods of peak electricity demand. Without additional transmission capacity, some individual provinces could need to install more generation or storage capacity than we project in both net-zero scenarios. In the Current Measures Scenario, interprovincial electricity trade grows more slowly. Figure R.24 shows our projections of net exports out of Canada and aggregate interprovincial trade volumes in the Global Net-zero Scenario. International and interprovincial trade remains relatively small when compared to total generation.

Electricity market developments in the U.S. may evolve differently than our projections. More, or less, exports could increase or decrease the incentive to build additional generation capacity in Canada. Likewise, the extent to which additional interprovincial electricity capacity is built would influence the extent provinces can benefit from trade with neighboring provinces and alter how much generation must be built in those provinces to meet growing electricity demand.

Figure R.24:
Net exports of electricity and interprovincial trade, Global Net-zero Scenario



Electricity production in the Territories and other remote and northern regions

Electricity systems in the Territories and remote and northern regions of some provinces are unique. These regions are not connected to the North American electricity grid, and in many communities, electricity is generated from small diesel-fired stations.

Diesel remains the main fuel source for the Territories in both net-zero scenarios

Electricity generation in Yukon and Northwest Territories is a mix of hydro, natural gas, and diesel-fired generation, and in Nunavut, diesel generation is the sole source of electricity. Combined, the Territories make up less than 1% of Canada's total electricity generation. In both net-zero scenarios, we project that the current forms of electricity in each territory remain the main sources over the projection period. Currently, diesel is often relied upon in remote communities because it is transportable, energy-dense, and readily available. However, the remoteness of communities can create supply security issues and high transportation costs for fuel. Diesel is also often used for space heating in addition to electricity generation in many of those regions.

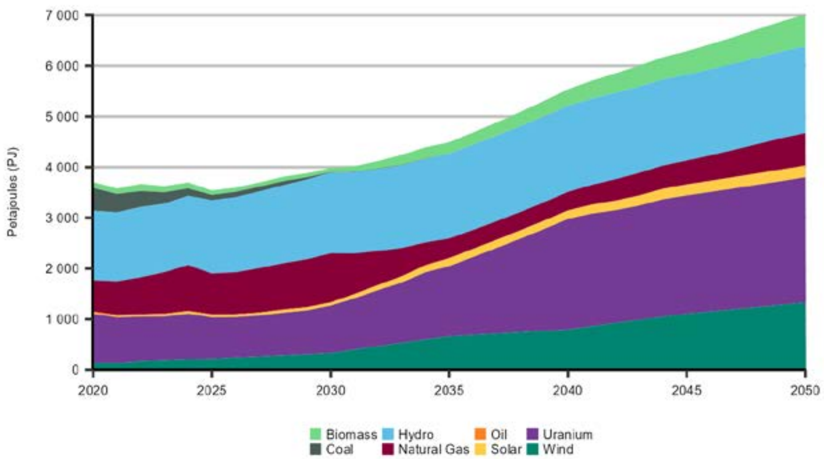
Some diesel consumption is offset with wind and solar generation built over the projection period. Combined, the Territories add 86 MW of wind over the projection period, and 118 MW of solar.[16] Together these represent 18% of generation in the territories by 2050.

16 The CER's Market Snapshot: Clean Energy Projects in Remote Indigenous and Northern Communities provides details on upcoming clean energy projects in these regions.

Energy use associated with electricity generation

Energy used to generate electricity made up a quarter of total primary energy use in Canada in 2021. We project energy use by the electricity sector to increase nearly 90% by 2050 in the Global Net-zero Scenario, 100% in the Canada Net-zero Scenario, and 30% Current Measures Scenario. Figure R.25 shows our projection of energy use to generate electricity in the Global Net-zero Scenario.

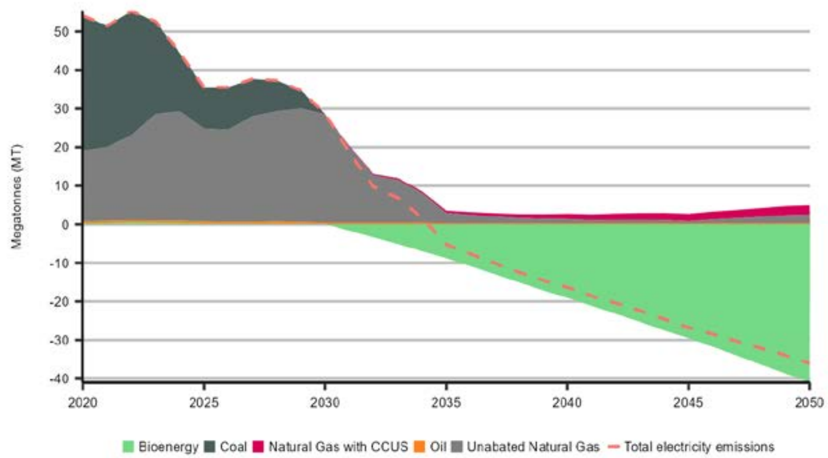
Figure R.25:
Energy use to generate electricity by fuel, Global Net-zero Scenario



GHG emissions associated with electricity generation

We project that GHG emissions from the electricity sector, which made up 8% of Canada's emissions in 2021, reaches net-zero by 2035 in both net-zero scenarios. After 2035, the electricity sector becomes a net-negative emitter, resulting in net-negative emissions of 36 MT by 2050 in the Global Net-zero Scenario, and 35 MT in the Canada Net-zero Scenario. Some types of generation result in positive emissions throughout the projection period, including the fraction of emissions CCUS does not capture, diesel generation in remote and northern communities, and limited amounts of unabated natural gas-fired generation. Figure R.26 shows GHG emissions of the electricity sector by fuel in the Global Net-zero Scenario.

Figure R.26:
GHG emissions from electricity generation, by fuel, Global Net-zero Scenario



KEY UNCERTAINTIES

Electricity

- **Export markets**: Electricity market developments in the U.S. will impact the development of Canada's electricity system. Higher or lower integration with the U.S. power system than we project could impact the amount and type of new electricity generation built in Canada.
- **Electricity transmission**: While our projections suggest building electricity transmission between provinces results in lower total system costs in both net-zero scenarios, building large-scale electricity transmission will be influenced by a diverse range of factors. Less transmission would change the electricity investment outcomes in our scenarios.
- **Societal preferences**: Electricity generation can have positive and negative impacts on the communities around them, including particulate emissions, safety concerns, visual impacts, and competition with other land uses. These factors will influence future electricity outcomes, but are beyond the scope of EF2023.

Oil and natural gas production

Crude oil, natural gas, and natural gas liquids (NGLs) are produced in Canada for domestic use as well as for export. Most of Canada's crude oil is produced in Alberta, along with significant volumes from Saskatchewan and offshore Newfoundland and Labrador. Nearly all of Canada's natural gas production is from Alberta and BC.

In this analysis, we project crude oil, natural gas, and NGL production by simulating investment and operational decisions of producers based on our assumptions about international and domestic crude oil and natural gas prices, applicable policies, resource characteristics, and the costs of production, including the costs of various technologies to reduce emissions. The prices of crude oil and natural gas that we assume account for the global supply and demand balance in each scenario. We assume that if Canadian producers can earn a profit, they choose to produce oil and gas.

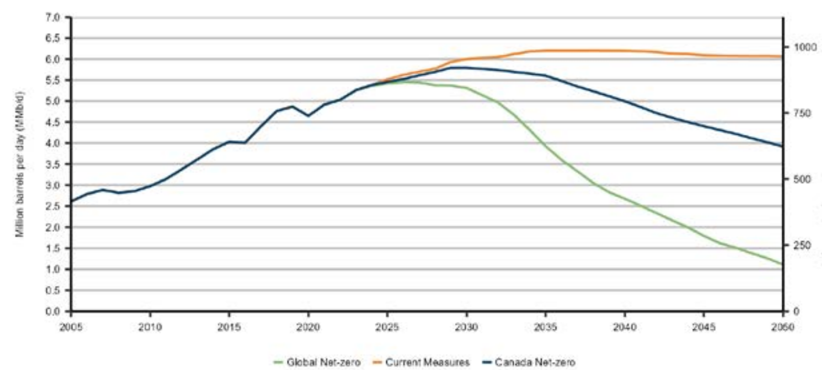
Crude oil

Canadian crude oil production has been growing steadily for many years, increasing 87% from 2005 to 2019. Production declined by 5% in 2020, largely due to the COVID-19 pandemic. In 2021, production started increasing again and averaged 4.9 million barrels per day (MMb/d) (781 thousand cubic metres per day ($10^3m^3/d$)). Production grew again in 2022 and reached its highest level ever at 5.0 MMb/d (800 $10^3m^3/d$).

Crude oil production declines in the long term in both net-zero scenarios

Total crude oil production continues to increase after 2022 in all three scenarios in the near term, because of relatively high prices over that period. However, each scenario evolves very differently in the medium and long term. Figure R.27 shows total crude oil production in all three scenarios.

Figure R.27:
Crude oil production (including condensate and pentanes plus), all scenarios



In the Global Net-zero Scenario, we project that crude oil production peaks in 2026, and then declines steadily thereafter, reaching 1.22 MMb/d (194 10^3m^3/d) in 2050, a 76% decrease from 2022 levels. In the Canada Net-zero Scenario, production continues to grow until near the end of the decade before beginning to decline, falling to 3.92 MMb/d (623 10^3m^3/d) by 2050. In the Current Measures Scenario, we project production grows to a peak of 6.20 MMb/d (986 10^3m^3/d) by 2035, and remains just below that level for the remainder of the projection period.

The differences between these scenarios are mostly explained by the different assumptions we make about the price of crude oil. We describe these assumptions in detail in the previous chapter, Scenarios and Assumptions. In the Global and Canada Net-zero scenarios, we align our assumptions with crude oil prices from the IEA's WEO2022 scenarios. In the Global Net-zero Scenario, we take the global crude oil price from the IEA's Net Zero Emissions by 2050 Scenario and in the Canada Net-zero Scenario, we use prices from the IEA's Announced Pledges Scenario. The prices we assume in the Current Measures Scenario are based on a review of price projections by various other organizations. Table R.2 shows our crude oil price assumptions.

Table R.2:
Brent crude oil price assumptions, all scenarios

	2030	**2050**
Scenario	**2022US$ per barrel**	**2022US$ per barrel**
Global Net-zero	35	24
Canada Net-zero	64	60
Current Measures	75	75

Our assumptions about climate policies also affect our projections of crude oil production. All scenarios include all policies currently in place. In the net-zero scenarios, we include any announced but not-yet-implemented climate policies to the extent feasible. These policies include the federal methane regulations, which aim to reduce methane emissions by 75% by 2030, and the oil and gas emissions cap. In both instances, the final policy design was not available before our modeling was complete. As a result, we relied on simplifying assumptions to include these policies in our analysis. Further details on those assumptions are available in Appendix 1: Domestic Climate Policy Assumptions.

KEY TRENDS
Crude oil production

- In the Global Net-zero Scenario, oil production falls by 76% from 2022 to 2050 to 1.22 MMb/d (194 10^3m^3/d) because global oil demand falls to very low levels, resulting low crude oil prices that challenge the economic viability of many Canadian producers.
- In the Canada Net-zero Scenario, production falls 22% from 2022 to 2050 to 3.92 MMb/d (623 10^3m^3/d), because oil prices are high enough to sustain more production.
- CCUS capacity in the oil sands peaks at 27 MT in 2033 in the Global Net-zero Scenario and 49 MT in 2035 in the Canada Net-zero Scenario.
- Oil sands emissions fall 94% from 2005 levels by 2050 in Global Net-zero Scenario and 76% from 2005 levels by 2050 in Canada Net-zero Scenario.

Canadian crude oil production includes three main types of production: oil sands, conventional, and offshore.

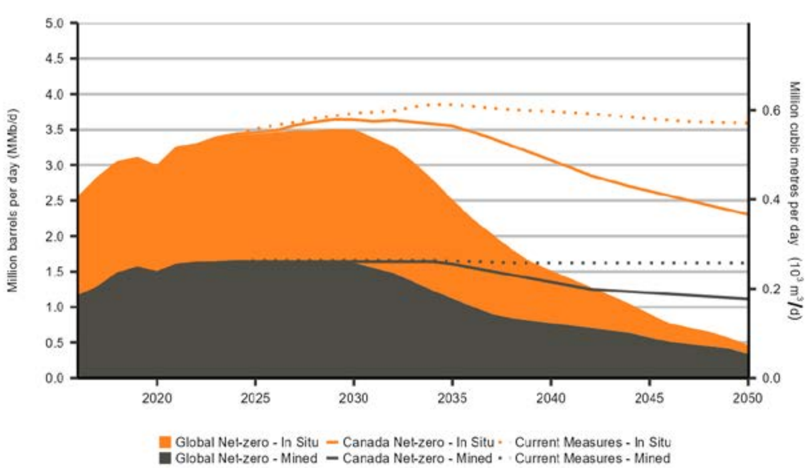
Oil sands production

Oil sands production comes from bitumen deposits located in Alberta, where bitumen is mined in surface pits or produced using wells and steam (called in-situ production). The oil sands made up nearly two-thirds of Canadian production in 2022.

Oil sands production grows at a similar pace in the near term in all three scenarios

Production is between 4 to 7% higher by 2030 compared to 2022 levels depending on the scenario. Most of this growth is from a small number of existing projects who expand their facilities. We project that oil sands production in each of the three scenarios differs considerably after 2030. These differences are mainly driven by our assumptions about global crude oil prices, which are lowest in the Global Net-zero Scenario, higher in the Canada Net-zero Scenario, and highest in the Current Measures Scenario. In addition, climate policies in each scenario influence investment decisions, including how producers use technology to reduce emissions. Figure R.28 shows oil sands production by facility type in all scenarios.

Figure R.28:
Oil sands production by type, all scenarios



Oil sands production falls after 2030 in the Global Net-zero Scenario

After 2030, oil sands production in the Global Net-zero Scenario begins to steadily decline. This decline is largely because oil prices fall to 2022US$35 per barrel in 2030 and continue to decrease thereafter. Oil prices fall because of much lower global demand for oil as more stringent climate policies are implemented globally, as demonstrated in the IEA's WEO2022 Net Zero Emissions by 2050 Scenario. In other words, oil producers around the globe are facing a rapidly shrinking market. Though falling prices are the dominant factor, our projections also factor in increasingly strong climate policies in Canada, which reduce emissions but also increase the costs of production.

Only the most efficient projects produce in 2050 in the Global Net-zero Scenario

Over the projection period, falling prices make it increasingly difficult for oil sands producers to recover their operating costs and keep projects running. Operating costs include fuel, maintenance, royalties paid to provincial governments, carbon pollution costs (including any remaining carbon pollution after CCUS is installed, as we assume CCUS captures 90% of emissions from large point sources), and, when necessary, the cost of diluent so bitumen can be diluted and shipped on pipelines. In our analysis, shortly after the total operating costs of a facility exceeds its revenue, it shuts down for the remainder of the projection period. Oil sands facilities that have the highest operating costs begin shutting down early in the 2030s. As oil prices continue to drop, more and more facilities shut down production, and only the lowest-cost projects are still producing in 2050. Oil sands production falls to 1.59 MMb/d (252 10^3m^3/d) in 2040 and 0.58 MMb/d (91 10^3m^3/d) in 2050, or 83% lower than in 2022. In-situ production falls faster than mining production because in-situ projects are more emissions-intensive, meaning they have higher carbon costs than oil sands mines.

Production declines less and more slowly in the Canada Net-zero scenario

In the Canada Net-zero Scenario, oil sands production also declines after 2030, but at a slower rate compared to the Global Net-zero Scenario. While global demand for oil falls in the IEA's WEO2022 Announced Pledges Scenario, demand is still much higher than in their Net Zero Emissions by 2050 Scenario, meaning oil prices are much higher. In the Canada Net-zero Scenario, oil sands production decreases in line with the gradual natural declines in production exhibited by oil sands projects, which become more mature over the projection period. Production in the Canada Net-zero Scenario falls from a peak of nearly 3.64 MMb/d (579 10^3m^3/d) in 2030 to 2.30 MMb/d (366 10^3m^3/d) by 2050, or 30% lower than 2022. Like in the Global Net-zero Scenario, in-situ production falls faster than mining production.

Oil sands production grows steadily in the Current Measures Scenario

In the Current Measures Scenario, we project that higher global prices and less stringent future climate policies result in continued growth in oil sands production over the projection period. Expansions of existing projects leads to much of the growth, with some greenfield projects also coming online. Oil sands production rises from 3.29 MMb/d (523 10^3m^3/d) in 2022 to 3.73 MMb/d (593 10^3m^3/d) in 2030 and largely holds steady, reaching 3.59 MMb/d (571 10^3m^3/d) by 2050.

