PATHWAYS TO DEEP DECARBONIZATION IN CANADA

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1 DECARBONIZATION PATHWAYS PROJECT

The Deep Decarbonization Pathways Project (DDPP) is an initiative of the United Nations Sustainable Development Solutions Network (UNSDSN) and Institute for Sustainable Development and International Relations (IDDRI). The Canadian project team is one of 16 country teams exploring national deep decarbonization pathways. This group of countries includes about 75 per cent of global greenhouse gases (GHGs), 85 per cent of the total world economy and, for Canada, represents 90 per cent of our export trade.

The objective of the DDPP is to explore elements of deep decarbonization consistent with limiting global temperatures to +2° C while maintaining global prosperity. The target is for all countries to hold greenhouse gas (GHG) emissions at 1.7 tonnes per capita by 2050. Setting this egalitarian global per capita emissions goal avoids contentious discussions about burden sharing associated with negotiating reduction targets required to limit GHG emissions to a level consistent with the 2°C global temperature increase.

Phase 1 of the project produced an interim report for the Climate Leaders' Summit in New York in September, 2014. Canada's Phase 1 country report was released at that time. The purpose of Phase 2, leading up to the United Nations Framework Convention on Climate Change's (UNFCCC) 21st Conference of the Parties (COP 21), is to develop a report to be tabled at COP 21 by the French presidency. Today, the DDPP has had a material impact on the UNFCCC negotiations, most notably adding the deep decarbonization language and emission trajectories to mid-century into the UNFCCC negotiating process and the global climate policy discourse, culminating in the G7 announcement in June 2015 to decarbonize by 2100.

In the Canadian context, the purpose of this report is to help reveal resilient decarbonization pathways that can be implemented today and scaled to deeper mitigation ambition in the longer term.

In addition to this introductory section, this report is organized into seven sections:

Section 2 provides the context for the Canadian deep decarbonization report, looking at global trends gleaned from our work with the 15 other global DDPP teams.

Section 3 provides an overview of Canada's GHG trajectory, looking particularly at how the new low oil price environment is driving GHGs in different segments of Canada's economy.

Section 4 presents Canada's deep decarbonization pathway developed for this report, including the policy package, the GHG outcomes, the main decarbonization pathways, investment needs and the impact of oil prices on Canada's economy.

Section 5 deconstructs the decarbonization pathways, exploring key technology trends and opportunities towards deep GHG reductions by mid-century.

Section 6 explores Canada's recently announced 2030 Intended Nationally Determined Contribution within the context of a 2°C emission reduction trajectory.

Section 7 provides a summary of opportunities to align short-term action with a deep decarbonization pathway.

2 GLOBAL PATHWAYS TO DECARBONIZATION

The Canadian DDPP team has been active in climate policy for a number of years, including developing many of the National Roundtable on Environment and Economy low carbon reports, including *Getting to 2050*, *Achieving 2050*, *Framing the Future* and *Parallel Paths*. The team has also worked with a number of Canadian jurisdictions, industry and non-governmental organizations to envision both short-term and longer-term policy pathways. This experience has enabled us to draw upon a long history of analysis and modelling to focus on Canadian deep decarbonization to 2050.

Complementing this domestic focus is our interactions with the 16 other project teams in the DDPP. Through a series of meetings and working groups, we have collectively begun to coalesce around deep decarbonization pathways that are resilient across countries but also mitigation ambition.

We observe that in virtually every country there are clean energy policies and technology drivers that are pushing global decarbonization trends. Several notable policy and technology trends are contributing to initial steps toward a +2°C world, including decarbonization of electricity production and energy-efficiency improvements in buildings and transport.

The benefits to Canada of these global trends are global technology spillovers, where access to clean and low-emitting technologies mean we are decarbonizing rapidly over time as new equipment is deployed to replace older stock. Global decarbonization trends will also help Canada to achieve deeper GHG reductions in the longer term as technology feasibility improves and costs fall.

Despite global trends towards progress in reducing the emission intensity of electricity production, buildings and transport, significant gaps in global technology exist that pose a challenge for Canadian deep decarbonization efforts. Some notable examples with a particular relevance to Canada's decarbonization aspirations include:

- Enhanced electric grid flexibility and storage to handle more intermittent renewables.
- Battery technology for urban vehicles.
- Energy-dense fuels for heavy, long-haul transport (advanced biofuels or hydrogen).
- Advanced low carbon extraction techniques for oil sands (e.g., solvent extraction, direct contact steam generation, radiofrequency heating).
- Carbon capture, storage and utilization for thermal electricity generation, industrial and oil and gas extraction steam and heat needs, and process emissions (e.g., from cement production).
- Enhanced use of very large electric heat pumps in industry for heating requirements (process heat, boilers, etc.).
- Alternative processes in heavy industry that use less or no fossil fuels. Some possibilities include: use of hydrogen instead of carbon as a reducing agent in iron and steel; enhanced steel recycling to allow more electric mill processing in place of virgin ore; and electrified ore separation in mining via crushing, immersion in acid baths and electrolysis, instead of heating for ore separation.
- Advanced carbon dioxide process sinks (e.g., direct air capture).

It is with this global backdrop that this second DDPP Canada report is provided. We look outside of Canada's borders to identify global decarbonization trends that will affect Canada and our ability to achieve deep decarbonization. We focus on identifying resilient pathways that policy can target regardless of the mitigation ambition, whether it is tentative, short-term steps or longer-term shifts towards deeper reductions.

The next section provides an overview of the modelling and analysis scenarios we developed to help explore these pathways.

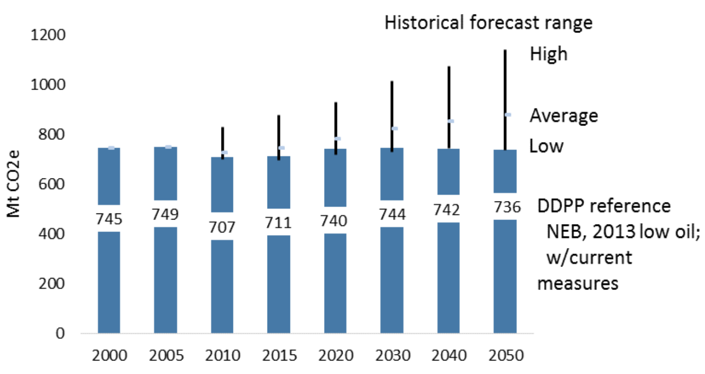
3 CANADA'S GHG EMISSION TRAJECTORY

The starting point for our exploration of Canada's decarbonization pathway is a reference case of emissions between now and 2050. We use this reference case as a benchmark against which policy and subsequent technology deployment drives down GHGs in the energy systems consistent with the 1.7 tonnes per capita DDPP target. To set the reference case, we use an energy and economic model, CIMS, to forecast demand for GHG intense goods and services, energy balances, technology deployment and ultimately emissions, and GEEM, a macroeconomic model, to forecast GDP, employment, economic structure and trade.

A significant determinant of any long-term GHG forecast for Canada is undoubtedly the future price of oil, where the trajectory of oil production and end use prices drive two very distinct energy economies. In a high oil price future, Canada can expect more oil and gas development, but also more economy-wide conservation, especially in transport, and low-emitting technology deployment. The opposite can be expected in a low oil price future.

Successive long-term GHG forecasts since 2007 had varied significantly primarily due to assumed oil and gas prices and the associated production and conservation responses. Our deep decarbonization pathways Canada (DDPC) Reference Forecast is provided in Figure 1, compared with various National Roundtable on Environment and Economy forecasts we have produced along with forecasts

Figure 1: GHG Historical, DDPC Reference Case Compared with Past Forecasts

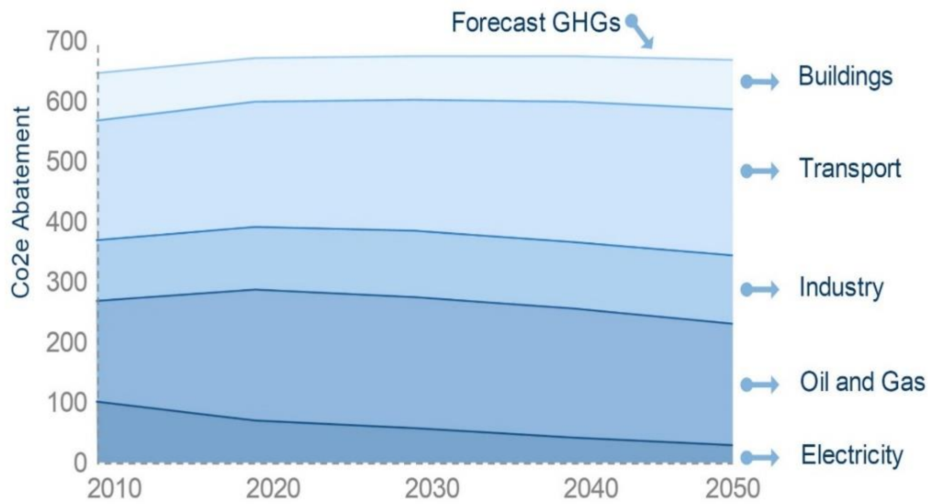


from the National Energy Board and Environment Canada.[1] In our newest reference case, we adopt the oil and gas price and production from the 2013 National Energy Board (NEB) low price case scenario, given its similarity to currently prevailing conditions in the global oil market. Figure 1 provides our forecast, compared with historical forecasts.

Given such volatility in the GHG forecasts, we explore more closely the impacts of alternative oil prices assumptions on Canada's emissions trajectory in the next section. Later in this report, we also take a closer look at the economic structural changes in Canada's economy that underline these swings in GHG emissions, as well as the production and emission scenarios in a +2°C world with constrained global demand and depressed oil prices.

The reference case includes all major existing greenhouse gas abatement policies of both federal and provincial governments in Canada, including B.C.'s carbon tax, Alberta's Specified Gas Emitters Regulation (SGER), Ontario's coal phase-out, Québec's cap and trade, and federal coal-fired electricity and vehicle efficiency regulations. Modelling was completed before Ontario's proposed cap-and-trade system was announced, and the details are not yet known; as a result, the proposed policy was excluded. Other similar initiatives are also included.

Figure 2: Reference Case Sector GHG Shares (no land-use GHGs)



[1] NEB and Environment Canada forecasts are to 2030. Post 2030 we linearly extrapolated the oil and NG price forecasts (these prices are established at the global and North American level) and used our GEEM macroeconomic model to calculate oil and NG output to 2050.

In the reference case, national emissions are relatively stable over the forecast period, reaching 736 million tonnes (Mt) in 2050 (666 Mt of energy emissions). This stability belies changes in emissions trends by sector, as shown in Figure 2. Emissions from fossil energy extraction and transport increase over the period, due to greater sector activity (and despite improvements to emissions intensity). The oil and gas GHG trajectory is interesting, with rising emissions to 2020 as new developments currently under construction come on line, but with very few new developments as long-term oil prices remain flat. Emissions from electricity decrease sharply from about 100 Mt in 2020 to under 30 Mt in 2050, due to a combination of provincial and federal regulations. Lastly, emissions from industry and buildings are relatively steady because growing sector output is more or less offset by improvements in emissions intensity as new high-efficiency equipment replaces old stock.

3.1 THE IMPACT OF OIL PRICES ON CANADA’S GHG TRAJECTORY

Clearly, long-term oil developments remain uncertain, especially the extent to which global demand will change in a decarbonizing world and the proportion of global demand that will be met by Canadian production for Canada, we simulated alternative oil price pathways to compare against our DDPC reference case. Not surprising, we find a significant variation in alternative long-term GHG forecasts, with the oil price and associated production being a major determinant of Canada’s emission trajectory, especially at the

Figure 3: Oil Price Trajectories

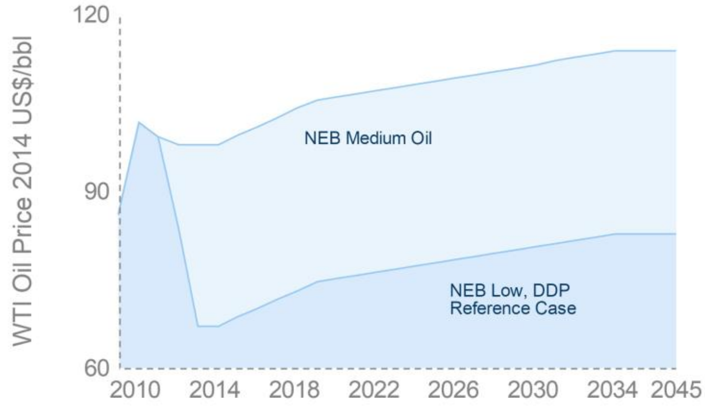


Figure 4: Oil Price Impact on Production

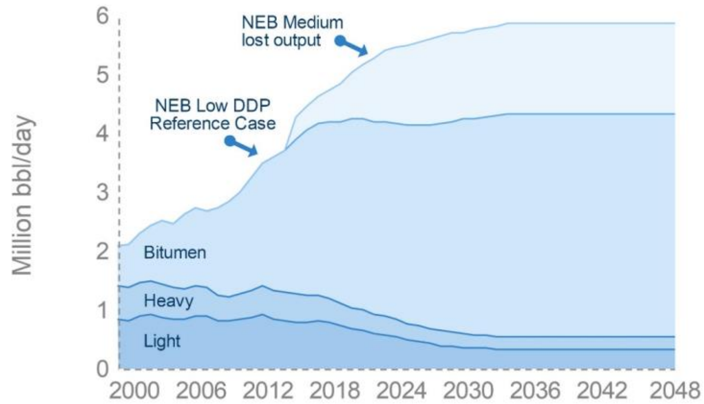
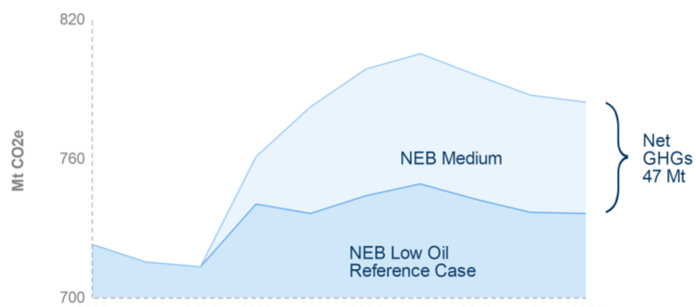


Figure 5: Oil Price Impact on GHGs



sector level.

The two oil price cases we compare include a deep decarbonization pathways Canada reference case and a high oil price scenario.

DDPC reference case, NEB low benchmark. Reflecting the 2014 collapse in oil prices we adopted the NEB low price scenario, which at the time of report writing was the only publicly available and credible long-term forecast reflecting current market trends. In our reference case, the long-term price of oil stabilizes at a yearly average of $83 after 2030, rising from an average of USD $67 for 2015 (in 2014 dollars), driving 4.3 million barrels per day of oil production. Henry Hub natural gas prices are about USD $4.8 per million British thermal units (MMBTU) with production of 11 billion cubic feet per day. This reference case essentially has production ramping up to 2020 then more or less stabilizing in the longer-term, with GHG emissions more or less stabilizing from today.

DDPC high oil price, NEB medium benchmark. The basis for the high oil price assumption is the 2013 NEB medium reference benchmark. In this scenario, oil prices climb to USD $114 in 2035, which we then assume remains constant through 2050. Oil production consequently increases to 7.6 million barrels per day by 2050. Natural gas prices rise to USD $6.7 per MMBTU and natural gas production increases to 17.4 billion cubic feet per day. In this scenario, emissions are about 20 Mt higher in 2020, but then stay about 50 to 60 Mt greater than the reference case to 2050 (Figure 3).

