Executive summary

Canadian Energy Outlook – 3rd edition

Pathways for a net-zero Canada

Horizon 2060

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About the Institut de l'énergie Trottier (IET)

The *Institut de l'énergie Trottier* (IET) was created in 2013 thanks to a generous donation from the Trottier Family Foundation. Its mission is to train a new generation of engineers and scientists with a systemic and trans-disciplinary understanding of energy issues, to support the search for sustainable solutions to help achieve the necessary transition, to disseminate knowledge, and to contribute to discussions of energy issues. Based at Polytechnique Montréal, the IET team includes professor-researchers from HEC, Polytechnique and Université de Montréal. This diversity of expertise allows the IET to assemble work teams that are trans-disciplinary, an aspect that is vital to a systemic understanding of energy issues in the context of combating climate change.

About the ESMIA Consultants

ESMIA offers a cutting-edge expertise in 3E (energy-economy-environment) integrated system modelling for the analysis of optimal energy and climate strategies. ESMIA puts forward a scientific approach guided by sophisticated mathematical models. The goal behind our implication is to offer solutions that allow achieving energy and climate goals without compromising economic growth. For 20 years, the ESMIA consultants provide a full range of services for the development of economy-wide energy system models for high-profile organizations worldwide. They also provide advisory services that focus on analyzing complex problems such as energy security, electrification, technology roadmap and energy transitions. ESMIA benefits for this purpose from its own integrated optimization model: The North American TIMES Energy Model (NATEM).

About the e3c Hub

The e3c Hub is a multidisciplinary research, transfer and training center of HEC Montréal, specializing in environment, energy and circular economy. Its mission is to contribute to a transition towards a sustainable society and economy, in conjunction with various stakeholders. To do this, the e3c Hub conducts research, runs a scientific program, and designs and organizes training courses and summer schools.

Executive summary

This third edition of the Canadian Energy Outlook is a modelling effort that explores the possible transformation pathways required to achieve net-zero GHG emissions in Canada, with a special focus on the energy system. Produced by independent researchers, this series of reports first presented an up-to-date overview of Canada's energy production and consumption, as well as GHG emissions sources (Langlois-Bertrand and Mousseau 2024). The second report of the series, presented here, builds on extensive techno-economic modelling to analyze trends that can be observed across the country. It examines, province by province, the optimal cost trajectories allowing to transform of the energy sector and reduce the country's greenhouse gas (GHG) emissions in the next decades, based on current and upcoming policies as well as national net-zero objectives. In the following months, other reports will follow, providing in-depth analyses of some of the questions raised by the modelling. This 3rd edition follows similar work done in previous editions of the Canadian Energy Outlook in 2018 and 2021.

This report uses a traditional format and projects energy production and consumption across Canada over the next decades according to various scenarios, while assessing the country's GHG emissions, including those coming from activities outside of the energy sector, such as those emitted by agriculture, waste and industrial processes, as well as fugitive emissions from oil and natural gas production. It focuses as well on the transformation of the economy and its dependency toward various GHG reduction measures adopted by the provinces and the federal government.

Results underline that :

(i) A net-zero target imposes that the set of choices made to orient the Canadian economy's transition must be compatible, already today, with reaching net-zero on the longer term;

(ii) If currently implemented and publicly announced measures at the federal and provincial levels point to a reduction of emissions on the short term, they remain insufficient to reach the 2030 emissions target;

(iii) From a cost-optimal perspective, oil and natural gas extraction and transformation, industry and electricity production should bear the largest share of emissions reductions in the coming years;

(iv) With rapid technological improvements and appropriate measures, the transition to a net-zero economy is affordable and could even be economically beneficial.

Scenarios toward net-zero emissions

Throughout this Outlook, we consider two GHG emissions reduction scenarios leading to net-zero as well as a reference scenario for the business-as-usual case which includes policies already in place (as described in Table ES.1). All scenarios are analyzed through the North American TIMES Energy Model (NATEM), a model which determines the optimal solution from a techno-economic standpoint while meeting imposed constraints, thereby providing a lower bound for the costs of the transition.

Table ES.1 – Description of the reference and GHG reduction scenarios used in NATEM modeling[1]

Name	Description
REF	The reference scenario. No constraining GHG reduction targets. Macroeconomic assumptions (GDP, population, oil and gas export prices) are aligned with the Canada Energy Regulator's projections as well as those of Statistics Canada, imposing no additional constraints in terms of GHG emissions. Includes all GHG reduction and energy policies already in place in addition to the Clean Electricity Regulations and Zero-Emissions Vehicle sales mandate.
NZ50	This scenario imposes a net-zero emissions target on total CO_2-eq by 2050, and a 40% reduction target by 2030, with respect to 2005.
NZ50PS	This scenario is identical to NZ50 except for cost projections for nuclear SMRs, which are higher.

[1] The NATEM model is an energy system optimization model implemented by ESMIA Constultants Inc. It uses the MARKAL-EFOM (TIMES) integrated system model generator, developed and distributed by the International Energy Agency's Energy Technology Systems Analysis Program (ETSAP) and used by institutions in around 70 countries..