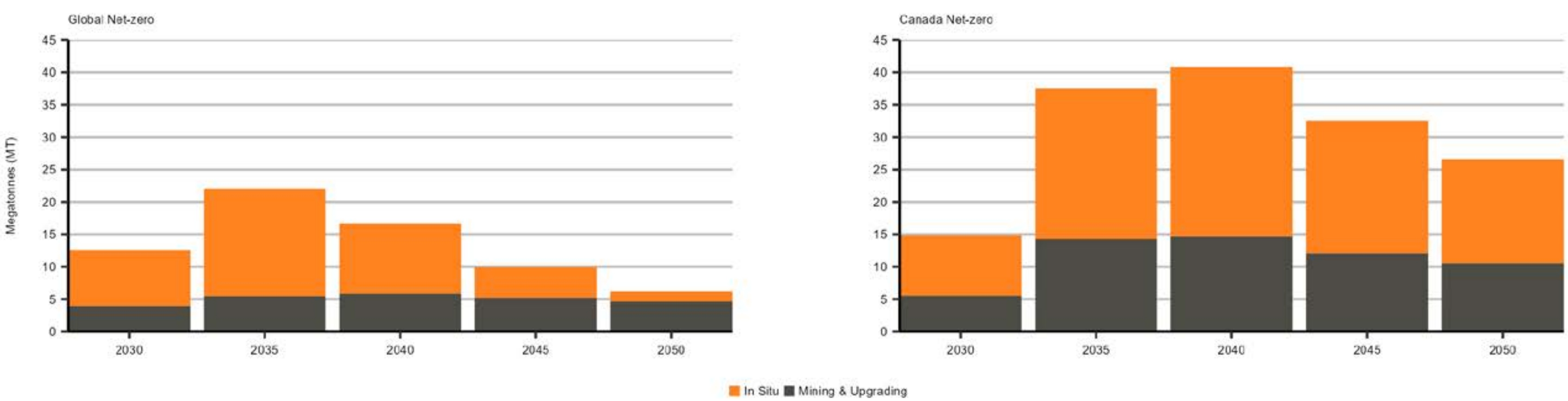
Oil sands producers significantly reduce emissions in both net-zero scenarios

This is due to increasingly strong climate policies, which cause oil sands producers to deploy emission-reduction technology. The primary source of GHG emissions from the oil sands is from burning natural gas, which is used to boil water to create steam for in-situ production and to create hydrogen to upgrade bitumen into synthetic crude oil.

Our modeling projects that CCUS is the most economic choice for many oil sands producers to reduce emissions. We project that oil sands producers retrofit existing projects with CCUS early in the projection period in both net-zero scenarios and install it on any new projects. In the Current Measures Scenario, only a small amount of CCUS is installed. Other decarbonization technologies have potential, like using solvents to help with bitumen recovery or SMRs to generate heat without using natural gas. Given our assumptions about the costs and characteristics of different technologies, CCUS is the primary choice for oil sands producers in both net-zero scenarios. However, our projections could show different decarbonization pathways if these technologies proved less costly or more effective than we assume.

In the Global Net-zero Scenario, we project that 12.5 MT of CO_2 is captured annually by 2030, increasing to a peak of 22.5 MT by 2036, as shown in Figure R.29. In the Canada Net-zero Scenario, producers rely even more on CCUS, mostly because oil sands production remains higher, reaching 15.0 MT of emissions captured in 2030 and 45.0 MT in 2037.

Figure R.29:
GHGs captured and permanently stored from the oil sands using CCUS, Global and Canada Net-zero scenarios



Overall, GHG emissions in the oil sands peak at 87 MT per year in 2023 in the Global Net-zero Scenario before falling to 61 MT per year in 2030 and 4 MT per year in 2050, a 94% drop from 2005 levels. GHG emissions peak at 88 MT per year in 2023 in the Canada Net-zero Scenario before falling to 55 MT per year in 2030 and to 8 MT per year in 2050. Some producers in the Global Net-zero Scenario choose not to add CCUS because oil prices are too low for them to install it and recover invested capital, and instead produce what bitumen they can before they shut down later in the projection period.

Photo credit: Suncor

What if carbon capture, utilization and storage (CCUS) technology is more expensive?

CCUS is a suite of technologies that capture CO_2, typically from the exhaust of industrial or power facilities. The captured CO_2 can then be permanently stored in geological formations deep underground or permanently mineralized in cement. CO_2 can also be potentially used to make products like synthetic fuels, rather than storing it. In this "What if" analysis, we focus on the application of CCUS in the oil sands.

Many modeling exercises have identified CCUS as a key technology for reducing emissions from sectors where reducing emissions through other methods like electrification or alternative fuels may be too difficult or costly. In its Net Zero Emissions by 2050 Scenario, the IEA projects CCUS will capture 6.2 gigatonnes of CO_2 by 2050, or nearly 17% of global CO_2 emissions in 2021. In that scenario, CCUS is mostly used in industry, power generation, and for hydrogen production.

Canada is currently adding more CCUS projects

In Canada, crude oil producers have been injecting captured CO_2 into oil wells to enhance recovery rates since the early 1980s. Saskatchewan's coal-fired Boundary Dam Generating Station added CCUS to one of its units in 2014 and has captured more than 5 MT of GHG emissions since. In Alberta, two carbon capture projects, Quest and Alberta Carbon Trunk Line, were commissioned in 2015 and 2020, respectively, increasing Alberta's annual carbon storage capacity to 3 MT by the end of 2022. Many new projects proposed in Alberta are described in detail in the CER Market Snapshot: New projects in Alberta could add significant carbon storage capacity by 2030. To encourage CCUS deployment, the federal government announced investment tax credits for CCUS projects that permanently store captured CO_2. We include these tax credits in our analysis.

CCUS deployment will depend on costs

In EF2023, we make assumptions about the costs of various technologies, including CCUS, in our oil sands analysis. The model then simulates the operational and investment decisions of oil sands producers based on those assumptions as well as other factors. However, the actual deployment of CCUS will strongly depend on its eventual costs. The costs we assume could be optimistic. In this "What if" analysis, we consider what oil sands production and CCUS deployment in the sector might look like if costs of CCUS are higher and deployment of CCUS is lower. Table R.3 shows the lifecycle costs we assume for the construction and operation of a CCUS facility, including the cost of transporting CO2 in a pipeline, in both net-zero scenarios and for this "What if" analysis.

Table R.3:
Lifecycle cost of construction and operation of CCUS facilities in the oil sands, including transportation, Net-zero scenarios and Low CCUS cases

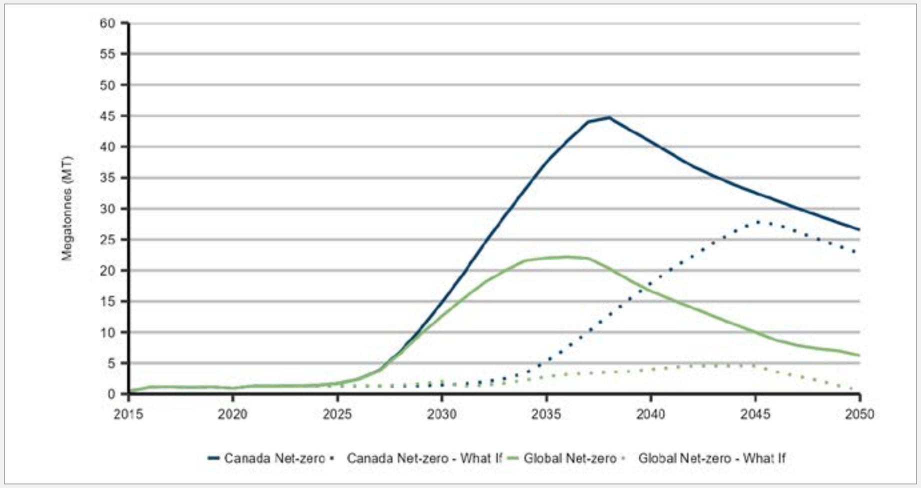
	2030		2050	
	2022$ per tonne	2022$ per tonne	2022$ per tonne	2022$ per tonne
	In-situ	Upgrading	In-situ	Upgrading
Global Net-zero and Canada Net zero Scenario	117	93	95	76
Global Net-zero and Canada Net-zero Low CCUS cases	233	186	191	152

In this "What if" analysis, the only assumption we change is the cost of CCUS, to see how sensitive oil sands production and emissions are to changes in CCUS cost. We keep our assumptions about policies and crude oil prices the same as in the main net-zero scenarios.

In the Global Net-zero Scenario, higher CCUS costs significantly reduce the use of CCUS

As shown in Figure R.30, producers build much less CCUS in the Global Net-zero Low CCUS Case than in the original scenario. However, as shown in Figure R.31, oil sands production is about the same in 2030. From 2030 to 2050, on the other hand, production falls faster than in the original Global Net-zero Scenario. More producers choose not to build CCUS and face higher operating costs as they pay for increasing costs for carbon pollution. Once those operating costs exceed revenues, projects begin to shut down, and production is 0.47 MMb/d (74 10^3m^3/d) lower in 2050 in the Global Net-zero Scenario Low CCUS Case. Emissions are 27% higher than in the original scenario in 2030, because less CCUS is installed by then, though are 7% lower in 2050, as production is lower.

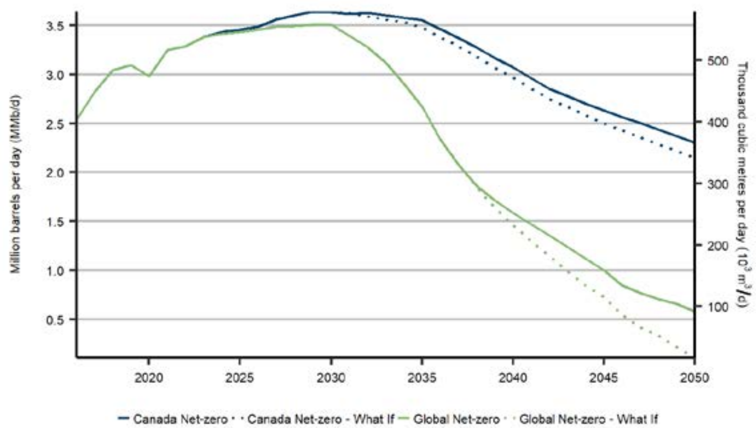
Figure R.30:
GHG emissions from the oil sands captured using CCUS, Global Net-zero and Canada Net-zero Scenarios and Low CCUS cases



Producers delay building CCUS in the Canada Net-zero Scenario Low CCUS Case

In the Canada Net-zero Scenario Low CCUS Case, producers delay adding CCUS because of higher costs, but still build similar amounts by 2050 as in the original scenario as CCUS costs decrease over time. Production from the oil sands is slightly lower in the original scenario, because while oil prices are high enough to keep existing projects running, there is somewhat lower investment in expanding production. Emissions are 33% higher in 2030 than in the original scenario, while they are roughly the same by 2050.

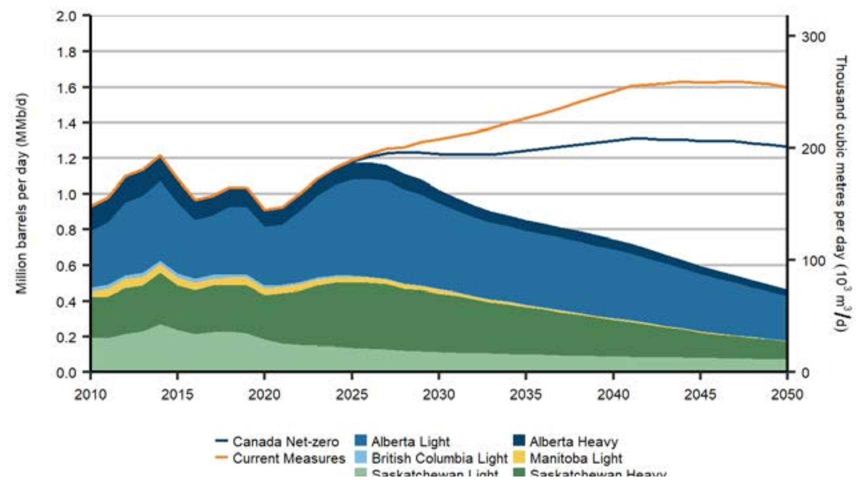
Figure R.31:
Oil sands production by type, Global and Canada Net-zero scenario, and total oil sands production, Low CCUS cases



Conventional onshore oil production

Alberta and Saskatchewan produce most onshore, conventional crude oil in Canada, with smaller amounts of production from Manitoba, BC, Northwest Territories, and Ontario. Conventional production was 1.01 MMb/d (160 10^3m^3/d) in 2022. Conventional crude oil can be classified as light or heavy, depending on the density of the oil. Western Canadian conventional crude oil production is roughly half light and half heavy. Figure R.32 shows conventional crude oil production in all three scenarios, and production by type in the Global Net-zero Scenario.

Figure R.32:
Conventional onshore oil production by province and type, Global Net-zero Scenario



In all three scenarios, conventional crude oil production increases toward 2025 as relatively high prices sustain drilling activity and production. Much of this growth is from tight oil in Alberta and Saskatchewan, and heavy oil production in Saskatchewan, particularly from thermal oil projects.

Conventional oil production declines after 2026 in the Global Net-zero Scenario

We project production to peak relatively soon in the Global Net-zero Scenario, reaching 1.18 MMb/d (188 10^3m^3/d) by 2026. After 2026, production declines steadily through the remainder of the projection period. Steadily declining crude oil prices reduces revenues for oil producers and results in less drilling for new production in following years, meaning not enough new production comes online to replace production declines in existing wells. By 2050, conventional crude oil production is 0.47 MMb/d (74 10^3m^3/d), 54% lower than in 2022. Most of the remaining production in 2050 is light crude oil, mainly because of declines in heavy oil production.

Production remains steady in the Canada Net-zero Scenario, and grows in the Current Measures Scenario

Conventional production continues to increase in the medium term in the Canada Net-zero Scenario, largely due to higher crude oil prices. Production increases gradually, reaching 1.22 MMb/d (195 10^3m^3/d) 2030 and staying near those levels until 2050. Conventional crude oil production grows the most in Current Measures Scenario, rising to 1.60 MMb/d (255 10^3m^3/d) in 2050.

Conventional oil is more resilient compared with the oil sands in the Canada Net-zero Scenario

Overall, in the Canada Net Zero Scenario, conventional production remains relatively resilient when compared to oil sands production, which falls. This is largely because the two sectors have very different cost structures and produce oil very differently. Projects in the oil sands have very high up-front costs and take years to build. In addition, oil sands production rates tend to decline slowly over the multi-decade life of a project, though this decline can be slowed if additional capital is invested. These factors mean that oil sands projects are built on the basis of recovering their upfront investments over a long period of time, and project proponents must consider the long-term uncertainty about global oil demand and crude oil prices in their investment decisions. Conventional producers, on the other hand, have a shorter time horizon to consider in their investment decisions. This is because tight oil wells, which make up most conventional wells being drilled today and over the projection period, produce most of their oil in the first few years after being drilled. In the Canada Net Zero Scenario, conventional producers respond to relatively high prices by drilling enough new wells to maintain relatively flat production through most of the projection period.

In both net-zero scenarios, conventional oil producers reduce emissions in response to the climate policies that we assume, like regulations to reduce methane emissions and the oil and gas emissions cap.

Compared to the oil sands, conventional oil production burns relatively little fuel, although it has higher methane emissions. The exception is Saskatchewan's thermal-heavy oil projects, which use natural gas much like Alberta's in-situ oil sands projects. In both net-zero scenarios, producers make technological and process changes, like restricting venting levels from devices like compressors and implementing leak detection and repair programs. We also project that, where feasible, the sector uses more electricity for production and processing.

Availability of crude oil export pipeline and rail capacity

A key issue for Canada's energy system over the last ten years has been export capacity of western Canadian oil export pipelines and crude-by-rail. When total export capacity is full, price differences between Canadian oil markets and our export markets expand, particularly during unexpected outages, which causes western Canadian oil producers to earn less revenue than they otherwise would. Figure R.33 is a simplified, illustrative comparison of our projected western Canadian crude oil supply available to export and an illustrative level of total export capacity from pipelines, planned pipeline expansions, and structural rail.[17] Available capacity on existing pipeline systems could be higher or lower than reflected in Figure R.33, because pipeline systems evolve over time. The level of structural crude-by-rail could also be higher or lower than reflected in this figure.

