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Engineering Net Zero

IS CANADA ON TRACK TO MEET ITS 2030 TARGETS?

Engineering Net Zero
In partnership with our planet

OUR NET ZERO BLUEPRINT FOR THE FUTURE

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REDUCING CARBON EMISSIONS REQUIRES A CONCERTED STRATEGY WITH THE PROVINCES

Executive Summary

Revised 2030 Greenhouse Gas Emission Milestones

The Government of Canada has recently announced new commitments, including emission reduction targets of 40-45% over the next eight years compared to the 2005 emissions levels, and a net zero greenhouse gas (GHG) emissions electrical network by 2035. This report examines the challenges and opportunities associated with the new 2030 greenhouse gas emissions target for Canada. The analysis herein has been conducted through internal consultations with SNC-Lavalin subject matter experts, supported by government and industry publications. This second Engineering Net Zero - Canada publication considers priority projects that can be deployed within a short timeframe.

Canada has not been able to achieve any significant reductions in total annual GHG emissions. While we see great improvements in the electricity sector, others such as the oil and gas, buildings and transportation sectors have increased GHG emissions, potentially driven by economic and population growth. In 2019, GHG emissions have diminished by only 1.1% since 2005. Maintaining the status quo in project development and technology rollout will not help us achieve our objectives. A fast-track reduction schedule by 2030 will require a shock to existing systems and significant commitments by all levels of government, industry, and society.

The 2020 data was not considered in this report since it portrays a slowdown in economic activity across all sectors due to the COVID-19 pandemic. This resulted in an atypical reduction in greenhouse gas emissions which is not representative of the long term trend.

Short-term proven solutions: the only way forward

Reducing carbon emissions requires a concerted strategy with the provinces that includes:

- Replacing fossil fuels with clean energy;
- Increasing non-emitting energy production;
- Developing new technology; and,
- Changing behaviours regarding energy consumption.

Deploying new and disruptive technologies on a large-scale will not be feasible within eight years, as many of these technologies are still under development. Furthermore, while solutions that rely on Canadians changing their way of life will be essential in our journey towards 2050 net zero GHG emissions, a significant shift in population behaviour is unlikely to be reflected in the 2030 GHG emission numbers.

The Canadian economic sectors will therefore need to look towards proven technologies, readily available today, to better understand the bottlenecks in their deployment and better target the rollout of incentive programs that will maximize their effectiveness. It is equally crucial to deploy these technologies in a sustainable, equitable, and ethically responsible way.

A balancing act between generation, load, and consumer behaviour

To replace energy from fossil fuels, large-scale electrical generation facilities such as hydro or nuclear energy plants can easily take a decade to develop, from planning to commissioning. While it is significantly faster to develop wind and solar power facilities, the energy and capacity expansion necessary to electrify all economic sectors will require a mix of all "zero emissions" power generation technologies. Comprehensive studies will need to be conducted to properly evaluate and optimize the potential solutions, considering the full lifecycle of each technology. This includes considerations for work methods, materials used, and the resulting environmental footprint.

Furthermore, extensive investments and time will be required to upgrade electrical transmission and distribution networks. At present, many Canadian utilities have not yet included the required grid expansion investments in their long-term plans, and few Canadian regulators are considering the Federal government's net zero targets in their demand forecasts.

On the load side, the rise in carbon taxes means that investors in industrial projects will require some assurance that the shift towards lower GHG emissions will not hurt the economic rationale of their projects and render their products less competitive in international markets.

An end-user paradigm shift will also be required in several other consumer-driven areas that contribute to GHG emissions. Changes to consumer behaviour, such as alternative choices in personal vehicles and home heating systems, will require a progressive rollout, which must also consider the end-of-life of existing goods before their replacement. Leadership will be required to drive these changes, along with strong incentive programs by the government.

A 2030 strategy needs to be devised with a focus on potential "quick wins" in specific sectors while putting in motion the social and economic changes that will enable Canada to meet its 2050 net zero GHG emissions targets.

An 8-year scenario for significant carbon reductions

In the path towards complete decarbonization, 2030 will be an important medium-term milestone. By then, a 40-45% reduction of GHG emissions levels is targeted for all industries combined. Three economic sectors will play a key role over the next eight years in helping reach the targets: electricity, transportation, and oil and gas.

Table E1 summarizes a few short-term actionable solutions based on technology readiness in the next eight years. Such technological advancements and upgrades to existing systems must be adopted promptly to stimulate further actions.

The reductions proposed in Table E1 would remove 195 Mt of carbon dioxide equivalent (CO_2e) emissions by 2030, a reduction of approximately 28% from 2005 levels, as shown in Figure E1. The 40-45% reduction target by 2030 requires additional immediate action to cut another 89-126 Mt of CO_2e emissions.

While these numbers focus on emission reductions at the source, carbon credit mechanisms may also be used to address the remaining balance of GHG emissions.

ECONOMIC SECTOR	GHG EMISSION REDUCTION MEASURE	LIMITATIONS / CHALLENGES	POTENTIAL REDUCTION BY 2030 (MT OF CO_2E)
Electricity	Retirement of coal	• Ensure buy-in from all provinces • Need to develop combined-cycle natural gas and nuclear power plants • Power grid limitations	40
	Addition of Renewable Generation: 5 to 7 GW/year of newly installed capacity from hydro, nuclear, solar and wind sources depending on local resources and geography	• Need to upgrade and reinforce a nearly exhausted transmission network to increase capacity • Development of new infrastructure • Resolution of challenges related to generation location • Coordination of interties to existing transmission network	Electrification of other economic sectors
Transportation	Battery electric vehicles: cars, and light and medium trucks (private and commercial)	• Consumer behavior • Charging infrastructure • Limitations in material supplies for production	35
	Hydrogen fuel vehicles: heavier vehicles	• Limited existing applications • Need for growth in electricity production • Lack of production, storage, distribution and dispensing facilities	Dependent on various techno-economic factors
Oil and gas	Methane Emissions Reduction: fugitive emissions and venting	• Precision in detection of fugitive emissions • Dependence on renewables to cut venting emissions from fossil fuels	30
	CCS/CCUS: Carbon capture, utilization for enhanced oil recovery and storage	• Development of CCUS facilities • Feasibility of interconnection to the ACTL pipelines	Dependent on various techno-economic factors
	Electrification: replacement of fossil fuels by renewables and small modular reactors	• Need to pause operations to complete retrofits • Dependence on electricity sector	
Buildings, agriculture, industrial, waste and other	30% emissions reduction per sector	• Need for significant regulation, investments, and incentives	90
Total potential emissions reduction by 2030 (Mt of CO_2e)			195

TABLE E1 SUMMARY OF SUGGESTED MEASURES BY ECONOMIC SECTOR

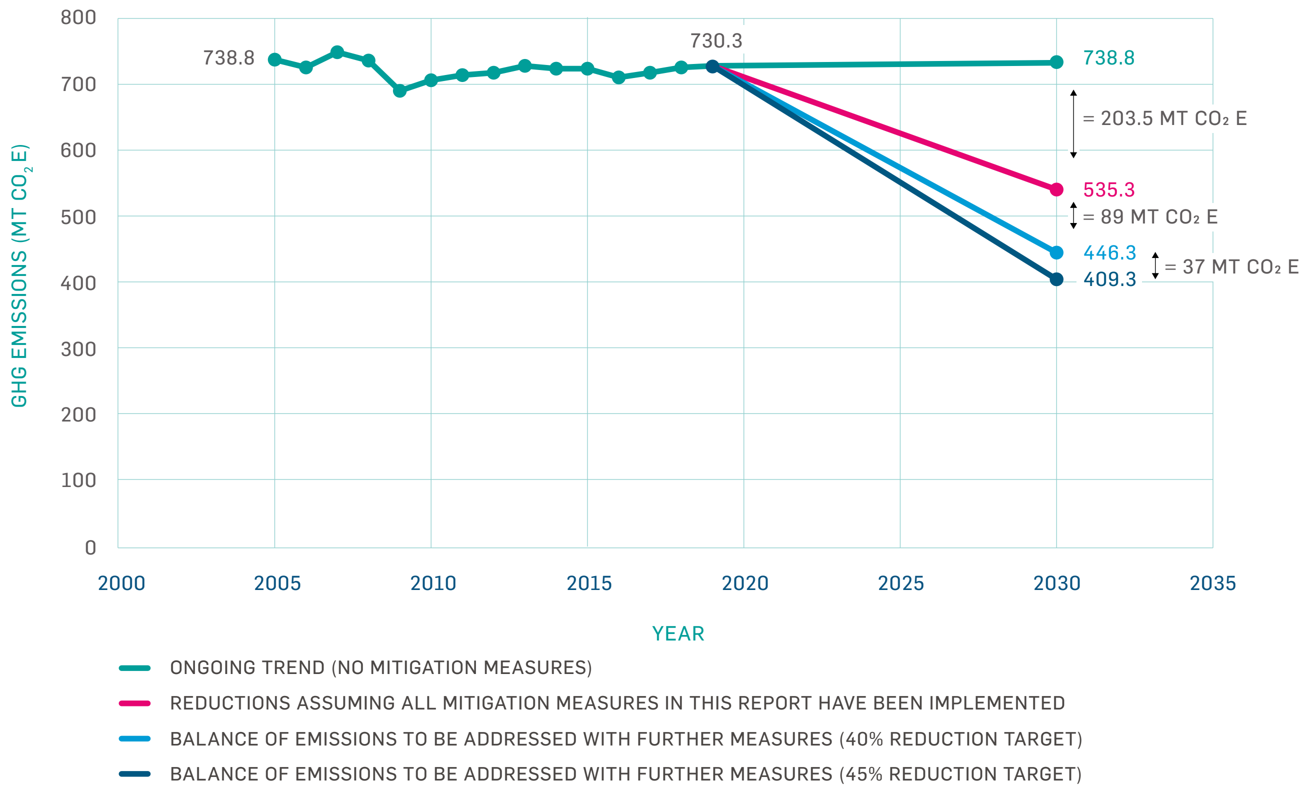


FIGURE E1 GHG EMISSIONS: ACHIEVABLE SHORT-TERM REDUCTION MEASURES VERSUS 2030 TARGETS [1]

Call to action

Canada has already made significant commitments at COP26, which focus on carbon pricing, phasing out coal generation, reducing oil and gas emissions (and more specifically methane emissions), implementing policies to mobilize private financing, increasing actions related to oceans, forests, and nature-based climate solutions, cleaner transportation, and Indigenous communities' leadership and engagement. In addition, the 2030 Emissions Reduction Plan issued by the Government of Canada in March 2022 provides $9 Billion in funding towards cutting emissions across all the economic sectors.

Further electrification of means of transport, oil and gas extraction and refining operations, industrial manufacturing processes, along with the development of Carbon Capture and Storage (CCS) facilities and the commercial availability of hydrogen-fuelled products may enable Canada to meet the decarbonization targets within the restricted timeframe.

Government support at all levels is indispensable to drive technological development forward and gradually implement the planned changes in the distinct yet interrelated industries. Further societal and economic stimulus is needed to alter consumer behaviour and fuel technological advancements respectively.

This is a call for a nationwide collaborative effort across economic sectors to accelerate the integration of selected technological and socio-economic changes required to reverse the environment-damaging trends, lessen the impact of climate change, and create a better future for generations to come.

[1] 2005-2019 data based on: Environment and Climate Change Canada. (2021).
National inventory report 1990–2019: greenhouse gas sources and sinks in Canada: part 1.

ACTION TODAY FOR A NET ZERO TOMORROW

1. 2030 greenhouse gas emissions milestone

On March 12, 2021, SNC-Lavalin published the Engineering Net Zero Canada report [Ref. 1], which provided an overview of emission reduction pathways within the Canadian economic sectors, as well as concrete actions that would enable Canada to achieve its 2050 net zero greenhouse gas (GHG) emission objectives. The present report examines the challenges and opportunities associated with the new 2030 GHG emissions target for Canada. In particular, the report identifies technical areas which could potentially be targeted to maximize GHG reductions within a limited timeframe.

The analysis conducted herein has been supported through internal consultations with SNC-Lavalin subject matter experts, informed by the Canadian government and industry publications, and considers priority projects that can be deployed in the short-term.

A. What is the new 2030 target?

Reducing carbon emissions has attracted a lot of attention lately, with several countries—including the U.S., the U.K. and Canada—revisiting their targets or announcing net zero target emissions for 2050. In November 2021, Canada participated in the United Nations Climate Change Conference (COP26), "the most important climate conference since the Paris agreement was adopted in 2015" [Ref. 2]. The Canadian Government made new commitments, including a greater emission reduction target of 40-45% over the next eight years compared to the 2005 emissions levels, and a net zero GHG emissions electrical power grid by 2035. The 2030 Emissions Reduction Plan [Ref. 3], issued by the Government of Canada in March 2022 provides $9 billion in funding towards cutting emissions in all the economic sectors.

Reducing carbon emissions requires a concerted strategy with the provinces that includes replacing fossil fuels with clean energies, increasing clean energy production, developing new technology, and changing behaviours regarding energy consumption. Deploying new and disruptive technologies on a large scale will not be feasible within an eight-year window, as many of these technologies are still under development. Similarly, while solutions that rely on Canadians changing their way of life will be essential in our journey towards 2050 net zero GHG emissions, a significant shift in population behaviour is unlikely to be reflected in the 2030 GHG emission numbers.

The Canadian economic sectors will therefore need to look towards proven technologies, readily available today, to better understand the bottlenecks in their deployment, and better target the rollout of incentive programs that will maximize their effectiveness. Our report focuses on specific segments within the economic sectors where significant carbon emission reductions could potentially be achieved in the next eight years, assuming the required socio-economic and political conditions will be in place. It is equally crucial that these technologies be deployed in a sustainable, equitable, and ethically responsible way.

To this end, SNC-Lavalin brought together experts from different disciplines to look at existing technology, ongoing research, and potential GHG reduction initiatives, with a focus on the following economic sectors: electricity, transportation, and oil and gas. It is important to note that the technology-driven solutions considered in this report are one part of the solution and would need to be supported by additional GHG reductions across all sectors to achieve the 45% reduction targets for Canada by 2030.

B. Recent trends in GHG emissions: Are we on track?

In December 2009, Canada committed to a 17% decrease in GHG emissions by 2030, based on reference year 2005. This target was revised to 30% as part of the Paris Agreement. The recent 2021 announcement increases the number to 40-45%. These GHG reduction targets are essential to combat climate change with efforts to limit the temperature increase to 1.5 degrees Celsius, as well as to position Canada as a leader in GHG-reducing processes and technologies.

In 2021, new records were set in Canada in terms of extreme weather conditions and events. Several heat waves occurred from coast-to-coast, the worst being on June 29th as British Columbia witnessed a temperature of 49.6 °C, a record high for one of the coldest countries in the world. Wildfires were uncontrollable in several provinces, covering skies in smoke. After this dry pattern, the West Coast set rainfall records in November with flooding causing disastrous damage. These rainfall storms in British Columbia were considered "the most destructive and expensive weather disaster in Canadian history" [Ref. 4].

A series of such catastrophic weather events may be Canada's cue to reassess the gravity of the situation and put in place an accelerated action plan to prevent future environmental catastrophes.

An analysis of the GHG emissions data, including trends over the past decade within Canada's various economic sectors is essential to effectively target GHG reduction initiatives. Figure 1 summarizes emissions trends since 2005 by economic sector for Canada. As it stands, Canada has not been able to achieve any significant reductions in total annual GHG emissions. While we can see great improvements in areas such as electricity, the oil and gas, buildings and transportation sectors have all seen gains in GHG emissions, which are potentially driven by economic and population growth.

As of 2019, Canada has reduced its GHG emissions by only 1.1% since 2005.

As such, the status quo in project development and technology rollout will not get us to where we need to go. A fast-track schedule for reductions by 2030 will require a shock to existing systems and significant commitments by all levels of government in Canada.