The impact of measures put in place

In sharp contrast with the previous edition of the Canadian Energy Outlook, policies recently put in place or on the verge of being adopted change the direction of the emissions trend for the country. Indeed, the projected impact of several recent and upcoming measures lead us to project a reduction of 14% of the country's emissions before 2030 from 2005 levels, and of 25% before 2050. These measures narrow the gap, especially on the shorter term, between the REF and NZ50 scenarios. Moreover, the REF scenario shows that targeted measures have a real impact, as illustrated for instance by the example of the zero-emission vehicle sales mandate which leads to a complete decarbonization of light-duty transport.

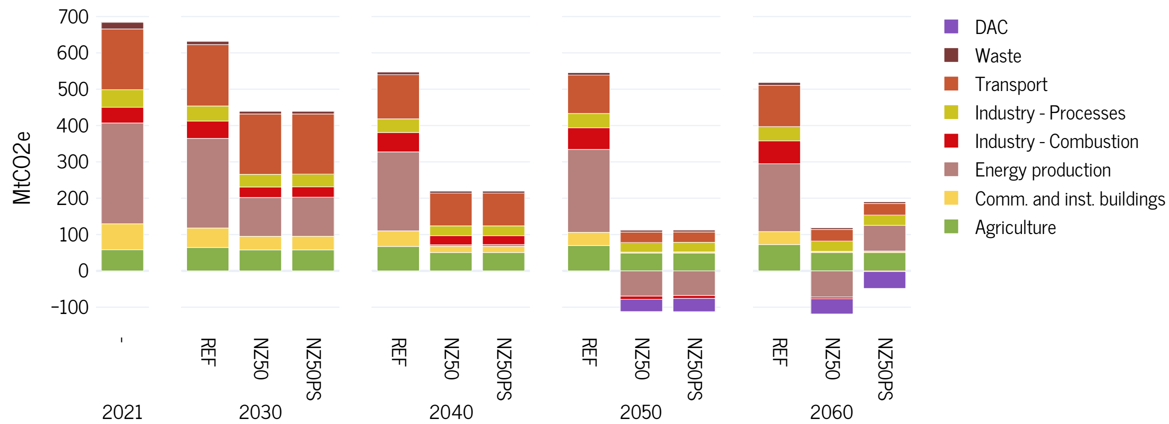
However, these measures remain largely insufficient to meet the GHG reduction target of -40% for 2030, or to set up a solid foundation to put the country on a net-zero trajectory. It is important to note that most of the recent developments emanate from the federal government, whereas provinces have largely failed to deploy new structuring measures able to contribute to the decarbonization of Canadian society.

Decarbonization in all economic sectors

A first observation from the modelling results reveals that **reaching net-zero at reasonable cost requires that all sectors in all provinces and territories realize a deep decarbonization**. Indeed, the challenge of net-zero necessitates not only reducing emissions to their lowest possible levels, but also compensating for remaining emissions that are too costly to eliminate. The latter includes specific applications where decar¬bonization is very costly or where technology is not yet available, but where demand is not projected to be eliminated, such as agriculture or industrial processes.

Moreover, non-energy emissions become the majority of what remains once carbon neutrality is reached, representing a different challenge from that of reducing emissions from energy consumption since it necessitates disruptive technological innovations, which are difficult to predict.

Figure ES.1 – Total GHG emissions by sector



The transformation of energy services

The share of fossil fuels drops markedly in net-zero scenarios, starting before 2030 and accelerating rapidly between 2030 and 2040. By 2060, oil and gas consumptions represent 14% of what it was in 2021 for both these sources. **Given the rapid pace of transformation needed, natural gas cannot serve as a transition energy**.

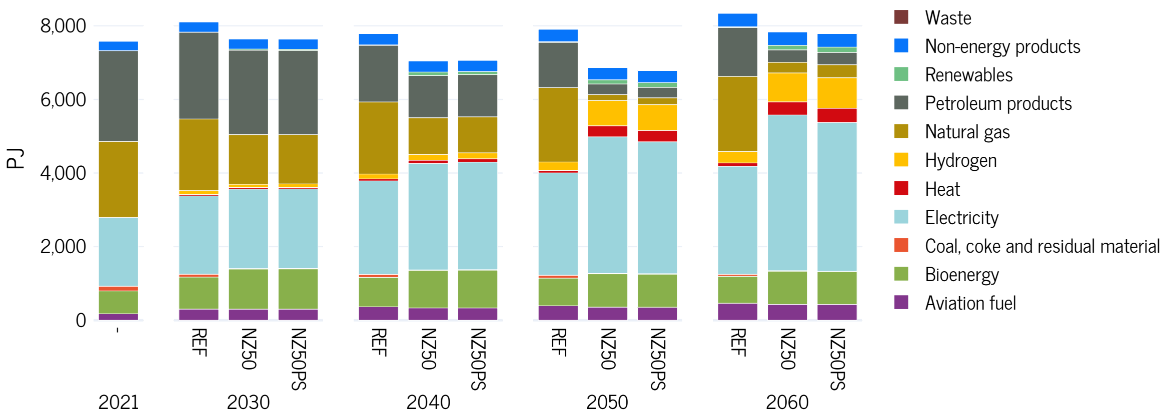
Until 2050, net-zero scenarios translate into reduced energy demand due in large part to energy efficiency and productivity gains (notably through electrification). These reductions occur without diminishing the services provided to the population. After 2050, however, since most cost-effective transformations with currently identified technologies have been realized, meeting increasing demand from a rising population results in significant energy consumption growth.