Comparing oil available for export and the amount of export capacity helps us to understand whether pipeline constraints might affect crude oil production. We do not, however, adjust projected crude oil production or what we assume for western Canadian oil prices based on potential constraints. That said, our near-term oil sands projections are largely based on publicly available producer investment plans, which could include expectations about future export capacity.

Crude oil available for export stays below export capacity in both net-zero scenarios

In the Global Net-zero Scenario, western Canadian crude oil available for export rises in the near term before falling after 2030, staying below the total export capacity throughout the projection period.

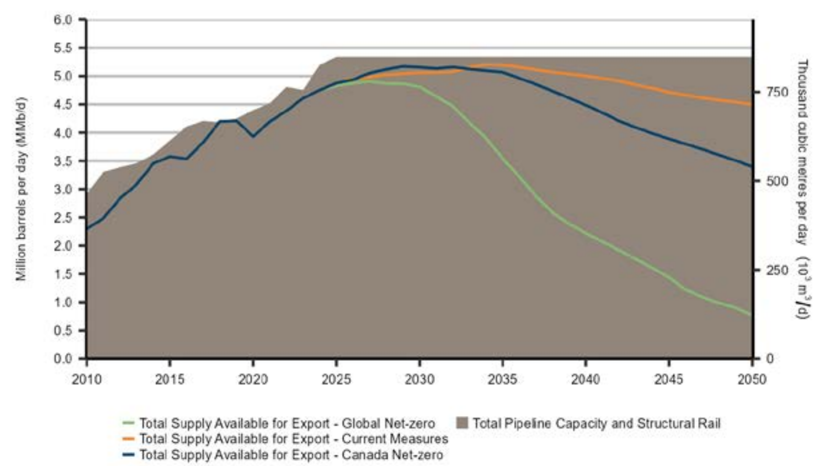
In the Canada Net-zero Scenario, western Canadian crude oil available for export rises more in the near term and remains higher than in the Global Net-zero Scenario after 2030, though still remains below export capacity. Declining demand for RPPs demand for RPPs in western Canada reduces demand for oil at local refineries, which leaves more production available for export. In the Current Measures Scenario, supply comes close to, but does not exceed, export capacity for much of the projection period, peaking in 2035, and declining gradually thereafter.

EF2023 does not explore the complex interactions between pipelines, energy supply, and energy demand

For example, some spare pipeline capacity can benefit crude oil producers by increasing flexibility as it could help producers more easily switch where they ship their oil, and therefore find higher values for their production. Spare capacity can also help ship oil that might otherwise back up into western Canada during pipeline maintenance or unplanned outages. On the other hand, excess capacity and long-term underutilization of pipelines could result in higher pipeline tolls for crude oil producers. Analysis of these considerations is beyond the scope of EF2023. We caution readers from drawing definitive conclusions from the illustrative comparison shown Figure R.33.

It is also important to note that estimates of total available pipeline capacity and the level of structural rail is uncertain and the result of many key assumptions. Table R.4 describes the assumptions underpinning Figure R.33.

Figure R.33:
Illustrative export capacity from pipelines and structural rail, crude oil pipeline capacity vs. total supply available for export, all scenarios



17 Structural rail refers to crude oil that is exported by rail regardless of a given WCS-WTI differential. Companies may choose to export crude oil by rail in this way due to a number of factors. These include existing contractual commitments, ownership of the crude-by-rail infrastructure, and the need to access locations not well connected by pipeline.

Table R.4:
Pipeline capacity assumptions for Figure R.33

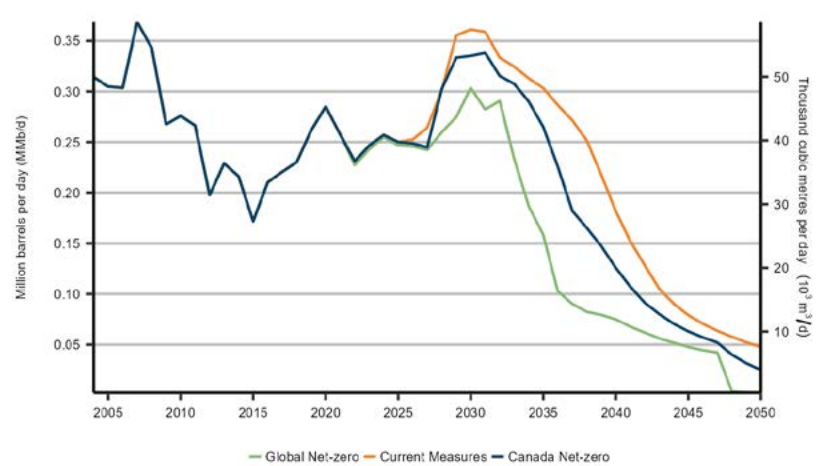
Name	Takeaway capacity (current or timing as noted) (Mb/d)	Capacity assumptions
Enbridge Mainline	3,290	Stated capacity includes the fully completed Line 3 Replacement Project which added 370 Mb/d of capacity to the Enbridge Mainline in late 2021.
Keystone	590	Capacity held fixed over the projection period. The cancelled Keystone XL project is not included in Figure R.33.
Trans Mountain	300	Capacity is held fixed over the projection period.
Trans Mountain Expansion	590	The Trans Mountain Expansion Project adds capacity starting in the first quarter of 2024 and increases to full capacity a few months later. This includes use of drag-reducing agents, which increase the capacity of the existing Trans Mountain line by 50 Mb/d.
Express	310	Capacity held fixed over the projection period.
Milk River	97	Capacity held fixed over the projection period.
Aurora/Rangeland	44	Capacity held fixed over the projection period.
Structural Rail	120	Capacity held fixed over the projection period.
Total	**5,363**	

Offshore oil production

Offshore oil production comes from wells drilled in Canada's offshore areas. Currently only Newfoundland and Labrador produces offshore oil. Offshore production was 0.23 MMb/d (37 10^3m^3/d) in 2022. While some production currently comes from Hibernia and other nearby fields, most offshore production now comes from the Hebron field, which came online in late 2017.

In all three scenarios, the Bay du Nord offshore project comes online in the late 2020s, increasing Newfoundland and Labrador's oil production. As shown in Figure R.34, the amount of production we project from the Bay du Nord facility varies by scenario, with the least amount of new production coming online in the Global Net-zero Scenario and the most coming online in the Current Measures Scenario. This is because oil prices in 2030 and later are lowest in the Global Net-zero Scenario and highest in the Current Measures Scenario.

Figure R.34:
Offshore oil production, all scenarios

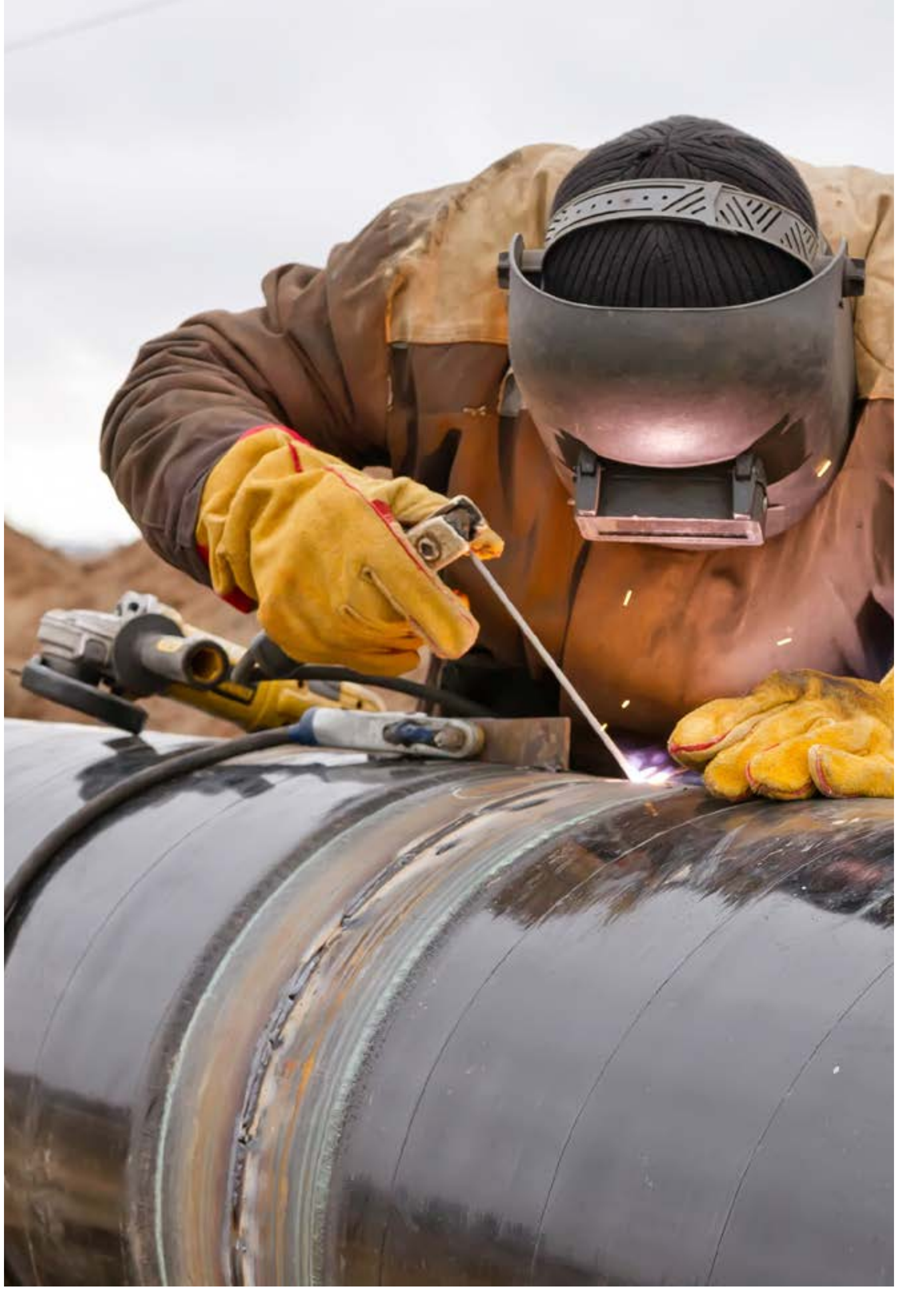


GHG emissions from offshore oil production peak around 2030 in all three scenarios, and then decrease toward 2050. In particular, GHG emissions decline faster than production in all three scenarios. This decrease is because older projects in Newfoundland and Labrador's offshore tend to have higher emission intensities and shut down before newer projects, which have lower emission intensities. This means the average emission intensity for a barrel of offshore oil falls over time, accelerating the decline in total emissions. Emissions fall to less than 5% of 2019 levels by 2050 in both net-zero scenarios.

KEY UNCERTAINTIES

Crude oil

- **The pace of global climate action:** Canada exports most of its oil production, meaning our producers depend on markets outside of Canada to buy most of our oil supply. Demand for Canadian oil depends very strongly on how aggressively the world pursues emission reductions.
- **Technology used to decarbonize the oil sands:** In EF2023, the oil sands mainly use CCUS to decarbonize. However, if CCUS costs, and the costs of other emission-reduction technology, like solvents and SMRs, do not significantly fall, or these technologies turn out to be inadequate, the oil sands may find decarbonization even more challenging. In a rush to decarbonize the sector, constraints on labour and supplies might prevent costs from falling as much as we assume.
- **Western Canadian export capacity:** Export capacity from western Canada consists of several pipelines, as well as rail and marine vessels. Interruptions or reductions to pipeline capacity, temporary or permanent, can affect western Canadian prices and production.



Natural gas

Alberta and BC produce most of the natural gas in Canada, with smaller amounts of production from Saskatchewan, Ontario, Northwest Territories, and New Brunswick. Natural gas production grew from 13.9 billion cubic feet per day (Bcf/d) (394 million cubic metres per day ($10^6m^3/d$)) in 2012 to 16.1 Bcf/d (456 $10^6m^3/d$) in 2021, and to 17.3 Bcf/d (490 $10^6m^3/d$) in 2022, because natural gas and natural gas liquid (NGL) prices rose significantly in 2021 after Russia invaded Ukraine.

Most natural gas in Canada comes from tight gas, which is from reservoirs that need to be hydraulically fractured to flow at economic rates. Most tight gas in Canada comes from the Montney Formation of BC and Alberta. In 2022, the Montney Formation produced 8.1 Bcf/d (228 $10^6m^3/d$), just less than half of Canada's gas production and up from 0.8 Bcf/d (23 $10^6m^3/d$) in 2010.

KEY TRENDS
Natural gas production

- In the Global Net-zero Scenario, gas production falls by over two thirds from 2022 to 2050, mostly because natural gas prices fall to much lower levels.
- In the Canada Net-zero Scenario, production falls 24% from 2022 to 2050, declining less than in the Global Net-zero Scenario due to somewhat higher prices for natural gas and higher liquified natural gas (LNG) export assumptions.
- The Montney Formation produces more than half of Canada's total gas production in all three scenarios starting in 2025, and more than 60% in 2050. Our projections for natural gas production largely depend on price

Our projections for natural gas production largely depend on price

Prices determine producer revenues and capital available to potentially invest in drilling new wells from year to year. Like crude oil prices, our natural gas price assumptions in both net-zero scenarios are from the IEA's WEO2022 scenarios, and the assumptions in the Current Measures Scenario are based on a review of price projections by various other organizations. Table R.5 shows our natural gas price assumptions. A related factor that influences our projections is the difference, or differential, between the Henry Hub gas price and local prices in western Canada. Factors such as bottlenecks on Canadian pipeline systems have affected this differential in the past. Differentials that vary from what we assume could cause production to differ from our projections.

Table R.5:
Henry Hub natural gas price assumptions, all scenarios

	2030	2050
Scenario	**2022US$ per MMBtu**	**2022US$ per MMBtu**
Global Net-zero	2.00	1.80
Canada Net-zero	3.70	2.60
Current Measures	3.75	4.40

Our natural gas projections depend on our assumptions about LNG exports. We describe our assumptions about LNG in detail in the Scenarios and Assumption chapter. In the Global Net-zero Scenario, we assume LNG exports begin in 2025, reaching 2.0 Bcf/d (57 $10^6m^3/d$) by 2029, and then dropping to 0.3 Bcf/d (8 $10^6m^3/d$) by 2046 in response to falling LNG demand globally. In the Canada Net-zero Scenario, LNG exports reach 3.8 Bcf/d (108 $10^6m^3/d$) by 2030. In the Current Measures Scenario, LNG exports are the highest, reaching 4.6 Bcf/d (131 $10^6m^3/d$) by 2034.

In the Global Net-zero Scenario, Canadian production peaks at 17.4 Bcf/d (492 10^6m^3/d) in 2023, because of relatively high gas prices in 2021 and 2022. After staying near those levels until 2026, production steadily falls to 5.5 Bcf/d (156 10^6m^3/d) in 2050, because of lower investment in drilling new wells. Producer revenues decrease, largely because of lower natural gas prices, but also higher costs related to reducing emissions and complying with various climate policies.

Natural gas production declines in the net-zero scenarios, and rises in the Current Measures Scenario

In the Canada Net-zero Scenario, production rises to 17.7 Bcf/d (500 10^6m^3/d) in 2030, because natural gas prices and LNG exports are higher than in the Global Net-zero Scenario. Production then falls to 11.0 Bcf/d (310 10^6m^3/d) in 2050, largely because of falling gas prices which reduces producer revenue and investment in drilling new gas wells. In the Current Measures Scenario, as gas prices grow from 2023 to 2050, LNG exports are higher than in the other two scenarios, and climate policies are less stringent than in the two net-zero scenarios, and production rises to 21.5 Bcf/d (607 10^6m^3/d) in 2050.

Montney Formation production grows and then falls by 2050 in both net-zero scenarios

In all scenarios, the geographic location of production shifts over the projection period. BC has grown its share of total Canadian natural gas production over the past several years and this continues over the projection period, as shown in Figure R.35. A key driver of this is the growth of production from the Montney Formation, located in northeast BC and northwest Alberta. Most of the production from Montney is currently from within BC, and we project that this continues to be the case over the projection period in all three scenarios. As shown in Figure R.36, production from the Montney increased from 0.8 Bcf/d (23 10^6m^3/d, or 6% of Canadian production) in 2010 to 8.1 Bcf/d (228 10^6m^3/d, or 47% of Canadian production) in 2022. In all three scenarios, the Montney Formation's share of production increases steadily, meaning that Canada's natural gas production is becoming more concentrated in one area. Production from the Montney Formation falls to 3.4 Bcf/d (98 10^6m^3/d) in 2050 in the Global Net-zero Scenario, 6.8 Bcf/d (194 10^6m^3/d) in the Canada Net-zero Scenario, and increases to 14.8 Bcf/d (420 10^6m^3/d) in the Current Measures Scenario.