Figure 5 compares the GHG trajectory of the two scenarios, highlighting the significant impact that oil and gas prices have on Canada's emission trajectory through production and consumption. The net impact of higher oil prices and production is to increase Canadian emissions by 47 Mt in 2050 or 7 per cent.

Overall, net emissions are dominated by the upstream fossil production in either oil price scenario, with transport emissions only somewhat offsetting upstream emissions. The key dynamics are threefold.

First, the higher oil prices scenario drives more fossil energy extraction, boosting sector emissions relative to our reference case by 82 Mt in 2050, or 12 per cent higher.

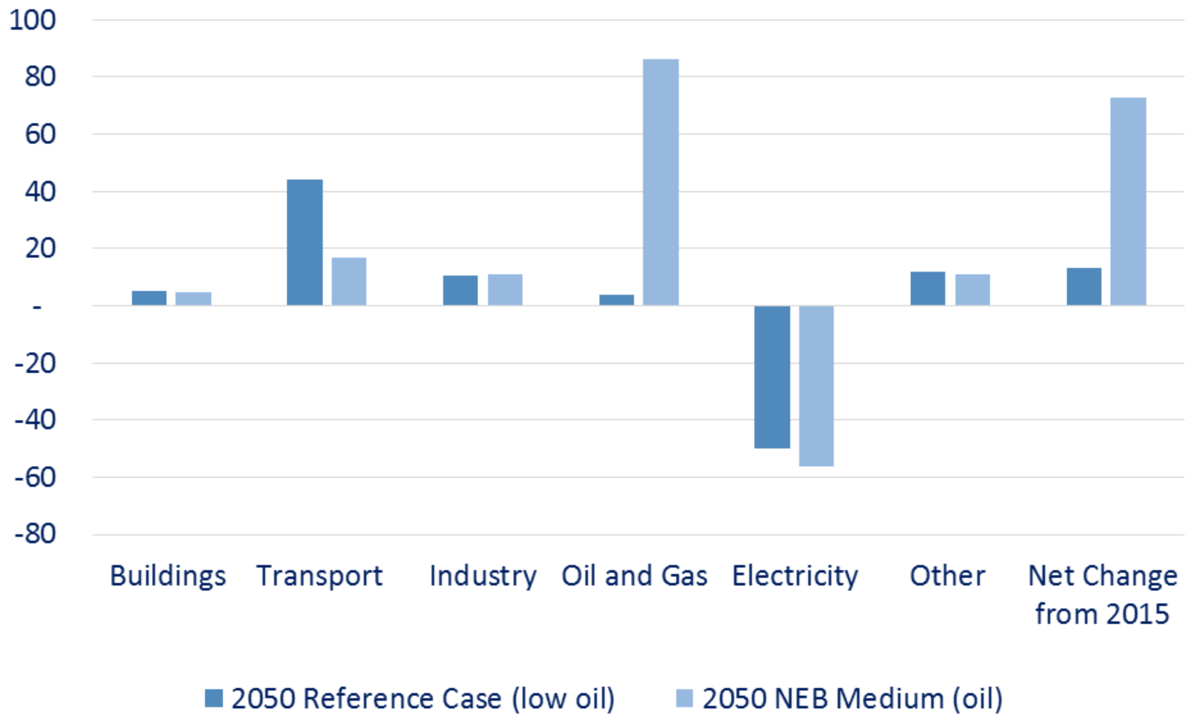
Second, there is an offsetting net effect on emissions as oil prices impact long-term technology deployment on the consumption side. Higher oil prices discourage the consumption of gasoline and diesel, with emissions in the NEB medium scenario down 4 per cent or 27 Mt. Ongoing energy-efficient regulations dampen the transport emissions rebound as the fuel economy of the transport fleet significantly improves to 2050.

The large relative drops of GHGs in both scenarios reflect Ontario's coal electricity phase-out, which delivers emission reductions before 2015, but also the federal coal-fire power electricity regulations that reduce the emission intensity of electricity after 2020, despite a 50 per cent expansion in electric demand between now and 2050.

Third, changes to energy prices induce minor fuel switching and changes to emissions in other sectors of the economy, such as buildings and industry.

Figure 6 shows the sector trends in 2050 relative to the reference case.

Figure 6: Change in Emissions in 2050 from 2015 Reference Case (Mt carbon dioxide equivalent)



4 CANADIAN PATHWAYS TOWARDS DEEP DECARBONIZATION

The deep decarbonization pathway for Canada (DDPC) developed in this report is one scenario toward ensuring economic prosperity while achieving global per capita emissions of 1.7 tonnes per capita by 2050, consistent with a 66% per cent probability of limiting global average temperature increases to 2°C. This target was set by the UNSDSN/IDDRI DDPP initiative to be consistent across all countries, essentially taking the global budget required to limit temperature changes to 2° C in 2050 and dividing by a forecast of the global population. This approach avoids many of the political challenges associated with the global burden sharing of carbon dioxide reductions, bypassing contentious issues such as past contributions to the global stock of carbon dioxide and development aspirations.

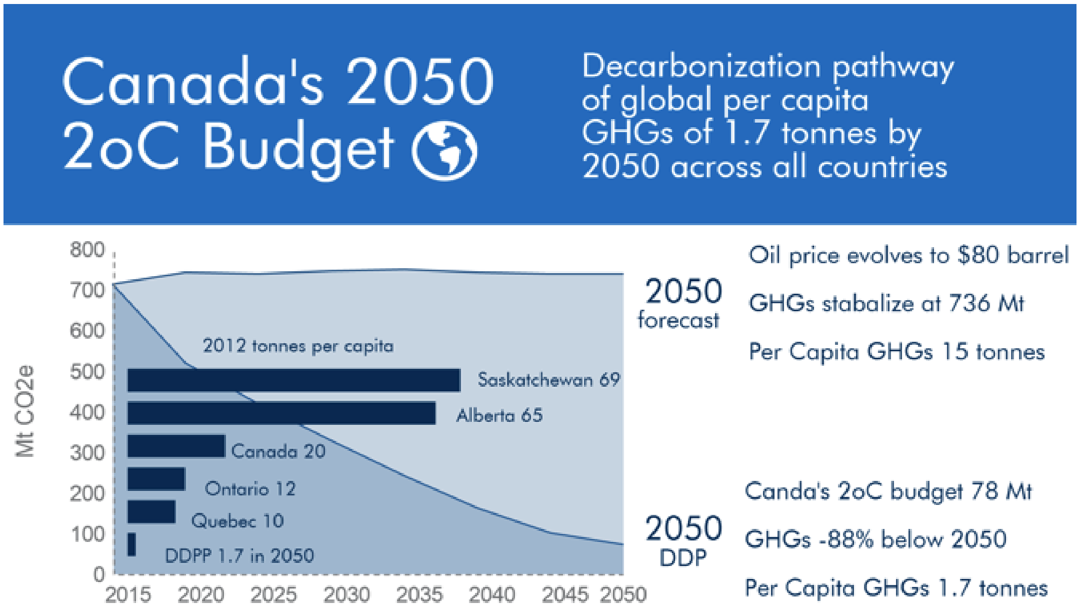
This DDPC implies dramatic reductions in GHG emissions in Canada, where per capita emissions are presently 21 tonnes, with our analysis and modelling indicating that this is truly a stretch scenario relative to current and forecast policy stringency. The main benefit of such a scenario, especially for Canada, is it identifies resilient policy pathways that can be implemented in the short term while being scalable to longer-term mitigation aspirations.

In this section, we look at the policy required to achieve the 1.7 tonnes per capita DDPC benchmark, deconstruct the emission pathways and provide an overview of the scale of the investment needed.

4.1 POLICY PACKAGE FOR A CANADIAN DEEP DECARBONIZATION PATHWAY

To achieve deep GHG reductions, the decarbonization pathway we simulate includes best-in-class regulations that strengthen existing policies for the electricity, buildings and transport sectors, as well as a cap and trade system to drive abatement in heavy industry and oil and gas. The policy package also includes a complementary carbon price on the rest of the economy that essentially mops up reductions to reach areas where the regulations do not go, and returns the revenues to reduced income and corporate taxes. These rather aggressive measures need to be implemented essentially immediately if deep decarbonization is to be achieved by 2050, which we as analysts realize is pushing the limits of plausibility. On the other hand, if strong policy is implemented soon, innovation of currently unknown technology is almost guaranteed to occur, making meeting the target somewhat more reasonable.

Figure 7: DDP Canada Pathway



The main elements of the policy package:

1. **Best-in-class regulations** require the use of zero or near-zero emission technologies in the buildings, transport and electricity sectors, applied to all new installations and retrofits. The requirements are as follows:
    - **Mandatory energy and GHG intensity regulations for buildings, vehicles and appliances.** These follow current federal and provincial regulation to the early mid-2020s, and then start dropping to a 90–99 per cent reduction in GHG intensity by 2045:

- **Buildings.** Regulations would trend down to require net-zero-energy residential buildings after 2025, and commercial buildings after 2035. This would be enabled by highly efficient building shells, electric space and water heaters with heat pumps for continuous load devices, solar hot water heaters and eventually solar photovoltaic (PV) as costs fall. Community heating opportunities identified thorough energy mapping is also an option.
- **Personal and freight transport.** Personal vehicles and light freight, because they have several options including efficiency, electrification, bio fuels, hydrogen and mode shifting**,** would be on a rolling 5-year schedule, with the announced long-run goal being for all new vehicles to decarbonize in the early 2030s. Heavy freight vehicles that have more limited options (including some rail-based mode shifting, efficiency, biofuels and hydrogen—batteries are not sufficiently power dense for freight) would be on a schedule to decarbonize by 2040.

2. **Mandatory 99 per cent controls for all landfill and industrial methane sources (landfill, pipelines, etc.).** Any remaining emissions would be charged as per the following policy.
3. **A hybrid carbon-pricing policy, differentiated by heavy industry and the rest of the economy:**
   - **A tradable GHG performance standard for heavy industry** (including electricity), evolving from -25 per cent from 2005 in 2020 to -90 per cent before 2050, using output-based allocations to address competiveness concerns. This system has the advantage that is produces an incentive for early "lumpy" emissions reduction projects, such as CCS in electricity with consequent innovation effects, the excess permits of which can be sold to other emitters. If desired, an absolute cap and trade system could be implemented instead with mostly similar effects.
   - **A flexible carbon price, either a carbon tax or an upstream cap and trade[2], covering the rest of the economy,** rising to CDN $50 by 2020 and then in $10 annual increments to 2050.[3] The funds are recycled half to lower personal income taxes and half to lower corporate income taxes. The charge would be flexible based on progress—the above charge was required to meet the DDPP target, but technological advancement driven by carbon pricing and complementary innovation policy would likely dramatically reduce the necessary price, as happened with the U.S. SO_x cap-and-trade system.
4. **A land-use policy package that values the net carbon flows of large parcels of land.** The policy would provide standardized valuation and accounting for net carbon

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[2] If the latter, the heavy industry cap and trade system would not be required, but the signal to adopt CCS (and consequent innovation) in electricity would be missing until the mid-2020s.

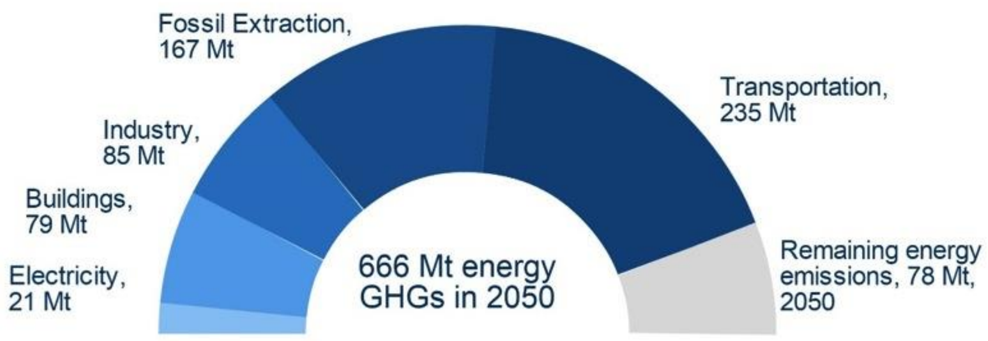
[3] All prices are in constant 2014 Canadian dollars unless otherwise denoted.

flows on agricultural, forested, brownfield and wild private lands. Government lands would be managed including net carbon flows in the mandate. Figure 7 provides an overview of the emission trajectory from the 2050 forecast to the 2050 DDPC target. Canada's +2°C budget works out to be about 75 Mt in 2050, or a 90 per cent reduction below the forecast levels. Per capita emissions move from 20 tonnes per capita today to 15 tonnes in the reference forecast and then transition down to 1.7 tonnes by 2050 in the DDPC pathway.

4.2 DDPC EMISSION OUTCOMES

In the DDPC, GHG emissions steadily decline from today's levels to 78 Mt by 2050, excluding agriculture. This level represents a decrease in energy related emissions of 88 per cent relative to reference case emissions in 2050. Nearly half of remaining emissions in the decarbonization pathway are from fossil energy extraction in 2050 (see Figure 8), but our analysis shows that this amount could vary depending on production levels (see Section 3.1). A further third are associated with industrial activity. The buildings, transport and electricity sectors almost completely decarbonize by 2050, accounting for less than a quarter of remaining emissions.

Figure 8: 2050 Energy Emissions below Reference Case by Sector



Below, we summarize the activities that contribute to the 78 Mt of remaining GHGs in 2050 in the DDPC scenario.

Fossil energy extraction (approximately 42 per cent of emissions in 2050):

- **Extraction and upgrading of bitumen from the oil sands.** Solvent extraction, direct contact steam generation (with process associated, automatic carbon dioxide sequestration) and CCS decrease the emissions intensity of oil sands production by about 90 per cent relative to today's levels. However, if production levels remain the same as in the Reference Case, this sector accounts for nearly a quarter (17 Mt) of remaining emissions in 2050.
- **Extraction of tight and shale gas.** The emissions intensity of unconventional natural gas production decreases dramatically due to improved operating practices such as the

extensive use of leak detection and repair technologies, electric motors for compression and conveyance, and CCS for formation gas stripping. Similarly to oil extraction, if production levels are fixed, the sector still accounts for almost a fifth (14 Mt) of remaining emissions.

Industrial activities (approximately 32 per cent):

- **Heat and steam production.** In cases where electricity or other zero emission technologies are infeasible for the production of heat and steam, fossil fuels are used in conjunction with CCS. Such processes related to the production of iron, steel, chemicals, metals and cement account for the bulk of remaining industrial emissions. These emissions could be largely eliminated by switching to electrolytic and hydrogen-based processes, or even radiofrequency heating, but this would require all new facilities to be based on the latter starting today and some premature scrapping of fossil fuel-based facilities. It would also require bulk access to decarbonized electricity.

Solid waste (approximately 6 per cent):

- Capping medium to large facilities and combusting the associated landfill gas by flaring or for electricity generation reduces the waste sector's emissions by about 80 per cent relative to current levels. However, due to numerous smaller facilities being difficult to regulate, these processes still generate GHG emissions, which account for about 5 Mt in 2050.