Decarbonizing buildings

Overall, **the replacement of fossil fuels-powered systems by electricity in space heating is a key contribution to GHG reduction for the commercial and residential sectors, even withing a short time horizon**. This suggests that the building sector can be decarbonized at relatively lost cost with current technologies. Transformations in the building sector compatible with net-zero are already under way, as reflected in REF, since heat pumps, improved building envelopes and other technologies result in important efficiency gains while eliminating emissions; however, the pace and extent of transformation in REF is far from sufficient to meet the requirements of a net-zero pathway.

Of course, as electrification of building heating increases the winter electric peak demand, various net-zero strategies not modeled here will need to be implemented to limit overbuilding electricity production and distribution infrastructure without compromising GHG reductions.

Figure ES.2 – Final energy consumption by source (outside of energy production)



The transport sector's challenges

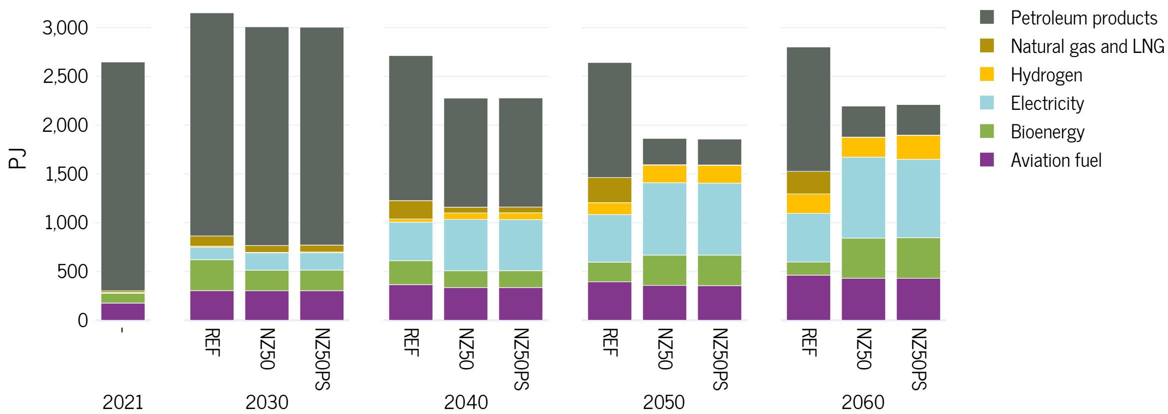
The transport sector produces 30 % of Canada's GHG emissions and saw its emissions increase almost continuously over the past 20 years. The impact of the COVID-19 pandemic, with restrictions on air transport and an increase in work from home, produce a sharp drop in demand for transport, but mostly in the passenger segment in 2020. From 2022 however, the rebound was significant, and no similar decrease in demand is expected for the future. On the contrary, demand should recover its historical trend of continuous increases.

Despite this return to growth in demand, he electrification of the transport sector projected for NZ scenarios translates into a 29.6% reduction in total energy demand, which demonstrates the remarkable inefficiency of combustion engines, imposed by the laws of thermodynamics. While the zero-emission vehicle sales mandate leads to the electrification of road passenger transport in the REF scenario, the absence of measures targeting other segments of transport currently leads to a decarbonization of the sector that is largely limited to light-duty vehicles.

The transformation of the transport sector is at the heart of GHG emissions reduction efforts, but it is difficult to achieve and will take considerable time, because of higher costs and technological challenges linked to merchandise, off-road, air and maritime transport. For heavy transport, the transformation of the sector depends on a number of competing technologies that have not yet reached the market on a large scale. Because of the importance of standardization and the need for technology-specific infrastructures (recharging, catenaries, hydrogen), the relative weight of these technologies will be largely determined by political choices rather than by cost. An approach taking into account regional characteristics on main transport routes may also be more effective given the various options.

Due to a lack of attention, the off-road sector plays a large role in maintaining substantial transport emissions in 2050 in all scenarios. Moreover, the transformations of marine and air transport are more costly and suffer from the absence of techno-economically viable solutions. This underlines the importance of keeping demand growth in check for these subsectors as a key component of the net-zero trajectory while expanding investments to develop technologies further.