Figure R.35:

Natural gas production by province, Global Net-zero Scenario, and total production, Canada Net-zero and Current Measures scenarios

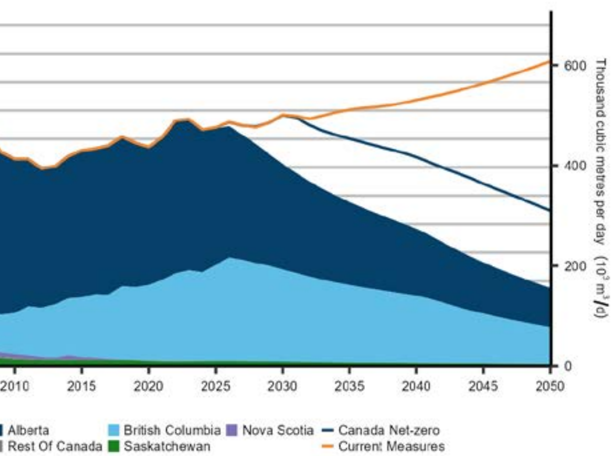
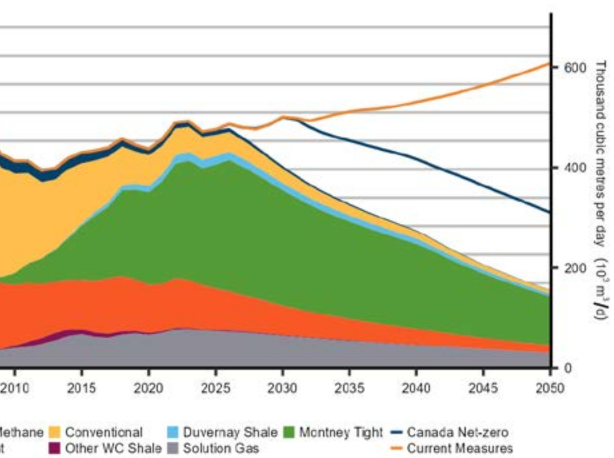


Figure R.36:

Natural gas production by type, Global Net-zero Scenario, and total production, Canada Net-zero and Current Measures scenarios



Emissions from natural gas production continue to decline in the net-zero scenarios

GHG emissions from the production and processing of natural gas peaked in 2007. In the Global Net-zero Scenario, emissions decline to 8 MT in 2050, a decrease of almost 90% from 2021 levels. This is largely because of falling natural gas production, but also because of various climate policies, including federal regulations aiming to reduce methane emissions by 75% by 2030. Electrification of the sector, where feasible, and the use of CCUS at larger natural gas-processing plants also contribute to declining emissions. The Canada Net-Zero Scenario follows a similar trend, with emissions falling to 9 MT in 2050. In the Current Measures Scenario, emissions decline to 2030 before rising to 42 MT in 2050 as production grows, and because policies do not become more stringent after 2030.

KEY UNCERTAINTIES

Natural gas

The pace of global climate action: Canada exports much of its natural gas production, meaning producers depend on markets outside of Canada to buy our gas supply. Demand for Canadian gas depends very strongly on how aggressively the world pursues emission reductions.

Technology used to decarbonize the oil sands: We project that CCUS is key to decarbonizing the oil sands, which allows natural gas to remain the main fuel supply for in-situ oil sands production. However, other potential technologies exist to decarbonize the oil sands, like solvents and SMRs, which do not consume natural gas. We do not project that these technologies are applied in the oil sands but if they become more attractive, western Canadian demand for natural gas could significantly fall, reducing natural gas prices and production. On the other hand, increased demand for solvents like propane and butanes could increase demand for NGLs, therefore increasing drilling for natural gas as a result.

Discounts for western Canadian natural gas: Differentials for western Canadian natural gas relative to Henry Hub could be affected by many things, including pipeline bottlenecks.

LNG exports: Small changes to economics can alter which projects are built and when, or when projects might shut down. In the Global Net-zero Scenario, the rapid decline in LNG exports from 2044 to 2046 could happen earlier if Canadian LNG exports are more costly relative to remaining global LNG supply, or exports could continue past 2050 if secured through long-term contracts.

Natural gas liquids

NGLs are produced along with natural gas, as well as from oil sands and refinery processes. Natural gas production is the main source of NGL production in Canada. Demand for certain NGLs adds value to natural gas production and is a driver of natural gas drilling. Raw natural gas at a wellhead is comprised primarily of methane, but often contains NGLs such as ethane, propane, butanes, pentanes, and condensate.

NGL production declines in the net-zero scenarios and grows in the Current Measures Scenario

Figure R.37 shows total NGL production by type in the Global Net-zero Scenario along with total combined NGL production in the Canada Net-zero and Current Measures scenarios. Production grows around 4% from 2022 to 2026 in the Global Net-zero Scenario, reaching 1.29 MMb/d (205 $10^3m^3/d$). Much of this production growth is condensate and pentanes plus. Condensate and pentanes plus are added to bitumen as a diluent to enable it to flow in pipelines and be loaded on to rail cars. Steady demand for condensate encourages natural gas drilling to focus on NGL-rich areas.

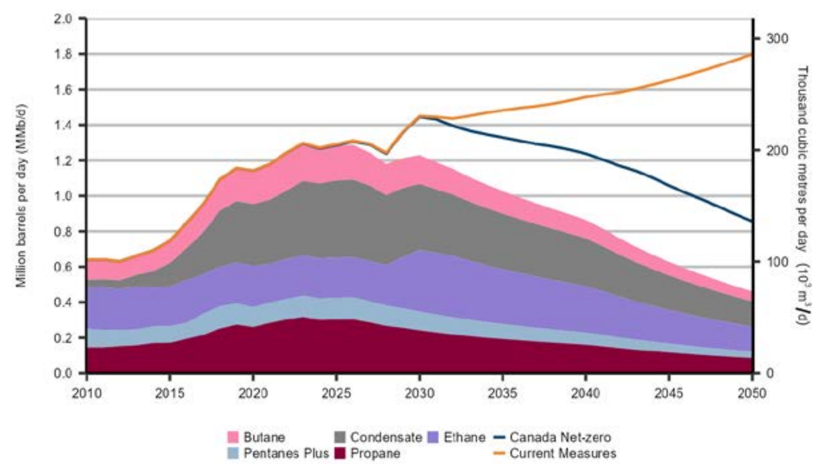
As low gas prices reduce gas drilling and gas production, total NGL production declines after 2030 in the Global Net-zero scenario. NGL production continues to fall, reaching to 0.46 MMb/d (73 $10^3m^3/d$) in 2050, 63% lower than in 2022.

KEY TRENDS

NGLs

- In the Global Net-zero Scenario, production rises to 1.29 MMb/d (205 $10^3m^3/d$) by 2026 before falling to 0.46 MMb/d (73 $10^3m^3/d$) in 2050 following natural gas production trends.
- NGL production is higher in the Canada Net-zero Scenario, increasing to 1.45 MMb/d (230 $10^3m^3/d$) by 2030 before falling to 0.86 MMb/d (136 $10^3m^3/d$) in 2050.

Figure R.37:
NGL production, by type, Global Net-zero Scenario, and total NGL production, Canada Net-zero and Current Measures scenarios



In the Canada Net-zero Scenario, NGL production grows by 16% from 2022 to 2030, and declines gradually through the remainder of the projection period. Like the Global Net-zero Scenario, NGL production growth is dominated by condensate, though propane and butanes production grow as well. In the Current Measures Scenario, total NGL production grows 45% from 2022 to 2050, reaching 1.80 MMb/d (286 $10^3m^3/d$). In this scenario, NGL production growth is a result of natural gas production growth.

KEY UNCERTAINTIES

NGLs

- **Natural gas production and LNG exports:** NGLs are a byproduct of natural gas production, and as such, any uncertainty discussed in the natural gas section applies for NGL projections.
- **Oil sands production:** The rate at which production grows in the oil sands, and the amount of diluent blending required, will affect the demand for condensate. Likewise, if solvents are widely adopted in the oil sands to reduce GHG emissions, demand for propane and butanes would increase.
- **Petrochemical development:** There is potential for ethane recovery to expand if there is an increase in the ethane extraction capacity and petrochemical facilities. This increase could be spurred by government programs, such as royalty credit incentives for petrochemical facilities in Alberta's Petrochemicals Diversification Program.
- **Global exports:** Several large-scale facilities have been approved by provincial and federal regulators to export some NGLs from the BC coast. The amount and composition of the NGLs exported at proposed and existing terminals could impact domestic NGL prices and the attractiveness of drilling for NGL-rich natural gas.

Energy use in the oil and gas sector

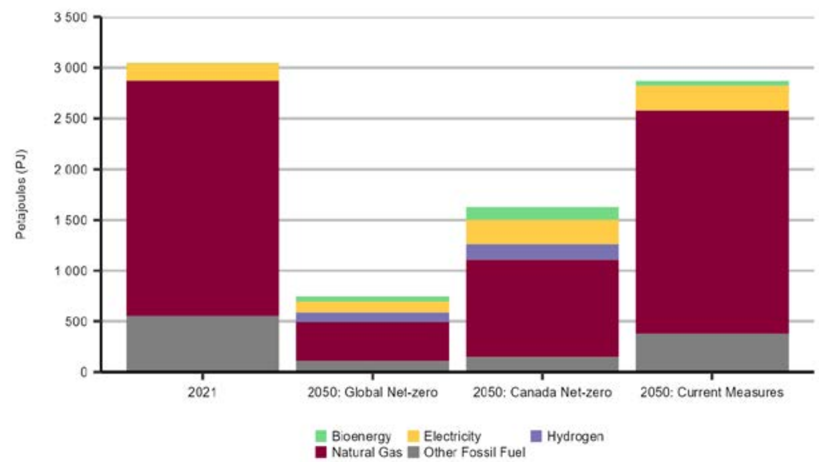
Canadian crude oil, natural gas, and NGLs are large sources of energy for domestic and international markets. However, the process of producing, processing, transporting, and refining these products requires a significant amount of energy. In 2021, the sector used around 3,000 petajoules (PJ) of energy, 27% of total Canadian end-use energy consumption.[18] Most of this energy was natural gas, not only in the oil sands, but to power oil and gas wells, natural gas processing, petroleum refining, and gas pipelines. Propane or electricity is often used to fuel operations at oil and gas wells, and electricity typically powers oil pipelines.

Over the projection period, the amount of energy used in each scenario is driven by the amount of future production, how fast energy efficiency improves, and additional energy used to run CCUS equipment, if any. Also, energy use to refine petroleum products and transport natural gas to end-users is driven largely by the domestic demand for those commodities.

In all three scenarios, energy use in the oil and gas sector grows in the near term

Energy use in the sector peaks in 2023 in the Global Net-zero Scenario and then falls by 75% by 2050 from 2021 levels, largely in line with falling production levels. In the Canada Net-zero Scenario, demand falls 47% from 2021 to 2050, as higher crude oil production results in higher demand for energy in the sector compared to the Global Net-zero Scenario. In both net-zero scenarios, falling Canadian demand for RPPs and natural gas reduce energy use for refining and transporting energy to end-users. Increased deployment of CCUS technology impacts energy use in both net-zero scenarios. Capturing, compressing, and transporting CO_2 from the exhaust stream of facilities takes energy. By 2050, energy used to power CCUS makes up 5% of oil and gas sector demands in the Global Net-zero Scenario, and 7% in the Canada Net-zero Scenario. In the Current Measures Scenario, efficiency improvements offset increased production levels and energy required for CCUS, and energy use in 2050 is 6% lower than in 2021. Figure R.38 shows total energy use in the oil and gas sector.

Figure R.38:
Energy use in the oil and gas sector by fuel, 2021 and all scenarios in 2050



18 This is end-use demand, so excludes on-site electricity generation, which is captured in primary demand.

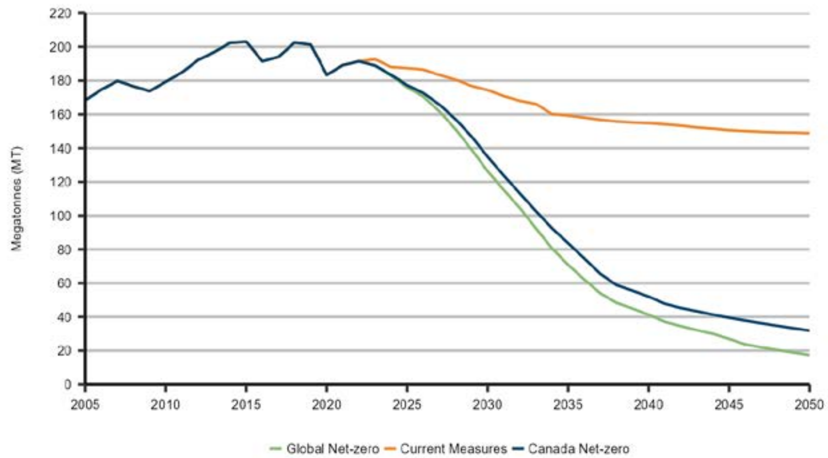
GHG emissions from the oil and gas sector

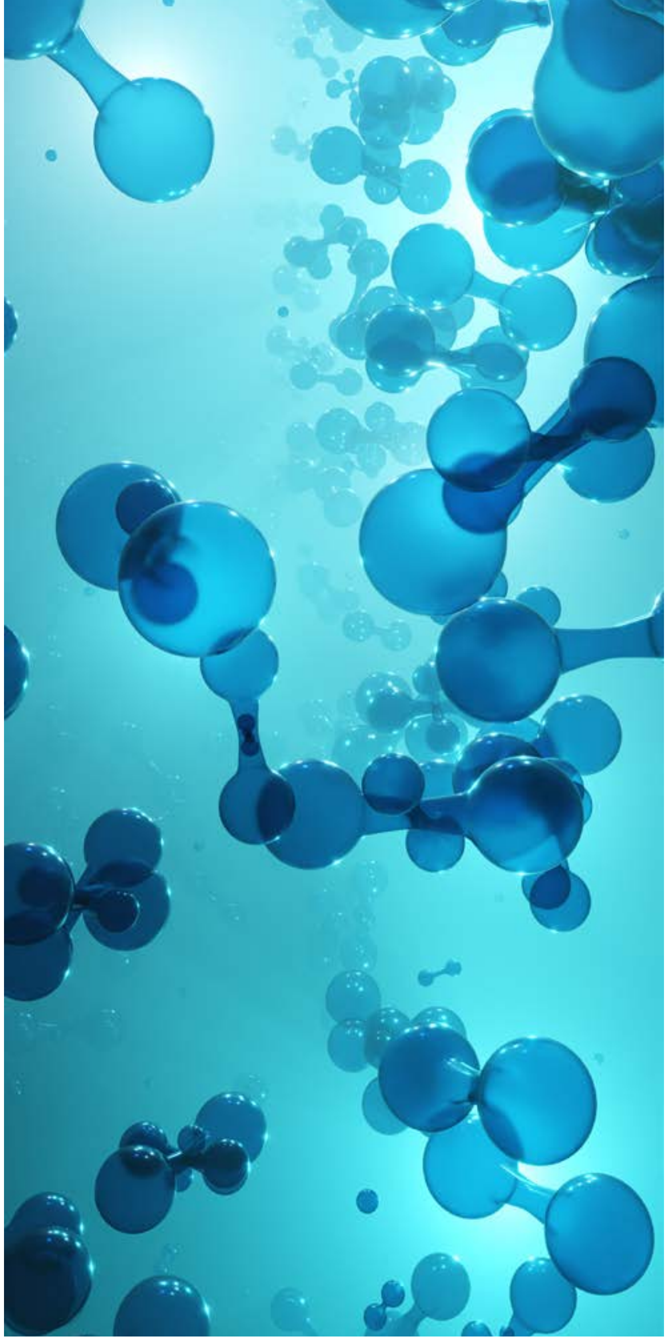
We describe the trends driving GHG emissions from the oil and gas sector in the previous sections of this chapter. In total, we project that GHG emissions from the oil and gas sector in the Global Net-zero Scenario fall from 189 MT in 2021 to 17 MT in 2050, a 90% decrease. In the Canada Net-zero Scenario, emissions fall to 32 MT in 2050, or 83% lower than 2021 levels. This includes GHG emissions from the production and transmission of oil and natural gas, and liquefaction of natural gas, refining of crude oil, and distribution of natural gas to end-users.

