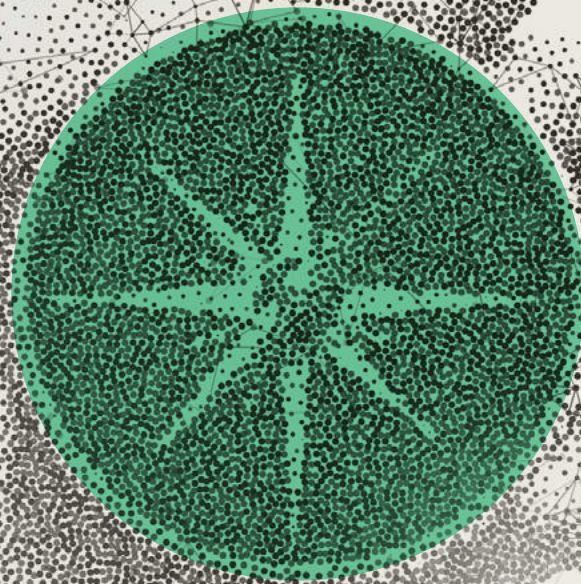




CANADA'S OPPORTUNITY PLAYBOOK:

Pathways to Strategic
Decarbonization



The Transition
Accelerator



L'Accélérateur
de transition

Canada's Opportunity Playbook:

Pathways to Strategic Decarbonization

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About The Transition Accelerator

Our Objective

The energy transition is disrupting global power. The Transition Accelerator is here to help Canada win — **economically** and **geopolitically**.

Our Work

The Transition Accelerator develops projects, partnerships, and strategies to ensure Canada is competitive in a carbon-neutral world. We're harnessing the global shift towards clean growth to secure permanent jobs, abundant energy, and strong regional economies across the country.

We work with 300+ partner organizations to build out pathways to a prosperous low-carbon economy and avoid costly dead-ends along the way. By connecting systems-level thinking with real-world analysis, we're enabling a more affordable, competitive, and resilient future for all Canadians.

Our Unique Approach

- We understand the current system in practice, not just in theory, identifying barriers to innovation and opportunities for change.
- We bring together industry, labour, government, Indigenous and other leaders to define shared visions of success for their sectors, regions, or communities.
- We mobilize partners to develop pathways to get there, understanding and refining them to ensure they are credible, capable, and compelling.
- We turn ideas into action and take steps down those pathways by launching projects and partnerships to build a more competitive future.

For more information or interview opportunities please contact communications@transitionaccelerator.ca

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Canada has the resources to compete in the clean energy economy but has yet to deploy them with the strategic coherence the moment requires.

Executive Summary

Decarbonizing Canada's energy system is no longer just an environmental imperative. It represents one of the main economic growth opportunities in coming years. However, successfully achieving these two objectives requires a more strategic approach to decarbonization: one that focuses on systems change rather than the incremental progress that has defined the last decade.

Instead of viewing climate change as a pollution control problem, this approach focuses on building the new systems that can contribute to the country's prosperity. And rather than treating the economy as an undifferentiated whole, which makes problems seem insurmountable, it focuses on sectoral and regional pathways that break the transformation into manageable steps.

Given the growing array of greenhouse gas reduction approaches, it can be challenging to know where to direct our efforts. Which approaches represent genuinely viable pathways to carbon neutrality that are ready for widescale deployment? Which can realistically strengthen Canada's position in global markets and promote meaningful economic development? And which are dead-end pathways that may deliver incremental, short-term emissions reductions but cannot scale to net zero and/or risk locking in carbon-intensive infrastructure?

This report addresses these questions across 14 sectors, articulating a strategic framework that identifies the pathways most capable of delivering system-level change while also capturing economic benefits for Canada along the way.

The report starts from a transition and energy systems perspective. Reaching net zero requires replacing the large-scale systems that generate emissions: the way Canadians produce and distribute electricity, move

people and goods, heat buildings, and make the materials the economy requires. These systems were built around fossil fuels. The future systems will be built around non-emitting electricity.

Working backwards from this electrified energy system, we can define the pathways that have the most potential. While it is not possible to anticipate every technological and economic development the coming years will bring, many system considerations and market signals are already clear. These indicate:

- **Electricity** will play the lead role in a decarbonized energy system. End-use electrification should be viewed as the top priority for most sectors that today rely on fossil fuels.
- **Net-zero fuels** can complement electricity in sectors where full electrification is not feasible.
- **Enhanced energy efficiency** can reduce the demand on new decarbonized energy.
- **Non-energy emissions** (waste, industrial processes, and agriculture) will require dedicated attention.
- **Residual emissions** should be driven as low as possible, with the remainder offset by carbon removal.

Adopting a strategic approach to decarbonization

Societal decarbonization is a process that will extend across multiple decades. Over this time, political priorities, economic conditions, national concerns, and the geopolitical context will continuously evolve. In acting today, we should prioritize pathways where alternative technologies are ready for wide deployment, and the potential gains for

households and industry are clear. Taking a strategic approach means we should:

1. Ensure decarbonization is integrated with the pursuit of other societal objectives, including enhanced prosperity, economic competitiveness, security, social welfare, and Indigenous reconciliation.
2. Seize electrification as the central link by building out supply and electrifying end-uses in transport, buildings, and industry.
3. Focus on creating the new rather than tearing down the old.
4. Embrace asymmetrical decarbonization. Provinces and sectors will proceed down varied pathways towards net zero at rates appropriate to their circumstances.
5. Prioritize practical steps needed to achieve decarbonization, and physical measures of progress.
6. Pay attention to costs and prices which are critical to both households and industrial competitiveness.