Figure ES.3 – Final energy consumption in the transport sector, by fuel



Combining strategies in the industrial sector

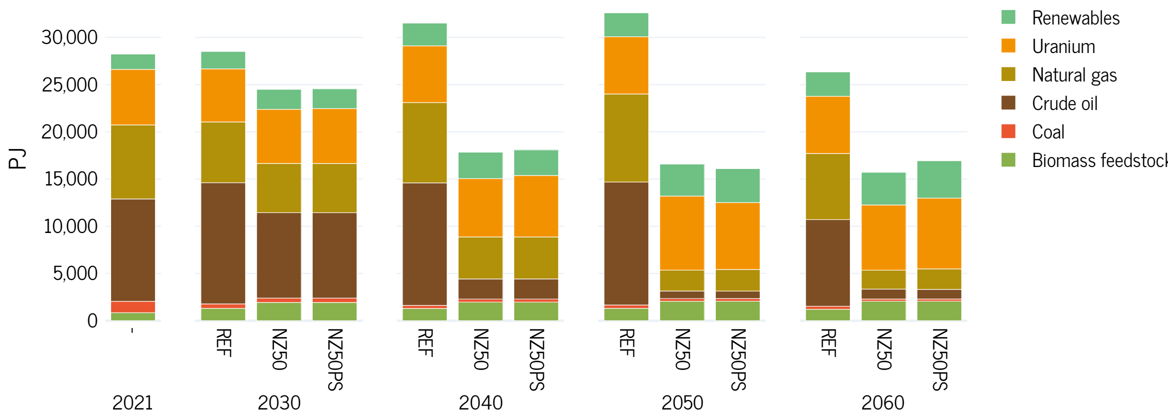
The current energy mix in the industrial sector, where bioenergy and electricity already play a major role, suggest that few low-hanging fruits are available to decarbonize on the short to medium term. NZ50 sees a rapid decarbonization of remaining sources (notably natural gas) after 2040 to meet the net-zero constraint. Hydrogen comes to play an important role in this post-2040 decarbonization, especially in the manufacturing and pulp and paper subsectors.

Decarbonizing industry goes through additional measures to induce transformations in the energy mix and innovations in processes. From this portrait, it is clear that decarbonizing industry requires tailored approaches to specific sectors and their processes. Roadmaps for key sectors should be developed as soon as possible to explore options for economically viable low-carbon process emissions in particular. If they are not, decarbonizing industrial processes in Canada will remain largely dependent on efforts and regulations in other parts of the world.

A higher share of emissions for agriculture

Although agriculture represents only 8.5% of current GHG emissions, it is projected to become the largest source of remaining emissions in net-zero scenarios, with around 49 $MtCO_2e$ or 44% of remaining net emissions in both 2050 and 2060. Agriculture emissions come both from energy combustion, for instance for heating and light, and from process emissions, such as from enteric fermentation or soils. Agricultural vehicle emissions are not included here and as they come under the off-road transport sector. If heat production can be decarbonized, few low-carbon solutions are currently available for process emissions, which represent by far the largest share of emissions from agriculture, at 95% today excluding emissions categorized under off-road transport (the latter are categorised under off road transport, and are almost completely electrified in net-zero scenarios).

Figure ES.4 – Primary energy production



Canada's energy production in a net-zero economy

Following current trends (REF scenario), Canada's energy production (Figure ES-4) is set to continue to grow until 2050. It will continue to be dominated by crude oil production, before diminishing after 2050 following a drop in exports. Natural gas production sees a growth until 2050 before also returning to its smaller levels of 2021 in 2060. **Natural gas production is more affected by domestic demand drivers than crude oil, but a rapid gap also emerges between NZ50 and REF.**

Net-zero scenarios require an accelerated transformation of the economy and a move away from fossil fuel industries, even before 2030. Doing otherwise will require more rapid and extensive emissions reductions in other sectors, as well as an even greater quantity of emissions capture, in order to reach net-zero, increasing the cost associated with net-zero pathways.

A net-negative power sector

With diminishing costs for electricity production, storage and electric technologies, the power sector is projected to expand in all scenarios (Figure ES.5). The share of electricity in the energy mix rises from 24% of the country's final energy consumption today to 52% in 2050 and 54% in 2060 in net-zero scenarios.

Electricity production increases considerably even in REF, following expected growth in demand, to meet the needs imposed by a transition toward a net-zero society.