On the energy supply end, to replace energy from fossil fuels, large-scale electrical generation facilities such as hydro or nuclear energy plants can easily take a decade to develop, from planning to commissioning (as discussed in SNC-Lavalin Engineering Net Zero Canada report [Ref. 1]). While it is significantly faster to develop wind and solar power facilities, the energy and capacity expansion necessary to electrify all economic sectors will require a mix of all "zero emissions" power generation technologies. Furthermore, extensive investments and much time will be required to upgrade electrical transmission and distribution networks.

At present, many Canadian utilities have not yet included the required grid expansion investments in their long-term plans, and the demand forecast of most Canadian regulators are not accounting for the net zero targets.

On the load side, the rise in carbon taxes means that investors in industrial projects will require some assurance that the shift towards lower GHG emissions will not hurt the economic rationale of their projects and make their products uncompetitive in international markets.

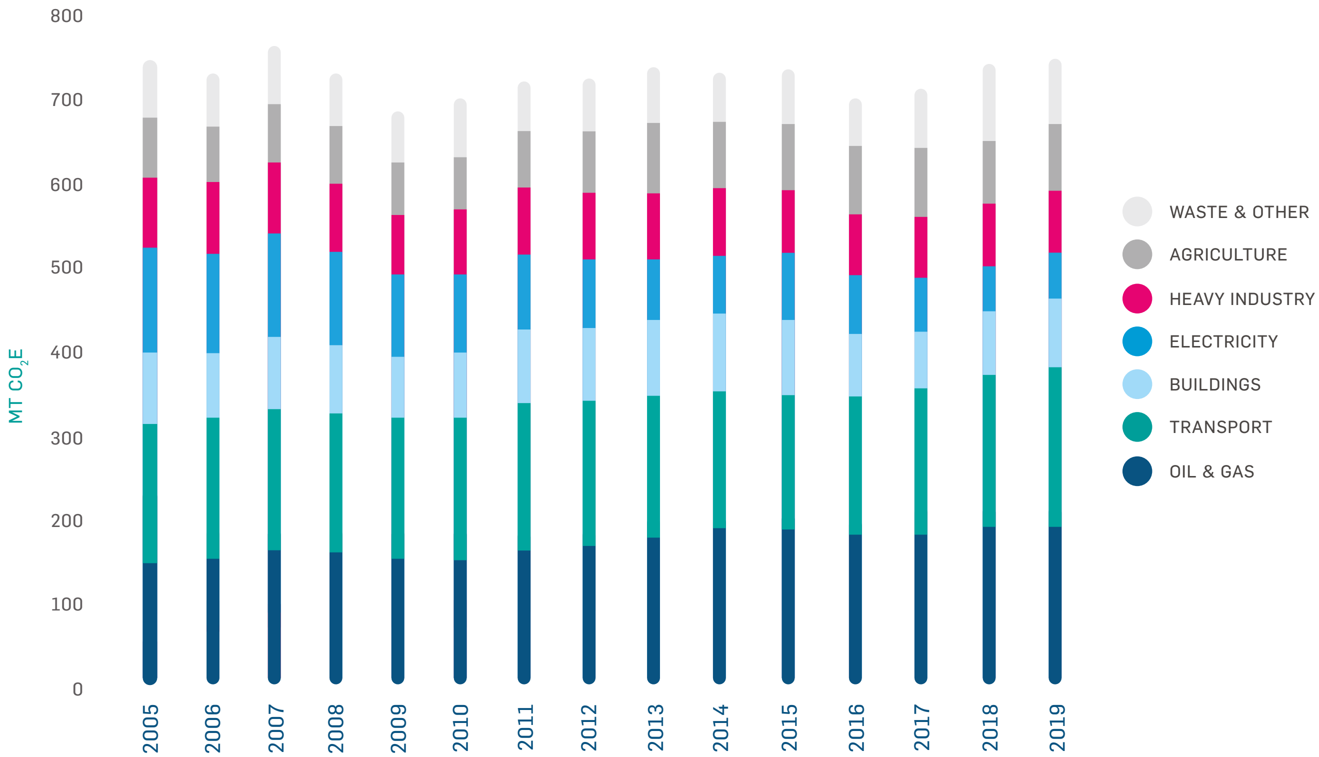


FIGURE 1 GHG EMISSIONS BY ECONOMIC SECTOR SINCE 2005 [REF. 5]

YEAR	OIL AND GAS	TRANSPORT	BUILDINGS	ELECTRICITY	HEAVY INDUSTRY	AGRICULTURE	WASTE AND OTHER	TOTAL
2005	159.9	160	84.3	117.6	87.4	72.2	57.4	**739**
2019	191.4	186	90.7	61.1	77.1	72.7	51.5	**730**
CO_2e Variation (Mt)	+32	+26	+6	-57	-10	+1	-6	**-8**
	+20%	+16%	+8%	-48%	-12%	+1%	-10%	**-1%**

TABLE 1 VARIATIONS IN GHG EMISSIONS BY ECONOMIC SECTOR SINCE 2005 [REF. 5]

An end-user paradigm shift will also be required in several other consumer-driven areas that contribute to GHG emissions. Changes to consumer behaviour, such as the use of personal vehicles or the choice of home heating systems, will require a progressive rollout, which must also consider the lifecycle of existing goods before their replacement. Leadership will be required to drive these changes, along with strong incentive programs from the government.

It is hard to foresee whether changes of this magnitude could possibly be completed in a period of eight years. Nevertheless, some gains could be achieved in the meantime.

A 2030 strategy needs to be devised with a focus on potential “quick wins” in specific sectors while putting in motion the social and economic changes that will enable Canada to meet its 2050 net zero GHG emissions targets.

For gains to be achieved by 2030 will require behavioral change from consumers, strong incentive programs from the government and innovative and adaptative industries.

C. Economics of carbon credits and carbon taxes

Canada and most provinces have committed to reducing their GHG emissions, and a carbon price signal is one of the key factors driving change. Most provinces have implemented a GHG cap and trade system, a carbon tax or a combination of the two. For provinces without their own program, the federal backstop system applies. This is a significant incentive for provinces to develop their own program and for communities to reduce GHG emissions.

The federal carbon tax applies to all fossil fuels. The cost was $40 per tonne in 2021 and will rise to $50 per tonne of carbon dioxide equivalent (CO_2e) in 2022.

Starting in 2023, the carbon tax is slated to increase yearly by $15 per tonne, up to $170 in 2030. Industries not included in a provincial regulatory system, such as a cap and trade mechanism, will be included in federal output-based performance standards to regulate their emissions.

As most industries and fossil fuel users will see a significant and predictable increase in their operational costs due to the carbon tax, or its equivalent, a shift from fossil fuels to alternative or less carbon-intensive energy sources is expected to happen.

D. So how do we cut 284-321 megatonnes of carbon dioxide equivalent emissions by 2030?

In 2005, Canada's total GHG emissions were 739 Mt, representing about 2% of overall global GHG emissions. Cutting 40-45% of our GHG emissions implies cutting around 284-321 Mt by 2030. If this target is to be achieved, reduction initiatives should focus first and foremost on areas with the most emissions, where techno-economically viable solutions already exist and could be deployed at scale. Corresponding targets could be derived from each economic sector, for instance:

- A reduction of 40 Mt CO_2e emissions in the electricity sector, driven by the retirement of coal power generation in Saskatchewan, Alberta, New Brunswick, and Nova Scotia. Furthermore, as discussed in SNC-Lavalin's Engineering Net Zero—Canada Report, GHG reduction pathways will be highly dependent on electrification using renewable and non-emitting energy. If at all realistic, this would entail the addition of up to 5 to 7 gigawatts (GW) of non-emitting generation per year, in turn requiring massive expansions and upgrades of transmission and distribution networks. Further reductions could be envisaged through the retirement of gas generation, unlikely to happen before 2030. These challenges are discussed in section 2.A.
- A reduction of 35 Mt CO_2e emissions in the transportation sector, by electrifying 30% of light and medium trucks. Trucks account for 57% of total emissions in transportation, so significant short-term gains could be achieved in this area. We also need to electrify 30% of personal vehicles to achieve the 35 Mt reduction. Advancements in transportation technologies are discussed further in section 2.B.
- A reduction of 30 Mt CO_2e emissions in the oil and gas sector, which will depend mainly on eliminating fugitive and venting emissions of methane gas. There have been encouraging results so far, as discussed in section 2.C, along with other potential solutions within the oil and gas sector.

In addition to the above, we assume a 30% reduction in other sectors (such as buildings, agriculture, industrial and waste). These reductions would eliminate another 90 Mt of CO_2e emissions. This is no small task, as emissions in these areas have remained steady or risen in recent years, despite previous targets to reduce GHG emissions by 2030. Each of these sectors will undoubtedly require significant regulation, investment, and incentives, and the level of disruption to these economic sectors will be unlike anything seen before.

Assuming that we achieve all the above, an additional 89-126 Mt CO_2e reduction would still be required across all different sectors to reduce CO_2e emissions by 40-45% Mt by 2030. Some potential pathways could include greater electrification of transport, the use of Carbon Capture and Storage (CCS) for thermal plants and industrial processes, electrification of oil and gas extraction and refining processes, and broad use of hydrogen energy. We also note that the numbers above focus on emission reductions at the source. Carbon credit mechanisms may also be used to address the remaining balance of GHG emissions and help achieve the 2030 targets.

The task above is monumental and, in contrast with the 2050 objectives, leaves less than a decade to rollout successfully. However, significant reductions will need to be demonstrated in the medium-term if we are to have a realistic chance at a net zero future.

The next section of the report will examine potential areas of reductions of GHG emissions in three key sectors: electricity, transportation, and oil and gas. It will discuss the status of various technological initiatives and bring to the forefront what has, and has not, worked so far.

TOWARDS A LOW CARBON FUTURE

2. Areas of focus

A. Electricity sector

I. PHASING OUT COAL BY 2030

In December 2018, the Government of Canada introduced a regulation to phase out coal-fired generation by 2030. Currently, coal-fired generation is being used in four Canadian provinces: Alberta, New Brunswick, Nova Scotia, and Saskatchewan [Ref. 6].

In the electricity sector, the vast majority of remaining emissions come from coal-fired power plants. The existing coal generation capacity is 8,800 megawatts (MW) of power across 14 plants, which emit approximately 40 Mt of CO_2e emissions annually. Nine of these 14 stations have an output of over 500 MW each and are equivalent to approximately 9,000 MW of large, concentrated baseload power generation. According to the U.S. Energy Information Administration, burning coal produces almost twice as much CO_2 emissions as burning natural gas, emitting up to 228.6[1] and 116.65[2] pounds of CO_2 per million British thermal unit (BTU) respectively [Ref. 7].

Alberta is aiming to retire coal power generation by 2023. Some of the retired coal facilities will be converted to combined-cycle natural gas plants, which have lower GHG emissions. The converted facilities will have the option to run initially using 30% hydrogen, with the possibility to retrofit the plants to run using 95% hydrogen in the future [Ref. 8]. Research and Development (R&D) efforts are still required as this solution alone cannot contribute to achieving the 2030 target. Alberta expects to replace the remaining coal capacity via solar and wind generation.

Although coal power generation retirement in Alberta entails a significant reduction in GHG emissions, it will likely not be sufficient to meet the country's COP26 commitments of reaching a net zero grid by 2035 [Ref. 2].

As of 2018 in New Brunswick, NB Power generated 12.2 terawatt-hours (TWh) of electricity. About 30% of this generation came from fossil fuels (coal, natural gas and petroleum) [Ref. 9]. The NB Power Integrated Resource Plan (IRP) "proposes to keep greenhouse gas emissions at current levels of about 3 million tonnes a year until 2040" [Ref. 10]. The existing IRP does not yet integrate the federal government's plans to reach the climate change goals.

Similarly, Nova Scotia Power (NSP)'s integrated resource plan does not assure that coal will be retired by 2040. Some of the plan's scenarios "have trajectories that retire all coal plants no later than 2030, while others retire them by 2040" [Ref. 11]. The development of the Atlantic Loop which is expected to provide clean power to Nova Scotia may lead to earlier coal retirements. The objective behind the Atlantic Loop project is to allow for retirement of coal-fired plants on the East Coast by transmitting hydropower from Quebec and Labrador to the provinces of New Brunswick, P.E.I. and Nova Scotia [Ref. 12].

In Saskatchewan, the provincial and federal government have signed an "equivalency agreement" to retire coal power generation by 2030 [Ref. 13]. The province is expected to replace the retired coal capacity by generating electricity in combined-cycle gas power plants and increasing its use of renewable energy. The use of modular nuclear reactors is also a possible contributor to GHG reduction and requires further study and consideration in the generation mix.

[1] In metrics, this converts to 104 kg CO_2 generated from coal power generation per BTUs
[2] In metrics, this converts to 53 kg CO_2 generated from open cycle gas turbine generation per BTUs

The four provinces' IRPs that rely on coal power generation generally do not support the use of carbon capture technology by 2030. However, this may change over time, as the need to reduce GHG emissions becomes more acute, and the technology becomes more economically competitive.

Unless coal generation is replaced by gas combined with CCS technology, the provinces will need to consider non-emitting options.

II. ELECTRIFICATION'S IMPACT ON LOAD DEMAND

Electrifying end-use energy services in the residential, commercial, transportation and manufacturing sectors is expected to increase electric load requirements significantly, a fact not yet fully accounted for in provincial IRPs. This section outlines a scenario that shows the potential scale of the impact of electrification on electricity demand.

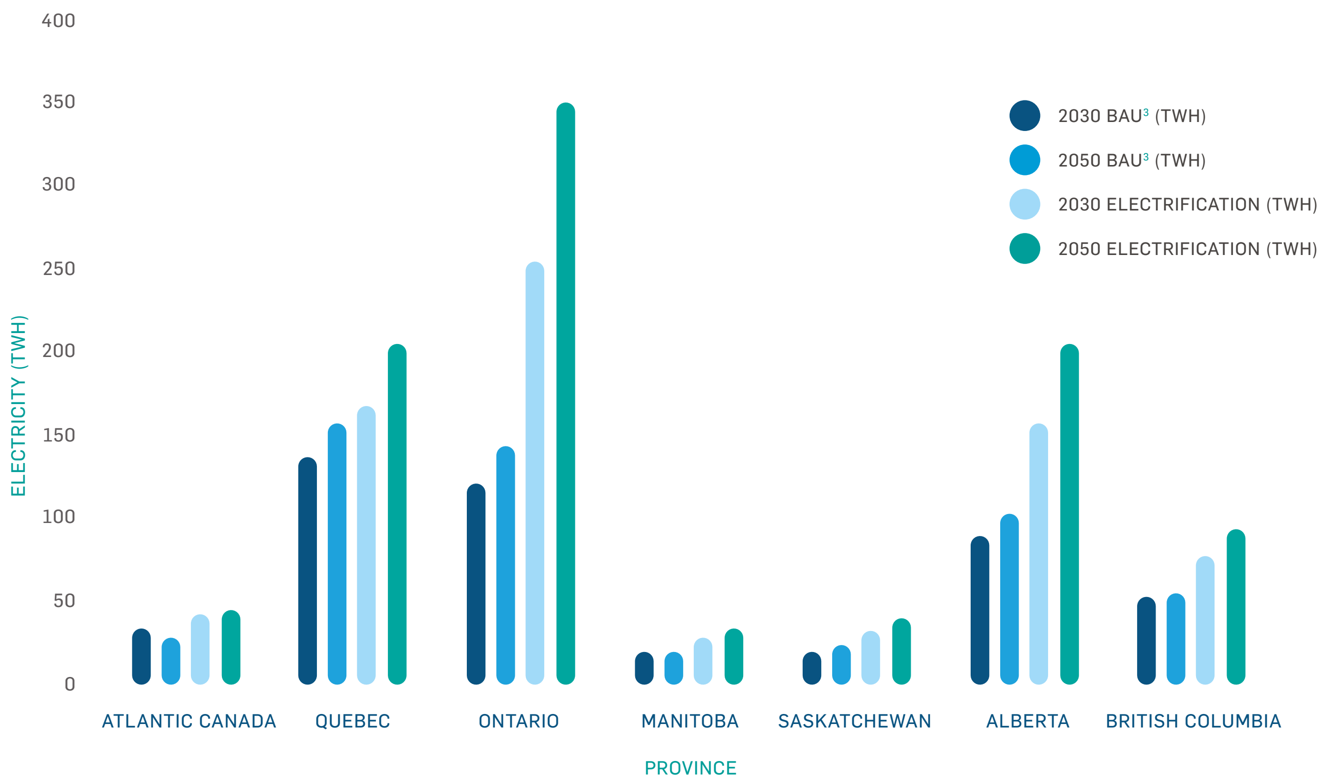


FIGURE 2 GHG EMISSIONS REDUCTION IN CANADA: POTENTIAL IMPACT OF ELECTRIFICATION ON ELECTRICITY CONSUMPTION[4]

[3] BAU: business as usual

[4] Electricity consumption values used to create the figure based on the CERI study [Ref. 14].