Taken together, these priorities point toward a clear strategic logic: move fast where the economics are compelling, build the foundations that unlock broader transformation, and avoid diverting scarce political and investment capital into battles that cannot yet be won.

Looking across 14 sectors, the assessment asks three questions of each: which pathways can deliver real system-level decarbonization, what decision-makers should do about them today, and how those actions should be sequenced. The answers determine where each sector sits across three tiers of strategic priority shown below.

Strategic Decarbonization Priorities for Canada

Immediate Priorities



Personal Mobility
(Light-duty vehicles
and mass transit)



Buildings



Electricity

Medium-term Opportunities



**Alternative
Fuels**



Aluminium



**Cement
& Concrete**



Hydrogen



**Medium and
Heavy-Duty
Vehicles**



Mining



Steel & Iron

Longer-term Plays



**Agricultural
& Agri-food**



Oil & Gas



**Chemicals &
Plastics**

This sequencing does not mean that longer-term sectors are not relevant today. Rather, it provides a clearer sense of where first to direct finite capital and policy efforts: the sectors with the most leverage to advance a competitive low-carbon economy.

At a sector level, each chapter reviews the current state of the sector, the key barriers to reaching net zero, and the technologies,

practices, and system changes most relevant to decarbonization. Various pathway elements are then evaluated against criteria covering the potential to reduce emissions, technical maturity and fit, economics, and social acceptability. Finally, the assessment assigns each pathway one of four core roles in the net-zero system.



Decarbonization Pathway

Can decarbonize the system and has several other benefits.



Enabling Pathway

Does not directly eliminate emissions but is essential to the successful deployment and performance of other pathways.



Niche Pathway

Can decarbonize a targeted sectoral or regional system.



Bridge Pathway

Serves to reduce emissions while full decarbonization options are developing and does not create an infrastructure lock-in.



Dead-End Pathway

Incompatible with a decarbonized system.

From Vision to Action

In addition to identifying where Canada should focus and in what sequence, the combination of sectoral assessments reveals a set of implementation challenges that extend beyond any single sector: the pathways are deeply interdependent, the global competition to lock in low-carbon value chains is well advanced, and the institutional capacity to coordinate across sectors at the required pace has to be built deliberately.

The urgency of getting this right comes into sharper focus in the global context. Canada's trading partners are deploying ambitious industrial policies to lock in positions in the clean energy economy. China now accounts for more than half of global solar capacity additions and 60% of global EV sales. The European Union, Japan, Korea, and India have all launched directed industrial packages. The window for Canada to establish defensible positions in sectors like battery materials, low-carbon aluminum, critical mineral processing, and EV manufacturing is open now but will not remain so indefinitely. A focused approach could secure approximately \$600 billion in annual clean energy export opportunities by 2035.[1]

This report argues that **Canada has the resources to compete in the clean energy economy but has yet to deploy them with the strategic coherence the moment requires.** Converting those foundations into a defensible economic position means treating the interconnected sectors in this report as a single industrial system to be built, not a set of parallel portfolios to be managed.

Reading this Report

Chapters 1 through 5 develop the transitions, energy systems and economic development perspective in greater depth. Chapter 5 presents the detailed sectoral pathway assessments that underpin the summary table on the previous page. Chapter 6 develops the implementation conditions and the choices that flow from them.

Together they offer a strategic foundation for the policy and investment decisions that will determine whether Canada builds the energy system of the future while growing its economy or arrives late to a new economy built somewhere else.

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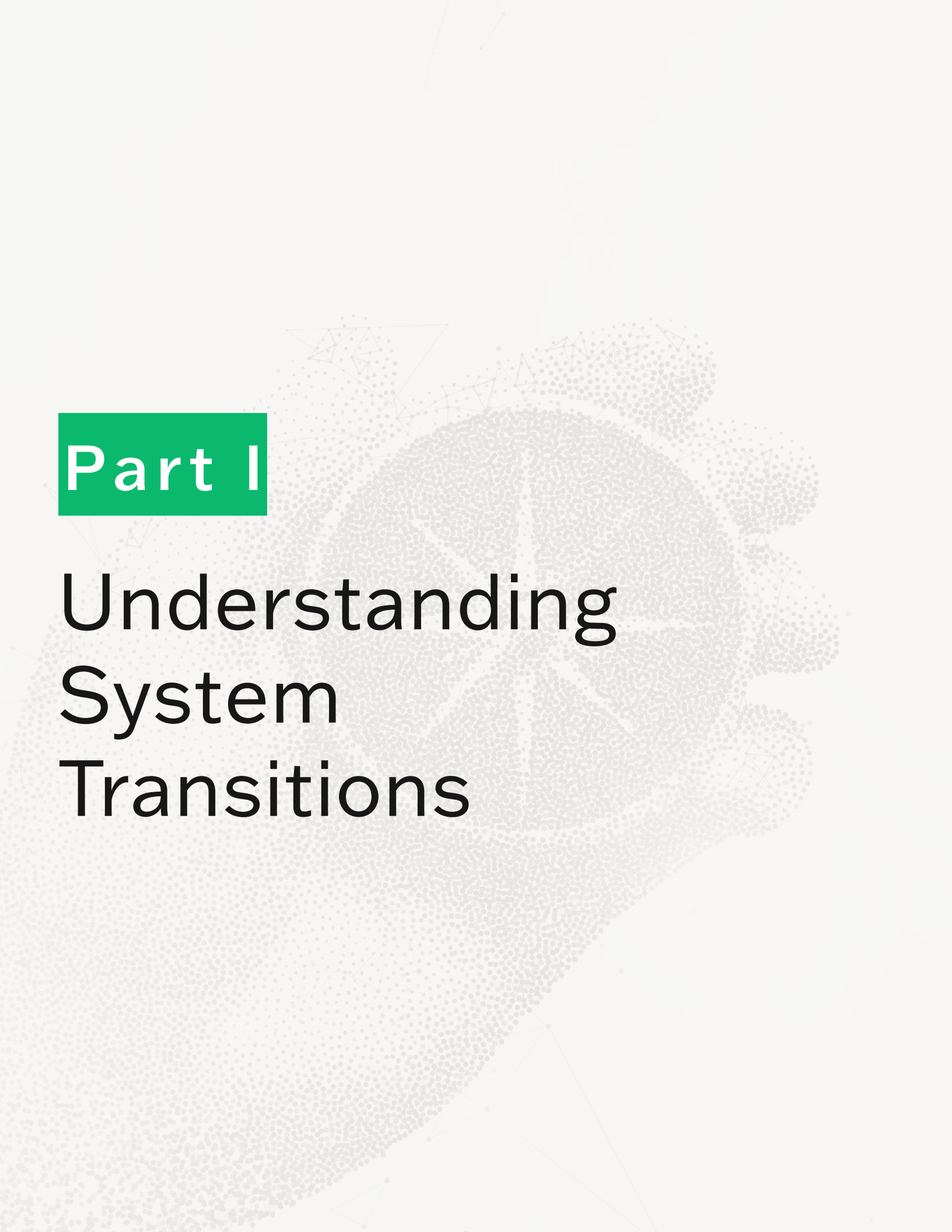
List of Abbreviations