In both net-zero scenarios, CCUS and methane mitigation play an important role reducing emissions in the oil and gas sector. In the Canada Net-zero Scenario, CCUS is particularly important because production of oil and natural gas is higher due to higher global demand and oil and gas prices. We also project some electrification of conventional oil and natural gas production currently met by fossil fuels. Some GHGs are still emitted in both net-zero scenarios by 2050 but Canada achieves net-zero because of negative emissions occurring in other sectors.

In the Current Measures Scenario, emissions from the oil and gas sector decline moderately over the projection to 149 MT in 2050, 21% lower than in 2021. This scenario has the highest oil and natural gas production. At the same time, our assumption of limited future climate action in Canada in that scenario means the industry applies less emission reduction technologies compared to the net-zero scenarios.

Figure R.39:
GHG emissions in the oil and gas sector, all scenarios





Hydrogen

There is increasing interest in using low-carbon hydrogen as a fuel in both Canada and globally. Like electricity, hydrogen can be an energy carrier that transports useable energy created elsewhere to another location. When consumed, hydrogen does not result in GHG emissions. For more information on the fundamentals of hydrogen, see the Government of Canada's Hydrogen Strategy, released in late 2020. Our focus in this section is on hydrogen use as an energy carrier and its production by methods that emit little or no CO_2.

We make projections about hydrogen use by simulating the energy choices of households and businesses, including the energy technologies and fuels they choose to use. We model hydrogen production to meet hydrogen use and export requirements. The type of hydrogen produced to meet that demand is based on technology costs, and the fuel availability and cost in different regions.

We project that low-emitting hydrogen use reaches over 8.5 MT[19] in 2050 in the Global Net-zero Scenario, about 12% of total energy use demand. In the Canada Net-zero Scenario, hydrogen use is slightly higher at nearly 9.5 MT. In the Current Measures Scenario, low-emitting hydrogen demand is less than 1 MT by 2050, as fossil fuels remain an economically attractive energy source for many applications suitable for hydrogen.

We assume some hydrogen exports in all scenarios, reaching 5 MT in the Global Net-zero Scenario in 2050, 4.5 MT in the Canada Net-zero Scenario, and 2.5 MT in the Current Measures Scenario.

KEY TRENDS
Hydrogen

- Hydrogen becomes a significant part of energy use in the net-zero scenarios, especially in the industrial and transportation sectors.
- Production of low emitting hydrogen comes from a mix of technologies, including natural gas with CCUS, electrolysis, and biomass gasification.

19 Hydrogen is typically measured by mass. One MT is equivalent to approximately 120 PJ in energy terms.

Hydrogen use

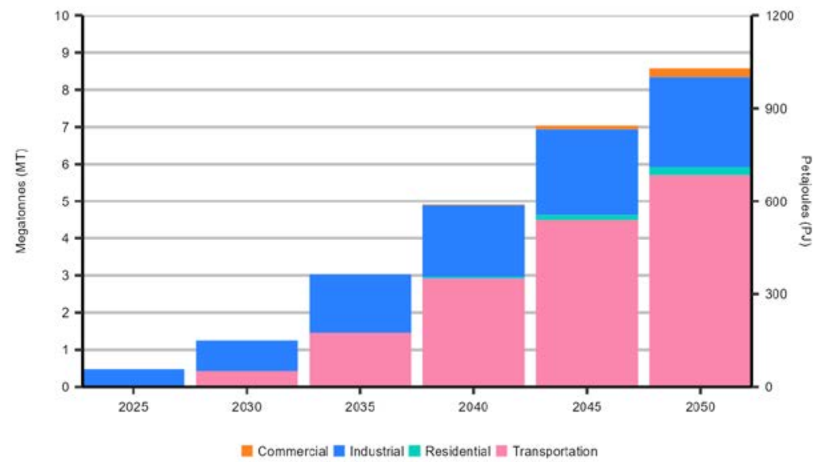
There are a wide variety of potential uses for hydrogen as an energy carrier in the energy system, ranging from transportation fuel, energy for building or industrial heat, or for electric power generation. Canada currently uses about 3 MT of hydrogen for industrial applications like oil sands upgrading and chemicals and fertilizer production. This existing hydrogen is counted as natural gas in Canada's energy balances, and in our data appendices. This production uses natural gas as a feedstock and results in CO_2 emissions that are not captured.

As discussed in the Energy Demand section of this chapter, we project hydrogen to become a key fuel in the heavy freight and industrial sectors in both net-zero scenarios. In the Global Net-zero Scenario, hydrogen use in transportation reaches nearly 5 MT by 2050, or nearly 30% of energy use in the transportation sector. Hydrogen primarily fuels long-haul transportation in heavy trucks, marine shipping, and hydrogen-based fuels are used to help decarbonize aviation. Hydrogen is used in industries like chemicals, iron and steel, and petroleum refining. Total industrial hydrogen use reaches 2.5 MT in the Global Net-zero Scenario, and 3 MT in the Canada-Net-zero Scenario, by 2050.

In both net-zero scenarios, hydrogen use grows modestly to 2035 and accelerates thereafter

We also project some use of hydrogen for building heating in both net-zero scenarios, but uptake is limited to blending with natural gas to be used in a natural gas furnace. However, the market share of natural gas furnaces declines over the projection period in the net-zero scenarios. As discussed in the Electricity section, we do not project any hydrogen use in the power sector in the Global Net-zero Scenario, and a small amount in the Canada Net-zero Scenario, reaching 0.13 MT by 2050. We also project that hydrogen produced from natural gas without capturing CO2 declines and is replaced by low-emitting hydrogen sources. Figure R.40 shows hydrogen demand by end-use in the Global Net-zero Scenario. In total, hydrogen's role in Canada's energy system is modest until 2035, at which point it accelerates and grows steadily to 2050 in the net-zero scenarios.

Figure R.40:
Hydrogen demand by end-use, Global Net-zero Scenario



What if the technologies to enable wide-scale adoption of hydrogen are more or less costly?

Canada is already one of the world's largest producers and users of hydrogen. Most of this occurs in Alberta where hydrogen is produced from natural gas and is used as a feedstock in various industrial applications. Alberta's Hydrogen Roadmap states 55% of production is used for heavy oil upgrading, 38% in the chemicals sector, and 7% for oil refining. At present, this hydrogen is produced using natural gas as a feedstock, a process which releases CO_2 emissions. According to the Alberta Energy Regulator, 19% of the hydrogen produced in Alberta in 2021 was from facilities equipped with CCUS, with the remaining at facilities venting the CO_2 to the atmosphere.

Many companies are actively expanding the production and use of hydrogen in Canada. An example of a recent project nearing completion is the Varennes Carbon Recycling plant, currently under construction in Quebec and aiming to be operational by 2025. The plant will produce biofuels and chemicals and will include an 87 MW electrolyzer to supply the hydrogen required for the process. Another example is the Air Products' Canada Net-Zero Hydrogen Energy Complex in Alberta, which will use natural gas as a feedstock to produce low-emission hydrogen using auto-thermal reforming technology, coupled with CCUS.

Federal and provincial governments are supporting the expansion of hydrogen as a fuel

The federal government, British Columbia, Alberta, Ontario, and Quebec have all recently developed hydrogen strategies or roadmaps. The federal government is working to implement an investment tax credit for clean hydrogen and, along with many provinces, is supporting various proposed projects through technology funds and incentive programs.

In EF2023, we make assumptions about the cost of the technologies used to produce hydrogen

Along with prices for inputs like natural gas and electricity, these technology costs translate into the cost of hydrogen we rely on for modeling in our scenarios. Production costs range from $1.50/kg to 10.50/kg in 2030, and $1.00/kg to 7.00/kg by 2050, depending on production technologies and region. Our energy use model then considers how the relative costs of different fuels impacts household and business decision-making when investing in new energy-consuming devices. We also make assumptions about technology that use hydrogen, such as medium- and heavy-duty freight trucks, the amount of hydrogen blended into natural gas networks, and hydrogen exports.

"What if" hydrogen supply and demand is higher or lower than in the Global Net-zero Scenario?

We project hydrogen use in Canada reaches 8.5 MT in 2050 in the Global Net-zero Scenario. However, there is a wide range of factors that could result in different hydrogen supply and demand in the future, including different costs for technologies to produce and use hydrogen, and different amounts of hydrogen produced for export. In this "What If" analysis, we explore the impact on our projections if the drivers of hydrogen supply and demand are higher or lower than in the Global Net-zero Scenario. To do so, we modeled the Low and High Hydrogen cases, each with unique assumptions on hydrogen supply and demand technology costs, as well as hydrogen produced for export. These are summarized in Table R.6.

Table R.6:

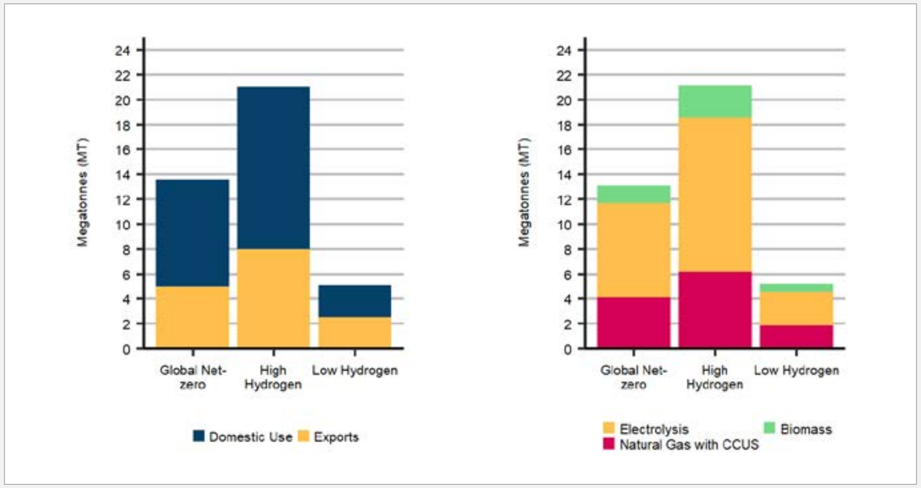
Hydrogen-specific assumptions, Global Net-zero Scenario and High and Low Hydrogen cases

	Global Net-zero Scenario	Low Hydrogen Case	High Hydrogen Case
Electrolyzer capital cost	Capital costs declines 84% by 2050.	Capital costs declines only 15% by 2050.	Capital costs are 10% lower than the Global Net-zero scenario in 2050.
Hydrogen production from natural gas using CCUS capital cost	Capital costs declines 40% by 2050.	Capital costs falls 25% by 2050.	Capital costs falls 50% by 2050.
Hydrogen in transportation	Fuel cell truck costs fall steadily, approaching parity with diesel vehicles in 2035-2050 period.	Fuel cell truck costs are less competitive with battery-electric trucks. Hydrogen-based fuels play a lesser role in shipping and aviation.	Fuel cell truck costs are more competitive with battery-electric trucks. Hydrogen-based fuels play a greater role in shipping and aviation.
Hydrogen blending in natural gas networks	Hydrogen blending is 15-20% by volume for most provinces.	Hydrogen blending limited to 5% by volume.	Hydrogen blending limited to 20% by volume.
Hydrogen produced for export	Hydrogen produced for export is 1 MT by 2030 and 5 MT by 2050.	Hydrogen produced for export is 1 MT by 2030 and 2.5 MT by 2050.	Hydrogen produced for export is 2.5 MT by 2030 and 8 MT by 2050.

The results of this “What if” analysis suggest that there is a wide range of possible levels of hydrogen use in the future. The Low Hydrogen Case shows a future where hydrogen plays a smaller role in Canada reaching net-zero by 2050. The High Hydrogen Case shows what could happen if hydrogen plays a bigger role in getting to net-zero. Figure R.41 compares hydrogen use and exports, as well as the technology used to produce it, in the Low and High Hydrogen cases and the Global Net-zero Scenario. In 2050, the Low Hydrogen Case shows demand and exports totaling 5 MT, 60% lower than in the Global Net-zero Scenario. The High Hydrogen Case shows demand and exports of 20 MT, 55% higher than in the Global Net-zero Scenario.

Figure R.41:

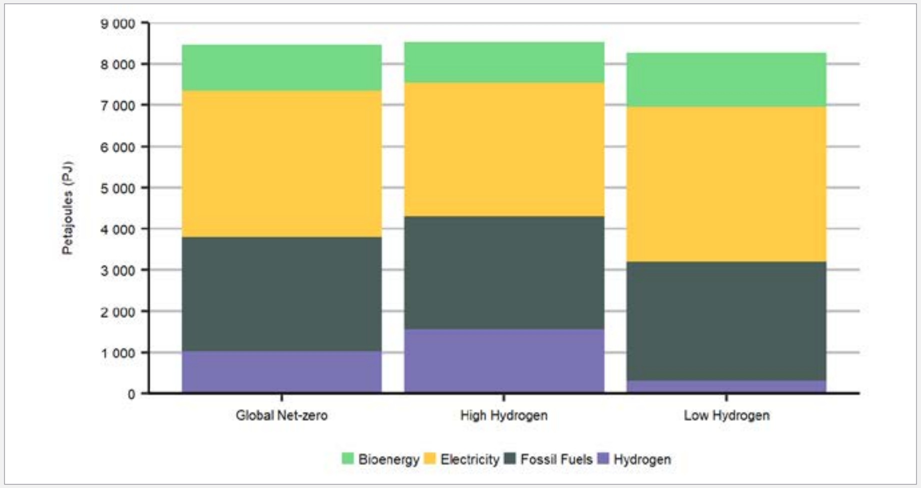
Hydrogen use and production in 2050, Global Net-zero Scenario, and High and Low Hydrogen cases



Higher or lower hydrogen use has implications for the overall end-use demand mix. Figure R.42 compares the end-use demand mix in 2050 for the Global Net-zero Scenario and the two hydrogen cases. In the Global Net-zero Scenario hydrogen makes up 12% of end-use demand in 2050, but this increases to nearly 20% in the High Hydrogen Case and falls to around 4% in the Low Hydrogen Case. At the end-use level, more hydrogen use in the High Hydrogen Case reduces electricity and bioenergy demands, while less hydrogen in the Low Hydrogen Case increases demands for electricity and bioenergy. Of course, energy is also needed to produce hydrogen, so compared to the Global Net-zero Scenario, overall demands for electricity and natural gas increase in the High Hydrogen Case and decrease in the Low Hydrogen Case.

Hydrogen is a versatile fuel that plays a key role in Canada's energy mix in the Global Net-zero scenario. At the same time, the adoption of hydrogen within Canada, and development of export markets for Canadian hydrogen is uncertain. This "What if" analysis projects a range of potential levels of Canadian hydrogen demand, and shows that there are important implications for other energy use trends, including electricity and natural gas.

Figure R.42:
End-use demand in 2050, Global Net-zero Scenario and High and Low Hydrogen cases



Hydrogen production

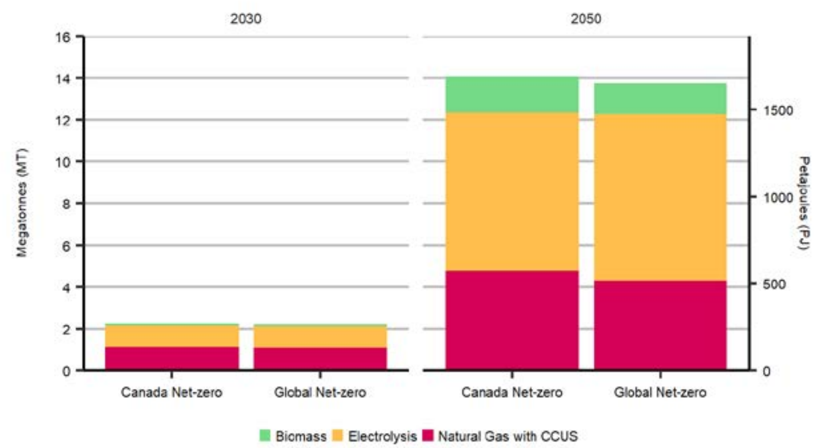
In EF2023, we model hydrogen production from three technologies:

- Natural gas-based production, which uses steam methane reformation or autothermal reformation processes. The CO_2 resulting from these processes is then captured and stored using CCUS. This process is sometimes referred to as blue hydrogen.
- Electrolysis, which uses water as a feedstock and emission-free electricity as an energy source. This process is sometimes referred to as green hydrogen.
- Biomass-based production, which uses biomass gasification to produce hydrogen. The CO_2 resulting from these processes may or may not then be captured and stored using CCUS.

For more information about different types of hydrogen production methods in Canada and around the globe see the CER Market Snapshot: [Hydrogen could be part of the global path to net-zero].