The scenario, presented in a study by the Canadian Energy Research Institute [Ref. 14], shows that electrification of the end load may double the demand for electricity in Canada by 2050, with the largest load increases expected in Ontario (2.5 times business as usual [BAU] scenario) and Alberta (2 times BAU). This is attributed to the large number of people who would switch from natural gas to electric heat, as well as to the electrification of passenger transportation. The lowest increase (20% higher than BAU) is seen in Quebec where most of the population already uses electric heat. Figure 2 presents the impact of electrification on electricity demand compared to the BAU case, by province or region. As shown, if we are to reach the 2050 target, more than half of the load increase will have already taken place by 2030. The Canadian grid is not on a path to meet this load in eight years.

A breakdown of the impact of electrification on each economic sector is presented in the following sections. This simplified analysis is meant to show the potential impact if the electrification pathway is fully adopted to reach net zero. However, the actual speed of market adoption of clean energy and the degree of electrification in each sector remains quite speculative, given the uncertainty associated with other clean energy pathway alternatives. Despite the constraints associated with electricity infrastructure, electrification will be one of the main ways to reach net zero and will result in a notable increase in electricity demand that needs to be accounted for while planning our clean energy transition.

ELECTRICITY DEMAND IN THE TRANSPORTATION SECTOR

To meet the 2050 net zero target, we consider a scenario where Canada would reduce GHG emissions related to light-duty vehicles by 30% by 2030. Under this ambitious scenario, CO_2e emissions would drop by 35 Mt and electricity demand would rise by 36 TWh, requiring a 5.4% increase in Canada's current electricity production.

Given the technical challenges associated with electrifying heavy trucking, it is fair to assume that this industry will eventually depend on hydrogen to meet the net zero goal. This is further discussed in Section 2.B.III—Heavy Trucks. It is unlikely that the industry will achieve widespread adoption of hydrogen by 2030 at the current rate of development and availability of hydrogen resources and infrastructure.

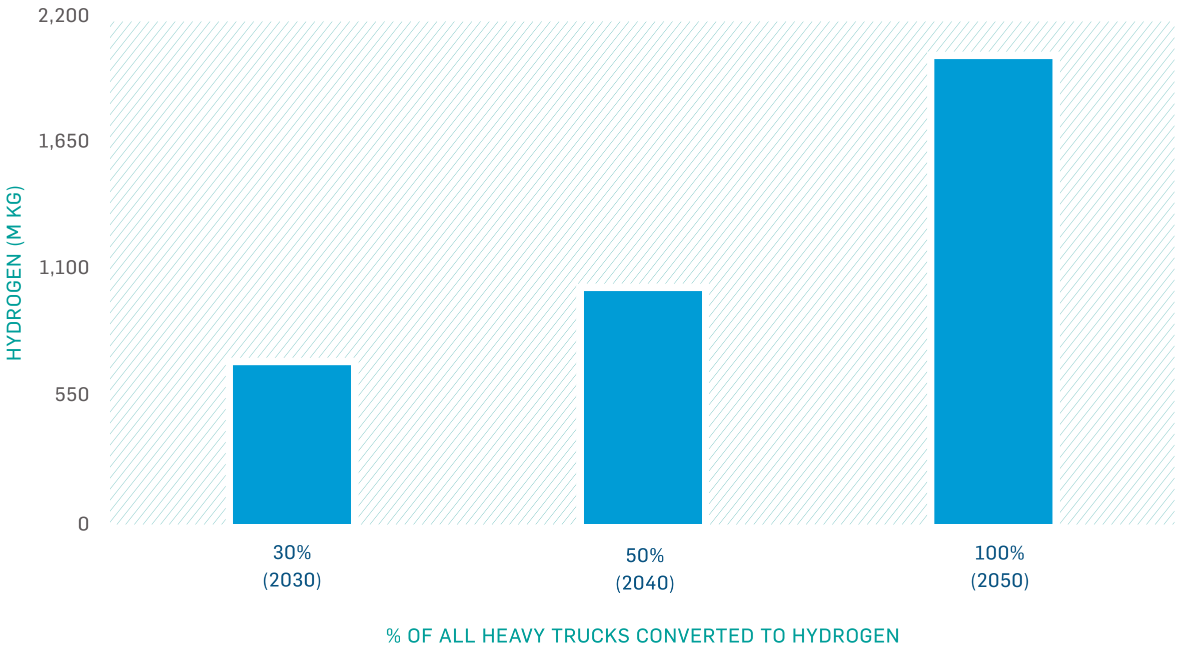


FIGURE 3 HYDROGEN REQUIRED TO POWER CANADA'S HEAVY TRUCKING INDUSTRY

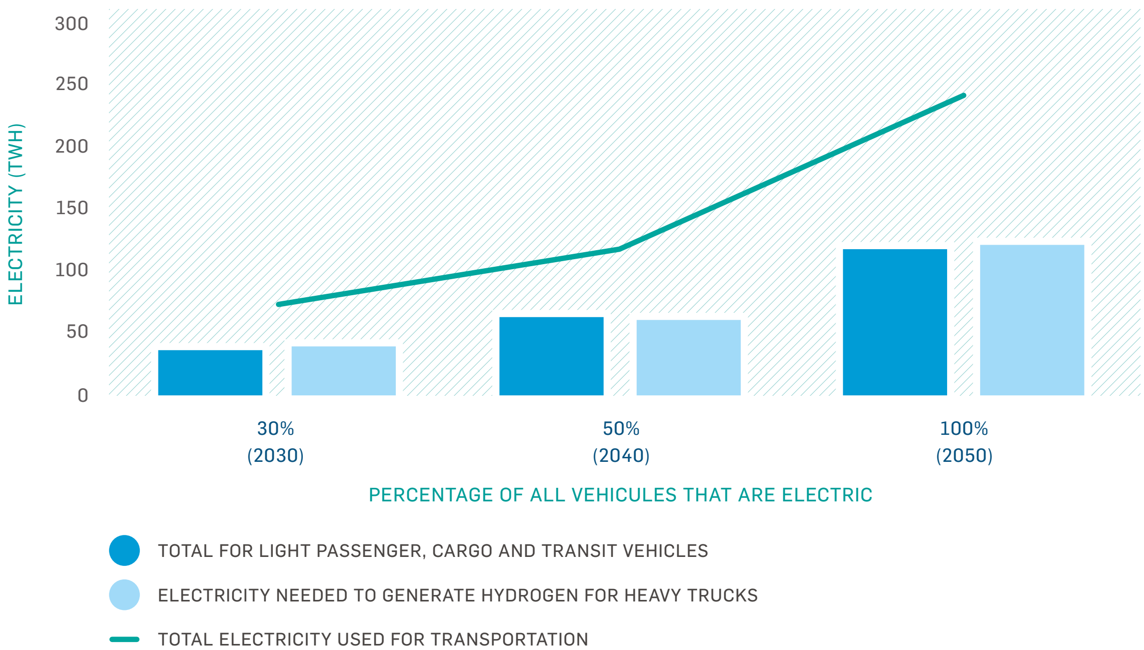


FIGURE 4 ESTIMATED ELECTRICITY REQUIREMENTS TO FULLY ELECTRIFY THE TRANSPORTATION SECTOR BY 2050

However, if it does, we could also cut these vehicles' annual CO_2e emissions by 30%. That would reduce CO_2e emissions by 11.7 Mt CO_2 and would require an additional 37 TWh in electricity generation annually—an approximate increase of 5.6% in Canada's current electricity generation to produce green hydrogen.

ELECTRICITY DEMAND IN THE BUILDINGS SECTOR

There are about 15 million households in Canada using various fuels for heating, including natural gas (about 7.5 million), fuel oil and propane (fewer than 1 million), electric resistance and heat pumps (about 6 million), and wood (fewer than 1 million). Assuming an ambitious scenario where we electrify 30% of the remaining non-electrical heating load by 2030, 60% by 2040, and 100% by 2050, and considering an average heating need per household of 20,000 kilowatt-hours (kWh) per year, this would translate into additional electricity demand of roughly 45 TWh by 2030, 90 TWh by 2040 and 150 TWh by 2050.

As per the Survey of Commercial and Institutional Energy Use, in 2009 there were roughly 482,000 commercial and industrial buildings in Canada totalling 800 million square metres of floor space [Ref. 15]. These buildings used approximately 840 Petajoules (PJ) of energy, of which 47% was electricity and 44% was natural gas. Switching 30% of the natural gas heating to electric heating of these buildings by 2030, 60% by 2040, and 100% by 2050 would increase electricity demand by 30 TWh, 60 TWh, and 100 TWh, respectively.

ELECTRICITY DEMAND IN THE INDUSTRIAL SECTOR

As per Statistics Canada, total energy use in the industrial sector reached 2,196 PJ in 2019 [Ref. 16]. Natural gas and electricity are the primary energy sources, with each meeting about 30% of the total demand. It is estimated that 50% of the total energy demand may switch from natural gas to electricity as it is extremely difficult and complex to fully electrify industrial processes. The 50% electrification would correspond to 100% space heating, 100% steam boilers and 50% process heating. If 30% of conversion from natural gas is achieved by 2030, 40% by 2040 and 50% by 2050, demand for electricity would rise by about 54 TWh by 2030, 72 TWh by 2040, and 90 TWh by 2050.

III. SUPPLY-SIDE OPTIONS TO MEET ELECTRIFICATION DEMAND

Canada's energy mix is rich in clean energy resources, including wind, solar, nuclear and hydro energy. It is fair to assume that most of the new supply of electricity until 2030 will come from wind and solar resources supported by combined-cycle power plants fuelled by natural gas, given the time required to develop large nuclear or hydro generation plants, and to electrify the transportation, building and manufacturing sectors.

The increased electrification load can be met by a wider deployment of wind and solar resources along with combined-cycle generation fired by clean fuel[5].

[5] A definition of clean fuel is available here:
https://www.nrcan.gc.ca/our-natural-resources/energy-sources-distribution/clean-fuels-fueling-the-future/23735

For an aggressive electrification scenario where most of the end uses are electrified, sizable baseload nuclear power and hydro generation will have to be developed to meet the demand. However, the implementation of new major hydro or nuclear generation projects by 2030 to meet the expected load increase associated with electrification is not expected because of the regulatory barriers and long project lifecycles.

Taking either large hydro or nuclear power as an example, building 9,000 MW (approximately 70 TWh) of power plants in Canada and having them online to cater to the aggressive electrification scenarios between 2030 and 2040 is achievable only under certain conditions. This added power would cover only some of the expected load increase discussed previously (i.e., 30% electrification of light transportation and 30% hydrogen-fuelled heavy transportation). The ambitious implementation of this level of generation would require at minimum:

FOR NUCLEAR:

- Selecting a ready-now technology that already has some degree of regulatory review and approval.
- Accelerating site licensing and environmental assessments compared to conventional timelines.
- Installing nuclear reactors in Ontario and Alberta, the two provinces that are expected to see the largest load increase due to electrification. New nuclear generation can make use of retired coal power generation sites and existing transmission infrastructure, thus making the development of these projects more appealing.

FOR HYDRO:

- Selecting a healthy combination of medium and large-scale hydro.
- Accelerating environmental assessments compared to conventional timelines.
- Reinforcing the power grid around the most remote hydro sites.
- Building new hydro generation projects in British Columbia, Quebec, Manitoba, and Newfoundland, combined with pan-Canadian grid interconnections.

The required build rate would be similar to the nuclear and hydro new build rates Canada achieved in the 1970s and 1980s. Canada could achieve this feat if this process starts in the coming two to three years with the launch of several projects in parallel. This would be a first step in the right direction, however, as discussed so far, a much greater build rate of power generation is still needed to meet the ambitious 2030 and 2050 targets.

IV. POWER GRID OPERATION BOTTLENECK

Most provincial integrated resource plans do not fully consider the impact of electrification on the electricity demand required to meet the near-term reduction of 40 to 45% of GHG emissions.

As discussed earlier, full electrification of most end users across all economic sectors may result in a massive jump in electricity demand, which could double by 2050.

Our transmission and distribution infrastructure is not ready to accommodate this increase and the system has little flexibility to integrate more intermittent renewable resources.

Unless sizable investments are made to strengthen the existing transmission infrastructure to meet the challenges ahead, we will risk losing the integrity and reliability of the grid needed to support the transition to green energy.

V. OPPORTUNITIES FOR GREENHOUSE GAS REDUCTIONS IN ELECTRICITY BY 2030

During the next eight years, the electricity sector must adopt and integrate alternative, clean sources of energy to meet the growing demand arising from the upcoming, unavoidable electrification of all economic sectors. Canada will need to further tap into its renewable resources to alleviate the environmental impact. Overall, the government has committed to a net zero power grid by 2035 [Ref. 2].

COMPLETE PHASE-OUT OF COAL

The federal government should fulfill its commitment to make Canada coal free by 2030 as discussed in section 2.A.I.

DEVELOPMENT OF THE PAN-CANADIAN GRID

We should speed up regulatory, permitting, procurement and construction activities needed to bring the Atlantic Loop into commercial operation before 2030. This Loop will help the Atlantic region retire coal power generation and get closer to meeting GHG reduction targets. Similarly, the Western Interconnections could help Alberta and Saskatchewan substitute coal generation by clean hydropower imports from British Columbia and Manitoba [Ref. 1].

DEVELOPMENT OF RENEWABLE GENERATION

As per section 2.A.III, the declining cost of wind and solar power plants represent a good opportunity to provide incremental clean power generation that can be deployed quickly to meet electrification demand and, in turn, reduce emissions across all economic sectors.

ENERGY STORAGE

To keep the system reliable and flexible, future wind and solar power plants should be paired with battery energy storage.

We should plan to develop long-duration bulk storage, such as pumped hydro or compressed air on the scale of hundreds of MWs to support wider integration of renewables after 2030.

Market regulations should be amended to provide more potential revenue streams for the multiple ancillary services that energy storage provides to the grid.

DISTRIBUTED GENERATION AND MICROGRIDS

Microgrid developments and distributed generation can provide clean energy for many communities across Canada, without costly and time-consuming development of long transmission lines.

SMART GRID

Developing smart grid control and communication backbone would allow us to maximize utilization of the existing distribution system.

B. Transportation sector

I. BREAKDOWN OF EMISSIONS

The transportation sector includes a variety of modes and vehicles, such as aviation (passenger and freight), deep-sea shipping, coastal shipping, local shipping (harbour ferries, tugboats and other port services vessels), rail freight, passenger rail (heavy rail), transit rail (light rail, metro, and streetcars), and road transportation. The latter can be broken down into the following subsectors: cars, light trucks, medium trucks, heavy trucks, motorbikes, school buses, transit buses, and construction and mining (or similar mineral extraction/processing plant) vehicles.

Altogether, the transportation sector creates a quarter of all GHG emissions, making it the second-largest contributor to GHG emissions in Canada. As shown in Table 2, road transportation accounts for much of the sector's emissions. The three largest emissions categories are cars, light and heavy trucks. Passenger air travel is also a heavy emitter and faces a challenging task in directing technological advancements towards a net zero future [Ref. 17]. Inherent technical difficulties affect the development and uptake of zero "tailpipe" emissions propulsion in many of these sectors. However, recent and ongoing efforts to overcome these obstacles are bringing commercial products to the market. Most notably, cleaner options have been introduced for cars, light trucks and, most recently, medium trucks. Short-sea battery electric ferries, as well as lighter electrified construction and service vehicles, have also been brought to the market.