ABBREVIATION	DEFINITION
4R	Right source, right rate, right time, right place
AB	Alberta
AER	Alberta Energy Regulator
AI	Artificial Intelligence
ASHP	Air Source Heat Pump
ATR	Autothermal Reforming
AZEHT	Alberta Zero-Emission Hydrogen Transit
B20	20% biodiesel / 80% petroleum diesel blend
BCA	Border Carbon Adjustment
BEB	Battery Electric Bus
BECCS	Bioenergy with Carbon Capture and Storage
BEV	Battery Electric Vehicle
BF	Blast Furnace
BMP	Best Management Practice
BOF	Basic Oxygen Furnace
BtL	Biomass-to-Liquids
CAD	Canadian Dollar
CCA	Capital Cost Allowance
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization, and Storage
CER	Clean Electricity Regulator
CFS	Clean Fuel Standard
CI	Carbon Intensity
CO ₂	Carbon Dioxide
CO ₂ e	Carbon Dioxide Equivalent
Co-gen	Cogeneration
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CPKC	Canadian Pacific Kansas City
C-SAF	Canadian Council for Sustainable Aviation Fuels
CUSMA	Canada-United States-Mexico Agreement
DAC	Direct Air Capture
DRI	Direct Reduced Iron
DR-grade	Direct Reduction Grade
E10	10% ethanol / 90% gasoline blend

ABBREVIATION	DEFINITION
E85	85% ethanol / 15% gasoline blend
EAF	Electric Arc Furnace
e-fuel	Electrofuel
EPR	Extended Producer Responsibility
e-SAF	Synthetic Sustainable Aviation Fuel
ESG	Environmental, Social and Governance
E.U.	European Union
EV	Electric Vehicle
e-waste	Electronic Waste
FCEVs	Fuel Cell Electric Vehicle
FOAK	First-of-a-kind
FT	Fischer-Tropsch
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
GWh	Gigawatt Hour
GWP	Global Warming Potential
H ₂	Hydrogen
H ₂ -DRI	Hydrogen-based Direct Reduced Iron
HBI	Hot Briquetted Iron
HD	Heavy Duty
HDVs	Heavy Duty Vehicles
HEFA	Hydroprocessed Esters and Fatty Acids
HEV	Hybrid Electric Vehicle
HFCs	Hydrofluorocarbons
HVAC	Heating, Ventilation and Air Conditioning
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
IP	Intellectual Property
IPCC	In-Pit Crushing and Conveying
IRP	Integrated Resource Plan
IT	Information Technology
kg	Kilogram
km	Kilometre
kW	Kilowatt
kWh	Kilowatt hour
L	Litre