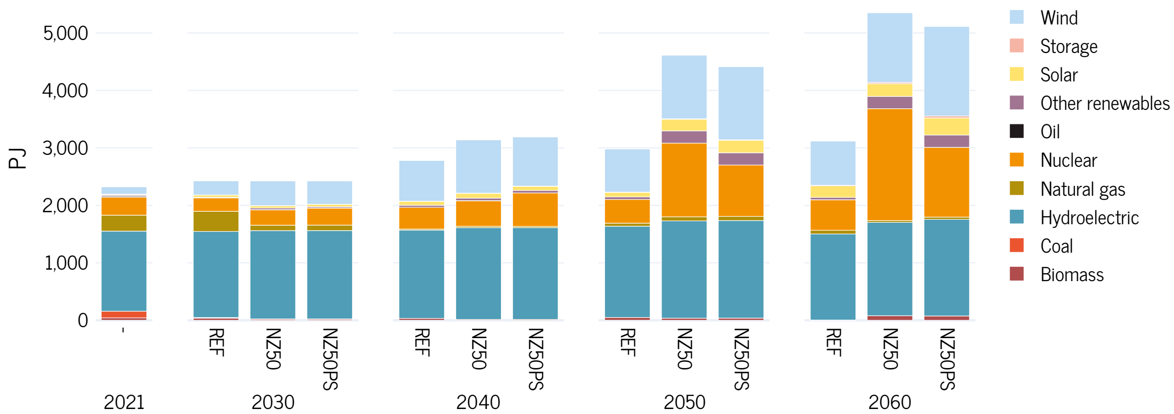
In the net-zero scenarios, the massive electrification of energy services in all sectors requires a twofold increase in production capacity by 2050 (in order to produce 1,280 TWh). NZ50 also shows that this growth accelerates considerably over time: by 2030, production levels follow a curve similar to REF, with a 4.6% increase. This underlines similarities in the drivers of electrification on the very short term for both REF and NZ50, largely imposed by regulation, notably in light-duty transport.

Projections in the NZ50 scenario are based on conservative assumptions regarding energy demand. As such, these hypotheses do not include the potential addition of new energy-intensive industries, and posit that more efficient technologies are deployed everywhere in replacement of fossil fuels.

As the Clean Electricity Regulations (CER) kick in, natural gas-fired generation decreases drastically in both REF and NZ50, and **natural gas with CCS production does not emerge as an important source**. With current cost projections, it is instead **wind, solar and small modular nuclear reactors (SMRs) that become the larger sources of electricity generation in the NZ50 scenario**. As for nuclear production, the main difference across scenarios is in the extent of its deployment, and SMRs in particular. Given higher capacity factors for nuclear generation, this deployment is supposed to be achieved at lower cost and would allow to provide the additional quantities of energy required by NZ50.

Given both technological and economic uncertainties associated with SMRs, which have yet to reach commercial scale anywhere in the world, more pessimistic cost hypotheses in scenario NZ50PS lead to a less extensive deployment of this technology, which would then be compensated by a stronger growth in other generation sources. The future of SMRs is clouded with uncertainties extending well beyond costs, such as social acceptance and construction delays.

Figure ES.5 – Electricity production by technology



The contribution of biomass to the mix is closely linked to the need for negative emissions. Wood-based generation comprises a small share of the total today (1.5%). In the REF scenario, the levels remain relatively constant throughout 2050, but in NZ50 this production is largely converted to BECCS facilities, contributing to negative emissions. This change only occurs after 2040 however, reflecting the high cost of this production. The growth continues to 2060, as more negative emissions are needed to maintain the net-zero equilibrium.

The oil and gas production paradox

Canada is a major **energy producer and exporter. As such, its energy production and export profile will be deeply affected both by changes in demand and by constraints on GHG emissions**. As CCS is not cost-competitive with projected energy prices, oil and gas production decreases significantly in net-zero scenarios even before 2030 (-16%) in order for production emissions to remain compatible with long¬er-term net-zero objectives. Before 2050, 93% of crude oil production is eliminated. Thus, **in a cost-optimal net-zero pathway, oil and gas production bears the brunt of reductions**, otherwise very costly additional reductions will become necessary in other sectors of the economy.

An evolving role for bioenergy

Bioenergy is expected to rapidly play an expanded role in order to meet growing demand on the short term. This role could be crucial to achieve reductions in the short term, while keeping costs in check and with¬out impeding later transformations. However, beyond a certain point, the availability of biomass and the remaining emissions associated with it combine to limit its role in approaching net-zero emissions.

Bioenergy's growing role in net-zero scenarios is not more of the same. In these, bioenergy's main applications are focused on the possibility of obtaining negative emissions through biochar, associated with the production of syngas, or through bioenergy with carbon capture and storage (BECCS) electricity and hydrogen production.

Variations in provincial contributions to net-zero

It is important to remember that the GHG constraints in our scenar¬ios are applied at the national level rather than by province and territory in order to optimize total spending. Accordingly, **depending on their energy profiles, some provinces and territories where de¬carbonization options are cheaper can move into net-negative emissions, while others can fall short of reaching net-zero**. For instance, changes to energy production will differ from one province to the other in correlation with resource distribution, availability and the evolution of the import/export mar¬ket, which is particularly important as more than half of Canada's primary energy production is destined for export.

As the complete report shows in detail for each of the provinces and territories, great provincial diversity in energy production and consumption leads to different challenges, for both the short and the longer term, in participating in the national effort to reach net-zero emissions at lowest cost. For instance, provinces with a decarbonized electricity system and a small industrial sector must approach the costliest sectors (such as transport) early on; the opposite is true for provinces with emission-intensive industries (such as oil and gas production) or carbon-intensive power generation since emissions reduction from these activities can be achieved rapidly at relatively low cost. Similarly, because of the high cost of transporting biomass, the availability of feedstocks in each province plays a large role in determining whether the results include BECCS electricity and/or hydrogen production in a specific province—and, as a result, the quantity of negative emissions for the province.