In light of the revised 2030 emissions targets, the importance of the technological barriers in some transportation subsectors cannot be overstated. Despite the significant work undertaken by academia, transportation equipment manufacturers, fuel providers, distributors, and their support industries, the following subsectors do not currently have a fully developed and commercially viable pathway to a zero emissions outcome:

- Shipping, with the exception of short voyages in harbours or sheltered waters, for which battery electric vessels have gained a foothold;
- Aviation, potentially the most complex sector to decarbonize;
- Heavy trucks;
- Mining, construction and similar equipment.

To illustrate the scale of the emissions reduction required within the transportation sector, consider that it would be necessary to replace every internal combustion engine (ICE) car, light truck and van in British Columbia, Ontario and Quebec by 2030 to meet the target!

The following sections explore feasible options for decarbonizing the sector's two largest emitters: cars and light trucks. Within the time period being considered, there are two viable net zero replacements for hydrocarbon-powered vehicles: battery electric vehicles and hydrogen-powered vehicles.

II. FUEL TECHNOLOGIES

BATTERY ELECTRIC VEHICLES

The current market offers a relatively large supply and variety of battery electric cars and light trucks for private and commercial buyers, with many more models in development. However, scaling battery electric technology to the heavier end of the road freight market is proving to be a challenge, as is providing large numbers of very high-power fast chargers[6] to service such batteries in a single location.

GHG EMISSIONS BY TRANSPORTATION MODE IN 2018 (MT CO_2E)

Light Trucks	56.82
Cars	34.62
Heavy Trucks	34.61
Passenger Air	22.67
Medium Trucks	21.60
Off-Road	8.64
Freight Rail	7.44
Marine	5.14
Urban Transit	2.53
School Buses	0.61
Freight Air	0.54
Motorcycles	0.39
Inter-City Buses	0.23
Passenger Rail	0.17

TABLE 2 GHG EMISSIONS BY TRANSPORTATION MODE IN 2018 [REF. 17]

[6] High power fast chargers are also called "Level 3" chargers. They supply DC power ranging from 150-350 kW. These are becoming increasingly available throughout Quebec, Ontario, Alberta and British Columbia [Ref. 19]. For comparison, a "Level 1" charger provides only 1.3 to 2.4 kW and connects to the household 120V electrical supply. "Level 2" chargers on the other hand connect to the 240V supply and can provide from 3 to 19 kW of power depending on the installation.

To achieve large-scale transition from hydrocarbon transportation to electric vehicles (EVs), we will also need to shift from long-range fuel transportation (by pipeline, road, rail or ship) to greater reliance on the electricity grid. Other EV adoption challenges include improving vehicle range (in comparison to conventional vehicles), a task closely related to the expansion of EV charging infrastructure. By 2030, we must also improve battery recycling options and production materials supply to permit the large-scale shift to battery electric vehicles. Battery electric vehicles use various types of lithium-ion batteries. This requires active thermal management (heating or cooling) of the battery pack to maintain it in a safe, operable condition, but that consumes battery energy. Active thermal management is generally required when ambient temperatures are outside the -5 to +35 degree range (with exceptions). The energy expended in managing the battery thermally results in a significant range reduction. Canada's climate exacerbates this effect more so than more temperate climates.

Despite these drawbacks, significant use of battery electric vehicles—mainly cars and light trucks—is realistically the only viable way to seriously reduce road transportation GHG emissions between now and 2030.

ELECTRIC VEHICLE INFRASTRUCTURE

As discussed previously, large-scale adoption of electric vehicles will likely give rise to substantial energy generation, transmission, distribution and low-voltage network challenges.

EV infrastructure in this report is taken to mean non-residentially installed level 2 and level 3 charging equipment and its immediate connection to the utility grid at low voltage (380 to 600 V three-phase AC) or medium voltage (4.16 kV to 69 kV AC) as determined by expected load demand. This is Canada's current approach to providing EV charging facilities and we can assume it will continue until at least 2030. Additional technologies that supplement or replace the utility connection with local renewable energy sources will likely also be deployed over the same period.

A pure supply and demand-driven solution to providing EV infrastructure faces the following obstacles:

1. Low and medium-voltage network capacity, which could be addressed with various technological solutions (at varying costs);
2. The charging and commercial model to be adopted (a pricing model that would pass the full costs of EV infrastructure solely to EV owners would make EV adoption less attractive);
3. A supply and demand conundrum—should we wait for EV adoption and then scale the infrastructure, or provide the infrastructure ahead of the projected curve?

ELECTRIC VEHICLE MARKET ADOPTION ISSUES

For both cars and light trucks, this report assumes the immediate pathway to decarbonization is the use of an EV alternative to a conventional ICE vehicle. This is seen as a realistic proposition, given that ICE vehicles in these categories could be replaced with available EV alternatives. However, a number of obstacles to adopting such changes make a purely market-led approach complex.

LIMITED RANGE AND CHARGING INFRASTRUCTURE

The major barriers, both in fundamental terms and terms of consumers' perceptions, are anxiety about vehicle range and the availability of charging infrastructure [Ref. 18]. Motorists are used to the flexibility and versatility of ICE vehicles with their almost unlimited range (given the wide availability of fuelling infrastructure) and quick refuelling time. If drivers voluntarily switch to EV alternatives, which may be more expensive and/or have fewer amenities, it is rational that they should expect to use their EV in a manner reasonably similar to the way they used their preceding ICE vehicle. Current EV users understand the need for charging time and for planning longer routes based on the available infrastructure; they see these inconveniences as a reasonable compromise, given the attractive driving characteristics and other features of EVs.

Many drivers considering EV purchases accept the technical limitation of vehicle range. The availability of charging infrastructure is seen as far more important because EV owners plan journeys around recharging opportunities. According to Natural Resources Canada [Ref. 20], there are over 7,400 EV chargers in Canada; the majority being level 2 chargers and level 3 DC fast chargers. The charging infrastructure is not growing quickly enough to facilitate a wholesale conversion of entire fleets of vehicles by 2030 in major metropolitan communities, where a significant proportion of Canadian vehicles are located.

There are considerable limitations to providing EV infrastructure in remote communities. Technological solutions to this problem are readily available, integrating with renewable resources and local microgrids, but many vehicles in these remote communities also have to travel beyond present and projected EV ranges. Accordingly, our predictions for the rate of EV adoption assume that most people in these areas will continue to use ICE vehicles beyond 2030.

Increases in vehicle range and availability of charging infrastructure are the two factors most often cited by users who wish to adopt an "all-electric" solution and by those contemplating their first EV purchase. For many users, the combination of limited vehicle range and lack of charging infrastructure requires significant accommodations in usage, making EV purchases seem undesirable.

MODEL CHOICE

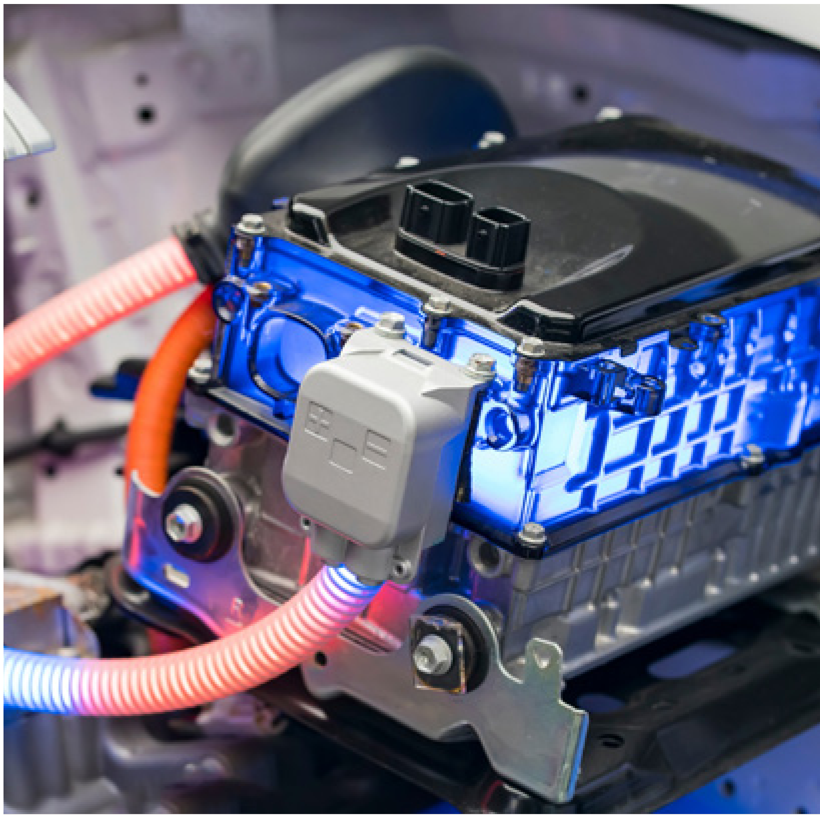
Another barrier to completely transitioning to battery electric vehicles is the lack of model options, in comparison to much more widely available ICE alternatives. The currently available range of EVs may not reflect the preferences of all consumers. The auto manufacturing industry is rapidly pivoting to build a much wider range of EV models, so this factor is expected to become less of an issue by 2030.

LIMITED MATERIAL SUPPLY AND RECYCLING

All present battery electric vehicles require significant amounts of rare earth materials and other elements to be technically and commercially attractive. The issue of lithium availability for battery packs is already widely known, but modern, high-performance motors (in particular, their strong permanent magnets) also require other rare earth materials, such as dysprosium and neodymium, which are globally in limited supply. Other available design options, such as the use of a conventional motor, can overcome a lack of rare earth materials. However, they are likely to have a significant impact on vehicle performance, range, and usability.

A recent article on the BBC website highlighted the quantity of these materials needed to enable the U.K. to meet its 2030 commitments to GHG reduction in the transportation sector via near-universal adoption of battery electric vehicles [Ref. 21]. Meeting the U.K.'s demand alone would require the world to triple its output of the ore-containing minerals, often at significant environmental cost.

Finally, the supply chain is virtually unable to extract these materials from end-of-use vehicles. Lithium-ion battery recycling is largely limited to repurposing propulsion batteries for static applications, where the cells have some additional years of useful life. However, safe raw material recycling requires a range of complicated processes, and few such processes are economically viable.



FUNDING

Thus far, most public charging facilities have been provided in the following ways, either alone or in combination:

- Through federal, provincial and municipal initiatives;
- By retail, office companies or landlords, to charge visitor or employee vehicles (these include facilities at numerous SNC-Lavalin office locations);
- By oil companies, as a complement to hydrocarbon fuelling;
- By electric utilities;
- By privately funded companies, such as ChargePoint, Flo, Electrify Canada.

Given that many private and commercial owners see the shortage of recharging facilities as the largest barrier to EV adoption, we need to consider how to provide charging infrastructure over the next decade in places that may not attract commercial funding.

In 2016, the federal government introduced the Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative [Ref. 22], which is summarized as follows:

"Budgets 2016 and 2017 provided $96.4M over six years (April 2016 to March 2022) to the Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative ('the Program') to establish a coast-to-coast network of fast-charging stations along the national highway systems, natural gas refuelling stations along key freight corridors and hydrogen refuelling stations in major metropolitan areas.

Building on this investment, Budget 2019 provided an additional $130M over five years (April 2019 to March 2024) to support Canada's mandatory zero emission vehicle (ZEV) penetration targets of 100% new vehicle sales by 2035, which required incremental funding to the Electric Vehicle and Alternative Fuel Infrastructure funding, to accelerate and densify infrastructure deployment. The investments go beyond the national highway system, and focus on EV level 2 charging at workplaces, commercial and multi-unit residential buildings, public places, on-street and projects for fleets (e.g., taxis, car sharing)."

Under this program, a wide range of bodies received funding, including provincial power companies, individual utilities, private development owners, car manufacturers, and EV charging intermediaries that provide infrastructure in return for a revenue share. Future initiatives could also tap into this wide range of EV infrastructure delivery methods.

If this program is to be scaled to serve the expected numbers of EVs in Canada, governments may need to bridge the funding gap. Most of the above models require some form of subsidy or capital injection, at the initial build stage or during the infrastructure's lifespan, which the public or private provider must recoup. Where there is public involvement, governments can do so through selective and/or general taxation measures.

Equally, governments can introduce legislation or regulations to stimulate the market and to encourage the private sector to provide infrastructure funding, to ensure that emissions keep dropping in the transportation sector.

HYDROGEN-POWERED VEHICLES

Despite a significant period of technological development[7], the difficulties of producing, handling, storing and dispensing hydrogen fuel have made the development of hydrogen-powered vehicles more complicated than the adoption of battery electric vehicles. Hydrogen fuel also requires a new primary distribution system, as very few existing pipelines are suitable for hydrogen use, due to a variety of technical factors.

Hydrogen is the smallest atom. As a result, many materials used to store and pipe other gases are too porous to contain H_2. The hydrogen diffuses through the material, leading to often significant product losses and, if the product loss is localized, danger of fire. Such leaks can make pipeline or storage vessel walls brittle, which accelerates failure.

[7] William Grove established the principles of the hydrogen fuel cell in 1839. Francis Bacon led the first practical demonstration of any form of fuel cell in 1938 and one for hydrogen/oxygen in 1958.

Although hydrogen has a very high specific energy, it needs to be heavily compressed or liquified to increase energy density to a level comparable to that of hydrocarbon fuels. Hydrogen liquefaction requires temperatures of -253 °C at atmospheric pressure and the transition from a gas to a supercritical fluid takes place at approximately 12 Bar and -240°C. The energy stored per unit of volume at this pressure is very small; hence hydrogen fuel systems tend to operate between 240 and 680 bar, or even higher. Keeping such fuel systems gas tight throughout a vehicle's life has proven to be a challenge for conventional compressed natural gas-powered vehicles, which tend to use lower pressures[8]. Some of these obstacles may eventually be offset with the use of ammonia as a hydrogen carrier. This solution is still under development and requires significantly more research.

Hydrogen may be converted to electricity for vehicle propulsion in a fuel cell (by far the largest application so far). However, a direct hydrogen internal combustion engine has been developed. That could allow for a non-electric drivetrain, which may remove some of the inherent material constraints noted for modern propulsion motors. The drivetrain approach also allows for an engine that can run on both hydrocarbon and hydrogen fuels, which would ease the logistical challenges involved in shifting from hydrocarbon to hydrogen fuelling, as hydrogen fuel may not initially be widely available throughout the country.

The inherent speed of gaseous refuelling versus any form of battery charging (for equivalent energy transfer), combined with the potential to develop high-power outputs for sustained periods without refuelling (which is challenging with batteries), means that hydrogen has significant prospects to be a better long-term technical option for heavy trucks, and for mining, agricultural, construction and similar uses.

VEHICLE	ICE VEHICLE MASS (KG)	COMPARABLE EV	EV MASS (KG)
Chevrolet Sonic	1,296	Chevrolet Bolt	1,616
Chevrolet Cruise	1,329	Chevrolet Volt	1,607
Nissan Versa	1,086	Nissan Leaf	1,560
Ford Mustang 5.0GT	1,692	Ford Mustang Mach E	1,993
Ford F-150 3.5 V6 Ecoboost SuperCrew	2,449	Ford F-150 Lightning	2,948

TABLE 3 COMPARISON OF MASS FOR ICE VEHICLES AND EVS

[8] This statement is based on the experience of many operators, as reported in numerous reports and studies, including those prepared by SNC-Lavalin for various clients.

Bulk production of hydrogen is examined in section 3. In addition, local, on-demand production of hydrogen through local air liquefaction plants is entirely feasible and may offer decarbonization solutions to more remote communities, where logistics and distance make it more difficult to replace hydrocarbon fuels.

As an example, Elbe-Weser Bahn is an integrated rail and transit bus operator in northeastern Germany, co-owned by municipalities and the state. It has adopted hydrogen-powered light rail vehicles, which regularly return to a base. That facilitates the use of a centralized hydrogen fuelling plant, which is the major cost element of hydrogen infrastructure. The fuelling plant generates hydrogen locally by fractionating air. The industrial gases company Linde AG funded the fuelling plant and associated infrastructure alongside the train depot. It sells other separated gases from the fractionation process to nearby industrial consumers to offset the capital and operational costs of the plant, making the hydrogen cost viable for the transit operator.