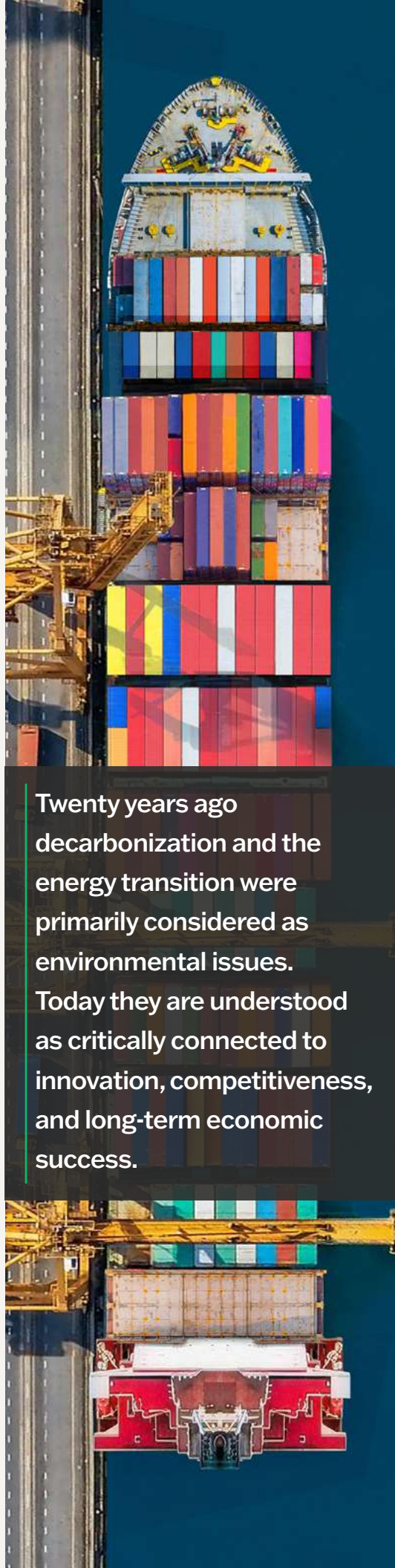
ABBREVIATION	DEFINITION
LCA	Life-Cycle Assessment
LCFS	Low Carbon Fuel Standard
LDVs	Light Duty Vehicles
LED	Light-Emitting Diode
LNG	Liquefied Natural Gas
LRT	Light Rail Transit
MB	Manitoba
MD	Medium Duty
MDV	Medium Duty Vehicle
MHDVs	Medium and Heavy-Duty Vehicles
MJ	Megajoules
MOE	Molten Oxide Electrolysis
MOU	Memorandum of Understanding
Mt	Megatonne
MURB	Multi-Unit Residential Building
MVR	Mechanical Vapour Recompression
MW	Megawatt
MWh	Megawatt hour
N ₂ O	Nitrous Oxide
NB	New Brunswick
NERC	North American Electric Reliability Corporation
NG	Natural Gas
NG-DRI	Natural Gas-based Direct Reduced Iron
NL	Newfoundland and Labrador
NO _x	Nitrogen Oxides
NRCan	Natural Resources Canada
Nox	Nitrous Oxide
NS	Nova Scotia
NT	Northwest Territories
NU	Nunavut
O&G	Oil and Gas
O&M	Operation and Maintenance
O ₂	Oxygen
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
ON	Ontario
PE	Polyethylene

ABBREVIATION	DEFINITION
PEI	Prince Edward Island
Petcoke	Petroleum Coke
PFC	Perfluorochemicals
PHEV	Plug-in Hybrid Electric Vehicle
PJ	Petajoule
PtL	Power-to-Liquids
PtX	Power-to-X
PV	Photovoltaic
QC	Quebec
R&D	Research and Development
RD	Renewable Diesel
RD&D	Research, Development and Demonstration
RNG	Renewable Natural Gas
SAF	Sustainable Aviation Fuels
SAGD	Steam-Assisted Gravity Drainage
SCM	Supplementary Cementitious Materials
SK	Saskatchewan
SMR	Small Modular Reactor
SMR	Steam Methane Reforming
SX-EW	Solvent Extraction-Electrowinning
TIER	Technology, Innovation, and Emissions Reduction
U.K.	United Kingdom
U.S.	United States of America
VOC	Volatile Organic Compound
YT	Yukon
ZETF	Zero Emission Transit Fund
ZEV	Zero-Emission Vehicle

The background features a large, faint, light-gray silhouette of a hand reaching upwards, composed of a dense grid of dots. Overlaid on this are several thin, light-gray geometric lines forming various triangles and polygons. A solid green rectangle is positioned on the left side of the image.

Part I

Understanding System Transitions



Twenty years ago decarbonization and the energy transition were primarily considered as environmental issues. Today they are understood as critically connected to innovation, competitiveness, and long-term economic success.

1. Introduction

Canada stands at a pivotal moment in its energy and economic history. The global transition away from fossil fuels is underway, reshaping industries, supply chains, and competitive positions across every major economy. How Canada navigates this multi-decade transition will determine its prosperity, energy security, and standing in the world.

The decisions that shape this transition are being made now. Governments are setting policy frameworks. Industries are committing capital. Investors are placing long-term bets. But not all courses of action are equal. Some align directly with Canada's decarbonization, economic and competitiveness objectives—they reduce costs, increase productivity, and build industrial advantage. Others do not. Getting these decisions right requires a clear-eyed view of where Canada's options stand, what is working, and where effort needs to be concentrated. That is the purpose of this report.

The report adopts a transition, energy systems, and economic development approach. Rather than treating climate change as a pollution control problem by focusing narrowly on emissions, it examines opportunities to transform the large-scale societal systems that generate these emissions. Today, major systems of social provisioning—the way we move people and goods, construct buildings, produce food, operate industry, and so on—remain dependent on greenhouse gas (GHG) emitting fossil fuels. Shifting them onto more sustainable trajectories is at the core of the net-zero challenge. This requires an understanding of how existing systems operate and the non-climate-related problems influencing their evolution. So, the focus of this report is not “tonnes to target” (although ultimately the math must add up!), but on transforming key systems into configurations compatible with net zero.

Throughout the report, we make the case that Canada's decarbonization must be closely linked to industrial and economic development goals that can ensure a prosperous future for Canadians. Building net-zero industry and services can increase the country's competitiveness and improve our quality of life.

Twenty years ago, decarbonization and the energy transition were primarily considered environmental issues. Today, they are understood as critically connected to innovation, competitiveness, and long-term economic success.[2,3]

The high-level analysis presented in this report is intended to complement the more detailed and ground-up regional and sectoral pathway work undertaken by The Transition Accelerator and other societal actors, as well as more comprehensive quantitative assessments.