Transport (approximately 10 per cent):

- **Fossil fuel consumption for air, marine and rail transport.** Some long-lived technology stock that relies on fossil fuels remains in service in 2050, such as aircraft, ships and trains.
- **Combustion of biofuels.** Third generation biofuels are extensively used for various transport modes, especially long-distance and heavy transport. The net emissions intensity of third generation biofuels (based on cellulosic ethanol or diesel running on switchgrass, woody biomass or algae feedstocks) is quite low, but their production does contribute to remaining transport emissions. Upstream emissions are also present in the biofuel-refining sector.

Utility electricity generation (approximately 8 per cent):

- The electricity sector expands rapidly as demand sectors electrify to reduce end-use emissions. However, the majority of electricity is generated by zero or near-zero emissions sources, including renewables benefitting from increased grid flexibility and grid-scale energy storage. The remaining 6 Mt is associated with natural gas and coal plants equipped with CCS. This could be eliminated if only solid oxide or molten carbonate fuel cells were used (approximately 99 per cent pure carbon dioxide emissions stream allows almost perfect capture) instead of post-combustion capture plants (which are modelled at 90 per cent effectiveness), or if more effective capture post-combustion methods were invented.

Buildings (approximately 1 per cent):

- Emissions are associated with limited natural gas and biomass that is combusted for various end-uses.

4.3 DECARBONIZATION PATHWAYS SCALABLE TO MITIGATION AMBITION

Our analysis identifies six pathways under three main themes that emerge from our analysis and modelling. Some of these pathways reinforce current trends—for example, continuing efforts to decarbonize electricity generation and improve energy efficiency in transport and buildings. Other pathways require transformative technologies, such as CCS, alternative non-fossil fuel processes in industry and alternative fuels for transport. Lastly, structural economic change reorients the economy toward less emission-intensive activities.

The six decarbonization pathways, organized under three themes, include:

1. **Deepening Current Trends.** This group of three pathways are the building blocks of current climate policy both in Canada and abroad. These pathways are characterized as having a broad and resilient portfolio of technically and economically feasible technologies now. Virtually every jurisdiction in Canada, and many globally, are pushing technology deployment and innovation with policy. To achieve deeper decarbonization, current policy and market trends are driving down costs and increasing technical feasibility, but need to be significantly deepened across the economy for deep decarbonization.
    - **Pathway 1: Decarbonized electrification.** Low-emitting electricity captures a much larger share of total energy use across the entire economy and provides a low-cost fuel-switching path for currently fossil fuel-based end uses.
    - **Pathway 2: Improving energy productivity.** Doubling down on current energy savings trends in buildings, vehicles and industry to capture the full and largely untapped stock of energy productivity potential.
    - **Pathway 3: Reduce, cap and utilize non-energy emissions.** This includes two low-cost actions with especially high impact. First, capping and utilizing of methane from landfills (methane is a much stronger greenhouse gas than carbon dioxide). Second, in the oil and gas sector, reduction of wellhead and pipeline venting and leaks, and replacement of gas actuated devices with electric ones where possible. In the past, much gas was released to the atmosphere, especially from heavy oil wells, because there wasn't sufficient gas relative to oil to pipe the gas to market. With the GHG value included, more gas would make it to market that is today escaping into the atmosphere. In both cases, the captured methane can sometimes be used to make electricity.

2. **Pushing Towards Next Generation Technologies.** These two pathways cover large shares of Canada's total GHG emissions, yet policy and innovation signals both at home and abroad are weak. As a result, while there are many technically feasible options available to drive down emissions, few have been commercialized. A particular area of risk for Canada is a lack of commercial abatement opportunities in our large and growing industrial sector, particularly oil and gas and other primary extraction. Deep decarbonization requires pushing next-generation technologies to drive down costs and improve feasibility in the longer term.

    - **Pathway 4: Move to zero emission transport fuels.** There is a technological race between electric batteries, non-food crop biofuels and hydrogen to power our personal and freight transport fleets. Electric vehicles currently have an edge in personal and urban freight vehicles, but do not have the power density for freight transport with known technology. Scaling up non-food crop biofuels (which do have the necessary power density) to take advantage of Canada's large biomass resource, however, requires significant technological advances and innovation.

    - **Pathway 5: Decarbonize industrial processes.** Significantly reducing both energy and process emissions faces technological hurdles, especially at deep decarbonization levels. Heavy industry is typically energy intense, and Canadian industry developed in a time with relatively low energy prices; it was, in fact, a competitive advantage for Canada. While many engineering pathways exist to virtually decarbonize heavy industry, they have not attracted significant innovation globally because there are few constraints on carbon to trigger innovation. Significantly reducing emissions from industrial processes will require the widespread deployment of new and transformative technologies that will require Canadian-specific and international innovation to become commercial.

3. **Pathways of Structural Economic Change (Pathway 6).** As the world transitions to a low-carbon future, and carbon becomes increasingly expensive, there will be natural shifts in the structure of Canada's economy. The shifts will be driven by our own policy, but also the demand for Canadian goods and services, particularly for Canada's oil and other natural resources. The question, then, is what does the structure of Canada's economy look like in a deeply decarbonized world? In a decarbonizing world, those economies that have become less exposed to trade in fossil fuels, while becoming more capital intense based on the production of domestic renewable electricity and other renewables, will likely weather shifting global demands with greater ease and resilience.

“DEEPEN CURRENT TRENDS BY CONTINUING TO DECARBONIZE ELECTRICITY AND IMPROVE ENERGY EFFICIENCY”

“PUSH TOWARDS NEXT-GENERATION TECHNOLOGIES IN INDUSTRY AND FUELS”

“STRUCTURAL ECONOMIC CHANGE REORIENTS THE ECONOMY TOWARDS LESS EMISSION-INTENSIVE ACTIVITY”

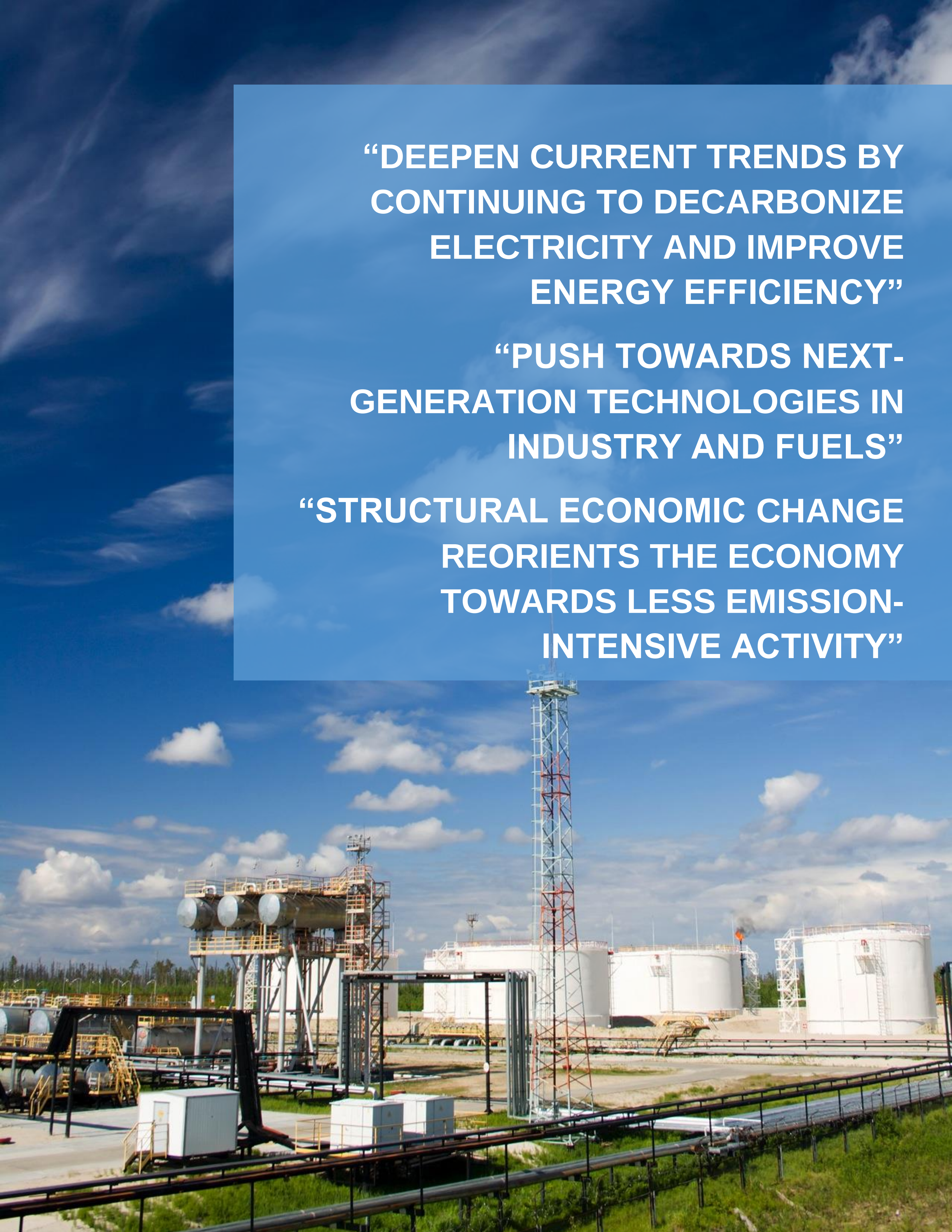
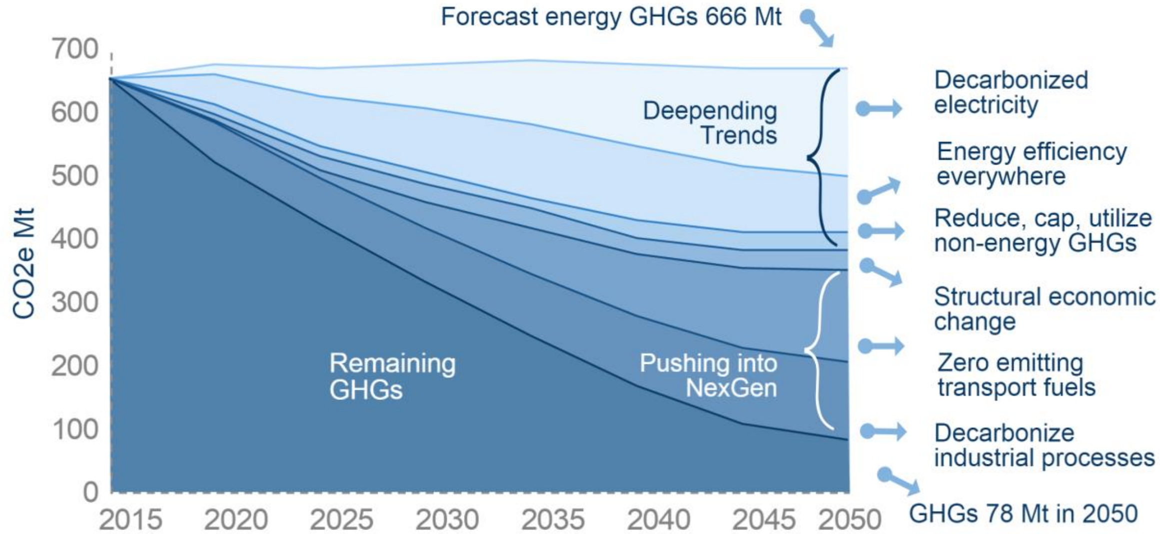


Figure 9 provides the graphical overview of the contribution of each of these pathways to decarbonization.

Figure 9: Deep Decarbonization Pathways to 2°C (excludes land-use emissions)



4.4 INVESTMENT FOR DEEP DECARBONIZATION

The level of transformational change outlined in the previous section requires significant investments to move the economy away from fossil fuels. In this section, we present the investment costs of deep decarbonization paid by firms and consumers (investment for consumers is here defined as payments for durable goods like refrigerators, cars, appliances and houses). Figure 10 provides a graphical representation. Even with the deep levels of decarbonization envisioned in the above scenario, capital investments are not that significant relative to historical levels, and in some cases represent savings.

In our decarbonization scenario, consumers experience an overall drop in investment costs of CDN $2.6 billion annually between 2015 and 2050, largely in the personal transport sector, with consumers switching to smaller, more efficient and cheaper vehicles. Mode switching to higher occupancy vehicles, transit, walking and cycling also reduce capital expenditure levels.

In total, firm level investment is an additional $16.2 billion annually between 2015 and 2050, representing an increase of 8 per cent over historic levels of private sector investment (Figure 10). The greatest amount of investment, both in absolute terms and relative to historic investment levels, is needed in the electricity sector. The incremental investment required amounts to $13.5 billion annually, representing an increase of 87 per cent relative to historic levels. It should be noted that significant incremental investment is already required in the reference case to meet growing electricity demand as well as various provincial and federal clean electricity policies. Therefore, the total investment needed relative to today's level is even higher than that reported.

The level of investment required in other sectors is much less than that observed in electricity. For example, the level of investment required in the upstream oil and gas sector for the adoption of advanced low emission technologies such as CCS, solvent extraction and direct contact steam generation in in-situ is only estimated to be $2.9 billion annually, just 6 per cent of historic levels of investment. These findings are consistent with those of other studies showing that the adoption of CCS and other best-in- class low carbon technologies increases oil sands production costs and decreases margins by less than $5 per barrel.[4]

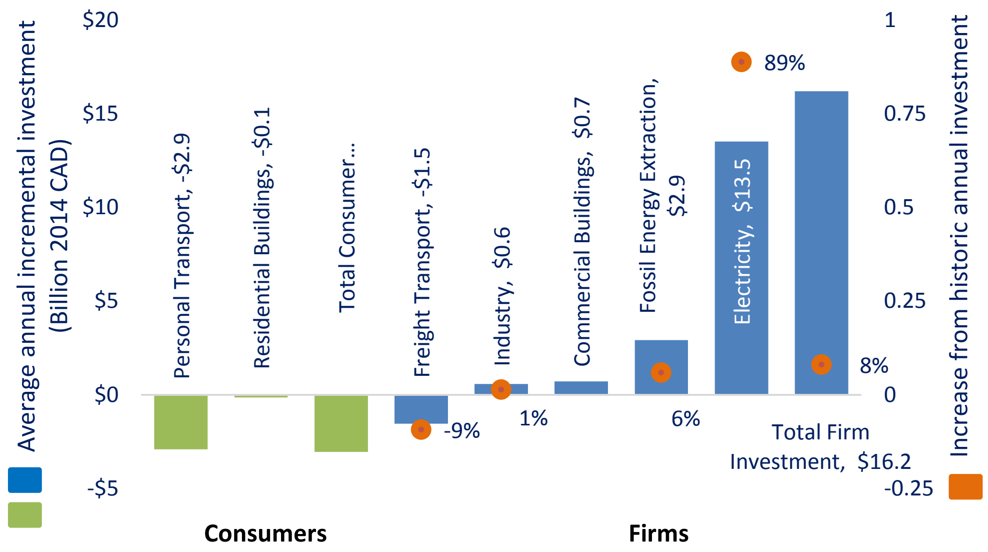
In the DDPC, investment in the commercial buildings sector increases by $700 million annually. These costs are associated with the purchase of lower emission equipment such as heat pumps for space and water heating, more efficient shells and retrofitting of older shells.

Investment in industry also increases by $600 million annually, representing an increase of 1 per cent over historic levels of investment in this sector. This investment is associated with various low-emission technologies, including efficiency, heat pumps, fuel switching, alternative processes and CCS. The investment impacts are dampened as the economy restructures toward less energy- and emission-intensive activities.

Similar to the personal transport sector, freight transport investment costs decrease in aggregate. This is largely due to mode switching to rail, which is more logistically complex but far cheaper per tonne and more energy efficient.