That type of arrangement is equally viable in Canada and some transit operators are expected to adopt it by 2030. However, more widespread adoption of hydrogen road vehicles is considered much less likely. Therefore, this report largely concentrates on the easiest technology to adopt by 2030: the electric vehicle.

III. MITIGATION MEASURES, BY VEHICLE TYPE

CARS

Cars account for 52.1 Mt of GHG emissions in Canada per year. Despite a pronounced increase in the number of cars registered over the preceding decade, and a general shift in consumer preferences from traditional sedans to SUVs and minivans—which are heavier, less aerodynamic, and generally less fuel efficient—GHG emissions have remained constant. This trend is attributed to significant advances in internal combustion engine efficiency and aerodynamics, the adoption of stop/start systems, low-rolling resistance tires, and an increasing proportion of hybrid and semi-hybrid/plug-in hybrid cars.

Similarly, uptake of battery electric cars is also rising, as are their capabilities and the range of vehicle models available for purchase. Government subsidies, available in certain provinces and territories have made it practical for many owners to buy lower-cost models. These subsidies offset the significantly higher purchase costs of EVs (when compared to similar ICE vehicles) and the expense of installing charging equipment at home. Many owners purchase a lower-end electric car for commuting and local trips, while retaining a gasoline pickup, car or SUV for longer distance journeys.

Regardless of the type of vehicle propulsion, mass is the largest single contributor to energy efficiency. Nearly all current EVs are heavier than their ICE counterparts[9] (see Table 3). This is primarily due to the weight of the battery and the associated structural support [Ref. 23].

If EVs could be made as light as their ICE counterparts, range and efficiency would climb and cost per kilometre would drop.

[9] All vehicle weights were obtained from manufacturers' specifications.

The variety of EVs in the car sector is set to change dramatically, as manufacturers switch to increasingly electrified product lines. Thus, choice, versatility and broader functionality may persuade more consumers to convert to EVs. To some extent, range issues are expected to diminish with increased choice and technological development.

LIGHT TRUCKS

Light trucks include a variety of vehicle types, generally up to 3,856 kg gross vehicle weight (GVW), such as:

- Cargo vans;
- Pickup trucks of various sizes;
- Similar derivatives based on the same chassis, often performing a very diverse range of tasks and duties.

Pickup trucks have an extremely large market share in North America. As an example, the Ford F-150 has consistently been the best-selling vehicle in the U.S.A. for many years. Customers value their versatility, high driving position and flexibility as a combined trade/work/family vehicle. Many consumers also perceive them as a “lifestyle choice” or as a “desirable vehicle”.

Many of these vehicles are in commercial service, where alternative vehicles may not meet all operational needs. Also, depending on the business model, commercial users may focus more on whole life costs or initial purchase costs than most private purchasers do.

Many manufacturers are bringing EV versions of these vehicles to the market, such as the Ford F-150 “Lightning” and Ford’s cargovan “E-Transit”.

For many owners and operators, these EV alternatives will present a good ownership proposition, particularly where the vehicles operate on a “return to base” principle after a work period, attractive to municipal utilities for example, potentially combined with bus electrification. Where EV charging infrastructure is available, range issues for longer duty cycles diminish.

For those vehicles working in remote areas, which need a long-range, or which require widely varying duties (city one week, wilderness the next), EV displacement of ICE powered vehicles will be more difficult.

MEDIUM TRUCKS

Medium trucks are typically heavier than 3856 kg and vary by type, duty, function and usage patterns. They are almost exclusively purchased by businesses. Most vehicles in this size range are twin- or multiple-axled, rigid wheelbase vehicles. Volvo offers a range of European (FE and FEL series) electric medium trucks up to a GVW of 13,600 kg (due to the weight of the battery), as well as the VNR range of electric trucks for the North American market [Ref. 24].

This category also encompasses short-range parcel delivery vehicles used in urban or semi-urban areas on a “return to base” principle. Most of them are gasoline powered. The intense start/stop use results in very poor fuel economy due to low drivetrain efficiency, and high emissions in populated areas.

Vehicle manufacturers in this category are also adapting to the EV revolution. General Motors is expected to bring such a vehicle to market shortly. Other vehicle builders, which use chassis and drivetrains from other manufacturers, are teaming with electric drivetrain producers to electrify their current and future offerings.

Most notably, UPS recently ordered 10,000 EVs from a U.K. company for deployment in North America and Europe [Ref. 25].

HEAVY TRUCKS

Heavy trucks are probably the most difficult form of road transit to decarbonize within the timeframes considered. This segment includes a wide range of vehicle and duty types, from long-haul tractor-trailer units to heavier, multi-axle, rigid-wheelbase trucks. Long-haul trucks may have ranges of 500 to 600 km per day, whereas a city-based aggregate truck may have the same energy requirements but only covers 50 to 150 km per day.

Manufacturers are working intensely to develop suitable EV heavy trucks for this market segment. However, at the time of writing, no vehicles of this type were commercially available. Established EV and EV drivetrain manufacturers are approaching this by scaling their existing technology. Other manufacturers believe that providing overhead electrical supply, like that used for streetcars, is a better approach.

Long- or line-haul trucking is an intensely competitive business, where downtime represents lost productivity and earnings. Consequently, owners require a quick “refuelling” solution, currently epitomized by the diesel fuel pump at a gas station, where even the largest trucks can be fully refuelled in 15 minutes. For these operations, daily range is often governed by working hours and rest regulations for the drivers, rather than vehicle and fuel endurance.

At the moment, in-situ battery recharging for such duty cycles takes much longer than ICE refuelling. A range of manufacturers have considered the concept of "changeable batteries" whereby a truck's spent battery pack would be replaced by a fully charged battery at a charging station. Considering the numbers of very large batteries that would need to be charged at such facilities along major highways, it is easy to see how such centres would not only consume large tracts of land but would also become very significant electrical load centres.

For those heavy trucks serving more local needs, such as transporting aggregates, ready-mixed cement, liquids and other bulk goods, a return-to-base EV charging strategy may be entirely sufficient. Each owner or operator would need to choose the right strategy to suit their circumstances. Nevertheless, even a small operator with a fleet of 10 or so trucks, all charging at night, would likely exceed current electrical service capacity at the base location.

In addition, accessible infrastructure for charging heavy trucks would need to be developed around major cities to allow such local vehicles to venture further, as required.

If it became necessary to provide a mix of in-situ charging for shorter range trucks and interchangeable batteries for longer-range vehicles, it could be complicated to build the required infrastructure.

There is increasing interest in developing hydrogen as the primary fuel source for this sector in the future. Hydrogen is attractive because it offers the potential to maintain existing operational practices, with short refuelling cycles and sustained high-power outputs, both of which are challenging to achieve using current EV technology.

MINING, CONSTRUCTION, AGRICULTURAL AND SIMILAR MACHINERY

This segment includes an extremely diverse range of vehicle types, purposes, ranges, duty cycles and usage conditions. EV alternatives to some smaller or less powerful machines will likely be developed and reach the market. For larger applications such as mines where equipment is dispersed over a large area and served by mobile fuel bowsers[10], some electrical solutions are being considered, such as conventional overhead electrification [Ref. 26], while a hydrogen-based solution is probably more likely.

To illustrate the energy conundrum some of these facilities face, one major manufacturer of mine haul trucks is investing in conventional overhead wired, battery electric and hydrogen fuel cell electric propulsion. All three propulsion systems may be offered to the market to cater to the extremely wide variation in uses for this type of equipment.

INTERCITY BUSES

Although intercity buses account for a minor proportion of transportation sector pollution, this sector is expected to phase out ICE propulsion in favour of ZEVs over time, following the lead of the urban transit bus sector, which is becoming increasingly EV based.

In most respects, the issues facing intercity buses are the same as those facing long-haul trucking, with similar pros and cons related to using interchangeable batteries or hydrogen.

TRANSIT AND SCHOOL BUSES

Recent developments have brought a number of commercially mature EV products to this marketplace. These bus fleets operate mainly on a return to base model that allows for bulk slow charging at a depot, potentially supplemented by fast charging at points along the route and at terminals.

[10] The down time needed to return such equipment to a charging facility (often over long distances) would likely severely affect the economics of the operation.

This market is now quite competitive, and this technology is mature. Many transit authorities across Canada have begun buying battery electric buses to replace their ICE fleets partially or fully.

School buses have a much more relaxed duty cycle than transit buses do, permitting both nighttime and daytime charging (between school arrivals and departures). Since EV charging loads are likely to increase most dramatically at night, there may be a requirement to transfer some of the load demand to daytime. That, in turn, would reduce the need to expand electricity infrastructure. The federal government has released funding to introduce approximately 3,000 battery electric school buses across the country.

IV. POTENTIAL FUTURE PATHWAYS IN ROAD TRANSPORTATION DECARBONIZATION

SNC-Lavalin foresees a wide range of potential pathways to decarbonizing the road transit sector. To maximize GHG reduction rates across the transportation sector, the following factors will need to be considered:

1. Some sectors of the transportation industry, such as aviation, face more formidable technical barriers to decarbonizing than others.
2. This may mean actively accelerating the deployment or uptake of available ZEV technologies—beyond the rate that marketplace pressures alone would achieve—to help offset emissions in harder-to-decarbonize sectors.
3. Multiple levels of government—along with governmental bodies, such as regulators—will need to be involved in the required transmission and distribution of electricity or hydrogen. While governments may take a hands-off approach to the vehicle market, they may have to play a much larger role in developing charging infrastructure.

4. This effort will touch nearly everyone who owns a vehicle, in time. Owners' resistance to ZEV alternatives arises from a range of logical and emotional responses. To encourage changes in behaviour, governments should consider protecting consumers from potentially high ZEV price inflation, providing usable charging and fuelling infrastructure ahead of adoption, and launching public education campaigns.
5. The challenges of Canada's environment, size and dispersed population may make it technically and/or operationally difficult to introduce ZEVs in remote communities.
6. Automotive manufacturers should be encouraged to keep developing lower emissions hydrocarbon-powered vehicles or hybrid vehicles. These will reduce emissions during the transition period and in circumstances where ICE will continue to be in service for the foreseeable future.

V. OPPORTUNITIES FOR GREENHOUSE GAS REDUCTIONS IN TRANSPORTATION BY 2030

SNC-Lavalin believes there will be many opportunities between now and 2030 to start reducing GHG emissions from road transportation.

The two most polluting forms of road transport are cars and light trucks. These vehicle types can be replaced by current or soon-to-be-released models of battery electric vehicles. Manufacturers are offering a steadily increasing range of ZEVs for private and commercial consumers.

Even without extensive recharging infrastructure, an EV is an acceptable replacement for an ICE vehicle for many consumers who use their vehicles mainly in and near cities. These drivers do not take many long-distance journeys and usually charge their vehicle at home with a Level 2 (240 V single phase) charger. This ownership and charging model may remain viable over the long-term for many other potential EV owners.

The largest barrier to adopting EVs is the coverage and availability of charging infrastructure, including facilities that can charge vehicles quickly. To encourage EV adoption, planned provision of charging facilities (as opposed to unplanned or market-led development) may be required, implying governmental intervention in some form.

This is especially important in small or remote communities, where the business case for solely commercial investment would not be strong. Additionally, there are currently inherent limitations in the supplies of certain elements and minerals necessary for EV production, and uncertainties regarding if and how to expand those supplies. Some of these materials come from countries with development challenges, which may make consistent supply uncertain.

The ability of EVs to replace a range of heavier vehicles or those with niche applications is currently limited, although development efforts are underway. Hydrogen—which offers the convenience and speed of liquid or gaseous refuelling, combined with the ability to develop high-power outputs for sustained periods—may be an attractive power source for these applications in the longer term.

Hydrogen vehicles are currently limited to some niche applications, such as transit buses. These can be fuelled via small-scale local production of hydrogen through air liquefaction or extraction of hydrogen from other industrial processes.

Large-scale hydrogen adoption is hindered by the lack of production, storage, distribution and dispensing facilities. These will need to be developed, potentially alongside a CO_2 market and distribution system. Again, governmental intervention to direct the development of suitable infrastructure may be required, given the scale of investment needed.

G. Oil and gas sector

I. BREAKDOWN OF EMISSIONS

Our economy relies heavily on oil and natural gas. However, extracting these fuels releases a large amount of GHGs, particularly CO_2 and methane. Over the last decade, the situation has become even more challenging , with an increase in GHG emissions associated with oil and gas operations, principally due to significant growth in the oil sands production industry. The oil and gas industry accounts for 26% of all carbon emissions in Canada—the highest proportion of any sector. It also accounts for 43% of all methane emissions in Canada, nearly half of them caused by unintentional leaks, often due to faulty equipment [Ref. 27]. "Well-to-pump" emissions account for 20-30 % of all GHG emissions in the lifecycle of crude oil. The remaining major portion of emissions is produced during oil combustion, during the consumption of oil-derived products [Ref. 28].

Oil and gas economic activities can be separated into five categories with distinct GHG emissions intensities, based on the geological formation from which the oil is extracted: conventional oil, oil sands, offshore oil, natural gas, and other.

CONVENTIONAL OIL

Conventional oil production involves pumping liquid oil from an oil deposit accessed vertically by drilling. This oil extraction method is straightforward and relatively inexpensive. Conventional oil production requires fewer refining operations than other methods, which gives it an additional economic and environmental advantage [Ref. 29]. GHGs released from conventional oil production comprise 13% of all emissions associated with this sector and increased by 20% between 1990 and 2019 [Ref. 30].

OIL SANDS

Oil sands are underground geological formations composed of a mixture of sand, water, clay and bitumen. The production of crude oil from oil sands requires more energy-intensive operations and "GHG-intensive" processes than conventional extraction does.

In Canada, two methods of extraction are employed to recover crude oil from oil sands depending on the depth of the reservoir. Approximately 20% of Canada's oil sands can be extracted by surface mining, performed when the oil sand deposit is within 70 metres of the surface. Most of the rest of Canada's bitumen is deep underground and is extracted using the "in-situ" method. This approach involves liquifying solid bitumen directly underground. That procedure requires water and steam from burned natural gas, which contributes to GHG emissions [Ref. 29].

The largest deposit of oil sands, the Athabasca deposit, is located in Alberta. The national abundance of oil sand deposits is driving the upward trend in crude oil production in Canada. Between 1990 and 2019, the rise in crude oil production increased GHG emissions from oil sands by 468% [Ref. 30]. According to Environment and Climate Change Canada, 43% of GHG emissions in the oil and gas sector result from oil sands production [Ref. 31].

OFFSHORE OIL

Offshore oil and natural gas production involve extraction from reservoirs under the seabed. Due to the difficulties of remote operation, an offshore project is more costly to develop and to operate. Regulations and approval from regulatory boards for Atlantic Canada's offshore projects are extensive, with the intent of reducing the risk of spills and other damage [Ref. 32]. The main advantage of offshore oil production is its emissions intensity, one of the lowest of the industry [Ref. 33]. Moreover, offshore production takes place on geographically isolated platforms. As a result, it is easier to detect and potentially prevent undesirable emissions [Ref. 34]. GHG emissions associated with frontier oil production, which includes offshore and Arctic production of crude oil, account for 1-2 % of total oil and gas GHG emissions (2 Mt CO_2e emissions) [Ref. 35].

NATURAL GAS

Like oil, natural gas can be extracted using conventional drilling methods or using unconventional techniques, such as hydraulic fracturing for natural gas trapped in rock formations [Ref. 36]. Between 1990 and 2019, the production of natural gas via unconventional techniques increased significantly, resulting in a 54% increase in GHG emissions. Emissions from natural gas account for 27.5% of the oil and gas sector's emissions [Ref. 30].

To attempt to meet the ambitious objective of reducing CO_2e emissions in the oil and gas sector by 60 Mt by 2030, the industry should focus on its biggest emitter. Data suggests that the largest GHG contributor in the oil and gas industry are the oil sands. The following sections outline recent environmental improvements and incentives in the oil sands industry and discuss the drawbacks that need to be resolved soon.