In the full sense, a **"transition pathway"** describes the sequence of multi-dimensional changes (to technologies, business strategies, policy and regulatory frameworks, social practices, financing, and so on) required to transform a system. Such pathways are detailed and context-dependent and differ by region and sector. Here we are concerned less with such fine-grained analysis and more with the broad strategic picture of major technical and social elements which can anchor transformative change, and the actions which can accelerate their deployment.

For the purposes of this report, we understand **"net zero"** to imply a society where any remaining GHG emissions are counterbalanced by removals. Since removal technologies involve many uncertainties, we emphasize reducing sector emissions towards zero, leaving the smallest residual to be handled through removals. Looking forward to mid-century, we assume that Canada will continue to experience economic and population growth roughly along the lines of

recent decades. Further, Canada's movement towards net zero is understood in the context of a coordinated international effort, even if progress across countries remains uneven.



The evaluation presented here is based on a review of existing literature, consultation with experts, and the practical experience of The Transition Accelerator. It presents a comprehensive high-level assessment of decarbonization pathway elements, highlighting important sectors and promising trends. Not all systems and sectors are covered, or covered in the same detail. Although the report draws on publicly available modelling work, it is not based on a specific modelling exercise. Its focus is rather to identify the broad avenues of advancement and their potential to deliver net-zero emissions along with other societal objectives.

The first version of this report appeared in January 2021. This second edition has been comprehensively updated, expanded to cover new sectors, and adjusted to reflect both advances in decarbonization and shifts in the domestic and international conjuncture that have occurred over the intervening five years.

The international landscape has shifted considerably since 2021. The wave of ambition that followed the 2015 Paris Climate Summit has met the friction of real-world pressures: the pandemic, wars, tariffs, controversies over immigration, fraying international alliances, economic challenges, and intensifying geopolitical tension have increasingly preoccupied

governments. Some countries that played a leading role in early decarbonization efforts have encountered problems such as rising electricity prices, challenges to grid resiliency as more variable renewables have been added, or lagging industrial competitiveness in low-carbon technologies. Meanwhile, fossil fuel incumbents, now alert to the structural threat the energy transition poses to their long-term revenue base, have become more organized and assertive in shaping policy debates around climate change.

Yet unexpected problems and temporary reverses are typical of large-scale societal transitions which span multiple decades (see Figure 1 and 2). Shifting the global development trajectory away from the unmitigated combustion of fossil fuels, which has powered industrial and societal development for more than 200 years, is not a simple task.

What the zoom reveals: Automobile adoption dropped sharply during the Great Depression and WWII — falling from ~60% to ~50%. Viewed alone, this looks like a failing technology. Zoom out and it's a blip in a 100-year S-curve.

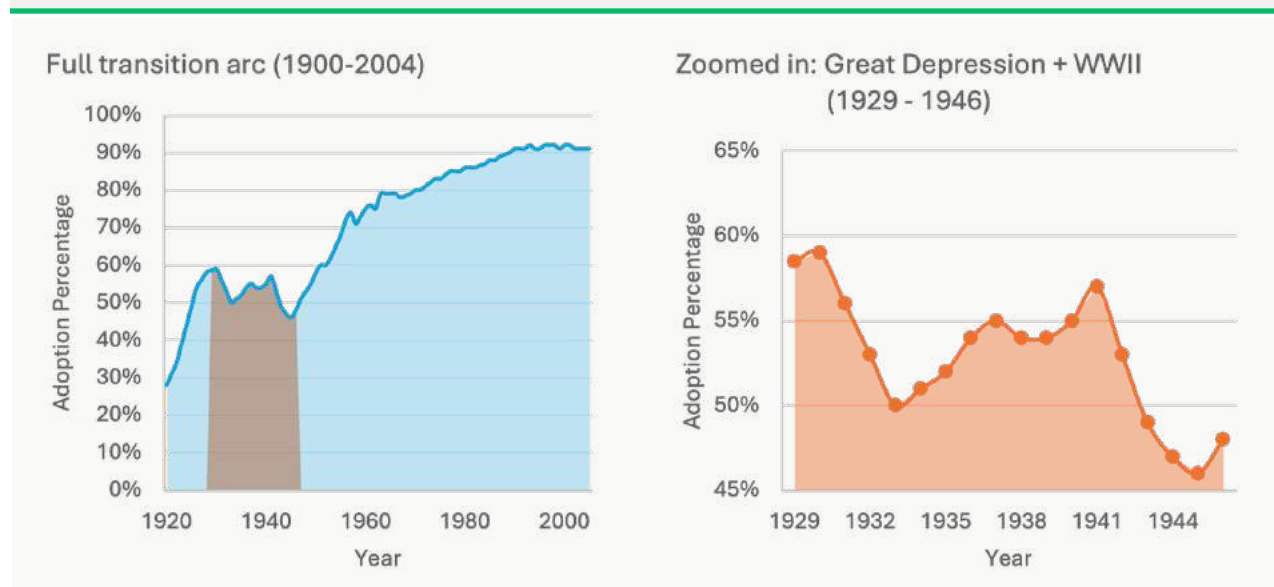


Figure 1. Adoption of automobiles in the United States and the effect of major global pressures
Adapted from Our World in Data[4]