In the Global Net-zero Scenario, low-emitting hydrogen production is about 2 MT by 2030, increasing to around 14 MT by 2050, with similar trends in the Canada Net-zero Scenario. By 2050, 32% of hydrogen production is natural gas-based, 58% is via electrolysis, and the remaining 10% is from biomass. The relatively high amount of electrolysis production is due to very large reductions in electrolyzer costs that we assume in the net-zero scenarios, which makes hydrogen produced from electricity the most cost-effective option in many regions. In the Current Measures Scenario, hydrogen production growth is limited, and largely from natural gas with CCUS. Figure R.43 shows hydrogen production by type of feedstock in both net-zero scenarios.

Figure R.43:
Hydrogen production by technology, Global and Canada Net-zero scenarios



Hydrogen created with bioenergy and using CCUS results in negative emissions

Biomass-based production of hydrogen increases to 1.5 MT in 2050 in the Global Net-zero Scenario. When coupled with CCUS, biomass hydrogen production results in negative emissions by permanently storing carbon that would otherwise be temporarily stored in plant matter. In the Global Net-zero Scenario, biomass hydrogen production results in 23 MT of negative GHG emissions by 2050.

Types of hydrogen production depend on local resources

We project that hydrogen production occurs in many provinces, with large volumes from Ontario, Alberta, Quebec, and BC. Hydrogen tends to be produced by electrolysis in regions rich with hydroelectric power, from natural gas in regions with lower cost natural gas and suitable CCUS storage reservoirs, and from biomass in regions with large biomass supplies. Notably, while electricity and hydrogen are both energy carriers, electricity itself is used to create hydrogen in our scenarios. There are energy losses in the electrolysis process but in some instances, there are benefits to using hydrogen instead of electricity. This is because hydrogen is more energy-dense compared to electricity stored in a battery. This makes it potentially attractive as a fuel for heavy freight compared to EVs, although this will ultimately depend on the future costs of both hydrogen and batteries.

Hydrogen exports are supplied with a mix of electrolysis and natural gas with CCUS

In the Global Net-zero scenario, we assume over 3 MT of hydrogen is provided by dedicated on- and off-shore wind electricity in Atlantic Canada. These exports use over 165 TWh of wind electricity per year to produce hydrogen for export in 2050.[20] In the Global Net-zero Scenario, energy used to produce hydrogen increases to about 20% of total primary energy demand by 2050. Of this energy use, 60% is electricity (including dedicated renewable projects that produce hydrogen for our assumed exports), 25% in natural gas, and the remaining 15% is biomass.

GHG emissions associated with hydrogen production

We project that GHG emissions from hydrogen production for use as an energy carrier are slightly positive from 2024 to 2032, a result of the fraction of emissions that are not captured by CCUS when hydrogen is produced from natural gas. By 2035, some biomass-based hydrogen production is coupled with CCUS and net emissions from the hydrogen sector become net-negative in both net-zero scenarios. By 2050, the net emissions from hydrogen production are -21 MT in the Global Net-zero Scenario and -25 MT in the Canada Net-zero Scenario.

KEY UNCERTAINTIES

Hydrogen

Domestic hydrogen markets and infrastructure: The use of hydrogen as a clean fuel, as projected in our net-zero scenarios, is currently in the early stages of development. The evolution of how and where hydrogen is adopted, the cost of production and end-use technologies, market pricing, and transportation infrastructure is uncertain. This could lead to different patterns of adoption than we project.

Hydrogen exports: There are various proposed projects aimed at producing hydrogen for export. Our scenarios include varying levels of hydrogen produced for export as well as associated dedicated offshore wind generation built to power hydrogen production. However, export volumes could be different than we assume depending on how global and domestic markets develop.

20 These volumes of electricity generation are not included in the electricity generation and capacity, or energy demand values, because they are assumed to not be separate from local electricity systems. The wind energy volumes are captured in the primary demand value discussed in the Energy Demand section.

Negative emissions

In most global and Canadian net-zero scenario analyses, net-zero outcomes include both positive and negative emissions that balance to zero at some point in the future. For some sources of GHG emissions, eliminating all emissions or reducing them at a pace sufficient to achieve zero emissions by 2050 may be very costly or impossible. In both of our net-zero scenarios, we project slightly positive emissions in 2050 in several sectors, including buildings, heavy industry, oil and gas, and transportation. These are balanced by negative emissions. Negative emissions can be realized in several ways, but all aim to remove CO_2 from the atmosphere on a permanent or long-term basis.

KEY TRENDS

Negative emissions

- Negative emissions play a key role in offsetting remaining emissions from other sectors.
- BECCS, direct air capture, and land use, land-use change and forestry (LULUCF) all play important roles in reaching net-zero.

Nature can act as a carbon sink capable of storing carbon through natural processes

Managing natural processes to capture and store GHG emissions is often referred to as nature-based solutions. An example of a nature-based solution is the federal government's 2 Billion Trees Commitment, which aims to plant two billion trees over 10 years to address both climate change and biodiversity loss.

LULUCF emission reductions are uncertain

We do not model nature-based solutions in EF2023. Instead, we make assumptions about the emissions and removals from natural processes, which we account for in our assumptions about land-use, land-use change and forestry (LULUCF). We describe these assumptions in the previous chapter, Scenarios and Assumptions. We assume negative emissions from the LULUCF of 50 MT by 2050 in both net-zero scenarios, and 13 MT in the Current Measures Scenario. However, there is some uncertainty on whether carbon stored through nature-based solutions will be permanent. Wildfires, infestations from insects like the pine beetle, or natural decay could release stored carbon and result in reduced impact from LULUCF in the future. Lower negative emissions from LULUCF would mean that greater emissions reductions from other sectors, or more negative emissions from other sources, would be needed to achieve net-zero emissions.

A second source of negative emissions in both net-zero scenarios is the use of bioenergy with carbon capture and storage technology (BECCS). We describe our projections for BECCS in the electricity and hydrogen sections earlier in this chapter. BECSS delivers negative emissions through the combustion of biomass such as trees or crop waste to generate electricity, and then uses CCUS to permanently store the emissions. We project that the use of BECSS results in around 60 MT of negative emissions in both net-zero scenarios.

DAC is used to achieve negative emissions in both net-zero scenarios

DAC technology, which we describe in more detail in the following text box, is another option to achieve negative GHG emissions. In our analysis, we model DAC based on our assumptions about its costs and the profitability of capturing CO_2 emissions directly from the atmosphere. We assume DAC facilities are compensated for capturing emissions by emitters who want to offset their own emissions.

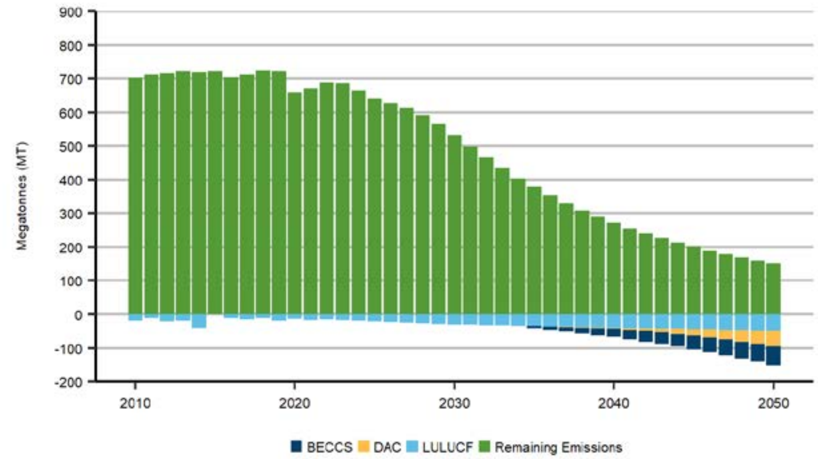
In the Global Net-zero Scenario, we project that DAC facilities begin capturing emissions in the late 2030s, and by 2050, DAC results in negative emissions of 46 MT. In the Canada Net-zero Scenario, DAC captures 55 MT of emissions by 2050 and in the Current Measures Scenario, no DAC facilities are constructed.

DAC technology requires significant energy to draw in air and separate, compress and store CO_2

There are a variety of DAC processes being tested and commercialized; in our modeling we assume DAC operations require both electricity and natural gas to power the process. Emissions from the natural gas used in the process are also captured and stored. By 2050, energy used to power DAC facilities makes up 4% of all end-use energy consumption in the Global Net-zero Scenario, and 5% in the Canada Net-zero Scenario.

Figure R.44 shows our assumptions about negative emissions from LULUCF and the negative emissions resulting from our modeling of BECCS and DAC, compared to total GHG emissions from the rest of the economy, in the Global Net-zero Scenario.

Figure R.44:
Net emissions, Global Net-zero Scenario



What if direct air capture (DAC) technology matures more quickly and is less costly?

DAC is an emerging technology that extracts CO_2 directly from the atmosphere through a mix of physical and chemical processes. The CO_2 can then be injected and stored in deep geological formations or be used as feedstock for different products such as synthetic fuels. By removing CO_2 directly from the atmosphere, DAC has the potential to offset emissions from the activities whose emissions are hardest or most expensive to avoid.

According to a recent report by the IEA on Direct Air Capture, there are 18 small-scale DAC plants operating in the world today, capturing a combined 0.01 MT CO_2 per year. Interest in DAC is growing; for example, by late 2024, U.S. oil producer Occidental Petroleum Corp aims to complete construction of the world's largest DAC plant, which could remove up to 1 MT CO_2 per year. This is the largest of a growing list of proposed DAC plants across North America and Europe.

DAC costs are uncertain, but may fall with time

While existing DAC plants demonstrate the technical feasibility of the technology, costs remain uncertain. Some estimates put the costs at between US$325 and US$785 per tonne of CO_2 captured for a plant built today.[21] In comparison, Canada's federal backstop carbon price is currently $65 per tonne of CO_2e.

DAC deployment will depend on building and operation costs, as well as prices for emissions captured

As with many emerging technologies, it is possible that DAC costs will fall as new projects come online. Similarly, a higher price on carbon could present an incentive to build DAC facilities, either through direct compensation for captured CO_2 or selling offsets to other industries looking to reduce their emissions. The role of DAC in Canada's net-zero pathways will depend on the future of climate policies and the extent to which its costs will decline.

In the IEA's Net Zero Emissions by 2050 Scenario, DAC facilities capture 90 MT of CO_2 by 2030 globally, less than half a percent of the CO_2 emissions the IEA projects to be emitted in that year. This number rises to 980 MT of CO_2 in 2050. Many other international net-zero pathways from other organizations see DAC taking a larger role in the future. Ultimately, the extent of its deployment will largely depend on its cost relative to other decarbonization options, as well as the price DAC facilities receive for emissions they capture.

In EF2023, we rely on assumptions about the cost of DAC, including the cost to absorb, isolate, transport, and store the CO_2. Our projections of DAC in different scenarios are based on its cost (as discussed in Table A.2) relative to other decarbonization technologies.

DAC deployment begins in the mid-2030s in the Global Net-zero Scenario

Given those assumptions, and the costs and characteristics of other carbon removal technologies, we project emission reductions from DAC to increase to 46 MT by 2050 in the Global Net-zero Scenario. We project most of the growth in DAC will occur starting in the mid-2030s once the most cost-effective decarbonization options are exhausted and the cost of DAC technology is lower.

DAC is an emerging and uncertain technology and could play a larger role in reducing Canada's emissions to net-zero. In this "What if" analysis, we model the High DAC Case, where we assume that the cost of DAC falls to 2022$125 per tonne of CO_2 by 2050, compared to 2022$230 per tonne of CO_2 in the Global Net-zero Scenario.

In the High DAC Case, DAC sequesters 85 MT CO_2 in 2050, nearly double that of the Global Net-zero Scenario. Figure R.45 compares the relative importance of DAC in reducing Canada's emissions, relative to Canada's net emissions of 732 MT in 2005.

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21 World Resources Institute: 6 Things to Know About Direct Air Capture

Figure R.45:

Negative emissions from DAC, as a % of total GHG emissions in 2005, all scenarios

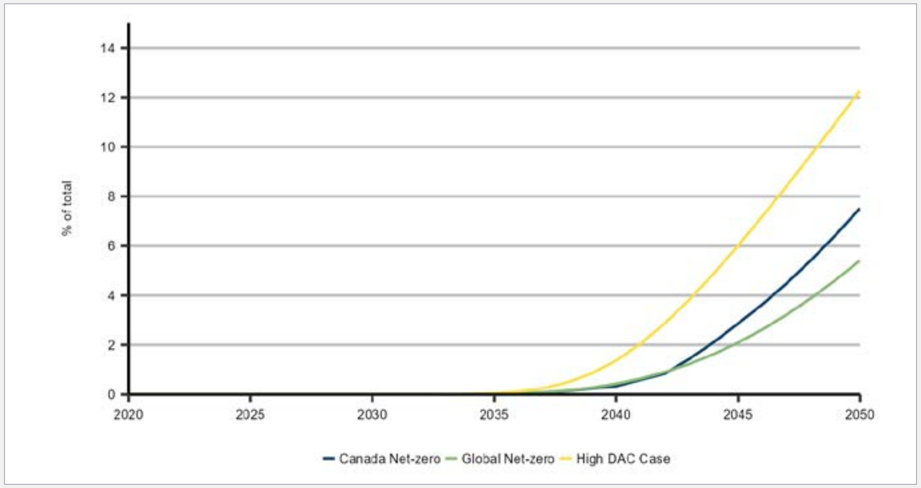
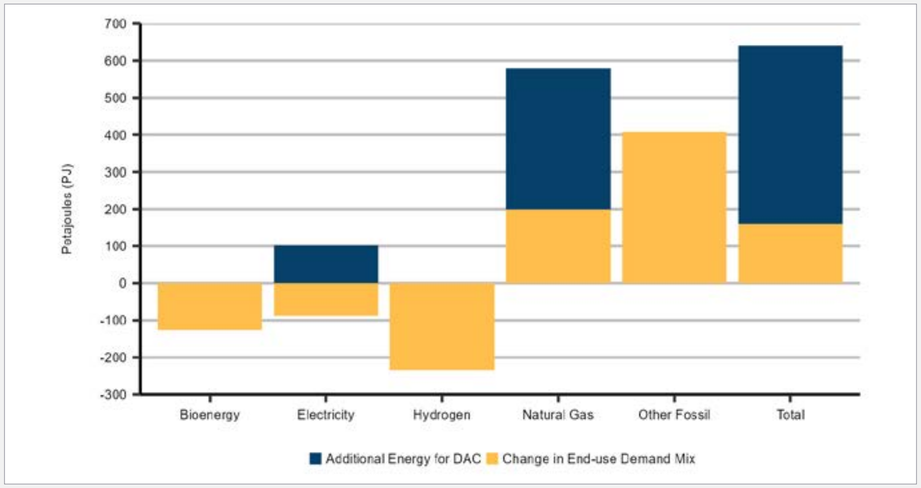


Figure R.46:

Difference in energy use between the Global Net-zero Scenario and High DAC Case in 2050, by fuel



Greater use of DAC also impacts the energy system. First, more negative emissions from DAC means that the pressure to reduce emissions in other sectors is lower compared to a net-zero scenario with few negative emissions. Second, DAC processes use a large amount of energy. In the High DAC Case, more natural gas and electricity is used to operate DAC facilities.

DAC use increases energy demand in the High DAC Case

Figure R.46 shows the difference in energy demand between the High DAC Case and the Global Net-zero Scenario in 2050. Additional use of DAC increases natural gas demand by 1.5 Bcf/d (42 $10^6 m^3/d$), and electricity by 3.5 TWh. In the rest of the economy, more natural gas and other fossil fuels are used in the High DAC Case in place of some electricity, bioenergy, and hydrogen. The net effect of these changes is an over 600 PJ increase in energy use by 2050 relative to the Global Net-zero Scenario, or about a 7% increase.

It is also possible that DAC might be used less than in the Global Net-zero Scenario. Less negative emissions from DAC would mean achieving net-zero will require more emission reductions from other parts of the economy. This could include greater use of electricity, bioenergy and hydrogen-based fuels, additional nature-based solutions to offset emissions, or a greater need for energy efficiency and conservation.

DAC could account for an important share of Canada's overall emission reductions. With faster technological advancement and increasing adoption, the High DAC Case shows a pathway where DAC accounts for over one tenth of the emission reductions required to reach net-zero. It also shows that greater DAC use could lead to significantly more natural gas and RPP demand than shown in the Global Net-zero Scenario.

KEY UNCERTAINTIES

Negative emissions

Reliance on nature-based solutions: In our analysis, we limited the reliance on nature-based solutions in order to focus more on the potential energy technologies available to reach net-zero. However, some recent Canadian net-zero studies assume higher contributions of land-use change to reach net-zero.[22] The ultimate contribution of these emissions is uncertain and could be higher or lower than we assumed.