II. WHAT HAS WORKED SO FAR?

Although the increase in production of oil and natural gas and the consequent spike in emissions requires drastic improvement of oil and gas processes in terms of environmental repercussions, efforts continue to be made to find practical ways to control and improve oil and gas operations. Incentives across the industry are leading to an observed decrease in emissions intensity, technological development, and several ongoing pilot projects.

DECREASING EMISSIONS INTENSITY

According to Canada's National inventory report, the primary drivers of GHG emissions in the oil and gas sector are production growth and emissions intensity, which corresponds to the amount of GHG emitted per barrel of oil produced [Ref. 31].

Over the past decades, the oil sands industry has improved the efficiency of its industrial processes, reduced fuel combustion requirements, and decreased vented gases, permitting a 34% decline in emissions intensity since 1990. In other words, emissions are growing more slowly in comparison to the pace of oil production growth [Ref. 37].

However, within the same timeframe, the emissions intensity of the entire oil production industry increased by approximately 10% due to the exhaustion of easily accessible oil reserves and the dependence on unconventional oil extraction methods. On the other hand, we observe a 2 percentage point decrease in emissions intensity for overall oil production since 2005, as per Figure 5.

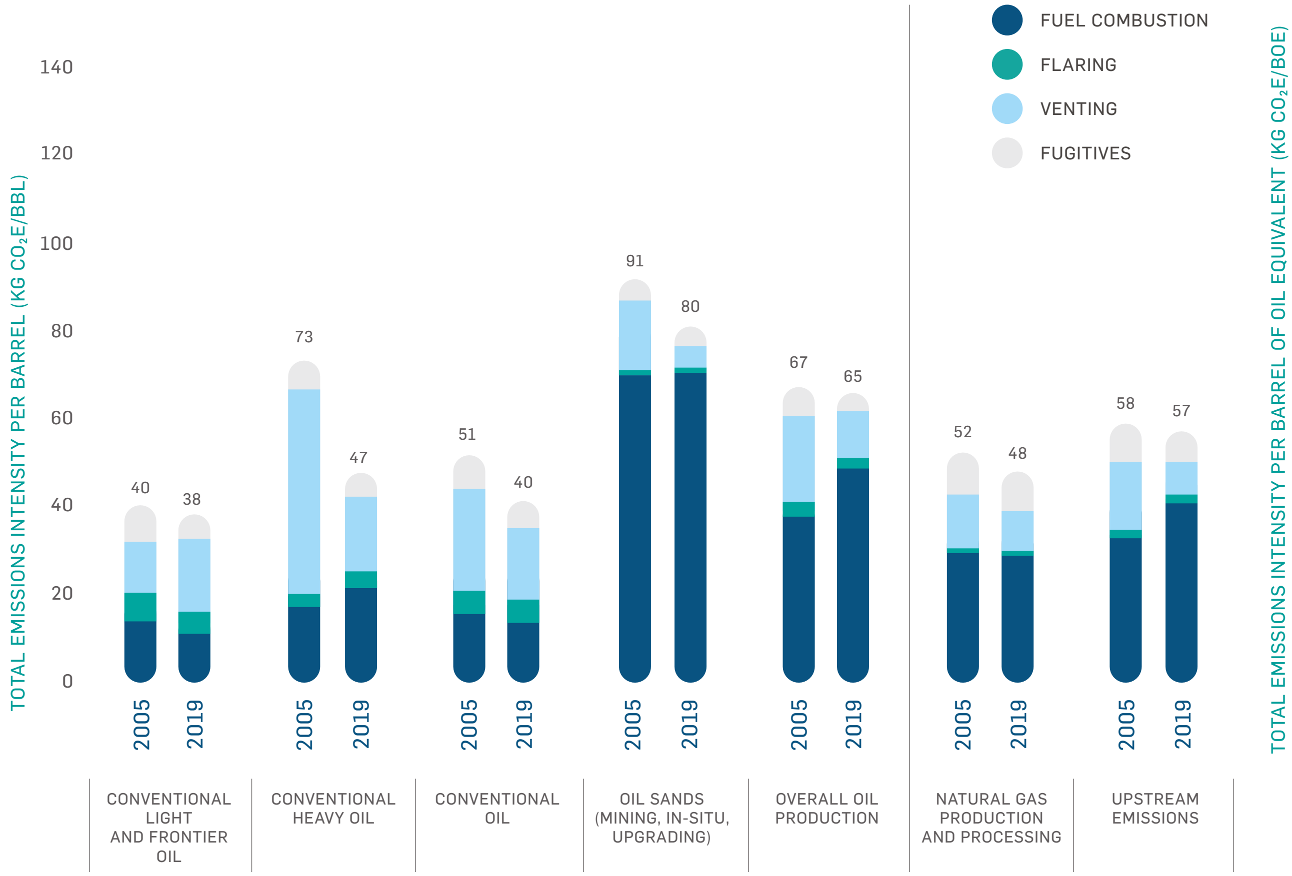


FIGURE 5 EMISSIONS INTENSITY (2005 AND 2019) BY SOURCE TYPE FOR OIL AND GAS [REF. 31]

Despite the significant drop in emissions intensity for oil sands mining and "in-situ" extraction, oil sands remain the most GHG-intensive method for oil production. That suggests that additional actions are required to improve process efficiency and further reduce emissions intensity, especially with respect to fuel combustion activities. This may be achieved through enhanced oil recovery (EOR) from existing reservoirs, leaked gas detection and capture technologies.

Taking into consideration the worldwide dependence on products derived from oil and natural gas, and the central role that oil exports play in the Canadian economy, oil and natural gas production is not expected to decrease by 2030. The emissions reduction challenges this sector faces can be addressed by developing new technologies to reduce air pollution caused by oil and gas extraction processes. Several attempts to green the industry are ongoing, with pilot projects proving their effectiveness. The technological advancements include retrofitting the existing facilities and additional steps in the oil production cycle.

CARBON CAPTURE, SEQUESTRATION AND UTILIZATION

Carbon Capture and Sequestration (CCS), which involves capturing CO_2 released into the atmosphere and storing it in underground geological formations, may reduce GHG emissions in the oil and gas sector by absorbing CO_2 released during extraction operations, for instance, by using heavy trucks or by burning fossil fuels to power industrial activities.

Canada's first commercial CCS facility, the Quest CCS facility managed by Shell Canada, has been operating since 2015, with a capture rate of 1.2 Mt of CO_2 per year. It captures CO_2 released by the Scotford Upgrader, a processing facility that refines bitumen from oil sands into crude oil. Once captured, the CO_2 is compressed, transported through pipelines, and injected for permanent storage in a saline formation near Thorhild, Alberta [Ref. 38].

The Alberta Carbon Trunk Line (ACTL) is a recently commissioned carbon capture utilization and storage (CCUS) system, with a capture rate of 1.3 Mt of CO_2 per year. The captured CO_2 is used for EOR at oil reservoirs near the end of their production lifecycle. The ACTL system is the world's largest-capacity CO_2 pipeline, with a capacity equivalent to nearly 20% of all emissions from Canadian oil sands [Ref. 39, Ref. 40, Ref. 41].

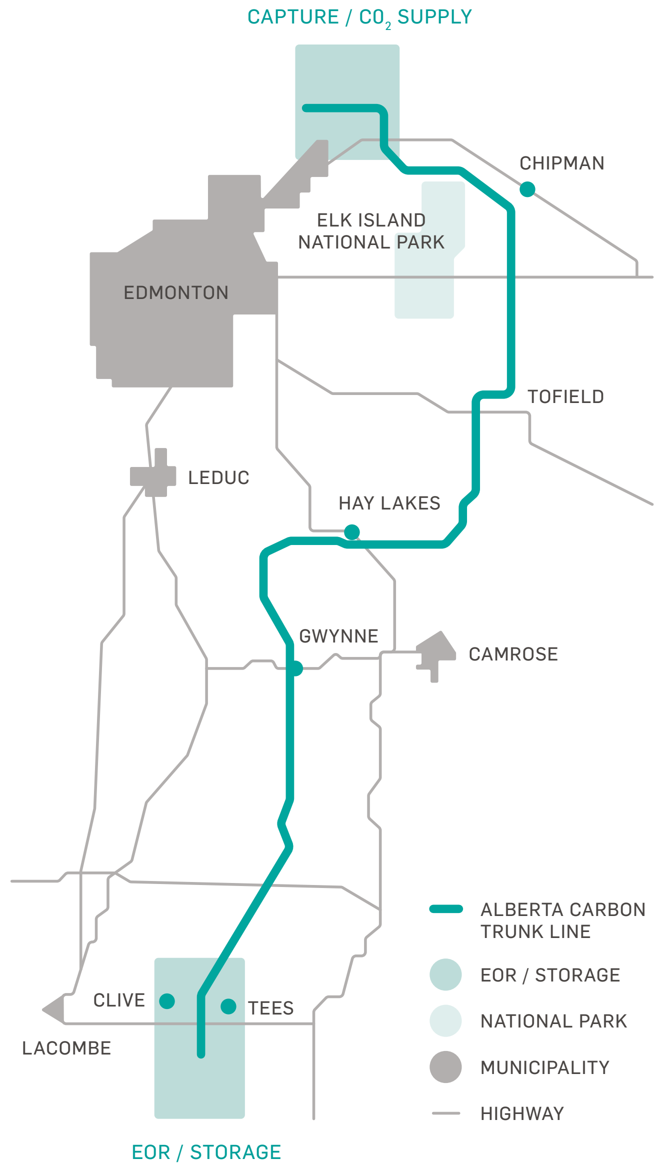


FIGURE 6 ALBERTA CARBON TRUNK LINE SYSTEM [REF. 40]

ENHANCED OIL RECOVERY

EOR involves injecting CO_2, chemicals or steam into existing oil reservoirs approaching the end of their conventional lifecycle to extract the remaining oil that could not be recovered using conventional methods. That oil usually accounts for 30 to 60% of the reservoir's initial oil deposit [Ref. 42]. The injected CO_2 remains trapped in the underground formation. Therefore, EOR provides a way to use CO_2 emissions and eliminates the need to exploit new sources of oil and build well sites, roads and infrastructure. EOR offers a CO_2 storage option and may result in "neutral, or even carbon-negative" emissions intensity [Ref. 43]. This mature technology will become more common with further development of CCUS facilities and infrastructure, specifically as part of the Alberta Carbon Trunk Line.

METHANE REDUCTION

Methane emissions represent a significant percentage of all oil and gas sector emissions. According to the Canadian Association of Petroleum Producers, "among the world's top 10 petroleum exporters, currently Canada alone has a methane reduction target" suggesting that the nation is leading the way towards responsible oil and gas production, and a clean future [Ref. 39].

One methane reduction technology currently under development is methane detection. Sensors complemented by software systems may help prevent methane leaks by rapidly identifying the source of the fugitive emission. In the Alberta Methane Field Challenge, competitors test their newly developed sensors on site. Methane capturing technologies, similar to CCUS systems, are another potential way to eliminate methane emissions.

According to the Government of Canada, methane is one of the "lowest-cost emission reduction opportunities for the sector" [Ref. 44]. Reducing methane emissions is the most realistic solution to achieving the 2030 target, as discussed later in this report.

SOLVENT-DRIVEN IN-SITU EXTRACTION

As mentioned, in-situ oil recovery involves injecting steam underground to liquefy bitumen so it can be pumped to the surface. Adding solvents, such as propane and butane, into the steam reduces the steam-oil ratio. That reduces and may eliminate the need for steam generation, making the process more efficient and reducing emissions [Ref. 45].

NATIONWIDE INCENTIVES

The federal government must provide financial support and incentives across economic sectors if it hopes to meet its ambitious GHG reduction objectives. Reducing GHG emissions is no longer simply a topic of conversation; targets and action plans have been created throughout the Canadian oil and gas industry. The Government of Canada has signed agreements with Alberta, British Columbia, and Saskatchewan to allow for "strengthened provincial methane regulations to replace the federal regulations" to motivate the provinces to go beyond federal expectations [Ref. 46].

Alberta has committed to meeting the Government of Canada's objective to reduce methane emissions in the oil and gas sector by 45% from 2012 levels by 2025. Several support programs, such as the Methane Technology Implementation Program, have been launched "to support installation of readily available methane reduction technologies at conventional oil and gas facilities" [Ref. 47]. British Columbia's provincial action plan, CleanBC, has a reduction target of 45% from 2014 levels by 2025. The BC Oil and Gas Commission has introduced new regulations to reduce methane emissions by 10.9 Mt over 10 years [Ref. 48]. The Government of Saskatchewan has a Methane Action Plan to reduce methane emissions in the oil and gas industry from venting and flaring activities by at least 38.2 Mt between 2020 and 2030 [Ref. 49].

A report by the Senate of Canada states that Canada is the "sole major producing jurisdiction with comprehensive GHG regulations," suggesting that our industry is incentivized to implement mitigation measures [Ref. 33].

In terms of financial support, federal and provincial funding programs are available to help the oil and gas industry transition to cleaner operating activities. An example of such a federal program is the $750-million Emissions Reduction Fund for onshore ($675 million) and offshore ($75 million) oil and gas activities [Ref. 50].

PILOT PROJECTS OF THE CANADIAN OIL SANDS INNOVATION ALLIANCE

The purpose of the Canadian Oil Sands Innovation Alliance (COSIA) is to accelerate improvement of the environmental performance of the Canadian oil sands industry. COSIA is proposing, developing and implementing pilot projects focused on reducing GHG emissions, such as the innovative Quest CCS project. According to its 2020 Annual Report, COSIA members have invested $249 million in 175 GHG technologies since 2012. In 2020, 14 active projects related to GHG emissions were underway through COSIA at a cost of $11 million [Ref. 51].

26

COSIA technical working groups support a broad portfolio of Innovation projects in four priority areas

15

Natural Sciences and Engineering Research Council (NSERC) academic research programs and are generating new knowledge

COSIA members represent over

90%

of total oil sands production

*cumulative from 2012-2020

	TECHNOLOGY DEVELOPMENT COST*	CONTRIBUTED TECHNOLOGIES*	ACTIVE PROJECTS	COST OF ACTIVE PROJECTS
LAND. COSIA aspires to be world leaders in land management, restoring the land and preserving biodiversity of plants and animals.	$174 MILLION	467	76	$51 MILLION
GHG. COSIA aspires to produce oil with lower greenhouse gas emissions than other sources of oil.	$249 MILLION	175	14	$11 MILLION
WATER. COSIA aspires to be world leaders in water management, producing Canadian energy with no adverse impact on water.	$592 MILLION	273	86	$319 MILLION
TAILINGS. COSIA aspires to transform tailings from waste into a resource that speeds up land and water reclamation.	$826 MILLION	228	57	$150 MILLION
TOTAL INVESTMENTS AND PROJECTS. Oil and gas companies are the largest spenders on clean technology in Canada. Canadian companies invest about $1.4 billion a year in clean technology - 75 per cent of that amount comes from the oil and gas industry.	$1.8 BILLION	1,143	233	$531 MILLION

SPECIFIC RESULTS. COSIA mining operators have reduced net water use intensity from the Athabasca River and its tributaries by **25 per cent**, down to **1.4 barrels** of Athabasca River water per barrel of oil produced (from 2.2 barrels in 2012).

COSIA in situ operators have reduced freshwater use by **46 per cent**, down to **0.19 barrels** of water per barrel of oil produced (from 0.36 barrels in 2012).

COSIA members have reduced the operating footprint intensity of in situ operations by **6 per cent** since 2012.