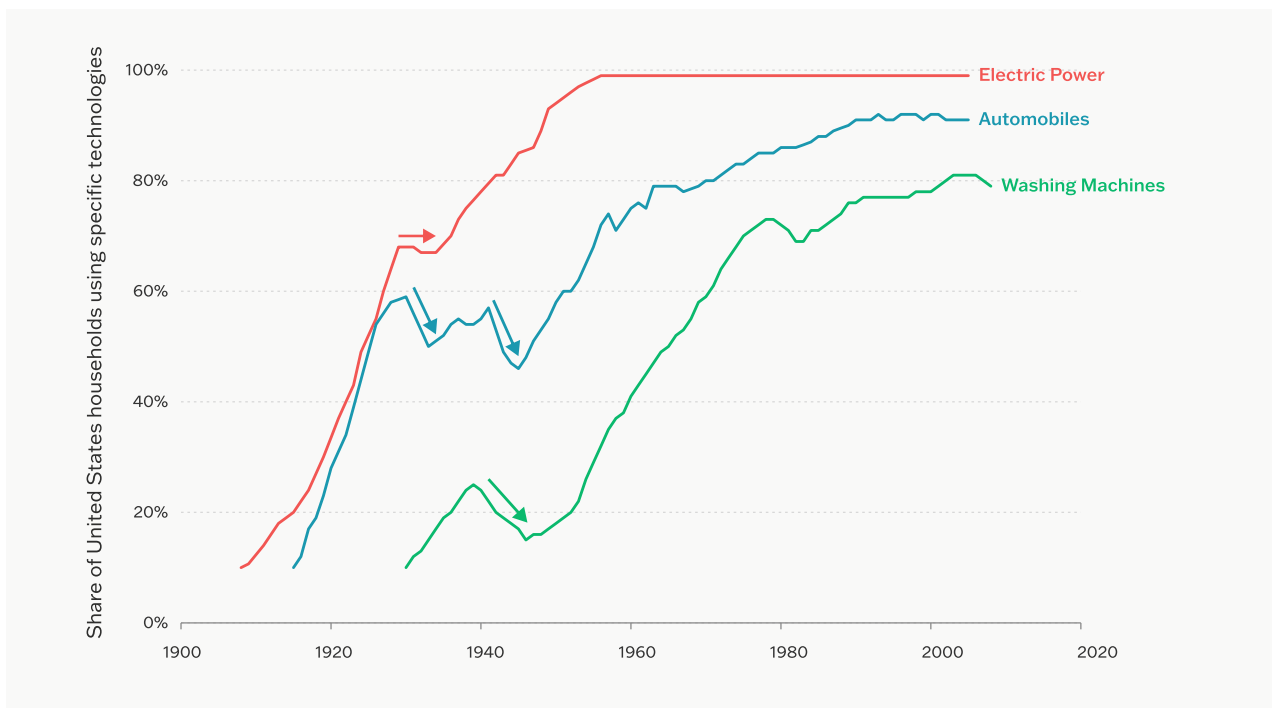


Figure 2. Adoption of electric power, automobiles, and washing machines in the United States between 1920 and 2004.

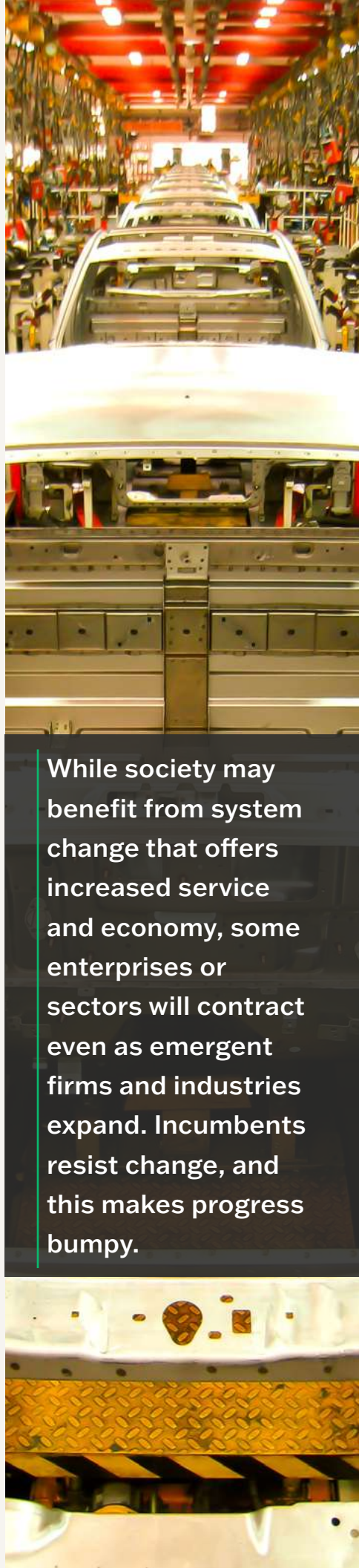
Adapted from Comin, Hobijn, and Our World in Data[4,5]

Above all, it is important to appreciate that, *despite political and economic headwinds*, the global momentum towards low-carbon technologies continues to advance. According to the International Energy Agency, global investment in clean energy (renewables, electricity grids, storage, EVs, nuclear, low-emission fuels, etc.) is now double that going to fossil fuels.[6] With sales of over 20 million units in 2025, EVs make up about 25% of global auto sales.[7] Global PV levelized costs of electricity fell 90% from 2010 to 2024, and renewable technologies and electric vehicles are now increasingly being adopted in developing countries.[8,9]

This analysis represents our best effort to systematize current understanding, set against a landscape where technologies are advancing, markets are shifting, and our collective understanding continues to evolve.