Even though many solutions are local or remain in the hands of the provinces, there is considerable common ground in some challenges and a crucial role to play for national efforts. Transportation, for instance, should be viewed from a national perspective. Some specific applications, such as space heating in buildings, can also be decarbonized early on across all provinces. Furthermore, provinces that currently have a highly emission-intensive electricity generation and little hydroelectric baseload generation face more significant grid infrastructure development challenges; a national plan to support cross-provincial interconnections would facilitate the required transformation of electricity generation, especially for these provinces.

Issues linked to net-zero pathways

The distinction between deep decarbonization and net-zero approaches

Net-zero scenarios show a very significant quantity of remaining emissions from all sectors combined (between 172 and 196 $MtCO_2e$ annually) in 2050, underscoring gaps in low-carbon technological solutions and the essential role of carefully applied carbon capture and storage (CCS) technologies in key sectors, including direct air capture (DAC) and bioenergy with CCS (BECCS), to help bring net emissions to zero. Increasing syngas production and use, which results in negative emissions from the biochar by-product, also plays an important role in this compensation.

To avoid the need for this degree of compensation, more attention should be paid not only to sectors like heavy merchandise transport that are unlikely to transform rapidly simply as a result of evolving economics, but also to sectors where little attention has been devoted to emissions despite playing a growing role in the future. The latter sectors include off-road transport, where emissions come from a diffuse set of sources but where reductions could be realized at relatively low cost. The analysis of NZ50 results also shows the difficulty of completely avoiding emissions from agricultural and industrial processes.

Carbon capture and storage (CCS) reserved for unavoidable emissions

Modeling results suggest that on-site CCS will first and foremost be applied to industrial processes for which CO_2 production is large¬ly unavoidable, as well as to biomass-based heat, hydrogen or power production where the net impact on emissions is largely negative. Bioenergy with carbon capture and storage (BECCS) is based on available technology and its use results in either electricity or hydrogen production, as well as heat for in¬dustrial applications. The contribution of syngas, which allows to store additional emissions in soils through biochar amendments, could be important as well.

Carbon capture occurs mainly in industry and BECCS hydrogen and electricity production. This is largely because **targeting net-zero instead of simple GHG reductions changes where capture will need to be used. Indeed, any carbon leakage (i.e., emissions not captured when CCS is applied) has to be compensated by negative emissions elsewhere, thus increasing the total cost of capture and favouring non-emitting approaches over CCS and, even more, emissions utilization (CCU)**.

While relying on carbon capture is a central part of the scenarios to net-zero, both costs and technological uncertainties serve as an important warning that projections may be too optimistic as to their true potential. It could become necessary, notably, to compensate an overly optimistic expectation of the volume of emissions that can be captured by deploying an even greater quantity of direct air capture (DAC) and negative emissions energy production (which is constrained in turn by biomass avail¬ability). However, the warning above concerns these options as well: almost no commercial scale installations exist at the moment, and several risks and unknown also apply to large-scale emission storage. **While it is urgent to study more extensively the realistic potential of these compensation options, devoting at least as much effort to innova¬tion in emission reductions as to capture seems essential.**

Deploying the infrastructure needed to make net-zero possible

Electricity buildout to match demand projections highlights the urgent need to solve implementation challenges; it also highlights the fact that maintaining the status quo will be insufficient to meet future needs. Demand projections for electricity clearly show that significant new infrastructure will be needed to increase generation capacity, improve load management and demand response, and upgrade distribution grids to match changing demand profiles that evolve with the electrification of many services previously supplied by other sources of energy. Meeting these challenges is already necessary in a world where current ambitions to achieve net-zero emissions are not being met. Upgrading electricity infrastructure to the levels suggested by the net-zero scenarios therefore requires planning to be urgently adapted to resolve or address implementation challenges (see Box 3.1), including the development of a clear vision toward 2050.

The unclear pathway of hydrogen and bioenergy

Many factors complicate the assessment of the exact role of bioenergy and hydrogen in net-zero trajectories. While cost projections may help determine an estimate of the extent of both these sources across sectors, other factors make the specifics of their deployment more uncertain. First, both hydrogen and bioenergy sources can be deployed in a host of technologies, many of which are interdependent. Second, significant technological hurdles remain for the transformation, transport and use of both products. While these are given a cost in the model, considerable uncertainties remain as to the ultimate capacity or willingness of the industry to overcome these hurdles as competitive low-carbon technologies also evolve.

The emissions accounting associated with negative emissions applications of bioenergy, including for the very production of green hydrogen, also remains challenging. Given the limited availability of biomass, its use for negative emissions involves a complex balancing of the transition to a net-zero society as a whole, including its use in BECCS electricity and hydrogen production as well as biochar, the decarbonization of hard-to-abate applications, etc.