[4] Bataille, C., N. Melton & M. Jaccard. (2014). Policy uncertainty and diffusion of carbon capture and storage in an optimal region. *Climate Policy*. Retrieved from http://dx.doi.org/10.1080/14693062.2014.953905

Figure 10: Change in Average Annual Investment Relative to Reference Case



Notes: All values are not discounted. Historic investment based on average annual values between 2000 and 2013 as reported by Statistics Canada (CANSIM Table 31-0002).

4.5 SENSITIVITY OF CANADA'S ECONOMIC STRUCTURE TO EXTERNAL PRICE SHOCKS: THE CASE OF OIL

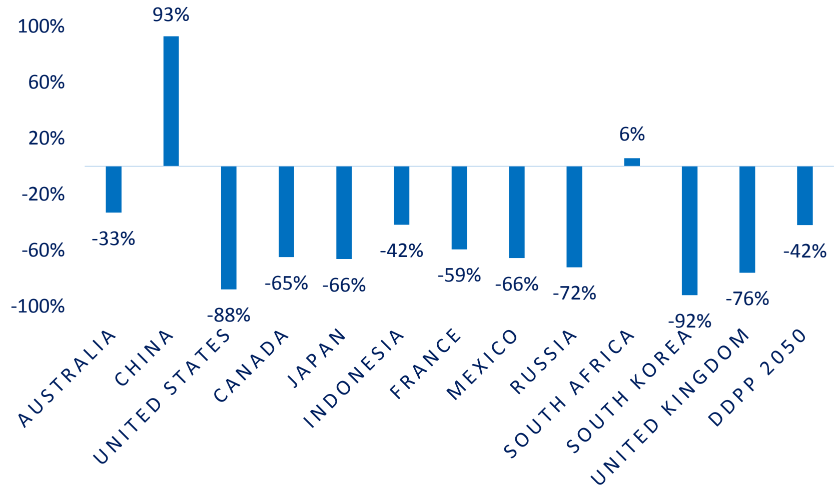
In a decarbonizing world we simply do not know how the demand and supply for oil and other GHG-intense goods will interact and where prices will settle. This is a huge uncertainty for Canada, a potential Achilles heel in terms of deep decarbonization with such a high proportion of the total economy in GHG intense primary extraction. One of the most valuable and visible sectors is the oil sands industry. But what room is there for the oil sands in a deeply decarbonized world, even if best available technology emissions controls are applied? What happens to Canada's overall economic structure with shifts in global oil demand? And with oil production driven directly by the price of oil, and indirectly by demand for refined petroleum products, just how resilient are Canada's long-term economic prospects in a decarbonizing world?

To address these questions, we assess three pathways and impacts on Canada's economic structure with the oil price evolving to differing levels in a decarbonizing world:

- Deep decarbonization with a high oil price, or **HIDDP**, with $114 per barrel in 2050 in today's prices (which is actually the NEB, 2013 Reference scenario). This scenario mirrors some of the International Energy Agency's 2°C scenarios that somewhat uncouple plummeting demand from long-term oil prices.

- Deep decarbonization with a medium oil price, or **MIDDP**, our main scenario more or less follows the NEB 2013 low pathway where oil stabilizes at $80 in the long term. The big difference from our DPPC reference case used throughout this document is that oil supply is allowed to rebalance in the GEEM model instead of following the exogenous NEB production forecast.
- Deep decarbonization with a low oil price, **LODDP,** where plummeting end-use demand coupled with excess global production stabilizes a long-term price at $40 in 2050. Using initial analysis from the 15 DDPP countries, the current view is that oil demand will likely fall in the order of 50 per cent in a deeply decarbonized world (Figure 11). This more or less aligns with assumptions by *World Energy Outlook, 2014* under a 450 ppm scenario. But unlike the *World Energy Outlook, 2014,* with such suppressed demand coupled with ongoing extraction technologies driving down costs, the pathway result in a significantly lower long-term oil price.

Figure 11: Global Oil Demand Relative to Today under Decarbonization



These three pathways were compared against the 2013 NEB low scenario, which we use as the reference point for our analysis, given its similarity to currently prevailing conditions in the global oil market. We show the estimated output based on the NEB Reference and Low Reference oil cases in Figure 12.

As a reminder, the DDPC policy package modelled includes:

- **Best-in-class regulations** require the use of zero or near-zero emission technologies in the buildings and transport sectors, applied to all new installations and retrofits**.**
- **A tradable GHG performance standard for heavy industry** (including electricity), evolving from -25 per cent from 2005 in 2016 to -90 per cent by 2045.

- **A carbon price covering the rest of the economy,** rising to $50 by 2020 and then in $10 annual increments to 2050. The final level of the carbon price will depend on unforeseeable technological developments induced by climate policies. The carbon price revenue is recycled half to lower personal income taxes and half to lower corporate income taxes.

To compare the impacts of the three oil price pathways on Canada's economic structure, we run the NEB reference case unconstrained on production in a version of the GEEM macroeconomic model where most of the provinces are disaggregated, allowing for new equilibria to emerge in energy supply and demand, factor markets and final demand across all economic sectors in Canada's total economy. We then compare these economic outcomes to our DDPC reference case (which uses the NEB, 2013 low oil case) to trace out the structural change impacts on Canada's economy of the different oil price and production trajectories. In each of these pathways the price of oil has an "upstream" effect on crude oil production levels and a "downstream" effect on gasoline and diesel prices.

Figure 12 shows total Canadian oil output estimated by GEEM under each of three structural change pathways:

- **HIDDP** has oil prices rising to $114 in 2035 and then stabilizing to 2050; oil output rises 1.5 million barrels per day (mbpd) above our DDPC reference case by 2050, topping out at 7.5 mbpd.
- **MIDDP** shares its oil price assumptions with the Low Reference case but not its output; with unconstrained output in the model, output falls roughly 1.5 million barrels per day by 2050 compared to our DDPC reference case.
- Finally, **LODDP** is based on conversations with global DDPP modellers (i.e., their view of possible oil prices in a deep decarbonized world). The price of oil evolves from 2015 in even steps down to $40/barrel by 2050, with production falling to about 850,000 barrels per day. This trajectory reflects global oil demand that has emerged from the DDPP process, where global demand falls in the order of 50 per cent by 2050 from current levels.

As discussed in Section 6.5, all three deep decarbonization scenarios include advanced low emissions oil sands technologies such as solvent extraction and direct contact steam generation, as well as large-scale implementation of CCS.

IN A DECARBONIZING WORLD WE SIMPLY DO NOT KNOW HOW THE DEMAND AND SUPPLY FOR OIL AND OTHER GHG-INTENSE GOODS WILL INTERACT AND WHERE PRICES WILL SETTLE.

Figure 12 Estimated Total Canadian Oil Production in Each Scenario

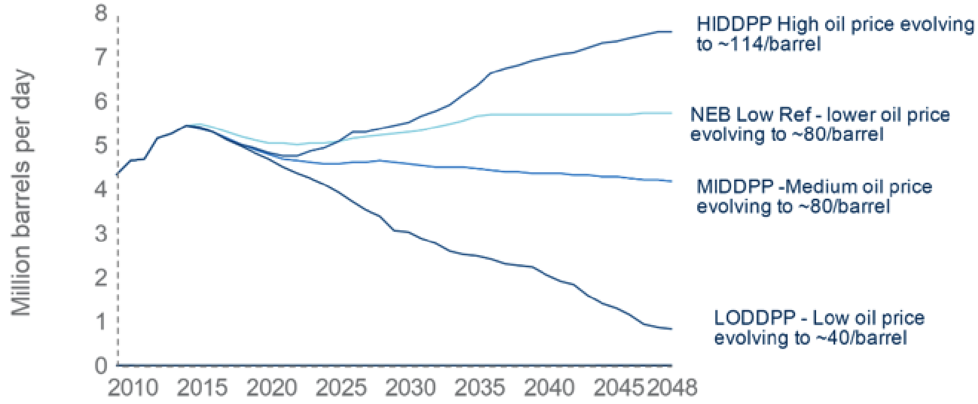


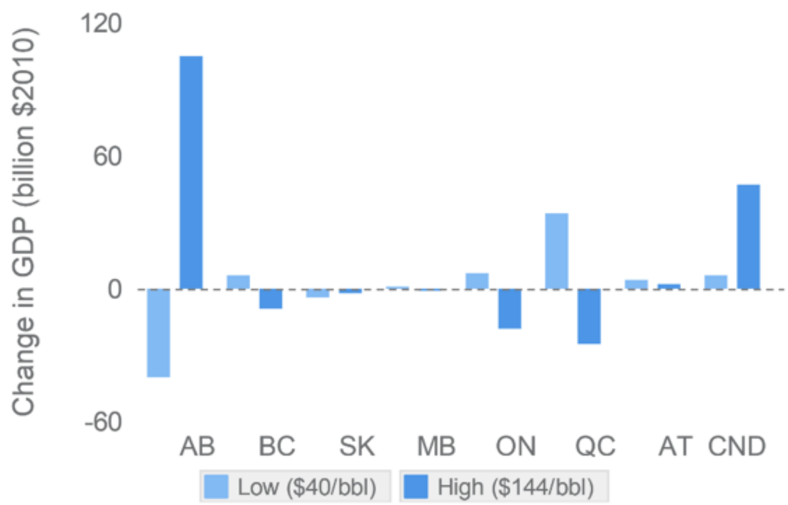
Table 1 provides a comparison of regional and national GDP under the scenarios. As can be seen, GDP at least doubles in all scenarios. Our major observation is that the uncontrolled combustion of fossil fuels is a high economic growth pathway, but not necessary for continued rates of high GDP growth. The impact varies between provinces. Alberta's economy is substantially smaller with decarbonization because of obvious effects on the fossil fuel industry, but still increases between 20 and 70 per cent in all cases relative to 2015. Our results indicate that oil prices are much more of a driver of Canada's total economy than decarbonization. Québec's economy actually grows with decarbonization because of its plentiful low-cost hydroelectricity, and benefits yet again from lower transport costs associated with lower oil prices in LODDPP.

Figure 13 shows the impact of the high and low price scenarios relative to the DDPC reference case. Alberta and Québec are again the most highly affected, with large gains to Alberta in the high oil pathway (HIDPP) accompanied by some losses to Québec and Ontario, while the low oil price negatively affects Alberta and benefits Ontario and Québec.

Table 1 Changes from 2015 in Regional GDP in 2050 (Relative to 2015=1)

	2050 DDP Reference ($80/barrel)	MIDDPP ($80/barrel)	HIDDPP ($114/barrel)	LODDP ($40/barrel)
AB	1.71	1.34	1.71	1.20
BC	2.42	2.14	2.10	2.17
SK	2.67	2.23	2.20	2.16
MB	2.71	2.50	2.47	2.51
ON	2.09	1.89	1.87	1.90
QC	2.29	2.47	2.40	2.57
AT	2.18	1.97	1.95	2.01
Canada	2.15	1.98	2.01	1.99

Figure 13 Impact of Changes in Oil Price on GDP in Decarbonization Scenario in 2050 (Relative to Reference)



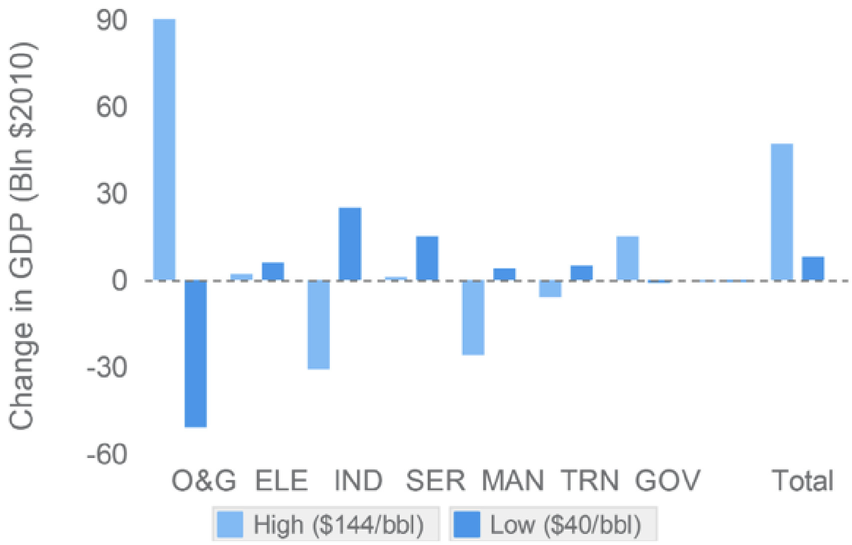
Now we look at the effect of the oil price pathways on economic structure, as defined by the aggregate and proportional output of firms. Table 2 gives detailed GDP by sector and scenario, showing changes due to changes in the oil price.

Figure 14 shows the biggest sector impacts of decarbonization are on the electricity and services industries, as well as on resource rents collected by government. Electricity GDP grows strongly because output and prices increase, while services decrease (while still more than doubling from 2002) due to the overall drag associated with the decarbonization policies. Industry, manufacturing and transport have an inverse relationship with oil prices due to transport costs (low prices raises industry GDP and vice versa).

Table 2 Changes from 2015 in Sectoral GDP in 2050 (2015 = 1)

	2050 REF ($80/barrel)	MIDDPP ($80/barrel)	HIDDPP ($114/barrel)	LODDPP ($40/barrel)
Conv. Oil	0.2	0.2	0.2	0.1
Oil sands	1.7	1.1	3.2	0.1
Refining	1.4	1.1	0.7	1.0
Natural Gas	0.9	0.7	0.8	0.7
Electricity	1.2	5.9	5.9	6.0
Cement-Lime	2.5	2.7	2.4	2.4
Pulp & paper	3.2	2.7	2.4	3.0
Iron & steel	1.7	1.3	1.2	1.3
Aluminum	2.7	2.8	2.6	2.8
Coal mining	2.0	2.9	2.7	3.0
Other industry	2.7	2.5	2.2	2.8
Services	2.3	1.9	1.9	2.0
Manufacturing	1.9	1.6	1.4	1.6
Trade	2.4	2.0	2.0	2.0
Transport	2.2	2.1	2.1	2.2
Government	2.5	2.2	2.2	2.2
Total	**2.2**	**2.0**	**2.0**	**2.0**

Figure 14 Impact of Changes in Oil Price on Sector GDP with DDPC Policies in 2050 (Relative to Reference Case)



In sum, oil prices, and not national decarbonization policy, are the key determinant of Canadian oil production and therefore our regional economic structure. Overall GDP is relatively unaffected, but with strong regional effects. Domestic deep decarbonization is feasible in all cases.

5 CANADIAN DEEP DECARBONIZATION PATHWAYS DECONSTRUCTED

In this section we deconstruct five of the six deep decarbonization pathways, exploring technology opportunities, gaps and areas where deep decarbonization pathways can be reinforced. The sixth pathway, structural change, was explored in the previous section.