FIGURE 7 OVERVIEW OF COSIA OBJECTIVES, PROJECTS AND ASSOCIATED COSTS [REF. 51]

PROJECT NAME	DESCRIPTION	POTENTIAL BENEFITS
Vacuum Insulated Tubing (VIT) [Ref. 52]	With steam-assisted gravity drainage (SAGD), steam is injected underground through tubes. VIT consists of two concentric tubes, insulated with a vacuum layer. The vacuum insulation restrains the injected steam from losing heat.	Improves the efficiency in wells by reducing the amount of steam needed to produce bitumen. Due to the reduced need to burn gas, GHG emissions are smaller.
COSIA in Space [Ref. 53]	Satellite technology is investigated to improve fugitive emissions measurement above mines and tailing ponds.	Permits more accurate detection of fugitive emissions (quantity, source location), which facilitates intervention and prevents leaks.
Gas Turbine Once Through Steam Generator [Ref. 54]	Burned natural gas produces electricity to power the facility in addition to fuelling SAGD, a method of bitumen extraction.	Producing its own electricity eliminates the need for the facility to rely on Alberta's power grid, which includes coal-fired power plants.
Molten Carbonate Fuel Cells [Ref. 55]	These fuel cells convert CO_2 captured from natural gas-fired plants into electricity, water and heat used for SAGD.	This technology uses captured CO_2, preventing it from being dispersed into the atmosphere. It also generates clean electricity.

TABLE 4 SEVERAL ONGOING COSIA PROJECTS

Table 4 summarizes a few of COSIA's creative case studies, all with a common objective to reduce greenhouse gas emissions in the oil sands industry. Although such innovative initiatives are far from the deployment phase and may not be commercially available by 2030, in the longer term, driving innovation is crucial to recover from the troubling global ecological conditions.

III. WHAT HASN'T WORKED SO FAR?

The constantly increasing demand for energy means that Canada still depends on the oil and gas sector. Current trends do not suggest that this will change in the coming decade. Despite the nationwide effort to reduce GHG emissions from oil and gas activities, the increase in oil and gas consumption —and, thus, production—has driven emission numbers upwards. Several obstacles currently prevent the industry from achieving the 2030 environmental performance targets. These challenges will require support of government, industry and individual consumers to overcome.

FINANCIAL OBSTACLES

Although funding programs exist for research and development of GHG reduction technologies, the costs associated with using such technologies at a commercial scale are unsustainable for most private companies. Whether they choose to pay the carbon tax or to invest in cleaner processes, the cost of producing oil increases. That drives up the market price of Canadian oil, making it less competitive internationally. Canadian oil resources are already known to be expensive to produce and export, suggesting that an additional layer of operation costs may severely affect Canada's position in global exports and lead to a loss of market share.

The COVID-19 pandemic had a severe impact on the global oil and gas industry [Ref. 56], which demonstrates the volatility of oil prices. Such uncertain circumstances highlight the challenge to acquire funding for a transition to green technologies. Oil price fluctuations bring an additional layer of risk that jeopardizes innovation projects, as investors are not willing to take the risk.

INSUFFICIENT INVESTMENTS AND REGULATORY BARRIERS

Time constraints are among the most pressing obstacles facing efforts to reduce GHG emissions. Current emission rates seem alarming, and we do not have unlimited time to develop solutions—quite the opposite, in fact. To accelerate change, more resources are needed, and those require funding.

Most current funding is allocated to researching new technologies and feasibility studies that, if successful, may develop into large-scale demonstration projects. However, the funding is insufficient for the costliest element of pilot projects: their on-site implementation, the costs of which must be absorbed by the private sector. Although technological advancements and solutions are appearing on the market, an acceleration driven by additional funding is needed to attract more resources to develop the projects on a commercial scale. Thus, supplementary funding from the provincial and federal governments and private investments will help companies finalize R&D, test innovative technologies on a large scale and integrate GHG-reducing techniques into existing industry mechanisms.

Regulatory approval processes and the need to adapt relevant legislation also make it difficult to deploy new technologies quickly. For instance, "the provinces of British Columbia and Saskatchewan have modified existing oil and gas laws to enable CO_2 storage". Alberta went beyond its next-door neighbours and has adopted carbon capture and storage legislation which "provides a permitting regime for exploration, injection, and storage, clarifies Crown ownership of pore space rights, and provides for long-term liability transfer to the Crown based on regulatory compliance" [Ref. 57]. Although regulatory processes consume precious time, such approvals are essential to deploying new technologies safely and avoiding further environmental harm.

Small modular reactors are an example of a technology that could help to decarbonize oil processing methods which are a large contributor to Canada's GHG emissions. Processes that use steam currently get it from fossil-fuel-powered boilers. Instead, certain types of small modular reactors could be used to produce high-temperature steam with virtually no GHG emissions. However, barring major changes to regulatory approvals and site licensing processes, it is unlikely to happen before the early-to-mid 2030s. As such, this report does not include any figures for GHG reductions related to this technology.

Insufficient funding, and the time needed for licensing and approvals, are thus making it difficult for private companies to adopt innovative technologies on a commercial scale at reasonable prices. These major obstacles should be addressed to allow for steady progress towards the 2030 targets.

DEPENDENCE ON OTHER SECTORS

The full production cycle of oil and gas is an intersectoral mix of energy-intensive operations. A complete decarbonization of the oil and gas industry thus depends on the decarbonization of other sectors as well, such as the electricity and transportation sectors.

Oil production requires energy for operations such as crushing rocks into fluids. Fossil fuels combustion, required to power generators that drive the extraction process, has the highest emission intensity among the most polluting operations in the oil and gas industry. Replacing fossil fuels with renewable, reliable, and affordable sources of electricity is necessary to make mining and refining activities environmentally sustainable.

Oil sands mining uses heavy trucks for mining operations, which contribute largely to GHG emissions. As discussed in the transportation section of this report, heavy trucks are the most challenging form of road transportation to decarbonize. Hydrogen-based haul trucks appear to be the most viable option to replace existing mine trucks, although overhead-wired and battery electric trucks are also possible solutions.

CONSUMER BEHAVIOUR

Although this section primarily covers GHG emissions from oil extraction and production, it is crucial to mention that 70 to 80% of emissions in the lifecycle of petroleum products arise from the combustion of oil-derived products. In other words, the biggest environmental impact comes from the end-user consumption. With a visible increase in demand for refined natural gas and oil by-products, consumer behaviour is a driving factor for oil and gas production and associated emissions. As mentioned in the SNC-Lavalin "Engineering Net Zero, Canadian Technical Report", most Canadians still drive gas-powered vehicles, commercial buildings are heated by natural gas, and wasteful behaviour results in inefficient use of plastics and other oil-based products. Consumer awareness has thus not reached every household.

Individual consumers must make a collective effort to adjust their consumption habits by shifting to alternative, clean products. Even though reducing domestic consumption of oil-derived products does not guarantee a decrease in production, since the unconsumed oil may be transported for international trade, the national environmental footprint would nevertheless improve.

IV. OPPORTUNITIES FOR GHG REDUCTIONS IN OIL AND GAS BY 2030

POTENTIAL REDUCTION PATHWAYS FOR 2030

The deadline targeted throughout this report is rapidly approaching, while the looming pressure to act is escalating. To pinpoint the measures that must be undertaken immediately, reduction pathways for 2050 discussed in the SNC-Lavalin "Engineering Net Zero, Canadian Technical Report" are reassessed for the 2030 milestone.

Presently, Carbon Capture and Sequestration technology—which we rely on heavily to meet the 2050 targets— is in the initial phases of integration in the oil and gas industry. A few projects have been commissioned and are currently operational, but the carbon capture rates are too low to have a serious impact on efforts to meet the 2030 targets. However, these CCS facilities may serve as models for future projects, which should allow for accelerated construction of new CCS plants in the oil sands industry before 2030. The captured CO_2 may be used for enhanced oil recovery, which could help decarbonize the industry. Given the rapidly approaching deadline, the industry cannot rely on carbon capture, utilization and storage technologies alone. Instead, it should combine this emissions reduction method with additional mitigation measures.

Using renewable resources instead of fossil fuels to power the facilities is a viable pathway towards the targeted emissions numbers for both 2050 and 2030. A sudden switch to non-emitting fuels is certainly impossible, but gradually retrofitting existing facilities to electrify them or use cleaner fuels for certain operations is an achievable short-term objective.

Creating a hydrogen market, which could encourage oil and gas operators to rely on this technology, requires incentives, as the accessibility and cost effectiveness of hydrogen fuel is still unproven. Given the time restriction, the 2030 mitigation plan should focus on alternative, readily available solutions.

Oil production caps and carbon tax mechanisms are established attempts to control GHG emissions in the oil and gas industry. However, based on growing emission rates, such sanctions will not be enough to achieve the desired outcome.

In the coming years, we may see an increase in offshore oil production, as access to offshore resources is becoming more economically feasible [Ref. 1]. However, before extraction operations begin, offshore projects undergo a multi-phase process, including site exploration, exploration drilling and development. The latter phase alone may take up to 10 years before production begins, suggesting that offshore oil and gas may not be a major player in the 2030 GHG emissions mitigation plan [Ref. 32]. Besides, although offshore production may result in smaller GHG emissions than onshore oil and gas extraction, the potential environmental damage from oil spills and other accidents should be a reason to undertake a thorough risk-reward analysis prior to relying on offshore production to reduce the industry's footprint.

METHANE EMISSIONS REDUCTION: LOW-HANGING FRUIT

The most viable way to reduce emissions in the oil and gas sector is by reducing methane emissions. In Canada, 13% of all GHG emissions are methane emissions, 43% of which result from oil and gas production [Ref. 27]. According to the Global Methane Assessment by the United Nations Environment Programme, the oil and gas sector has great potential for mitigation of methane emissions at low or negative costs [Ref. 58]. The two main sources of released methane are venting and fugitive emissions, accounting for 52% and 42% of all of the sector's methane emissions, respectively. [Ref. 59, Ref. 60, Ref. 61].

Venting and fugitive emissions are imperfections in current operations, offering the possibility to act quickly and benefit economically while improving the industry's efficiency.

Methane-capturing technologies complemented by the prevention of leaks would allow the oil and gas industry to approach the targeted environmental footprint. Eliminating fugitive emissions is an accessible solution to reducing the industry's environmental impact without extensive funding and technological additions to existing systems. The International Energy Agency (IEA) estimates that "around 75% of total oil and gas methane emissions could be avoided" globally, if all methane abatement options discussed in the IEA report "were to be deployed across the oil and gas value chains" [Ref. 62]. In Canada, 30 Mt out of 40 Mt of CO_2e methane emissions could be eliminated in the short term from the oil and gas industry. This is a 2030 commitment that has already been made by our government at COP26 [Ref. 2].

OTHER PROSPECTIVE GAINS

The replacement of fossil fuels by renewable energy and the integration of additional CCS facilities with CO_2 utilization for enhanced oil recovery are also viable pathways to reaching the 2030 objective, although they require significantly more government support. These solutions for market decarbonization may contribute to cutting part of the remaining emissions within the time limits.

NET ZERO CARBON. NET ZERO EXCUSES.

ACTION TODAY FOR A NET ZERO TOMORROW

3. Is there a short-term role for hydrogen and CCS?

To decarbonize our economy, we will need to address a diverse set of industrial processes and activities that consume very large amounts of energy and are pillars of our resource-driven economy. In the literature, net zero models for 2050 have generally relied significantly on CCS and hydrogen energy.

Alternative fuels have already been deployed to reduce emissions in sectors such as freight transportation, industrial processes, and alternative thermal generation. Hydrogen may serve as both an energy vector and an energy store, and it can contribute to industry decarbonization, domestic heating, and transportation. Moreover, hydrogen can be generated from electrolysis, which is a 100% clean process that would enable Canada to further tap into its renewable electrical power resources.

Like hydrogen, CCS is critical to proposed net zero carbon scenarios. CCS can be used to decarbonize multiple sectors, including power generation, heavy industry, heating, transportation and waste, and to remove CO_2 directly from the atmosphere.

While the technical know-how in these areas can be drawn from other industries such as oil and gas, broad deployment to reduce GHG emissions faces many economic and technical challenges that will have a direct effect on reducing GHG emissions by 2030, given the significant changes to incentives, policies, and infrastructure needed to deploy these technologies at scale.

Regardless of these challenges, the industry momentum is very high for CCS to be deployed in the short-term to address the largest group of emissions.

I. HYDROGEN DEPLOYMENT CHALLENGES

In 2018, global production of hydrogen amounted to approximately 70 megatonne (Mt). Around three quarters of this production was derived from natural gas through steam methane reforming using 6% of global natural gas. Approximately 23% of the hydrogen was derived from coal, accounting for 2% of global coal use. These two production methods generated approximately 830 Mt of CO_2 in 2018, an amount far greater than Canada's total annual CO_2 emissions [Ref. 63].

Hydrogen is classified in terms of its ecological footprint depending on its method of production. Grey hydrogen, produced from fossil fuels, is the most abundant form of hydrogen. Blue hydrogen is also produced from non-renewable sources of energy but uses CCS in the process which reduces the environmental impact. Green hydrogen is a product of electrolysis of water and clean energy which makes it a greenhouse gas-free alternative energy carrier [Ref. 1, Ref. 64].

To adopt hydrogen in our economy as a leading energy carrier, developers must make considerable adjustments such as deploying more electrolysis plants, coupling steam methane production with carbon capture technology, developing hydrogen-capable pipeline infrastructure, building hydrogen storage facilities, improving transportation technologies, and coordinating the supply chain with consumer demands [Ref. 65].

Although hydrogen presents an opportunity to decarbonize many industries, several challenges currently prevent its deployment as a leading fuel source. These include challenges related to large-scale production, transportation and storage infrastructure, economics, and round-trip efficiencies. The latter corresponds to the percentage of electricity that reaches the consumer after electricity has been converted to hydrogen and back for end usage as per Figure 8.

On one hand, producing green hydrogen requires abundant sources of renewable energy, sources of quality water for electrolysis, and construction of electrolyzer plants near power generation plants. The cost of production of hydrogen through electrolysis and transportation is the subject of much R&D to try and bring down the operating cost to economically viable levels [Ref. 66]. Luckily, 67% of Canada's energy is generated from renewable sources [Ref. 67]. As Canada is rich in fresh water, the main challenge for green hydrogen production is the incorporation of electrolysis plants into the process.

On the other hand, large-scale production of hydrogen using advanced gas reforming is highly dependent on the development of techniques such as Carbon Capture and Sequestration, allowing for production of blue hydrogen. Hydrogen can also be produced from nuclear power [Ref. 64].

The most attractive solution for transporting hydrogen gas is via a network of pipelines. Some parts of the 80,000 km of existing natural gas pipelines and related storage facilities across Canada could possibly be reused and modified [Ref. 68]. However, significant research and testing must be conducted to ensure that the pipelines reflect the constraints posed by hydrogen gas, including the need to prevent fractures.

In a hydrogen market, ammonia may act as a "zero-carbon hydrogen carrier". In comparison to alternative options of hydrogen carriers, "dehydrogenation" of ammonia does not require an additional step for recycling carbon once the elements are separated. The challenge of hydrogen storage and transportation may be addressed by converting pure hydrogen to ammonia, which is commonly transported over long distances in liquid form. From an economic perspective, large-scale ammonia production is already optimized in terms of costs as this chemical compound is widely used in several industries [Ref. 69].

Although the production of hydrogen may increase as climate change awareness rises, current production costs suggest that significant technological innovation is necessary to make hydrogen competitive. Besides, production costs are only part of the whole system cost of delivering hydrogen-based energy. The International Energy Agency (IEA) states that green hydrogen is 2 to 3 times more expensive than its natural gas-based alternative, grey hydrogen [Ref. 70]. The acceleration of innovation efforts, commercial deployment and the use of subsidies may help gradually close the gap.

To optimize system design, the potential round-trip efficiency of hydrogen must be considered. Depending on its area of application, hydrogen may not be the most efficient solution, as conversion and system losses add up. For instance, as shown in Figure 8, converting hydrogen back to electricity results in 26% efficiency, suggesting that during peak power demand, alternative sources of energy available at a specific location must be explored [Ref. 1].