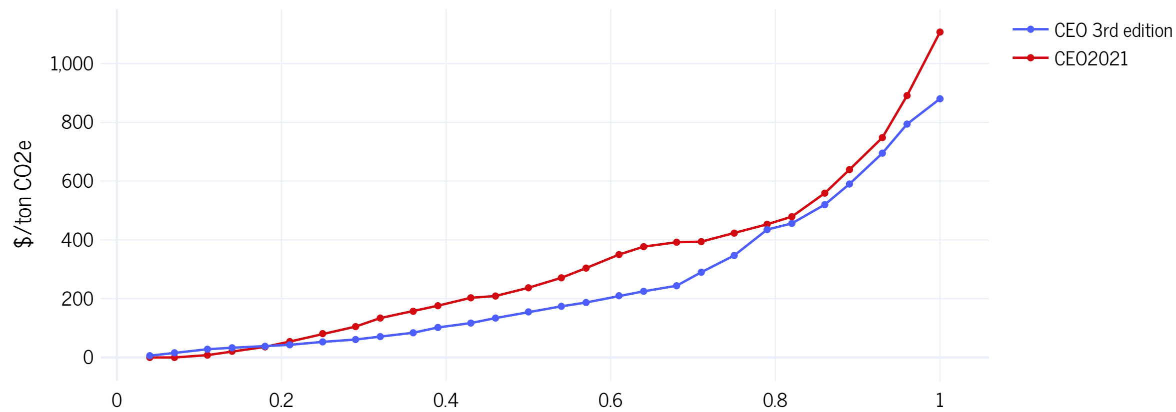
Independently from the hypotheses used concerning the availability of biomass, the role of bioenergy in emissions reduction efforts shows how it is essential to manage this resource with great precaution if its potential is to be harnessed, notably because of the decarbonization options it also presents outside of energy use.

The decreasing costs of net-zero pathways

Since no country has yet completed the shift from fossil fuels to low-carbon sources of energy, the economic implications of these transitions are uncertain. Diverging assessments suggest that energy transitions may either fuel future prosperity or become an economic burden. Transitions will call for important investments but will also generate savings.

A look at the marginal costs of reducing emissions over time helps illustrate how the challenge of deep reductions becomes more difficult, and thus costly, over time. Comparing the results with those obtained in the Canadian Energy Outlook 2021 (Langlois-Bertrand et al. 2021) shows that the marginal cost for the last tonne reduced in the current NZ50 is 880$/tonne, while the cost of the same last tonne to reach net zero in 2021 was $1,100. Technological developments since the previous Outlook, which help not only with providing emission reduction solutions, but also with reducing uncertainties about technological

Figure ES.6 – Marginal cost of GHG reductions, NZ50 scenario compared with REF



paths and their costs, have in less than three years resulted in a very significant marginal cost reduction. This is also visible in the gap between the two curves before reductions reach 80% of what is needed for net zero, where marginal costs for this editions' NZ50 scenario are well under those of 2021, despite the fact that the current REF scenario already reduces emissions well beyond its 2021 equivalent.

This shows how marginal costs are a rapidly moving target: as significant action is taken to reduce emissions, innovation leads to a decrease in the cost of further reductions. This is achieved as new technologies, solutions, approaches and applications are put in place. As a result, projected marginal costs are reduced as the transition occurs. More importantly, as countries move on the transition, the higher levels estimated for the last tonne reduced become less relevant since it affects a smaller proportion of reductions.

Yet it should also be emphasized that the marginal price for the last tonne is controlled by our estimation of carbon capture and sequestration (CCS) technologies, both on industrial sites and in direct air capture (DAC) installations. These technologies present a number of physical and technical challenges that have yet to be overcome before moving to scale. This uncertainty contrasts with the low-carbon technologies that cost less but are also already deployed, providing much greater confidence as to their role in the energy transition.

A need for improved regulations, programs and constraints on emissions

Results from the reference scenario show that **current regulations, programs and constraints on emissions, including the Clean Electricity Regulations and the Zero-Emission Vehicle sales mandate, are not sufficient** for Canada to meet both its 2030 and 2050 targets. **Even when including the** substantial measures introduced by the federal government over the past few years, the expected reduction is 14% for 2030, significantly short of the national emissions reduction target of -40% to -45% while adding the impact of nature-based solutions estimated by Environment and Climate Change Canada as well as carbon credit imports from California bring this reduction to only 20%.

This demonstrates that it is almost structurally impossible for Canada to meet its climate objectives for 2030 and that, in order to correct the course for the 2050 horizon, it is urgent to put in place additional public policies with clear and quantifiable indicators and objectives. Part of this reflection must focus on the implications of net-zero emissions. These policies should not wait to aggressively target sectors where pace is the only variation across scenarios and where technological uncertainties are the fewest. Simultaneously, road maps and structuring measures must be elaborated to target sectors where few reductions are expected, such as heavy and off-road transport, industrial processes and agriculture.