5.1 DEEPENING TRENDS PATHWAY 1: DECARBONIZED ELECTRIFICATION

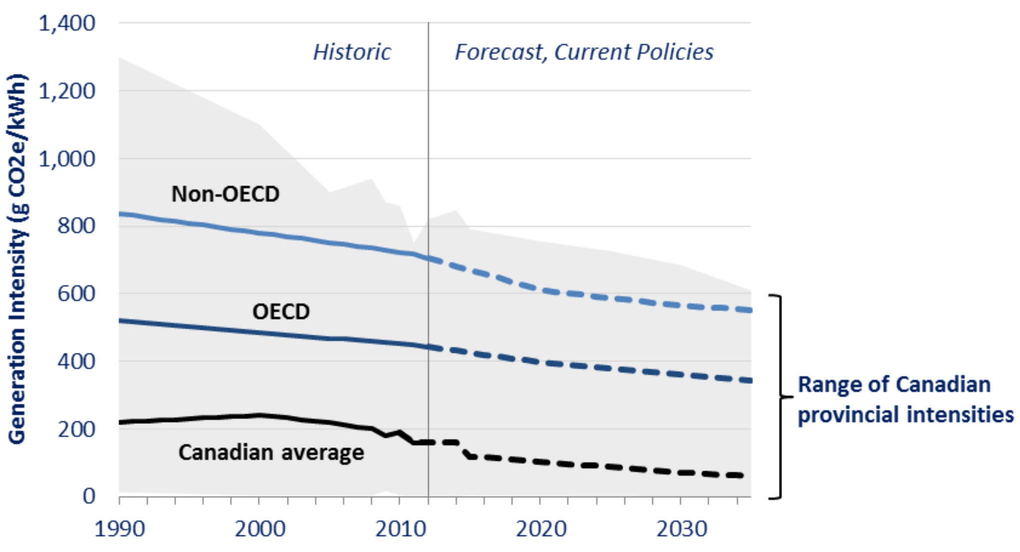
Fuel switching to decarbonized electricity is the single most significant pathway toward achieving deep emissions reduction globally. It allows demand sectors to reduce their end-use emissions by switching from refined petroleum products, natural gas and other fossil fuels to clean electricity. This abatement is only made possible through both decarbonization of existing electricity generation as well as a large expansion of new zero emissions electricity sources. This trend is already evident, with electricity production moving strongly towards decarbonization in the developed world, including in Canada (see Figure 15).

Electricity production is decarbonizing. Canada's emissions intensity of electricity generation stood at 160 grams per kilowatt hour (g/kWh) in 2012, well below the Organisation for Economic Co-operation and Development (OECD) average of 448 g/kWh. While the overall Canadian average intensity is well below the OECD average, there is variation in the emission intensity of electricity generation between provinces. The hydro-dominated provinces of B.C., Manitoba and Québec have emission intensities under 10 g/kWh. By contrast, thermal-dominated provinces such as Alberta, Saskatchewan and Nova Scotia all have emission intensities exceeding 700 g/kWh, and in some cases above the non-OECD average (Figure 15).

Three trends are driving future emissions from generation:

1. **Renewables penetration.** New sources of renewable generation are being added quickly, especially as wind and solar production costs fall and their capabilities improve to capture energy from a given environment effectively and economically.
2. **Regulations are decarbonizing electricity.** Provincial and federal regulations are driving down the intensity of production by effectively banning the construction of new coal-fired plants, which will help reduce the emissions intensity in thermal provinces gradually over time as these units are retired. In response to current provincial and federal policies, the average national emissions intensity decreases to 29 g/kWh by 2050.
3. **Natural gas demand remains resilient.** Natural gas-fired electricity remains popular in many regions and is allowed under current regulations in most jurisdictions. The current commercial standard, combined cycle turbines, have roughly half the emissions of coal plants at a comparable level of generation, but still emit 300–400 g CO_2/kWh. To be useful for decarbonized fuel switching, all electricity emissions must move to 100 g CO_2/kWh or less.

Figure 15 Emissions Intensity of Canadian Electricity Generation



Sources: (1) Canadian historic data from Environment Canada (2014), *National Inventory Report 1990–2012.* (2) Canadian forecast data from Navius modelling. (3) International data from International Energy Agency (2013), *World Energy Outlook.*

The DDPC accelerates decarbonized electrification. The DDPC scenario envisions a large increase in electricity generation, with the share of electricity rising to almost half of total final energy consumption by 2050 (see Figure 16). This translates into a more than doubling of electricity supply between now and 2050 in the DDPC scenario.

Another important trend in both the baseline and the DDPC scenario is a continual decarbonization of electricity. Central to the drop in emission intensity is a portfolio of low-emitting technologies, where all capture significant market share in the DDPC scenario. The decarbonized electrification pathway is characterized as having a large number of technically and economically feasible technologies whose penetration can be accelerated through policy.

Figure 16: Electricity as a Share of National Energy Consumption

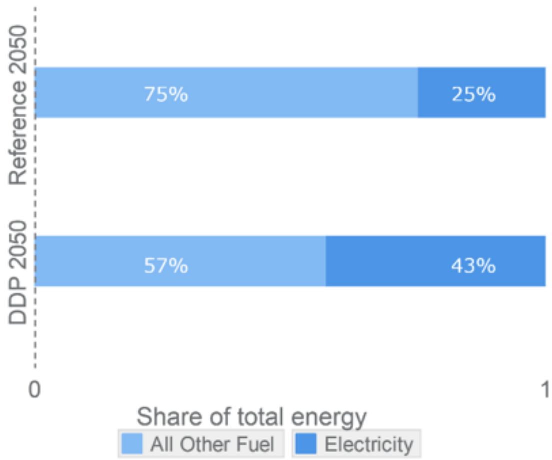
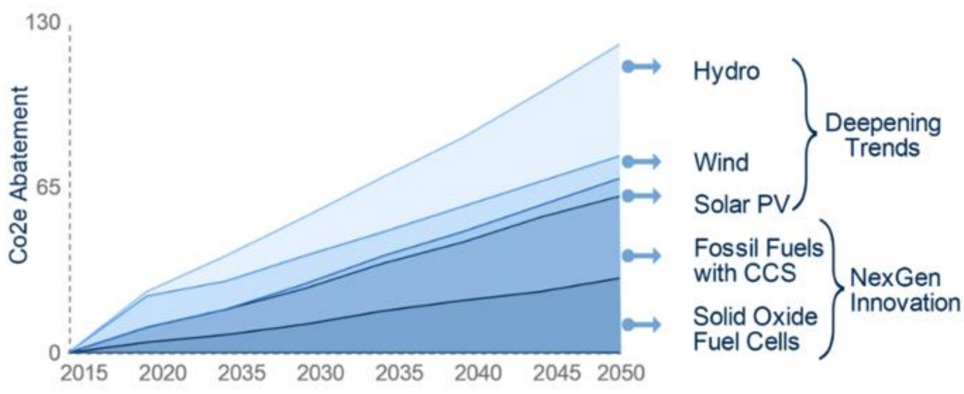


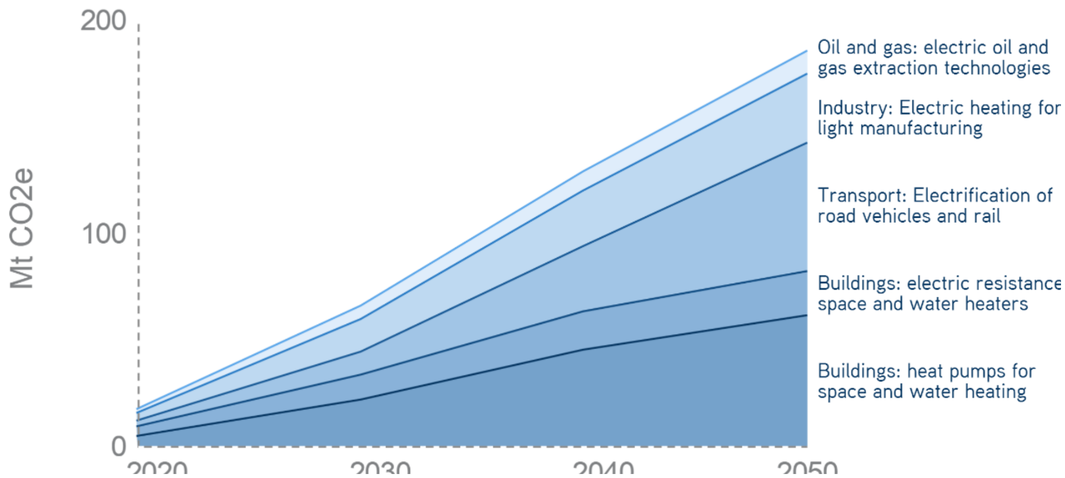
Figure 17: Abatement from Decarbonized Electricity in DDPC



Electricity-consuming technologies become widely deployed. Decarbonized electricity enables abatement in virtually all demand sectors, as shown in Figure 18. The greatest abatement potential is in the buildings sector, which in the DDPC pathway moves towards electric resistance heating and heat pumps for space conditioning and water heating. The electrification of certain transport modes is also an important decarbonization trend. These modes include light passenger vehicles, light and medium freight transport, and rail. In the pathway, electric vehicles account for nearly 100 per cent of all light-duty passenger vehicles in 2050 (see Figure 19), which is a significant increase in the current trend towards less than 20 per cent in the reference case.

Finally, electrification also provides abatement opportunities in light manufacturing, industry, and oil and gas extraction. These opportunities include electric boilers and heat pumps for process heat requirements, as well as process changes such as electric arc steel production and oxygen production for direct contact steam generation in oil sands production. Looking further down the road, almost all industrial processes can be switched to an electrolytic or hydrogen based production process, which eliminates the need for fossil fuels. A large amount of bulk decarbonized electricity is required, however.

Figure 18 Electrification Abatement by Sector and Action



"FUEL SWITCHING TO DECARBONIZED ELECTRICITY IS THE SINGLE MOST SIGNIFICANT PATHWAY TOWARD ACHIEVING DEEP EMISSIONS REDUCTION GLOBALLY"

Figure 19 Electrification in Light-Duty Passenger Vehicles, Reference Market Shares

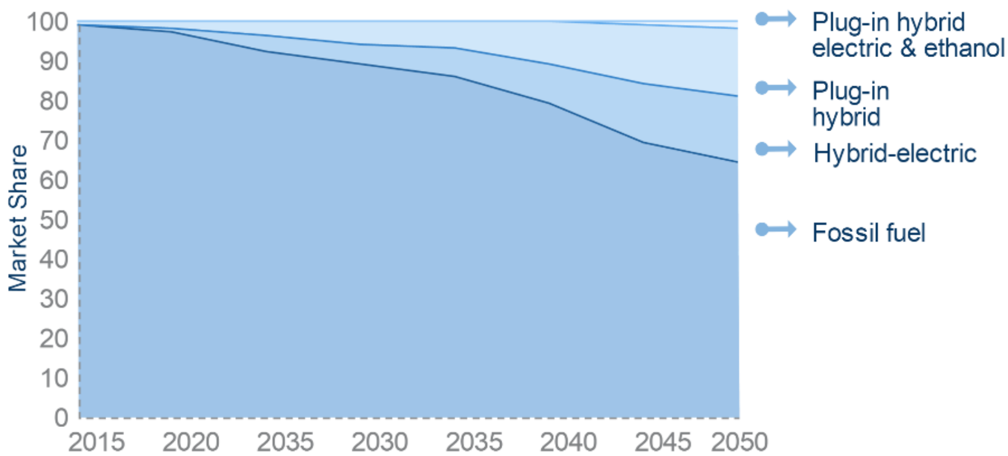
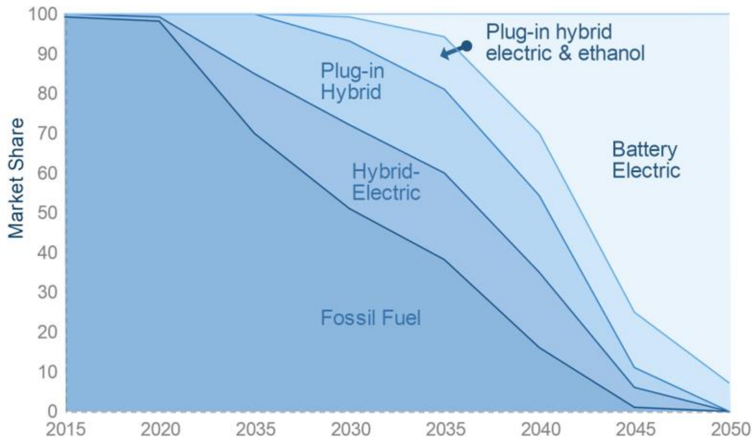


Figure 20 Electrification in Light-Duty Passenger Vehicles, DDPC Market Shares



5.2 DEEPENING TRENDS PATHWAY 2: IMPROVING ENERGY PRODUCTIVITY

Improving end-use energy productivity is an important decarbonization pathway across many sectors of the economy. In the reference case we see energy productivity improving considerably due to technological change driven by energy prices and energy efficiency regulations that improve energy performance, primarily in buildings and transportation. In the DDPC, this process is accelerated and deepened considerably.

Figure 21 provides an overview of the GHG reductions potential by sector under the energy productivity pathway. As can be seen, there is significant efficiency potential in the buildings and transport sectors. More energy-efficient technologies are also adopted in the industrial sector and electricity sectors, but fuel switching away from fossil generation accounts for much of this efficiency gain.

The energy productivity potential in the industrial and electricity sectors is further eroded by the widespread adoption of CCS in the DDPC, which offsets the overall energy-efficiency improvements. This dynamic occurs because additional energy is required to capture, compress and inject carbon dioxide into the ground. Figure 22 provides a view of the net energy productivity gain if CCS is widely deployed in a deep decarbonization pathway.

Given the importance of energy productivity in the buildings and transport sectors, the remainder of this section focuses on productivity trends in those two sectors.

Figure 21 GHG Reductions from Energy Productivity in DDPC

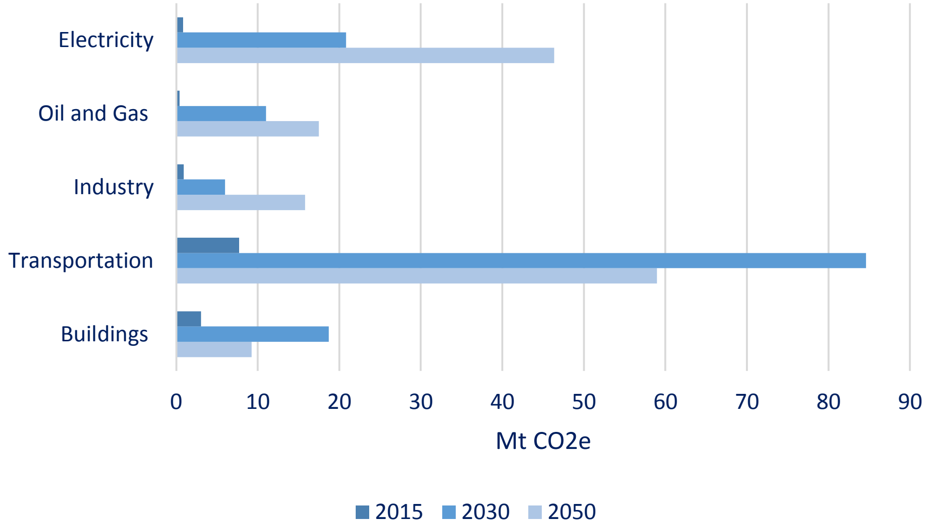
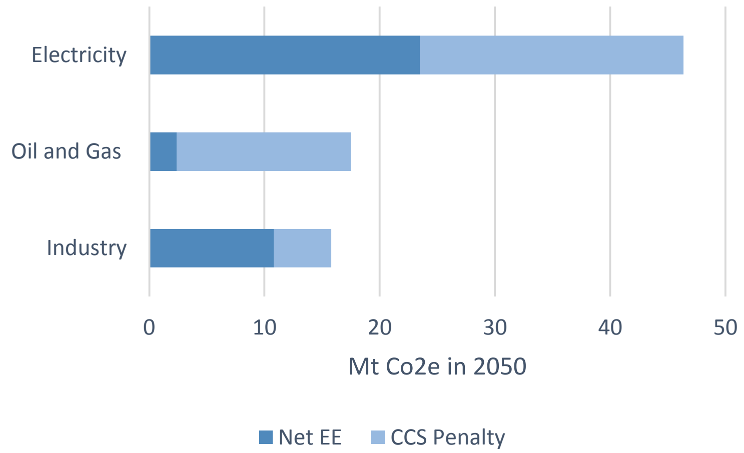


Figure 22 DDPC CCS Penalty Relative to Total Energy Productivity Improvement, 2050



Deepening energy productivity in buildings. Building and appliance efficiency standards are advancing quickly (Figure 24). In Canada, various provincial building codes and federal energy-efficiency standards are requiring energy-efficiency improvements in residential and commercial buildings. Figure 24 shows the rapid improvements in residential building space heating energy intensity that have occurred since 1990 and that are likely to occur in response to current policies, using an example from Ontario. In 1990, an average of 0.79 gigajoules per square metre (GJ/m^2) of space heating energy was required for residential buildings in Canada. By 2012, this requirement had dropped to 0.47 GJ/m^2.