We welcome commentary and feedback that can sharpen the analysis and rectify mistakes. Through this engagement we seek to contribute to the broader societal debate about the net zero challenge and the contours of the Canada we wish to see emerge over coming decades.

The report is organized into three parts. The first deals with our basic approach, outlining what we mean by “transition” and “energy system” perspectives, briefly examining the issues of non-energy-related emissions and GHG removals, and exploring a strategic approach to decarbonization. The second part presents the analysis of specific system and sector pathway elements. And the third offers some general conclusions and implementation considerations.



While society may benefit from system change that offers increased service and economy, some enterprises or sectors will contract even as emergent firms and industries expand. Incumbents resist change, and this makes progress bumpy.

2. Accelerating System Transitions

Getting to net zero will require major changes in the large-scale systems we use to meet societal needs, including the way we produce and distribute energy, move people and goods, and build our cities.[10,11] Although change in such systems is typically incremental, there have been many dramatic transformations in the past: consider the emergence of a transport system based around the personal automobile,[12] the build-out of electricity systems to provide power for homes and businesses,[13] or the ways computing, the digital economy and AI are altering how we live today.

These “system transitions”, which may take several decades, involve interconnected changes to technologies, social practices, business models, regulations and societal norms.[12,14,15] Transitions are periods of considerable uncertainty, since it is unclear how fast change will come and which approach will pan out. They are accompanied by significant distributional impacts. [16] While society may benefit from system change that offers increased service and economy, some enterprises or sectors will contract even as emergent firms and industries expand. Incumbents resist change, and this makes progress bumpy.[17,18] Moreover, there are always multiple ways to apply new technologies, social practices, or business models, which articulate different values and/or provide alternative distributions of benefit. So, transitions inevitably involve struggles over the direction and pace of change.[19,20]

It is no surprise, then, that governments, politics, and policy play an important role in system transitions.[21,22] States may see strategic, military, or commercial advantage in emergent technological systems (for instance the development of steam ships, satellites, drones, or AI). Changes to regulatory frameworks and property rights are normally required to unleash the potential of new approaches. And incumbents and challengers alike compete actively to shape the rules in their favour.

Transitions typically pass through three stages: emergence, diffusion, and system reconfiguration.[23] *Emergence* is about developing and testing alternatives. Dissatisfaction with the established way of doing things spurs innovators to experiment. At first, new technologies are expensive and imperfect, and the designs and business models that will allow widespread adoption are unclear. Novel solutions typically emerge in protected niches, where users are willing to pay over the odds and ignore functional shortcomings. Solar cells, for example, found early application generating power for spacecraft and in remote locations. As innovators gain experience with the new technology, a combination of favorable circumstances (problems with the existing regime, changes in political or economic context) may allow a more direct challenge to the status quo.[24,25]

During the *diffusion* phase, the new approach gains adherents and improves functionality, and prices fall with economies of scale. Positive feedback loops kick in as consumers

become increasingly familiar with the new technology, infrastructure is built out, complementary innovations come to market, and more favorable policy and regulatory frameworks are put in place. As this phase advances, incumbents may become increasingly alarmed by the rapid progress of the challengers and very public struggles over the direction of change may emerge.[26,27]

Eventually, change impacts the overall configuration of the system. Sometimes, the novel elements are incorporated through realignment while important features of the previous system remain, but on other occasions a new system almost entirely replaces the old. With this *reconfiguration*, regulatory and policy frameworks become fully aligned with the new arrangements, linkages to other systems are stabilized, and challengers become the new incumbents.[28] These three phases trace out a classic S curve, where a long preparatory phase gives way to widespread deployment and ultimately system transformation (see Figure 3).