While calls for focusing on more sober energy use and on citizens' responsibility have multiplied, the role of daily individual actions in reaching net-zero targets on the 2050 horizon remains limited and constrained to only a few sectors. Because of the structure of the Canadian economy, less than 20% of all GHG emissions can be attributed to the direct choices of citizens in their personal life, including residential space heating and personal transport. Indirect emissions associated with the consumption of various products are important, but for the large part of imported goods, these emissions are not attributed to Canada.

It is therefore important that governments focus their actions first and foremost on industry and the energy sector as well as commercial actors more generally, in order to decarbonize their activities and make their energy consumption significantly more productive.

Conclusions drawn from this Outlook

The results and analysis presented in this report point to several important conclusions.

1. **Net-zero changes everything and the 2030 target must not hinder the long-term goal.** Given the urgency to reach net-zero, all efforts and investments made from today must enable a net-zero society and focus especially on maximizing the number of net-zero activities.
2. **Even though some recent policies are an important step in the right direction, more is needed, in particular from the provinces.** Current policies take a significant step in initiating transformations compatible with reaching net zero. However, as the results from the last few chapters indicate, the measures in place are far from sufficient to reach either the 2030 reduction target or net-zero emissions by 2050.
3. **Building the backbone of the energy system needed to enable net zero by 2050 is a colossal task that requires rapidly planning and realizing massive infrastructure transformations while improving energy productivity and reducing the cost of this deployment.** Even when including all economically viable energy efficiency measures, new needs in terms of energy production, transport and distribution infrastructure remain vast. Our results are also likely to be an underestimation of true needs, since the nature of the model, which is based on optimization, supposes that transformations will generate few overhead costs.
4. **The dramatic expansion of electricity's role in the mix is not simply a challenge in terms of infrastructure construction since it requires a complete rethinking of how to support an economy mainly with electricity as opposed to the traditional energy mix used in the past.** Beyond technical issues, the changes that come with a much greater need for resilient networks may be underappreciated as more people become reliant on electricity for more services, including the most essential ones. What's more, industrial development will need to be planned in conjunction with network deployment, in rupture with the past.
5. **Additional measures are needed for the transport sector.** Even though the electrification of light-duty vehicles is made possible by measures put in place, it is clearly necessary to implement vigorous measures to decarbonize heavy road and maritime transport as well as off-road vehicles.
6. **Transformations in industry require specific roadmaps, including for process emissions.** Opportunities differ significantly according to subsectors and, in any case, industrial process emissions only decrease by 46% in NZ50.
7. **Assessing the role of biomass in decarbonization pathways, including beyond bioenergy, is necessary.** Answering these questions will require the availability of much better data to map out the different resources and activities linked to biomass, and to enable comparative analyses of the options and realistic potential of its contribution to net-zero pathways, for instance in low-carbon building materials.
8. **Exploring and planning the deployment of negative emissions options is urgent.** Part of this uncertainty must be remedied by gaining more experience with any or all negative emissions technologies to establish a more realistic assessment of their potential, through both pilot projects and certain commercial-scale attempts.
9. **While modelling does not answer every question about the future, it does however provide guidance on how to think about choices that must be made today to make it possible to attain net zero.** This means that the specific evolution in the understanding of agriculture and nature-based solutions, as well as of technologies under intense development such as hydrogen, small nuclear reactors, large-scale energy storage, many industrial processes, and heavy transport, is still uncertain and even unknown. Their future is dependent not only on further research and technological progress, but also on political orientations and choices that will lock in some of the infrastructure-heavy solutions (such as catenary or hydrogen-powered trucks) early-on and, by doing so, reduce the number of possible futures to consider.

Reconciling discourse and reality : a share responsibility

The above observations, drawn from the modelling results as well as an analysis of the recent evolution of Canada's energy system and GHG emissions, should concern all Canadians. Canada's constitution means that the power of defining climate goals and the responsibility for reaching them are shared by many orders of governments. Over the last two decades, we should recognize that this structure has largely failed to deliver the promised transformations. Recent transformative measures introduced by provinces remain rare, while the current federal government deployed the majority of efforts, which remain insufficient.

As this report suggests, more significant efforts are necessary to enable Canada to reach the GHG targets it has adopted. The depth and speed of transformation needed to do so require strategy, coordination and efficiency that is almost unheard of in Canada. Nonetheless, as demonstrated, this is not impossible. From a purely techno-economic point of view, this transformation is affordable and realistic. However, **it requires governments, industry and citizens to think and act boldly and in the most open fashion, to accept risk and failure, to embrace change, and to understand that we cannot wait for the perfect solution before we begin to take action**.

What the net-zero Canadian economy would actually look like remains misunderstood. Considerable attention from all political and economic actors and from citizens across the country is necessary to expand this understanding. For this reason, the third part of this Canadian Energy Outlook, to be published over coming months, will provide deeper insights into some of these questions.