Figure 24 Residential Building Space Heating Intensity by Vintage (Ontario)

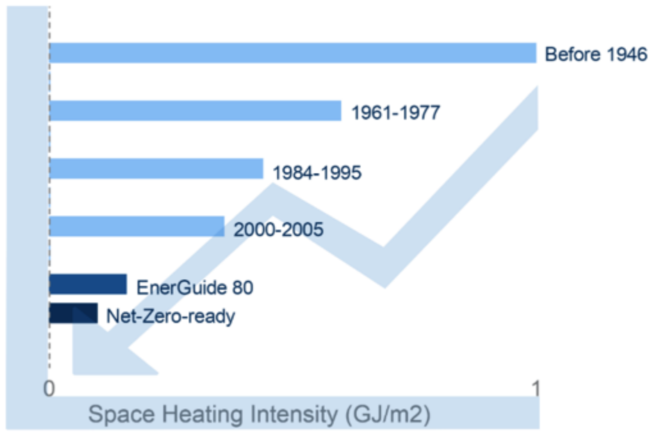
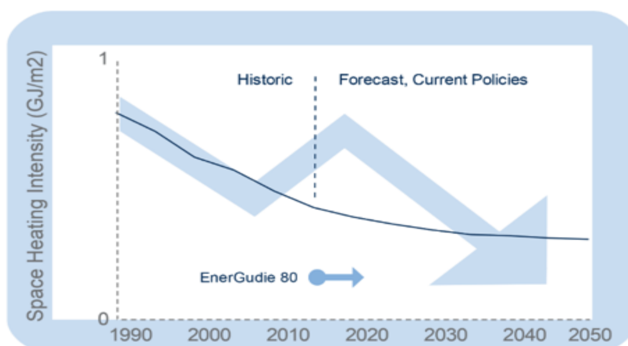


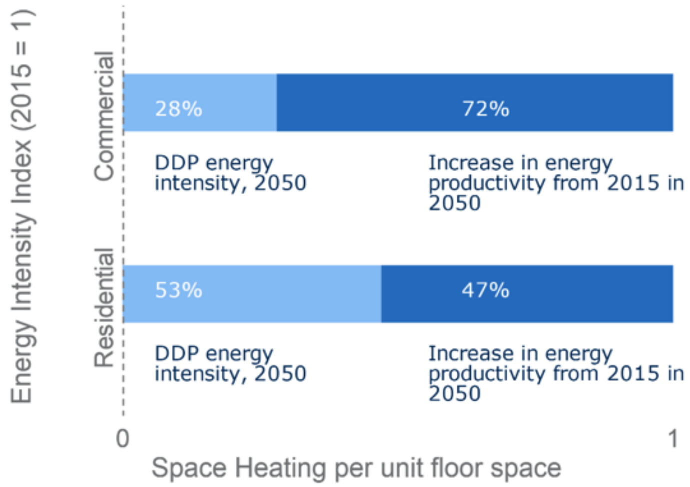
Figure 23 Residential Building Space, Historical and DDPC



In several provinces, current new construction must meet EnerGuide 80 standards, which could reduce new residential building space heating intensity to less than 0.2 GJ/m^2. However, it takes a great deal of time for building standards to influence the entire building stock due to the long life span of buildings unless substantial retrofits are taken, and even then compliance is not perfect. Additionally, the absolute changes in energy intensity achieved by incremental policies is becoming smaller. This explains the flattening curve in Figure 23. What could change about how the building stock fits in the energy system, however, is that the advent of reasonable cost solar panels and net-zero ready energy standards could conceivably make the building stock a net electricity and energy producer in the future.

Under the DPPC, significant additional measures target the buildings sector by mid-century. By 2050, buildings consume between 53 and 72 per cent less energy per square metre, due in large part to the adoption of heat pumps for space conditioning and water heating. While existing regulations do not penalize the use of natural gas-fired furnaces and water heaters, the reduction in cost of electric heat pumps coupled with the DPPC policy significantly increases their penetration for space conditioning and water heating, without eliminating natural gas entirely.

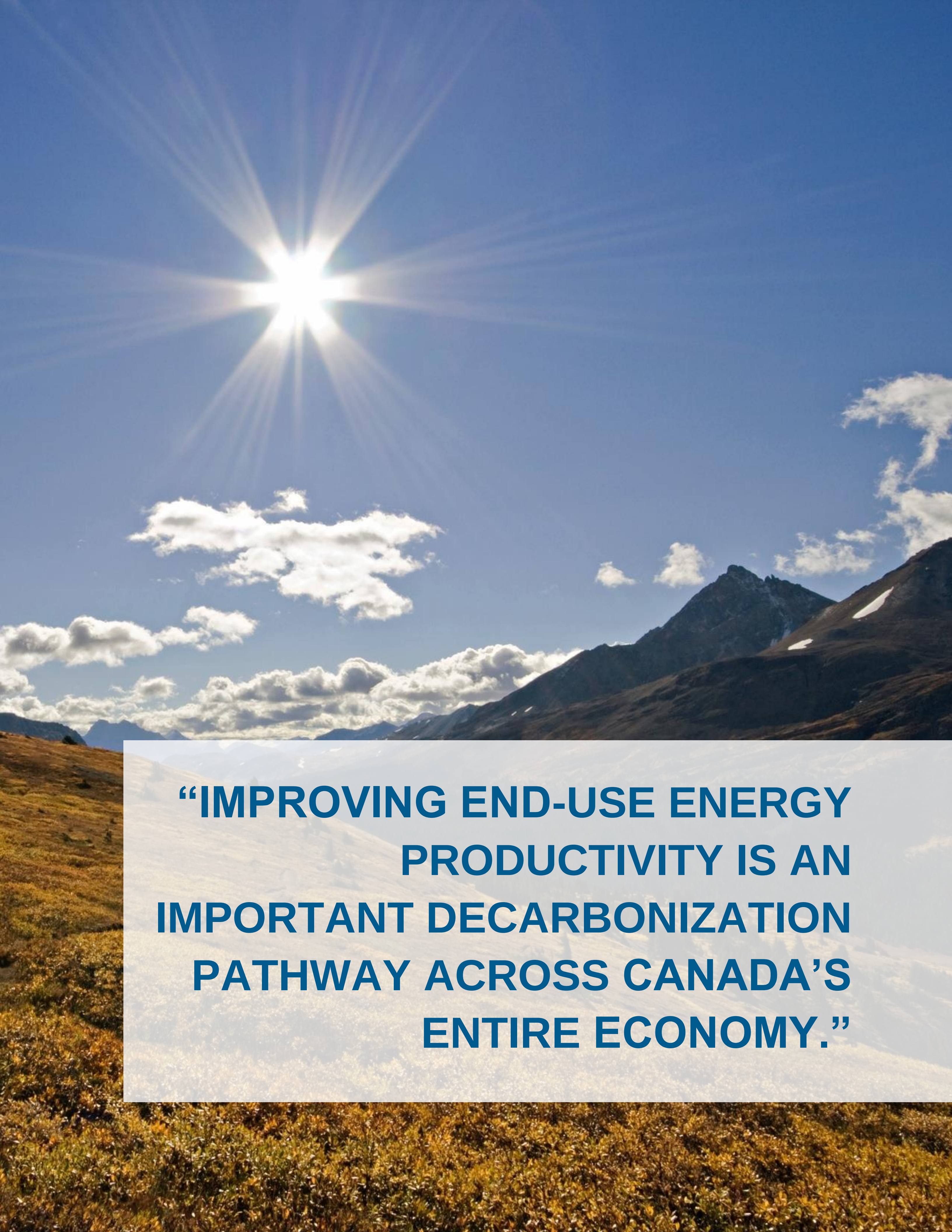
Figure 25 Residential Building Space, Improved Energy Productivity 2015 to 2050



Deepening transportation efficiency. Canada is enjoying global spillovers in vehicle efficiency as the global trend helps increase efficiency, while federal and provincial vehicle regulations accelerate the trend. Figure 26 shows how the improved efficiency impacts average fleet emissions for new cars in Canada, the United States and the European Union. Between 2000 and 2010, fleet emissions in Canada decreased from 193 grams per kilometre (g/km) to 166 g/km, a drop of 14 per cent. Standards in Canada align with those of the United States and require fleet average emissions to reach 97 g/km by 2025. The fuel efficiencies of the Toyota Prius V hybrid and the Prius plug-in hybrid are shown for context.

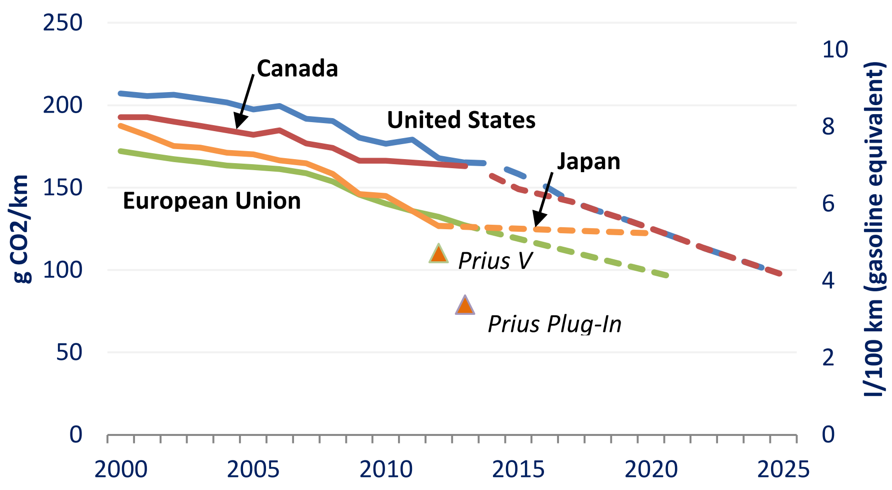
Figure 27 shows improvements in energy intensity in the DDPC for the freight and personal transport sectors. The energy intensity of personal transport drops even more substantially, due to both the efficiency of technologies (e.g., the hybridization of vehicles and adoption of smaller cars) as well as mode shifting (e.g., switching from single-occupancy to high-occupancy vehicles, or from cars to trains). The energy per passenger kilometre travelled drops by almost 70 per cent from 2015 to 2050.

In Figure 28, we see that transport has a variety of pathways that can deliver emission reductions but it is energy efficiency gains that drive short to medium-term reductions. Energy efficiency provides the most feasible pathway in the short to medium term. Large efficiency gains are also associated with electrification because vehicles no longer use internal combustion engines (ICEs). ICEs have a maximum theoretical efficiency of 50 per cent of turning energy into motion (the best available cars today are approximately 38 per cent efficient) while electric motors are 90–99 per cent efficient at turning energy into motion (in terms of decarbonization, how the electricity is made matters as well). In the medium to longer term, cellulosic ethanol and biodiesel made from woody biomass or algae, or perhaps hydrogen, will be needed to replace fossil fuels.



“IMPROVING END-USE ENERGY PRODUCTIVITY IS AN IMPORTANT DECARBONIZATION PATHWAY ACROSS CANADA’S ENTIRE ECONOMY.”

Figure 26 Historical Fleet CO_2 Emissions Performance and Proposed Standards for Cars



Sources: (1) The International Council for Clean Transportation (2014), Global passenger vehicle standards. http://www.theicct.org/info-tools/global-passenger-vehicle-standards (2) Prius performance based on updated EPA test cycle, 60 per cent city driving and 40 per cent highway driving.

Figure 27 DDPC Energy Productivity Change 2015 to 2050, Personal Transport

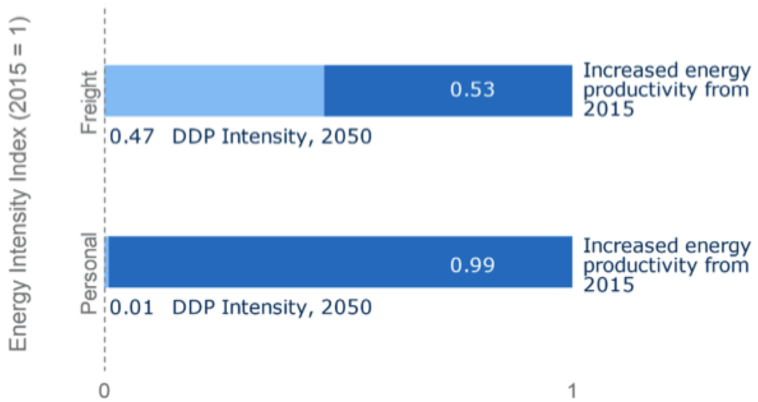
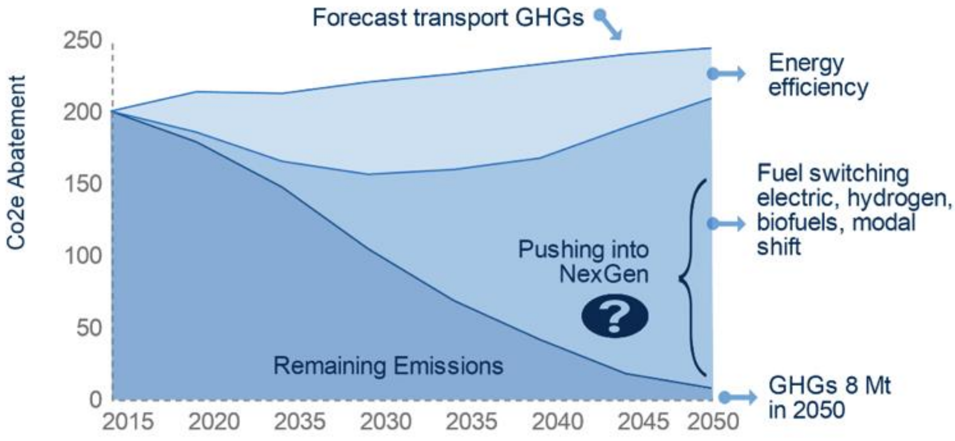


Figure 28 DDPC Energy Efficiency GHG Abatement in Transport



5.3 DEEPENING TRENDS 3: REDUCE, CAP AND UTILIZE NON-ENERGY EMISSIONS

Non-combustion emissions are emitted from various sources, including oil and gas infrastructure, various industrial processes, agricultural practices[5] and landfills. These sources are in large part unregulated in Canada, and represent a source of low-cost abatement options.