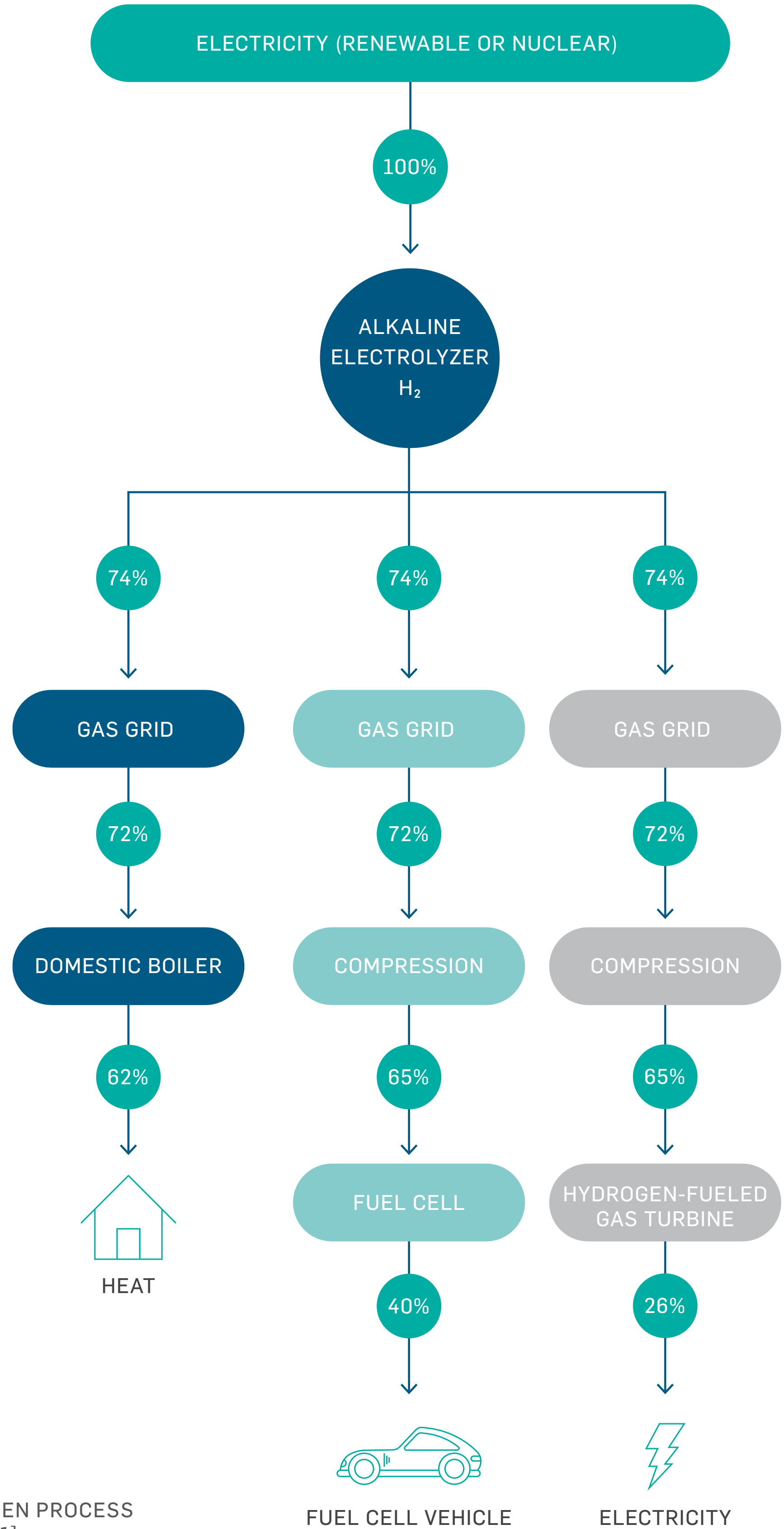


FIGURE 8 HYDROGEN PROCESS EFFICIENCY [REF. 1]

II. CARBON DIOXIDE CAPTURE DEPLOYMENT CHALLENGES

In 2019, CO_2 accounted for approximately 582 Mt out of Canada's 730 Mt of total CO_2e greenhouse gas emissions [Ref. 31]. CH_4 (98 Mt CO_2e), N_2O (37 Mt CO_2e), and HFCs, PFCs, SF_6 and NF_3 (13 Mt CO_2e) correspond to the sources of the remaining 148 Mt of CO_2e emissions [Ref. 31]. With CO_2 emissions rising annually in some sectors, CCS technologies are key to meeting the established targets. Although existing techniques have been tested and have proven reliable over decades, with various operational projects in place, large-scale carbon sequestration poses a challenge.

Carbon capture technologies are grouped into three types: post-combustion, pre-combustion and oxy-fuel combustion. These techniques share a purpose to isolate CO_2 from the other gaseous compounds emitted simultaneously. Table 5 describes the processes as well as their respective advantages and disadvantages.

Capture technologies are expensive, accounting for 70 to 80% of the total costs of a CCS system [Ref. 71]. This suggests that extensive research must be conducted to reduce the costs of capturing CO_2 from fuel gases prior to fully relying on CCS as a practical way to decarbonize the economy. Fortunately, federal and provincial governments in Canada are investing in CCS technology development, with four large-scale projects ongoing at the time of this publication [Ref. 72].

Current CCS technology can capture up to 90% of CO_2 emissions. However, studies suggest that capture rates of 95% or higher may be technically achievable [Ref. 73]. "Negative" carbon emissions technologies are also being explored such as direct air capture, afforestation, cloud treatment with alkali and several others [Ref. 74].

CAPTURE TECHNIQUE	PROCESS	ADVANTAGES	DISADVANTAGES
Post-combustion	Separation of CO_2 from gases released from combustion of fossil fuels	Most mature technique, easy retrofitting, compatible with existing plants	Low efficiency resulting from low CO_2 concentration in captured gas
Pre-combustion	Separation of CO_2 from gases released during "pre-treatment" (e.g. gasification) of fossil fuels	High concentrations of CO_2, high efficiency	Lowest thermal efficiency, energy penalties and efficiency decay
Oxy-fuel combustion	Separation of CO_2 from gases released by burning of fossil fuels in oxygen (O_2) rather than air	Very high concentrations of CO_2 (80%), high efficiency, require smaller equipment	Production of O_2 is energy intensive and costly; possibility of corrosion

TABLE 5 OVERVIEW OF CARBON CAPTURE AND SEQUESTRATION (CCS) TECHNIQUES [REF. 71]

In addition to the challenge posed by the cost of capture technology, wide-scale CCS deployment is hampered by the cost of CO_2 transportation, and of storage or use of the captured CO_2. In certain regions of Canada, a CCS system is more economical because the CO_2 can be injected into existing hydrocarbon reservoirs to enhance hydrocarbon recovery. However, this is usually not an option, and expensive transportation and storage options are required. Recognizing this challenge as a potential opportunity, some organizations are developing technologies to employ CO_2 to derive new products, or new or existing processes (e.g. for "building materials" or "to enhance yields of biological processes" [Ref. 75]). Most of these technologies are in early development stages and not ready to be deployed at a sufficient scale to have a significant impact on atmospheric CO_2 concentrations by 2030.

High costs for research, development and realization will be incurred as capture technologies are incorporated into existing processes. However, the Intergovernmental Panel on Climate Change has estimated that limiting global warming to 2°C would be 138% more expensive without CCS technologies, suggesting that the use of this technology is inevitable in the near future [Ref. 76].

LEADING A LOW CARBON FUTURE

4. What can be done in the next 8 years

In the path towards complete decarbonization, 2030 will be a key milestone. By then, a 40-45% reduction of GHG emissions levels is targeted for all industries combined.

This report discussed carbon emission reduction measures in three economic sectors with significant potential for improvement over the next eight years: electricity, transportation, and oil and gas.

Also provided is an understanding of the context and issues associated with decarbonization, with an emphasis on proven technologies that are readily available for deployment today. The technology-driven solutions discussed remain one part of the overall solution and would need to be supported by additional GHG reductions across all sectors.

Table 6 summarizes the proposed solutions for alleviating GHG emissions, by economic sector, based on technology readiness in the next eight years. Such technological advancements and upgrades to existing systems must be adopted promptly to stimulate further actions and achieve the intended ambitious goal.

Decarbonizing the transportation and oil and gas sectors depends heavily on the upgrades and reinforcements to be done in the electricity sector. As estimated in the SNC-Lavalin's Engineering Net Zero 2050 report [Ref. 1], besides replacing coal-fired power plants, each year Canada will need to build facilities capable of generating 5 to 7 GW of electricity from non-emitting sources to decarbonize all industries. By 2030, this additional 40 to 56 GW capacity may allow for a 5 to 10% reduction in GHG emissions per sector, as many processes will shift from operating on fossil fuels to operating on clean energy.

In developing new renewable and non-emitting electricity generation resources, we must not lose sight of the fact that all infrastructure will inherently have a carbon footprint. Comprehensive studies will need to be conducted to properly evaluate and optimize the potential solutions, considering the full lifecycle of each technology. This includes considerations for work methods, materials used, and the resulting environmental footprint.

To sustain the momentum towards net zero objectives, the presented pathways should be accompanied by a 30% reduction in the industries not covered in this report, including buildings, agriculture, industrial, waste and others.

Added to reductions from the initiatives discussed in this report, that would result in a total reduction of 195 Mt of CO_2e emissions by 2030, a reduction of approximately 28% from 2005 levels, as shown in Figure 9. We also note that the numbers above focus on emission reductions at the source. Carbon credit mechanisms may additionally be used to address the remaining balance of GHG emissions and help achieve the 2030 targets.

ECONOMIC SECTOR	GHG EMISSION REDUCTION MEASURE	LIMITATIONS / CHALLENGES	POTENTIAL REDUCTION BY 2030 (MT OF CO_2E)
Electricity	Retirement of coal	• Ensure buy-in from all provinces • Need to develop combined-cycle natural gas and nuclear power plants • Power grid limitations	40
	Addition of Renewable Generation: 5 to 7 GW/ year of newly installed capacity from hydro, nuclear, solar and wind sources depending on local resources and geography	• Need to upgrade and reinforce a nearly exhausted transmission network to increase capacity • Development of new infrastructure • Resolution of challenges related to generation location • Coordination of interties to existing transmission network	Electrification of other economic sectors
Transportation	Battery electric vehicles: cars and light and medium trucks (private and commercial)	• Consumer behavior • Charging infrastructure • Limitations in material supplies for production	35
	Hydrogen fuel vehicles: heavier vehicles	• Limited existing applications • Need for growth in electricity production • Lack of production, storage, distribution and dispensing facilities	Dependent on various techno-economic factors
Oil and gas	Methane Emissions Reduction: fugitive emissions and venting	• Precision in detection of fugitive emissions • Dependence on renewables to cut venting emissions from fossil fuels	30
	CCS/CCUS: Carbon capture, utilization for enhanced oil recovery and storage	• Development of CCUS facilities • Feasibility of interconnection to the ACTL pipelines	Dependent on various techno-economic factors
	Electrification: replacement of fossil fuels by renewables and small modular reactors	• Need to pause operations to complete retrofits • Dependence on electricity sector	
Buildings, agriculture, industrial, waste and other	30% emissions reduction per sector	• Need for significant regulation, investments, and incentives	90
Total potential emissions reduction by 2030 (Mt of CO_2e)			195

TABLE 6 SUMMARY OF SUGGESTED MEASURES BY ECONOMIC SECTOR

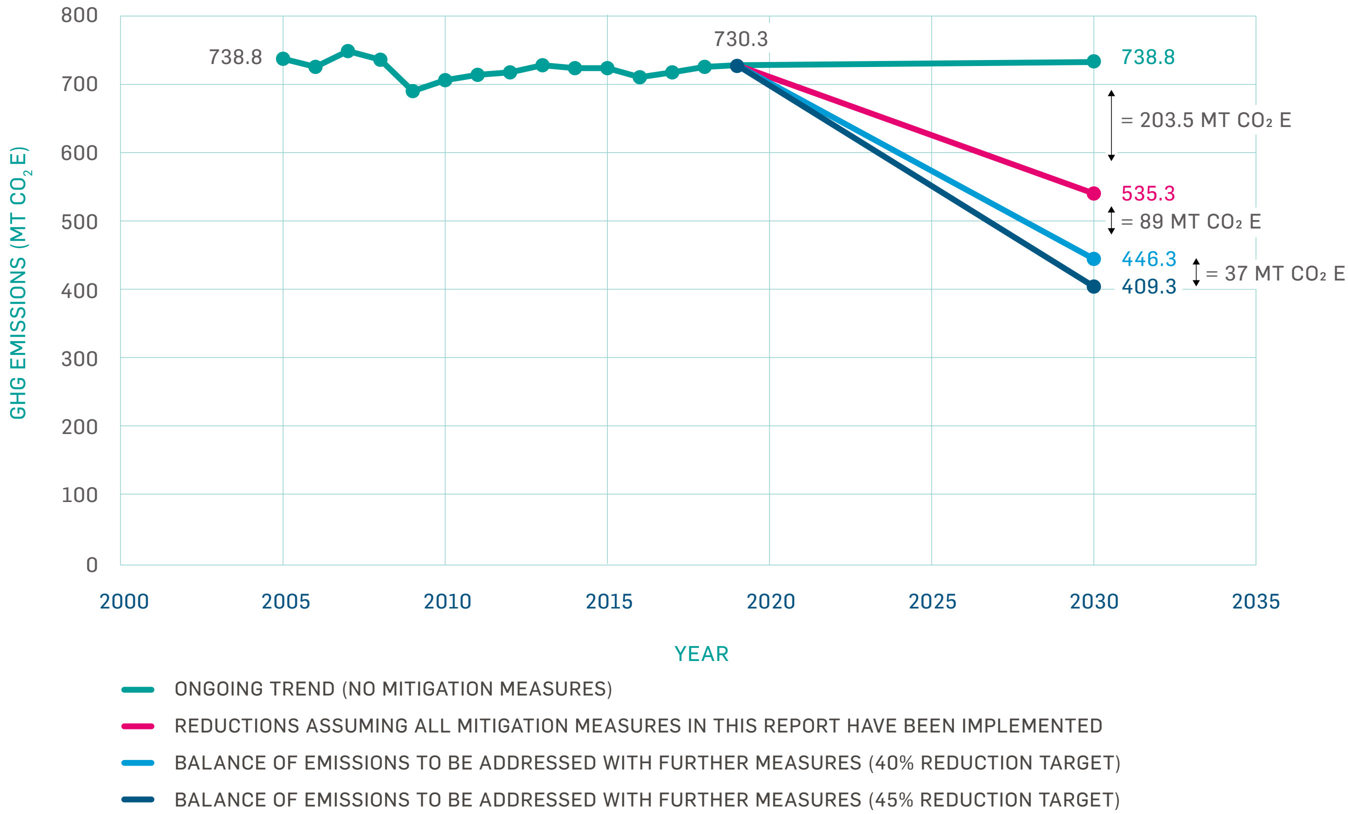


FIGURE 9 GHG EMISSIONS: ACHIEVABLE SHORT-TERM REDUCTION MEASURES VERSUS 2030 TARGETS [11]

To reach the 40-45% reduction target by 2030, further actions to the ones presented in Table 6 must be undertaken immediately to cut an additional 89-126 Mt of CO_2e emissions. Governmental support at all levels is indispensable to drive technological development forward and gradually implement the planned changes in the distinct yet interrelated industries. Further societal and economic stimulus is needed to alter consumer behaviour and fuel technological advancements, respectively.

Canada has already made significant commitments at COP26 [Ref. 2], which focus on carbon pricing, phasing out of coal generation, reducing oil and gas emissions (and more specifically methane emissions), implementing policies to mobilize private financing, increasing actions related to oceans, forests, and nature-based climate solutions, cleaner transportation, and indigenous communities leadership and engagement.

The 2030 Emissions Reduction Plan [Ref. 3]. issued by the Government of Canada in March 2022 will provide $9 Billion in funding towards cutting emissions in all the economic sectors.

Further electrification of means of transport, oil and gas extraction and refining operations, and industrial manufacturing processes, along with the development of CCS facilities and the commercial availability of hydrogen-fuelled products may allow Canada to meet the decarbonization targets within the restricted timeframe.

This is a call for a nationwide collaborative effort across economic sectors to accelerate the integration of selected techno and socio-economic changes required to reverse the environment-damaging trends, lessen the impact of climate change, and allow a better future for generations to come.

[11] 2005-2019 data based on: Environment and Climate Change Canada. (2021). National inventory report 1990–2019: greenhouse gas sources and sinks in Canada: part 1.

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