Direct Air Capture: There is considerable uncertainty around the ability of DAC to contribute to Canada's emission reductions. Cost trends could be significantly higher than we assume in the Global and Canada Net-zero Scenarios, and lead to different outcomes.

Balancing remaining emissions with negative offsets: The balance of negative emissions versus remaining emissions in our scenarios is in line with other Canadian net-zero studies. If negative emission technologies progress less quickly than we assume, faster reductions will be needed in other areas of the economy, potentially involving stronger policy action. On the other hand, if negative emissions develop faster, it is possible less stringent policies will be needed to achieve net-zero emissions.

22 The Canadian Climate Institute assumes a land-use contribution of -80 MT by 2030 and -105 MT by 2050, and ECCC's recent Canada's Long-Term Strategy Submission to the UNFCCC assumes -100 MT by 2050 in all scenarios.

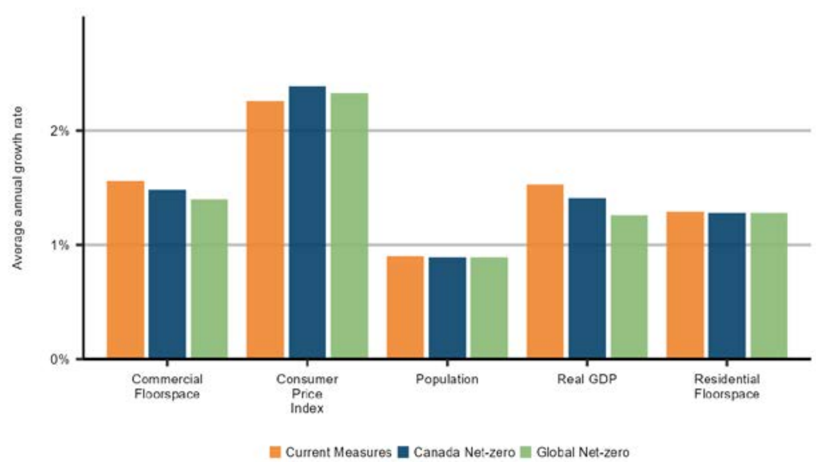
Macroeconomics

The economy is a key driver of the energy system. Economic growth, industrial output, inflation, exchange rates, global demand, and population growth all influence energy supply and demand trends. The way they evolve will have a direct impact on Canada's transition towards net-zero.

KEY TRENDS
Macroeconomics

- Continued population and economic growth across all scenarios.
- Slightly slower growth in the Global Net-zero and Canada Net-zero scenarios.

Figure R.47:
Economic indicators, annual % change from 2019 to 2050, all scenarios



The long-term projections for key economic variables are in Figure R.47. Real (adjusted for inflation) economic growth averages 1.4% per year over the projection period in the Global Net-zero scenario. Growth is slightly higher in the Canada Net-zero and Current Measures scenarios, largely driven by stronger oil and gas prices, production, and export levels. The Canada-US exchange rate varies across the three scenarios, also related to the large variation in oil and gas activity and prices.

Economic growth over the projection is generally slower than the historical average in all three scenarios. Reasons for slower growth include an aging population and slower global economic growth.

KEY UNCERTAINTIES
Macroeconomics

Global economic growth: Future global uncertainties, such as demand for Canadian exports, technology development, and commodity prices could impact future Canadian economic growth. This is especially true for the Global Net-zero Scenario, as policies and technologies used to reduce global emissions could lead to different macroeconomic outcomes than shown here. Likewise, geopolitical events, such as the Russian invasion of Ukraine, could impact future growth trends.

Impacts of climate change: The three scenarios do not include macroeconomic estimates of damages related to climate change. These could significantly reduce economic growth, particularly in scenarios like Current Measures, where only limited measures to reduce climate change are included.

Cost of decarbonization: The net-zero scenarios assume declining costs for key technologies, such as EVs, heat pumps, electrolyzers, and DAC. If these cost reductions do not materialize, achieving net-zero by 2050 could be more costly and involve lower economic growth than shown here.

Access and Explore Energy Future Data

- Figure Data (Excel) – Download the EF2023 figure data.
- Full dataset (Open Gov) – Download all of the EF2023 data at once.
- Data Appendix – Access customizable, downloadable tables arranged by variables.
- Interactive Visualization – Interact and visualize EF2023 data behind long-term energy outlooks.

Student Resources

In partnership with Ingenium, the CER developed educational activities based on Canada's forecasted energy demand and supply.

Targeted at students between the grades of 9 and 11, the activities encourage students and educators to explore Canada's energy ecosystem using an interactive tool. This tool allows users explore how the future of energy in Canada over the long term. The material and student resources are available here.

About the CER

The Canada Energy Regulator (CER) works to keep energy moving safely across the country. We review energy development projects and share energy information. We enforce some of the strictest safety and environmental standards in the world in a manner that respects the Government of Canada's commitments to the rights of the Indigenous peoples of Canada. The CER regulates:

- Oil & Gas Pipelines – Construction, operation, and abandonment of interprovincial and international pipelines and related tolls and tariffs.
- Electricity Transmission – Construction and operation of international power lines and designated interprovincial power lines.
- Exports & Energy Markets – Exports of certain energy products; monitoring aspects of energy supply, demand, production, development, and trade.
- Exploration & production – Oil and gas exploration and production activities in the offshore and on frontier lands not covered by an accord.
- Offshore renewables – Offshore renewable projects and offshore power lines.

The Energy Information Program is one of four core CER responsibilities. We collect, monitor, analyze, and publish fact-based information on energy markets and supply, sources of energy, and the safety and security of pipelines and international power lines. Using tools like interactive pipeline maps and visualizations, we make complex pipeline and energy market data user-friendly and accessible.

Our Commitment:

- Canadians have access to and use energy information for knowledge, research, and decision-making.
- Canadians have access to community-specific information about CER-regulated pipelines, powerlines, and other energy infrastructure.
- Broader and deeper collaboration with stakeholders and partners informs our energy information.

About this Report

The CER's Energy Information core responsibility is closely linked to its mandate and responsibilities under the Canadian Energy Regulator Act (CER Act), which includes advising and reporting on energy matters. As well, under Part 7 of the CER Act, the Commission of the CER authorizes the export of natural gas, natural gas liquids, crude oil and petroleum products, and electricity. The Commission of the CER must not issue an authorization for the export of oil and gas unless it is satisfied that the quantity to be exported is surplus to Canadian requirements. The CER's monitoring of energy markets and assessments of Canadian energy requirements and trends helps support the discharge of its regulatory responsibilities. This report, Canada's Energy Future 2023: Energy Supply and Demand Projections to 2050, is the continuation of the Canada's Energy Future series, and projects long-term Canadian energy supply and demand trends.

EF2023 was prepared by CER technical staff.

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Appendix 1: Domestic Climate Policy Assumptions

Domestic climate policies include laws, regulations, and programs put in place by governments with the goal of reducing GHG emissions. Around 80% of Canada's GHG emissions are energy-related, so climate policy aimed at reducing emissions will affect Canada's energy system. We make assumptions about the climate policies we model in each scenario in EF2023. This appendix includes additional details about the climate policy assumptions, beyond those included in the Scenarios and Assumptions chapter.

Federal, provincial, and territorial climate policies that are currently in place are the basis of the Current Measures Scenario. A policy is "in place" if it was enacted prior to March 2023. We do not include announced policies that are not yet implemented in the Current Measures Scenario.

The Global and Canada Net-zero scenarios include all in-place federal, provincial, and territorial climate policies. Both net-zero scenarios also include all announced but not-yet-implemented policies, to the extent possible. We applied the following criteria to determine whether an announced policy was included in our net-zero scenarios:

- The policy was announced prior to March 2023
- Sufficient details exist to model the policy

Final details of some of these policies were not available at the time of analysis. We include these policies by relying on assumptions about them, as necessary.

Table A1.1 provides an overview of all major federal policies included in the three scenarios. Table A2.2 provides an overview of key policies in provinces and territories. In the Global Net-zero and Canada Net-zero scenarios, if the federal policy is more stringent than its regional equivalent, the federal one is modelled instead.

For an exhaustive review of climate measures in Canada, see Environment and Climate Change Canada's Fifth Biennial Report on Climate Change, and Canada's revised NDC.

All dollar values are given in $2022 Canadian unless otherwise stated.

Table A1.1:

Overview of Major Federal Policies in the Global Net-zero, Canada Net-zero, and Current Measures Scenarios

Policy	**Description**	**Global Net-zero and Canada Net-zero Scenarios**	**Current Measures Scenario**
Backstop carbon pricing	Applies a regulatory charge on fossil fuels at the end-use level based on the relative GHG emissions intensity of fuels.	The fuel charge rises from $50 per tonne ($50/t) by 2022, then to $140/t ($170/t in nominal dollars, not adjusted for inflation) by 2030. It remains constant in nominal terms from 2030 to 2050 or $95/t in inflation-adjusted terms by 2050. Our modelling assumes most provincial systems follow this schedule, and by 2030 all provinces and territories match the federal price.	
Aggregate cost of carbon	A hypothetical suite of policies, regulations, and programs in the 2030 to 2050 period represented by a carbon price that is added to the backstop carbon pricing.	The aggregate cost of carbon is added to the carbon price backstop in both scenarios. 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.	Not included
Output-based pricing system (OBPS)	A performance-based carbon pricing system for industrial facilities. Applies the carbon price for every ton of excess emissions above a specified annual intensity limit. This system maintains a marginal incentive for reducing CO_2 emissions, but reduces the average cost of compliance so industries can maintain international competitiveness.	Global Net-zero Scenario: A 2% yearly tightening rate on emissions intensity is applied from 2023 to 2030, followed by a 3% tightening rate until all emissions are covered in 2050. The backstop carbon price and aggregate cost of carbon is applied to emissions above the intensity limit. Canada Net-zero Scenario: A 2% yearly tightening rate on emissions intensity is applied from 2023 to 2050. The backstop carbon price and aggregate cost of carbon is applied to emissions above the intensity limit. Given that the rest of the world does not reach net-zero in the Canada Net-zero Scenario, this trajectory maintains a level of support for trade-exposed industries.	Most industrial sectors are required to reduce their emissions intensity by 20% relative to their 2014 to 2016 average from 2020 to 2050. If a facility exceeds the emissions intensity limit, it must pay the backstop carbon price on excess emissions or submit eligible credits. If a facility's emissions are below the limit, it receives credits to sell or use later for compliance.

Policy	Description	Global Net-zero and Canada Net-zero Scenarios	Current Measures Scenario
Oil and gas emissions cap	A cap on emissions from the upstream oil and gas sector at a pace and scale necessary to achieve Canada's goal of net-zero by 2050, while allowing the sector to compete in a transitioning global economy.	At the time of analysis, the oil and gas emissions cap was announced but was still in development. To model the emissions cap, we developed some simplifying assumptions for modeling purposes. These assumptions have no bearing on what the final policy will include. The cap covers only upstream production sectors (oil sands, conventional oil production, natural gas production and processing). It covers all GHG emissions, including carbon dioxide and methane. The cap requires a minimum emissions reduction of 31% in total from 2005 from these sectors by 2030. We allow two years of flex time in meeting the 2030 target to account for the length of time large-scale infrastructure like carbon capture, utilization, and storage (CCUS) takes to develop. The cap declines to a 60% reduction from 2005 by 2040, and net-zero by 2050. In 2050, we allow the sector to achieve net-zero with negative emission offsets from direct air capture (DAC) and/or other net-negative sectors. These are capped at a maximum of 25 megatonnes (MT) to ensure most reductions occur within the sector, while also allowing flexibility for emissions abatement. The cap is met by a sector-specific aggregate cost of carbon rising over time.	Not included.
Methane regulations for the upstream oil and gas sector	Oil and gas facilities are required to reduce their methane emissions either through adoption of new methane control technologies or process change.	Facilities must reduce their methane emissions by 40-45% from 2012 levels by 2025 and 75% by 2030.	Facilities must reduce their methane emissions by 40-45% from 2012 levels by 2025.
Investment tax credit for CCUS	A federal investment tax credit for CCUS projects that permanently store captured CO2 in geological storage or in concrete.	An investment tax credit for capital investments in CCUS. Tax credit is set at 50% of upfront costs for CCUS. The tax credit for carbon capture is 50% until 2030, 25% from 2031-2040, and 0% onwards.	

Policy	Description	Global Net-zero and Canada Net-zero Scenarios	Current Measures Scenario
Net-zero accelerator initiative and strategic innovation fund	A federal investment of $3 billion over five years for the development and adoption of low-carbon technologies in all industrial sectors. Budget 2021 provided an additional $5 billion over seven years for the Net Zero Accelerator.	Development and adoption of low-carbon technologies in the industrial sector. Examples include fuel switching to low-carbon heat sources, adoption of inert anodes, CCUS, replacing fossil fuel feedstocks, hydrogen-based steel making, and DAC.	Examples include fuel switching to low-carbon heat sources, adoption of inert anodes, and CCUS.
Clean Electricity Regulations	The Clean Electricity Regulations would establish an emissions performance standard having an intensity form (i.e., t/GWh). It would be set at a stringent, near-zero value in line with direct emissions from well-performing, low-emitting generation such as, geothermal or combined cycle natural gas with CCS.	Net-zero electricity generation by 2035 through to 2050. Small generating units and those that produce electricity for remote communities are excluded from the regulation. The full regulatory details of the Clean Electricity Regulations are still under development. We follow the details in the Proposed Frame for the Clean Electricity Regulations.	Not included. Electricity generation facilities are covered under the OBPS.
Phase out of coal-fired generation of electricity	A carbon intensity performance standard for coal-fired power plants.	Limits emissions intensity of existing coal-fired electricity generation to 420 t/CO_2e per gigawatt hour (GWh) by 2030.	
National energy code for buildings	Sets out technical requirements for the energy-efficient design and construction of new buildings.	New buildings are "net-zero energy ready" by 2030 and net-zero by 2050. These codes are still under development, so we follow modeling in the Emission Reduction Plan that result in substantial increases in the efficiency of building shells.	Assumes that the 2017 building code applies throughout the projection period, with marginal efficiency improvements to building shells and space conditioning.
Energy Efficiency Regulations	Minimum energy efficiency standards for energy-using technologies in the residential, commercial, and industrial sectors (e.g. space conditioning equipment, water heaters, household appliances, lighting).	Marginal efficiency gains occur from 2030-2050.	Includes Amendment 17 to the Energy Efficiency Regulations. Energy efficiency gains end in 2030 and are carried through to 2050.
Hydrofluorocarbon (HFC) regulation	A phase down of HFC consumption from a baseline.	An 85% reduction in consumption of HFCs by 2050 from 2019 levels.	

Policy	Description	Global Net-zero and Canada Net-zero Scenarios	Current Measures Scenario
Zero Emissions Vehicle (ZEV) mandate	A sales mandate for new light-, medium-, and heavy-duty vehicles that increases in stringency over time.	The ZEV sales target for light-duty vehicles is 20% by 2026, 60% by 2030, and 100% by 2035. Medium- and heavy-duty sales targets are 35% by 2030 and 100% by 2040, where feasible. At the time of analysis, these regulations were still under development. We made the simplifying assumption that 80% of sales met the threshold of “feasible” by 2040, and over 95% by 2050.	Not included. Provincial mandates for ZEV sales can be found in Table A.1.2
ZEV incentives	Major policies include the iZev subsidy program, the iMHZEV subsidy program, funding for charging network initiatives, and tax write-offs for businesses.	Vehicle purchase rebates and assumptions on the build-out of infrastructure needed for charging and refueling ZEVs.	
Light-duty vehicle GHG emissions standards	New light-duty vehicles sold in Canada must meet progressively more stringent GHG emissions standards.	Incorporates LDV-1 (2011-2016) and LDV-2 (2017-2026) Light-duty vehicle GHG emission standards. In the projection period, new light-duty vehicle fuel economy improves approximately 5% per year to 2026.	
Heavy-duty vehicle GHG emission standards	New heavy-duty vehicles sold in Canada must meet progressively more stringent GHG emission standards.	Incorporates HDV-1 (2014-2018) and HDV-2 (2021-2027) heavy-duty vehicle GHG emission standards. In the projection period, new heavy-duty vehicle fuel economy improves approximately 2-3% per year to 2027.	
Clean fuel regulations	Reduction in carbon intensity of gasoline and diesel over time, through several mechanisms, including: supplying low-carbon fuels (e.g. ethanol), end-use fuel switching in transportation fuels (e.g. electric and hydrogen vehicles), and upstream projects (e.g. CCS).	Carbon intensity decrease of 12g CO_2e/megajoule (CO_2e/MJ) below 2016 levels by 2030. Post 2030, we make the simplifying assumption that fuels continue the same rate of decrease (about 1.2g CO_2e/MJ per year). This decrease is modeled as an increasing share of renewable fuels and increased renewable natural gas blending, incentivized by the regulation’s credit creation mechanism.	Carbon intensity decrease of 12g CO_2e/MJ below 2016 levels by 2030.
Renewable fuel regulations	Minimum renewable fuel content for all regions except for Newfoundland and Labrador and the Territories.	Specifies a minimum renewable fuel content of 5% in gasoline and 2% in diesel fuel sold in Canada by volume.	