Our analysis shows that close to 30 Mt of carbon dioxide equivalent (CO_2e) can be abated from these sources annually, as shown in Figure 29. Landfill gas can be abated by capturing it and combusting it to provide electricity, as is already happening at various sites across the country. The oil and gas sector is one of the largest sources of abatement potential, with opportunities to reduce emissions related to: applying CCS to natural gas formation gas; capture and flaring or pipelining of well head venting; reducing pipeline leaks; replacing gas actuated devices with electric ones; and reducing other fugitive and unintentional releases beyond those required by existing provincial regulations. Opportunities to reduce industrial process emissions are more challenging and concentrated in the iron and steel, aluminum, chemicals and cement sectors; reducing these emissions requires CCS or major process changes, such as the use of hydrogen instead of coking coal as a reducing agent in iron and steel production.

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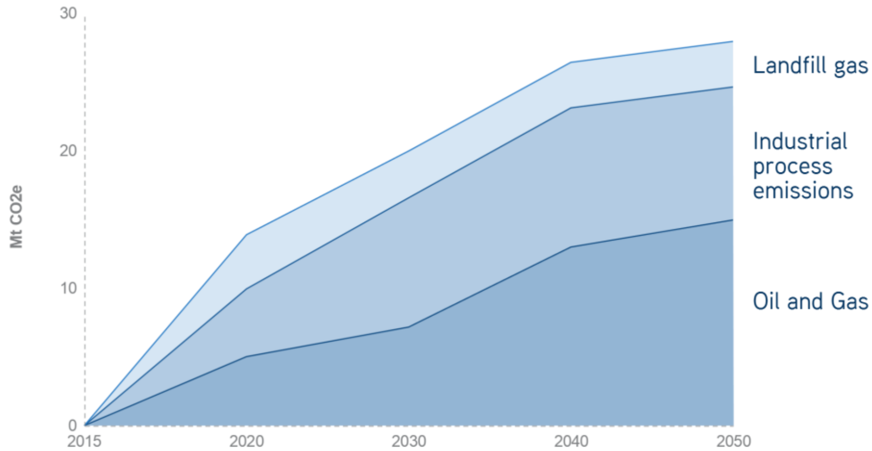
[5] Agricultural emissions amounted to 56 Mt CO_2e in 2012. In keeping with the DDPP global process, land-use emissions were not included in this analysis.

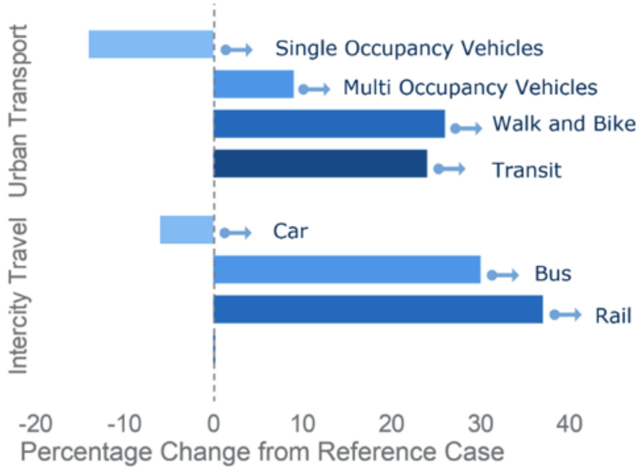
Figure 29 Abatement of fugitive and industrial process emissions



5.4 NEXGEN PATHWAY 4: MOVE TO ZERO EMISSION TRANSPORT FUELS

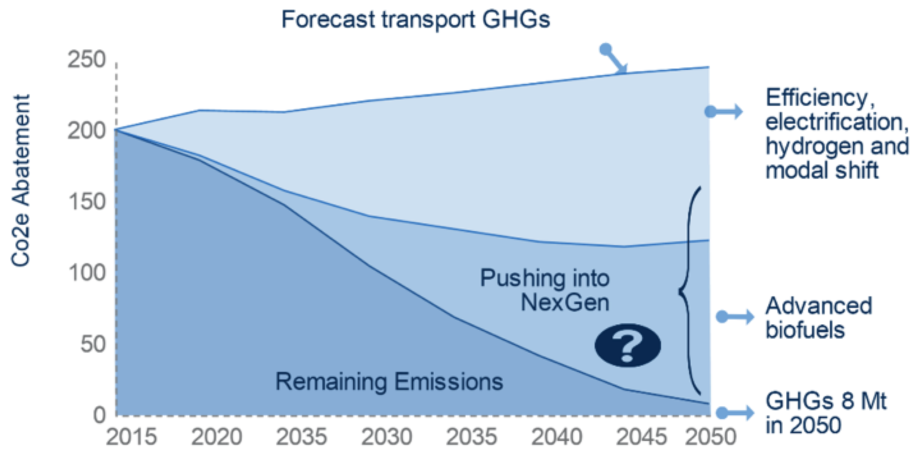
The full decarbonization of transport fuels is likely to be a significant challenge requiring several advancements from today's technology. The good news is electrification of personal, light freight and rail transport is a promising abatement option using technology we would recognize today. Mode shifting also has much promise, especially in personal transport and long haul freight (Figure 30). Not all transport modes are suitable for electrification, however. In particular, the energy density of batteries at our current and near-term technology level is likely not conducive to long-distance trucking, marine and air transport. For these modes, other zero or near-zero emission fuels will be necessary to achieve deep decarbonization.

Figure 30 Modal Shifting and Behavioural Change in 2050



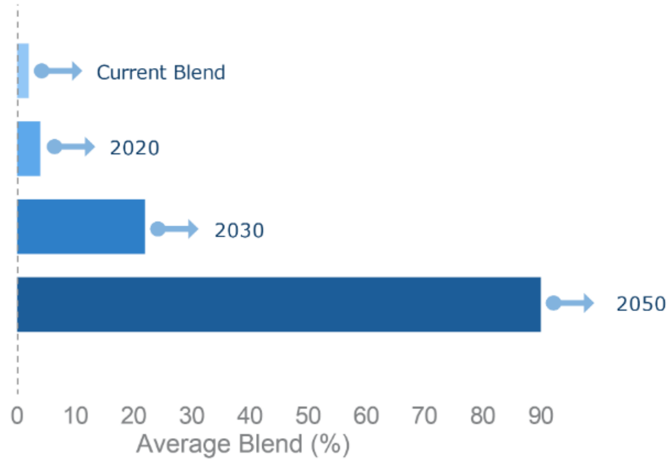
For freight, significant modal shifting to rail coupled with high-efficiency electric engines bend down emissions in the long-term, but much trucking remains. All remaining diesel consumption for trucking, rail and marine therefore relies on a biodiesel blend. Biofuels, including ethanol and biodiesel, are already being blended into refined petroleum fuels in Canada due to various provincial and federal regulations. In the DDPC, the share of biofuels blended into liquid transport fuels needs to rise steadily to around 90 per cent by 2050 (see Figure 32).

Figure 31 Biofuels GHG Abatement in Transportation



This development is contingent on successful commercialization of advanced biofuel production technologies that do not rely on agricultural land suitable for food crops. This includes third generation cellulosic biofuels based on switchgrass, wood residue, algae, etc. In the DDPC, the majority of aircraft energy is still from fossil fuel jet fuel, based on a long-lived airplane stock based on today's technology and assuming a limited ability to blend biofuels into current jet fuel.

Figure 32 Average blend of biofuels in liquid transport fuels



CANADA'S DECARBONIZATION PATHWAY RELIES HEAVILY ON NEXGEN TECHNOLOGIES, INCREASING THE RISK PROFILE OF THE PATHWAY.

ADDITIONAL INNOVATION, BOTH AT HOME AND ABROAD, WILL BE NEEDED TO FULLY REALIZE THIS PATHWAY.

An alternative and/or complementary low-emission transport fuel is hydrogen. Hydrogen-fuel-cell-powered vehicles would be more efficient than gasoline or diesel internal combustion engines, but hydrogen faces several challenges, including the development of onboard vehicle storage and the build-out of a fueling and supply infrastructure. Bulk hydrogen is available via methane reformation or electrolysis, but the first would require capture and storage of the carbon dioxide by-product in the DDPC, and the latter lots of electricity from virtually zero GHG electricity generation (e.g., renewable or nuclear).

In summary, this pathway relies heavily on NexGen technologies to reach deep decarbonization, increasing the risk profile of the pathway. Additional innovation, both at home and abroad, will be needed to fully capitalize on this pathway.

5.5 NEXGEN PATHWAY 5: DECARBONIZE INDUSTRIAL PROCESSES

In this section a Canadian deep decarbonization pathway is first explored for industry, followed by oil and gas. Of all the six major pathways to deep decarbonization, none relies more on NexGen technologies than industrial processes.

Decarbonizing heat and steam in industry. Heat and steam is required for many industrial activities, the production of which is a significant contributor to emissions. In the reference case, the majority of process heat is generated using fossil fuel-powered boilers and cogeneration. Biomass is also used, particularly in the pulp and paper industry, while a small amount of heat is provided by electric boilers, predominantly in light manufacturing in provinces with cheap hydroelectricity.

In the DPPC, virtually every industrial process is transformed to a low emitting technology (Figure 33 excludes oil and gas, which is discussed below). Not surprisingly given the diversity of industrial process, there are a number of abatement pathways that differ significantly. Overall in the DDPC, the share of process heat provided by fossil fuel powered boilers and cogeneration drops to 17 per cent in 2050 from 56 per cent in the reference case.

Efficiency improvements and process changes in manufacturing activities also lead to a reduction in the demand for process heat. In the DDPC, the demand for process heat drops 16 per cent relative to the reference case in 2050. Process changes also account for a significant share of abatement. However, the process change wedge in Figure 33 is likely an underestimate because we have not accounted for all potential process changes, including but not limited to: using hydrogen sourced from renewable electricity as a reactant and feedstock, bio-based feedstocks that replace petrochemicals and switching from heat-based pyrolytic chemical reactions to electricity based electrolytic reactions.

A variety of types of carbon capture and storage is widely adopted, with only 5 per cent of process heat being provided by fossil fuels without some form of CCS by 2050. The penetration of pre-combustion CCS in the production of hydrogen and ammonia, as well industries such as lime and cement production, reaches over 90 per cent by 2050.

The market share of electric boilers expands to almost 40 per cent in 2050 from about 7 per cent in the reference case. The use of biomass for heat expands as well, reaching 45 per cent of the market climbing up from 36 per cent in the reference case. Lastly, electric-driven heat-pump technology, appropriate for some low-grade heating and drying requirements in manufacturing, is deployed in the DDPC.

Figure 33 Industry GHG Abatement (no oil and gas)

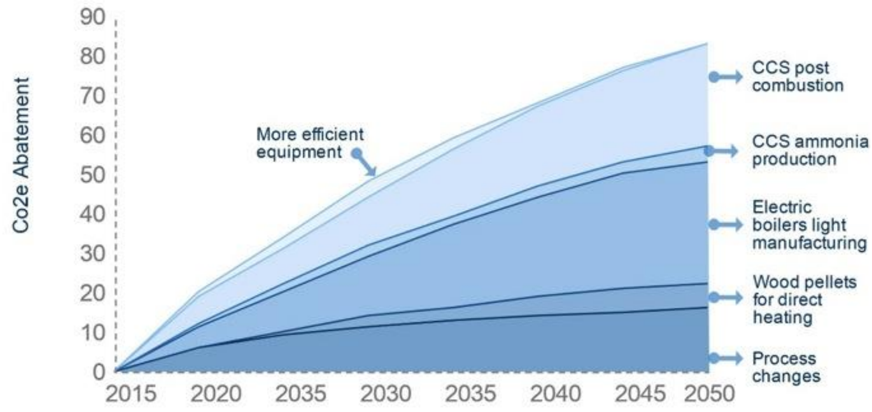
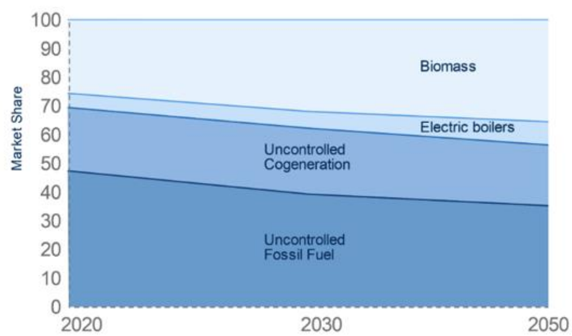
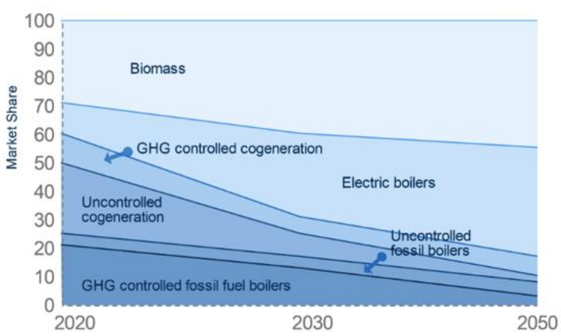


Figure 34 Industry Process Market Shares (no oil and gas)





Decarbonizing heat and steam in the oil and gas sector. There are several emerging technologies that could enable upstream decarbonization in the oil and gas sector.

For formation carbon dioxide from oil and gas wells, CCS deployment reaches 100 per cent by 2050 while CCS is widely adopted for process heat and steam requirements in the oil sands and heavy oil processes. But CCS is not the full story, and new and innovative processes show significant promise for oil sands production.

In-situ bitumen extraction currently involves the injection of steam into a bitumen reservoir. The steam reduces the viscosity of the bitumen, allowing it to be pumped to the surface. This can be accomplished using cyclic steam stimulation (CSS) or steam assisted gravity drainage (SAGD).

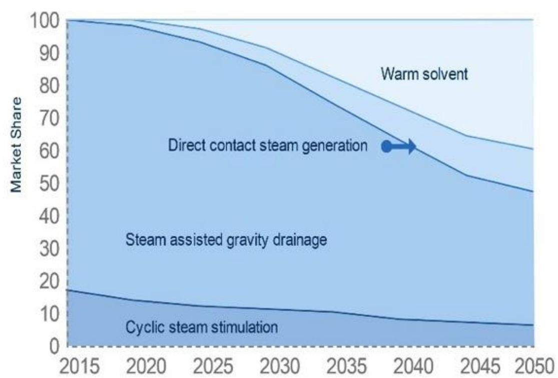
For both of these processes, steam is produced with standard industrial boilers (i.e., "once through steam generation" or OTSG). Various emerging technologies exist that could dramatically lower the energy and emissions intensity of in situ operations, including:

- Direct contact steam generation, a significant variant on (SAGD). Waste bitumen coke (or another combustible) is combusted in a slurry with pure oxygen in the well. Much of the carbon dioxide produced remains in the well (i.e., auto-sequestration) and the bitumen is pumped up.
- Warm solvent in-situ where an organic solvent such as propane, heated to 40–50℃, is used to extract the bitumen.

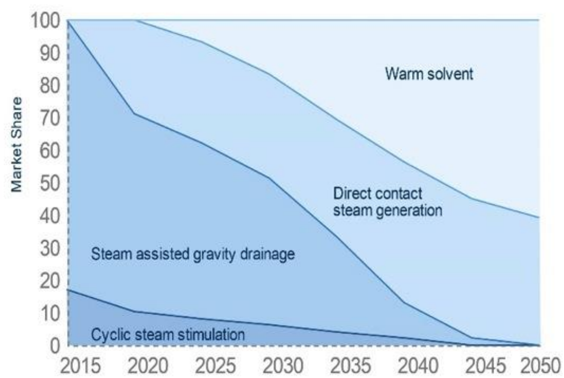
These technologies have the potential to reduce GHG emissions by up to 85 per cent relative to SAGD.[6] Figure 35 shows the market share of in situ oil sands technologies in both the reference case and decarbonization scenarios. In the reference case, advanced technologies such as DCSG and solvent extraction are anticipated to gain widespread use because they reduce energy costs for firms. In the decarbonization scenario, the adoption of these technologies is accelerated such that by 2050 they account for the entire market. As a consequence, the emissions intensity of in-situ production falls to less than 0.01 t CO_2e/barrel, a decrease of over 85 per cent from today's levels in the DDPC.

Figure 35 In Situ Oil Sands Production Technology Market Shares

Reference Case



DDPC



[6] Note that both technologies are pre-commercial and undergoing pilot plant testing, so while our parameterization is based on engineering studies, it is still uncertain.

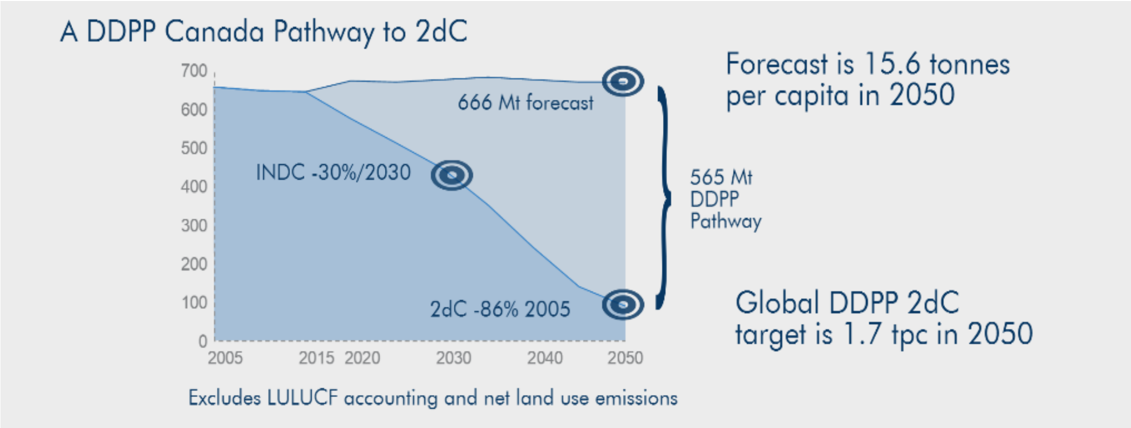
6 CANADA'S INTENDED NATIONALLY DETERMINED CONTRIBUTION AND THE PATHWAY TO 2°C

Canada announced its Intended Nationally Determined Contribution (INDC) in May 2015, pledging a -30 per cent reduction from 2005 levels by 2030, which translates into 524 Mt in 2030 off a forecast of 798 Mt (including land-use GHGs). Canada's INDC is deep by any measure given current emissions trends, and is likely to be dependent on a suite of aggressive provincial policies[7] and new federal policies. We note that the Government of Canada has now made a nod to deep decarbonization with its INDC.

The first question is whether or not the INDC is consistent with a 2°C pathway. Our assessment is that Canada's INDC is on one of several possible emissions reduction pathways consistent with a 2°C objective (Figure 36). With the INDC 2030 target achieved, it would then be another policy and technology stretch to reduce emissions from a forecast level of 16 tonnes per capita in 2050 to the UNSDSN/IDDRI DDPP goal of 1.7 tonnes per capita in 2050. However, it would also not likely be the cost-effective pathway to 2050.

[7] Ontario's target is equivalent to 37 per cent below 1990 levels by 2030, which it intends to achieve with a suite of policies including an existing coal phase out and Western Climate Initiative (WCI) cap-and-trade system. Quebéc's target is 20 per cent below 1990 levels by 2020, again the centerpiece being the WCI cap-and-trade system among a suite of policies. B.C.'s target is 33 per cent below 2007 levels by 2020, via system-wide carbon tax ($30/tonne) and virtually 100 per cent clean requirement for electricity. Alberta's target is 50 Mt below business as usual, via its own intensity-based cap-and-trade system and CCS program.

Figure 36 Canada's INDC and the DDPC 2oC Pathway

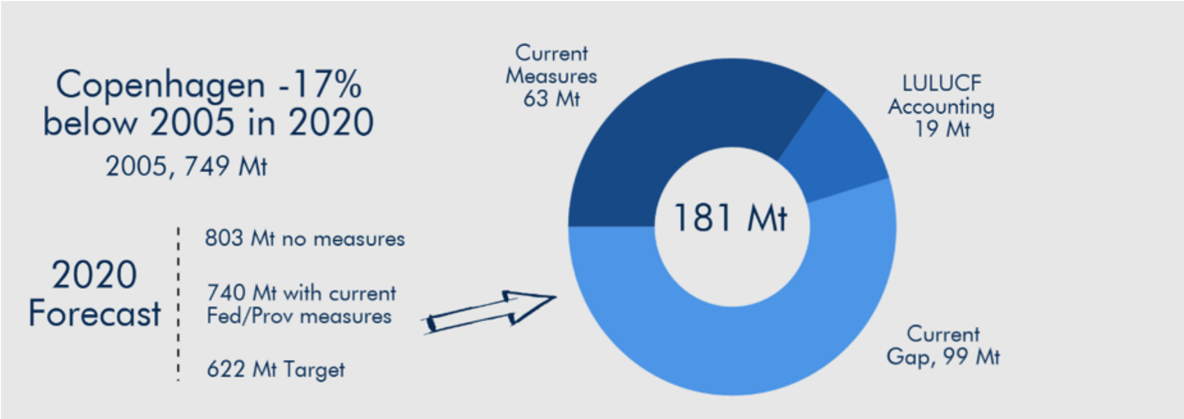


Policy credibility is key to deep decarbonization. Aligning emission reductions with the 2°C pathway while achieving Canada's 2030 target would require a significant ratcheting down from current federal and provincial policies. This effort would also have to start effective immediately if costs were to be minimized and effectiveness assured. But there are obviously significant risks with this INDC and achievement of deep decarbonization by mid-century. The most significant risk is a lack of historical political action to align emission policies with stated aspirational targets.

Canada's current target of -17 per cent from 2005 levels by 2020, matched to the U.S. during the 2009 Copenhagen era, is unlikely to be met (Figure 37). This despite 15 years of deep analysis and numerous federal plans to implement policies to achieve Canada's Kyoto target and then the Copenhagen target. Political will at the federal level has simply not been there, which has been made worse by slow U.S. federal action, raising concerns over carbon cost misalignment and adverse competitiveness impacts. At the provincial level, there has been some movement, notably Ontario's coal fire electricity ban and British Columbia's carbon tax. Still, as the figure indicates, current measures to date have not placed Canada on a trajectory to achieve its 2020 Copenhagen target.

If both the INDC and deeper decarbonization are to be realized, this political commitment needs to shift significantly.

Figure 37 Canada's Progress to its 2020 Copenhagen Target

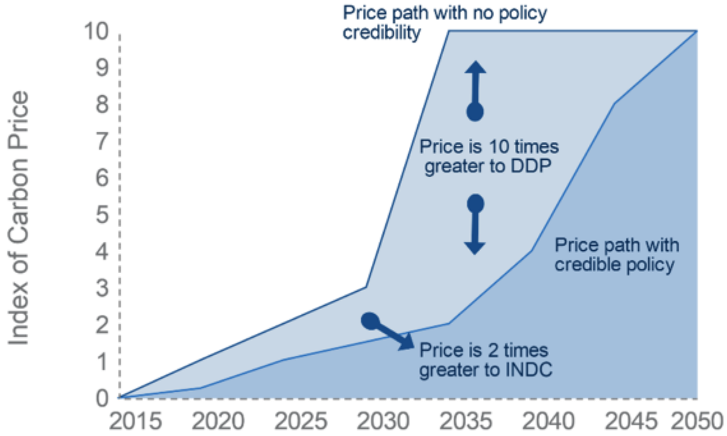


Central to policy success is a credible and durable carbon policy signal over the long term. To highlight the importance of a credible and durable policy, we assessed two carbon cost pathways that achieve the same emission reductions aligned with Canada's INDC and then the 1.7 tonnes per capita by 2050. In one scenario, we assume that businesses and consumers believe carbon policies are credible and will continue to be strengthened in the future, which has the effect of increasing the short-term carbon costs that affect technology and behavioural choices. In the second scenario, we assume there is no policy credibility and businesses and households make myopic decisions based on short-term carbon costs, fully discounting any future carbon costs. There are two important outcomes of comparing these two scenarios:

1. First, with only short-term policy credibility (i.e. investors are unsure about its long-term direction and strength), there is a real risk of locking in capital now that would be inconsistent with both the 2030 target and longer deep decarbonization
2. Second, carbon costs have to rise significantly to achieve the same target in a scenario with no policy credibility. To the extent businesses and consumers do not believe Canada has a credible policy to achieve its emission reductions targets, policy stringency, reflected in carbon costs, has to rise significantly above levels consistent with the more credible policy (Figure 38). Our estimates indicate that absent credible policy, carbon costs are more than double between now and 2030 for the same INDC target.

Simply put, delay is costly. To the extent Canada delays policy action, costs rise and path dependency on high emitting capital stock locks Canada into a high emitting pathway. Strong and credible policy signals, aligned with long-term decarbonisation aspirations, can do much to set expectations that value the future cost of carbon, therefore impacting behaviour and technology deployment.

Figure 38 Canada's INDC and the DDPC 2oC Pathway



7 CANADA'S 2°C PREPAREDNESS

On policy architecture, Canada's deep decarbonization preparedness is mixed. Canada is likely on the right path in electricity, buildings and personal transport, but policy signals need to be tightened and certainly broadened. Québec and B.C. with their broad carbon pricing are probably most prepared, with encouraging signs from Ontario developing a broad-based cap-and-trade system with linkages to California and Québec. Alberta's recently announced policy update and signals of broadening the policy to cover more emissions is also a step in the right direction.

Doubling down on current policy signals in the electricity sector is central to deep decarbonization, with a need to trend towards zero-emissions electricity, ideally for all new baseload generation starting today. Following on this, if we go deeper towards decarbonization there will be significantly more electricity demand above current demand trajectories, with a doubling of investment to support the scaled up electrification. Finally, because of its trade regulation role, the federal government could provide very meaningful aid facilitating a national discussion and helping finance coordinated national transmission networks to move renewable electricity to load centres, for example from Manitoba, northern Ontario and Québec to southern Ontario.

Stronger signals are also needed that all new personal transport, appliances and buildings will eventually be regulated to zero GHG intensity by the late 2030s or early 2040s, but that regulations will be flexible, performance based, and reflect the diverse portfolio of existing and emerging technologies. Commercial buildings and vehicle efficiency have lagged behind personal transportation and this will need to change, with a significant short-term opportunity to ratchet down existing policy levers.

While Canada is prepared in some policy areas, in others it is not. In both industrial GHGs and liquid fossil fuels, concerted new mitigation policies will be needed to drive more reductions, but also to send innovation signals. Canada has enormous opportunities associated with biofuel feedstocks (for heavy freight) and a large and very usable carbon storage capacity, especially underneath northeast B.C., Alberta and Saskatchewan, but these advantages must be supported and capitalized in areas such as:

- Coordinated national research and development and deployment support for bulk non-food crop biofuels for heavy freight and aviation.

- A clear national legal framework for use of carbon capture and storage (pipelining, liability, etc.), as well as upfront infrastructure support for carbon dioxide pipelining.

Canada's current policy path is insufficient to the challenge in heavy industry and the oil and gas sector. While mitigation solutions exist, innovation and commercialization signals provided by B.C.'s carbon tax, Alberta's SGER and Québec's cap and trade are far too weak to drive innovation consistent with longer-term decarbonization. Weak domestic innovation signals are consistent with weak global policy signals, diminishing the chance of global technology spillovers to help drive down costs and increase feasibility. In additional to stronger mitigation signals, complementary innovation policy is currently nascent, despite being critical to reduce fossil fuel-based process heat requirements, especially in primary extraction of all kinds.

For industry and the oil and gas sector, stronger polices to drive down emissions are needed, which will send innovation signals. These policy signals are an important step to galvanize the national business culture toward innovation, development of markets for nascent solutions and technical capacity building. To complement this primarily policy shift, complementary innovation investments will be required. But innovation research and development spending alone will be insufficient to make the transition towards deeper decarbonization.

Canada's currently fragmented subnational policies are a long-term decarbonization risk. With the current low levels of mitigation ambition, the risk of high-cost outcomes due to limited pools of regional abatement is not significant. But in time, with more ambition, risk will rise as regional low cost abatement opportunities are exhausted. Eventual linking of policies, whether through direct linking or indirect linking through national flexibility mechanisms such as offsets, is central to decarbonization. The same applies to regional and national innovation policies, to coordinate efforts across jurisdictions.

On economic structure, there is a large risk associated with Canada getting caught with a large GHG-intense primary extraction and heavy industry sector that just cannot compete in a world with border tax adjustments based on the GHG intensity of products, like the well-to-wheels California low-carbon requirement. We also note that economic resiliency is tightly tied with low-carbon-intensity technologies in manufacturing, buildings and transport systems, making oil price swings less impactful. Our analysis shows that Canada's economy can be resilient in a decarbonizing world, provided we implement policy to adapt soon. This requires policies as strong as or stronger than those of our trading partners, effective immediately.

While it is true that unified and nationally consistent carbon pricing is needed to reduce emissions and drive innovation in corners of Canada's economy, pricing alone is not enough. Removing fossil fuel subsidies will be needed to unwind negative carbon prices in fossil fuel production and consumption. Complementary regulations will be needed to reach into the buildings and transport sectors, where carbon-pricing signals may not work as well (e.g., because of the separation between owners and renters in buildings, and unpriced benefits in transport). Adding broad-based innovation signals will also help drive down costs and increase feasibility in the longer term, with information programs helping to remove biases towards low-emitting and energy-saving equipment and behaviours. Indeed, information is always a policy complement and governments should continue to roll out information programs to help reinforce primary mitigation policies. Information, however, is not a substitute for strong policy signals using regulations or carbon pricing. Finally, there is a role for green public procurement, where governments can showcase new technologies in their vehicle fleets and buildings.

Looking forward, Canada needs to better understand its land-use emissions and their associated abatement potential. With decarbonization, there is a high probability that significant quantities of lower-cost emission reductions will be needed to push towards net-zero and net-negative emissions. This is a high priority frontier of Canadian climate policy knowledge. Indeed, understanding net negative emission sources is a trend that will only grow in importance in a deeply decarbonizing world.

In sum, our report card is mixed. We are doing well and need to do better with electricity, buildings and personal transport. However our track record for heavy industry, primary extraction and oil and gas will not support achieving the aggressive reductions required. To minimize both climate and economic risks, we need to become global leaders in decarbonization policy and innovation in these sectors, not laggards.

Canada's national circumstances may include some seemingly obvious impediments to long-term decarbonization, but with thoughtful, long-term policy, the costs and risks are manageable. Decarbonization is not about shuttering industry but rather using policy and enabling markets to realign investment across Canada's entire economy to compete in a decarbonizing world. With myopic and delayed decarbonization policy, all bets are off, and Canada lays exposed to increasingly hawkish climate geopolitics and continued market access barriers.