Policy	Description	Global Net-zero and Canada Net-zero Scenarios	Current Measures Scenario
Northern REACHE program	Program to reduce diesel use for electricity and heat in remote communities.	Increase the market share of alternative technologies.	
Fertilizer emissions reduction target	Target to reduce greenhouse gas emissions from fertilizer application in agriculture by 30% below 2020 levels by 2030	2030 target met, with reductions starting in 2023 and additional reductions achieved post 2030.	Not included.
Proposed municipal solid waste (MSW) landfill methane emissions regulations	Proposed approaches for MSW landfills to help meet Canada's commitment under the Global Methane Pledge of reducing global methane emissions by 30% below 2020 levels by 2030.	MSW landfill methane emissions are reduced by 45% below 2020 levels by 2030 (as per federal government projections), with additional reductions achieved post-2030.	Not included.

Table A1.2

Overview of the major provincial policies included in all three scenarios[23]

Region	Policy	Description
British Columbia	Zero Emissions Vehicle Act	Requires automakers to sell a minimum share of zero- or low-emission vehicles via a credit market. Achieves 10% light-duty zero-emission vehicles sales by 2025, 30% by 2030, and 100% by 2040.
	CleanBC Go Electric Program	Incentives for electric vehicles and charging station installation. Includes rebates for light-duty vehicles of up to $3,000 and up to 50% of charger installations.
	CleanBC Industry Fund	Government investment into low-emission technologies using a portion of carbon pricing revenue above $30/tCO_2e$ to support competitiveness in industry.
	CleanBC Better Homes and Better Buildings program	Incentives for residential and commercial building efficiency improvements.
	Energy Efficiency Act	Sets energy efficiency performance standards for energy-using technologies.
	Low Carbon Fuel Standard	Requires a decrease in the average carbon intensity of 30% by 2030 from 2020 for transport fuels through several compliance pathways.
	Renewable Fuel Regulation	A minimum renewable fuel content of 5% ethanol for gasoline and 3% biodiesel for diesel fuel.
	Renewable Natural Gas Regulation	Requires that 15% of natural gas consumption be provided by renewable natural gas by 2030.

23 In the Global Net-zero and Canada Net-zero scenarios, if the federal policy is more stringent than its regional equivalent, the federal one is modelled instead.

Region	Policy	Description
Alberta	Renewable Fuels Standard (RFS)	Requires renewable fuels to be blended into gasoline and diesel fuel.
	CCUS investments	Investments in CCUS projects, including the Alberta Carbon Trunk Line and Quest projects.
	Methane emissions reduction regulation	Requires the reduction of methane emissions from oil and gas operations by 45% by 2025 relative to 2014 levels.
Saskatchewan	Ethanol Fuel Regulations and Renewable Diesel Act	Regulations requiring a minimum of 7.5% of ethanol content in gasoline and 2% biodiesel content in diesel.
	Methane Action Plan	Requires the reduction of methane emissions from oil and gas operations by 45% by 2025 relative to 2015 levels.
Manitoba	Biofuels Mandate amendment	Regulations requiring a minimum of 10% ethanol content in gasoline and 2% biodiesel content in diesel.
	Efficiency Manitoba Act	Rebates and other incentives on lighting, air conditioning, and building shell rebates across residential, commercial, and some industrial sectors.
	Green Energy Equipment tax credit	A 15% tax credit on geothermal heat pumps in residential and commercial sectors.
Ontario	Cleaner Transportation Fuels: Renewable content requirements for gasoline and diesel fuels	A regulation requiring 15% ethanol content in gasoline and 4% biodiesel content in diesel by 2030.

Region	Policy	Description
Quebec	Western Climate Initiative cap-and-trade regime	A cap-and-trade system for industrial and electricity sectors, as well as fossil fuel distributors. Declining annual caps are set out to 2030 and the revenue generated by the policy is invested in low-carbon technologies. As caps are not set after 2030, the federal pricing systems (fuel charge and OBPS) apply.
	Renewable Natural Gas Regulation	Minimum 5% renewable natural gas content in natural gas by 2025.
	Chauffez Vert Program	Rebates for residential renewable energy space or water heating systems, if replacing fossil fuel system.
	Roulez Vert Program	Incentives for electric vehicles and charging station installations. Rebates include up to $8,000 for new vehicles and $600 for home charging stations.
	Zero Emissions vehicle standard	Requires automakers to sell a minimum share of zero- or low-emission vehicles via a credit market. The credit target is 100% by 2035.
New Brunswick	Energy Efficiency programs	Provides purchase incentives for energy efficient appliances in residential, commercial, and industrial sectors.
Nova Scotia	EfficiencyNS Programs	Incentives for residential, commercial, transportation and some industrial sectors. Incentives include the transition from oil heating to electric, heat pumps, and charging stations.
Newfoundland and Labrador	Energy Efficiency Programs	Incentives for residential, commercial, and some industrial sectors. These programs include a home energy savings program, heat pump rebates, and commercial sector rebates for select appliances.

Region	Policy	Description
Prince Edward Island	EfficiencyPEI Rebates	Incentives for residential, commercial, and some industrial sectors. Various rebates on energy-efficient appliances, such as heat pumps, solar systems, biomass heating, and fuel-efficient furnaces.
Northwest Territories	2030 Energy Strategy	Measures that aim to support low-carbon energy for transportation and space heating. Includes promoting the use of wood as an alternative source of energy to fossil fuels, supporting the development and implementation of community energy plans, incentives for energy efficiency and alternative energy projects, support for alternatives to diesel electricity generators, rebates for zero- and low-emission vehicles.
Yukon	Our Clean Future	Measures including 10% ZEV new sales by 2025 and 30% by 2030, ZEV rebates, blending of renewable fuels into diesel and gasoline, energy efficiency incentives and regulations, and renewable energy projects for remote communities.

Appendix 2: Technology Assumptions

This appendix outlines key technology assumptions included in the Current Measures, Global Net-zero, and Canada Net-zero Scenarios. The percent changes in the assumptions are relative to 2021 unless otherwise noted. All costs are in $2022 CAD unless otherwise noted.

Table A2.1

Key Technology Assumptions

	Global Net-zero	Canada Net-zero	Current Measures
Buildings			
Heat pumps[a]	Cost declines 15% by 2030 and 40% by 2050.	Cost declines 13% by 2030 and 34% by 2050.	Cost declines 7% by 2030 and 20% by 2050.
Building shell*	Efficiency of new buildings improves 80% by 2050.	Efficiency of new buildings improves 80% by 2050.	Efficiency of new buildings varies regionally from 20-50% by 2050.
Hydrogen and renewable natural gas (RNG) blending	Hydrogen: Maximum blending of 20% by volume, which occurs where economics are favourable. RNG: feedstock supply constraints limit blending up to 10-15% of natural gas content by 2050.		Hydrogen price remains high and thus no blending occurs. RNG: only provinces with RNG mandates.
Heavy industry			
Carbon capture, utilization, and storage (CCUS) [b]	Capture costs are different by industry and range from $45-200/ tCO_2 by 2030 and $30-160/ tCO_2 from 2030-2050.		Capture costs are different by industry and range from $45-200/ tCO2 through the projection period.
Iron and steel: electric arc furnaces (EAF)	Some facilities transition from coal to EAF[c] and from coal to direct reduced iron EAF.[d]		
Hydrogen in steel production: Hydrogen direct reduced Iron (H2-Dri)[e]	Assume availability of technology at scale and adoption of economic conditions allow.		Assume technology is not available at scale.
Aluminum production: Inert anodes[f]	20% adoption by 2030 and a linear incline to 100% by 2050.		20% adoption of inert anodes.

Hydrogen and renewable natural gas blending	Hydrogen: Maximum blending of 20% by volume, blending occurs where economics are favourable. RNG: supply constraints limit blending up to 10-15% of natural gas content by 2050.		Hydrogen price remains too high for blending to occur. RNG: only provinces with RNG mandates.
Transportation			
Passenger battery electric vehicles[g]	Vehicle cost declines from by 30% by 2030 and 38% by 2050 (compared to $40-60,000 currently).	Vehicle cost declines 28% by 2030 and 36% by 2050.	Vehicle cost declines 26% by 2030 and 33% by 2050.
Medium and heavy-duty hydrogen fuel cell trucks[h]	Fuel cell truck costs fall steadily, approaching parity with diesel vehicles in the 2035-2050 period (approximately $150,000 to $200,000 for a Class 8 diesel truck).		Fuel Cell truck costs remain near current levels.
Medium and heavy-duty battery electric trucks[i]	Battery electric truck costs fall steadily, approaching parity with diesel vehicles in the 2035-2050 period (approximately $150,000 to $200,000 for a Class 8 diesel truck).		Battery electric and fuel cell truck costs remain near current levels.
Sustainable aviation fuel[j]	Following IEA WEO international context, 40% of jet fuel needs met with bioenergy, 30% with hydrogen-based aviation fuel by 2050.		Not included.
Electricity Generation			
Wind electricity[k]	Capital cost declines from $1,900/kW in 2020 to $1,752/kW by 2030 and $1,630/kW by 2050 (14% below 2020).	Capital cost declines from $1,900/kW in 2020 to $1,763/kW by 2030 and $1,668/kW by 2050 (12% below 2020).	Capital cost declines from $1,900/kW in 2020 to $1,791/kW by 2030 and $1,736/kW by 2050 (9% below 2020).
Solar electricity[l]	Capital cost declines from $1,400/kW in 2020 to $790/kW by 2030 and $535/kW by 2050 (62% below 2020).	Capital cost declines from $1,400/kW in 2020 to $840/kW by 2030 and $585/kW by 2050 (58% below 2020).	Capital cost declines from $1,400/kW in 2020 to $905/kW by 2030 and $675/kW by 2050 (52% below 2020).
Battery storage (4 hr) [m]	Capital cost declines from $2,198/kW in 2020 to $952/kW by 2030 and $549/kW by 2050 (75% below 2020).	Capital cost declines from $2,198/kW in 2020 to $1,261/kW by 2030 and $925/kW by 2050 (58% below 2020).	Capital cost declines from $2,198/kW in 2020 to $1,563/kW by 2030 and $1,506/kW by 2050 (32% below 2020).

Natural gas combined cycle with CCS[n]	Capital cost declines from \$3,705/kW in 2020 to \$2,625/kW by 2030 and \$2,075/kW by 2050 (44% below 2020).	Capital cost declines from \$3,705/kW in 2020 to \$3,005/kW by 2030 and \$2,530/kW by 2050 (32% below 2020).	Capital cost declines from \$3,705/kW in 2020 to \$3,385/kW by 2030 and \$2,990/kW by 2050 (19% below 2020).
Nuclear small modular reactors[o]	Capital cost declines from \$9,262/kW in 2020 to \$8,348/kW by 2030 and \$6,519/kW by 2050 (30% below 2020).	Capital cost declines from \$9,262/kW in 2020 to \$8,348/kW by 2030 and \$6,519/kW by 2050 (30% below 2020).	Capital cost declines from \$9,262/kW in 2020 to \$8,595/kW by 2030 and \$7,400/kW by 2050 (20% below 2020).
Oil and Gas Production			
Carbon capture, utilization, and storage[p]	Capture costs range from \$45-125/tCO_2 by 2030 and \$30-90/tCO_2 from 2030-2050.		
Oil sands process efficiency	Oil sands process efficiency improves by 1% per year.		
Hydrogen			
Electrolyzer[q]	Capital cost declines 80% by 2030 and 84% by 2050.	Capital cost declines 74% by 2030 and 82% by 2050.	Capital cost declines 62% by 2030 and 70% by 2050.
Natural gas with CCUS	Capital cost declines 25% by 2030 and 40% by 2050.		Capital cost declines 20% by 2030 and 25% by 2050.
Biomass	Capital cost declines 18% by 2030 and 25% by 2050.		Capital cost declines 16% by 2030 and 20% by 2050.
Transportation and distribution of hydrogen	We assume appropriate transmission and distribution networks gets built to safely and reliably transport hydrogen from producers to consumers, to enable hydrogen adoption throughout the energy system.		
Carbon Management and Non-energy GHG Emissions			
Direct air capture[r]	Capture cost declines to \$330/tCO_2 by 2035 and \$230/tCO_2 by 2050.	Capture cost declines to \$350/tCO_2 by 2035 and \$250/tCO_2 by 2050.	Capture cost remains at \$400 to \$450/tCO_2 over the projection period.
Land-use, land-use change, and forestry (LULUCF)[s]	30 and 50 million tonnes of carbon dioxide equivalent (Mt of CO_2e) removed by 2030 and 2050, respectively. This assumption is based on a literature review of other Canadian net-zero projections and on the feasibility of nature-based climate solutions in Canada, including an on Nature-Based Climate Solutions from the Council of Canadian Academies.		13 megatonnes (MT) of CO_2e removed by 2030 and kept at same level to 2050. Consistent with recent projections from Environment and Climate Change Canada (ECCC).

Waste[t]	Assumes GHG emissions from solid waste disposal are reduced by 45% below 2020 levels by 2030, in line with the estimated impact of proposed landfill methane regulations. Assumes additional reductions are achieved by 2050 to a level of 57% below 2020 levels via other waste diversion and reduction measures.	Waste and GHG emissions generation intensity factors follow historical 2001 to 2021 trends for 2022 to 2050, based on the 2023 national inventory report (NIR) data.
Non-energy agriculture[u]	GHG emissions intensity of enteric fermentation,* manure management, and agricultural soils activities declines as of 2023 to a conservative average of 23% below current measures' levels in 2050, based on a review of the literature. Also assumes the Government of Canada's fertilizer emissions reduction target of 30% below 2020 levels by 2030 is met, then increases linearly to a 40% reduction by 2040 and 50% by 2050.	Animal and crop production activities' GHG emissions intensity factors follow historical 2001 to 2021 trends for 2022 to 2050 if negative (based on 2023 NIR 2023 data), or decline at 0.25%/yr.

Sources and notes:

a. IEA World Energy Outlook 2022, NREL Electrification Futures Study.

b. Various sources including: Global CCS Institute, Leeson et al 2017, International CCS Knowledge Centre, IEA Levelized cost of CO_2 capture.

c. For an example of coal to EAF see Algoma Steel.

d. For an example of coal to direct reduced iron EAF see ArcelorMittal Dofasco.

e. IEA Clean Energy Technology Guide.

f. For an example of intert anodes see Elysis Carbon-Free Aluminum Facility.

g. IEA World Energy Outlook 2022, EIA Annual Energy Outlook 2022.

h. EPRI US-REGEN Documentation Version 2021 LCRI, On-Road Fleet Vehicles.

i. EPRI US-REGEN Documentation Version 2021 LCRI, On-Road Fleet Vehicles.

j. IEA World Energy Outlook 2022, Canada's Aviation Climate Action Plan.

k. NREL Annual Technology Baseline, IEA World Energy Outlook 2022.

l. NREL Annual Technology Baseline, IEA World Energy Outlook 2022.

m. NREL Annual Technology Baseline, IEA World Energy Outlook 2022.

n. NREL Annual Technology Baseline, IEA World Energy Outlook 2022.

o. NRCan 2020, NREL Annual Technology Baseline.

p. Various sources including: Global CCS Institute, Leeson et al 2017, International CCS Knowledge Centre, IEA Levelized cost of CO_2 capture, Quest Carbon Capture and Storage Project: Annual Report, Ordorica-Garcia, et al 2011.

q. IEA World Energy Outlook 2022.

r. EPRI US-REGEN Documentation Version 2021 LCRI, IEA Direct Air Capture 2022.

s. Canada's 8th National Communication and 5th Biennial Report 2022, Canada's LTS submission to the UNFCCC 2022, CCA NBCS 2022, Drever et al. 2021, Smith 2020.

t. Canada's 8th National Communication and 5th Biennial Report 2022, Canada's 2030 emissions reduction plan, Chapter 3 2022.

u. McKinsey, Agriculture and climate change 2020, RBC, The Next Green Revolution 2022, SPI, NZ: Implications for Canadian Agriculture 2021, Trottier, Canadian Energy Outlook 2021.

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