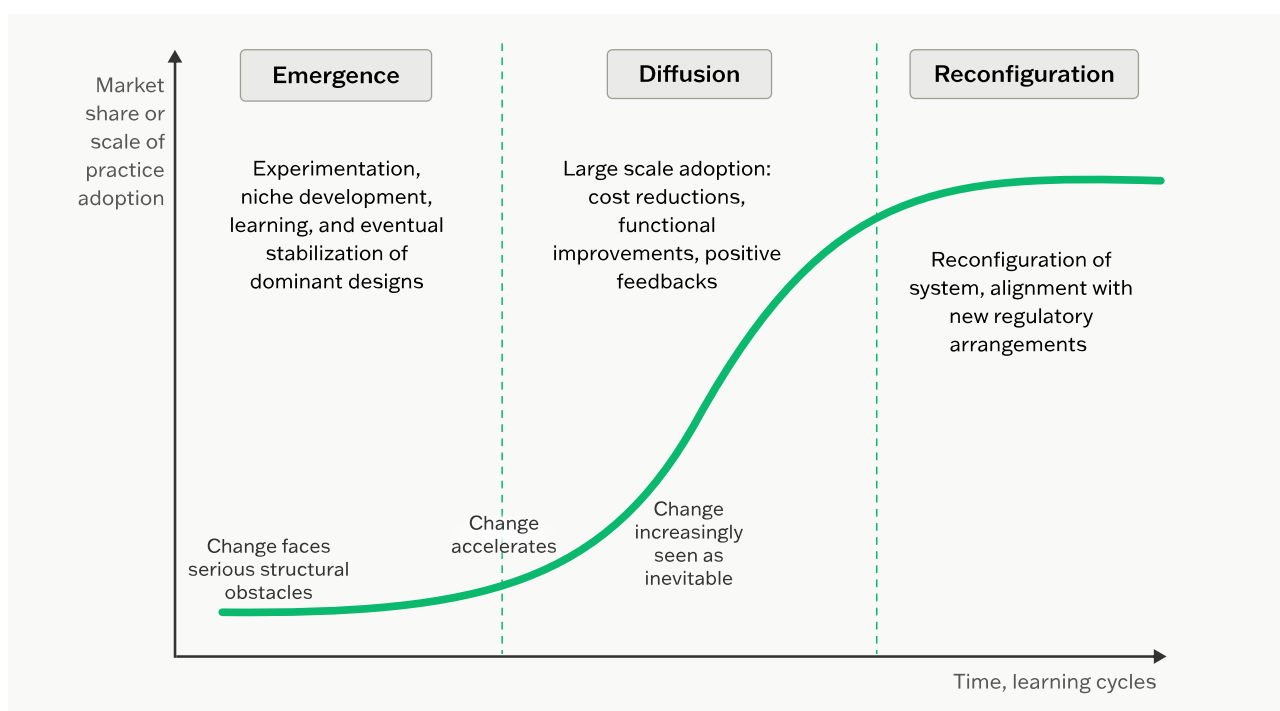


Figure 3. Typical S curve of technology or practice adoption and system transition.

Adapted from Victor, Geels and Sharpe, 2019[77]

Approaching the climate challenge from the perspective of system transitions brings to the fore issues that can help the design of transformational pathways and the formulation of supportive policy. In the first place, while it is common to talk about “the energy transition” as a single phenomenon, decarbonizing the economy will actually involve a series of interrelated transitions across distinct sectoral systems: personal mobility, freight movement, agri-food, and more.[10,11] Each has its own dynamics and different obstacles and enabling factors. Moreover, climate change is not the only problem in these systems, nor is it typically the most powerful driver of change. Cost pressures, competitiveness, demographic shifts, security concerns and technological disruption often exert more immediate influence. Thus, effective decarbonization strategy must work with these forces, not in spite of them.

Some sectors are already being disturbed by powerful disruptive currents that go well beyond climate policy. The auto sector is being reshaped by electric and autonomous vehicles, as well as by new mobility platforms like ride-hailing apps. Housing is under pressure from an affordability crisis that is forcing a rethink of how and where Canada builds.[29-32] Integrating decarbonization initiatives with solutions to broader challenges, including Canada’s drive to diversify trade and build economic resilience in light of evolving geopolitical tensions, is therefore critical.

Other policy implications of a transition approach to reaching net zero include:

- Accelerating system changes that achieve net zero (and other societal objectives) should be the focus of policy design, rather than trying to secure the lowest-cost incremental GHG reductions by a specified date. In many cases the cheapest or most

obvious abatement opportunities are not part of a transformational pathway, and investing in them wastes time and resources that can better be devoted to more strategic efforts.

- Policy should be attuned to the particularities of the **sector** and **region** under consideration. Only in this way can it empower innovators and target the specific barriers that are preventing change. Agri-food, personal mobility, and buildings involve different technologies, actors, and regulatory frameworks, and specific pathways and policy supports are required in each context.
- An understanding of transition phases (emergence, diffusion, reconfiguration) can help guide the design of the policy mix at each stage of the transformational process (see Box on the next page). A vast array of policies, including R&D support, infrastructure investment, regulations, tax measures, subsidies, and public education can be applied. At a certain point, phase-out measures may be required, including retirement dates for specific processes, fuels, or technologies, as well as measures to compensate those disadvantaged by change. But mistakes in timing the introduction of such measures can be counterproductive.
- At the appropriate moment, governments must be prepared to back particular technologies and social and business practices that can accelerate net-zero pathways and economic development. Although there is understandable hesitation about “picking winners”, governments need to fill a central role in focusing investment on the most promising options, funding critical infrastructure, reducing uncertainty for private investors, and facilitating economies of scale. Despite the rhetoric about “letting the market

decide”, governments have always made choices about technological options—especially large-scale energy technologies. The Trans-Canada Highway, the nuclear industry, and oil sands development all required deliberate public commitment. The task is now to apply that same resolve to the technologies and infrastructure of the next energy system.[21,22,33,34]

- While international factors (including climate agreements, technological advances, globally integrated supply chains, geopolitical rivalries, and trade tensions) will impact the pace and orientation of change in key sectors, national governments still retain powerful levers to influence development trajectories.[21,34]

Focusing policy to accelerate change at different transition phases

EMERGENCE

Policy Goal: encourage emergence of alternatives that can potentially lead to system transformation capable of delivering net zero GHG emissions and other societal goals.

Policy Approach: support portfolio of R&D focused on particular sector/problems; fund experiments and demonstration programs; articulate visions of the most promising alternatives to coordinate actors; facilitate knowledge sharing across target sectors; fund intermediary actors to network innovators and develop best practices; encourage early application niches (for example, through public procurement).

DIFFUSION

Policy Goal: accelerate improvement and large-scale deployment of novel approaches that can lead to positive system transformation.

Policy Approach: encourage economies of scale, ‘learning by doing’, and the availability of complementary technologies; support development of standards and codes; support build out of core infrastructure; stimulate demand with purchase subsidies and public procurement; mobilize investment with grants, loans, tax incentives; apply regulations and fiscal measures to raise pressure on incumbents and create market opportunities for new entrants; conduct public education; assist those disadvantaged by changes or less able to enjoy collective benefits.

RECONFIGURATION

Policy Goal: carry through the transformation of the system to achieve net zero and other societal objectives.

Policy Approach: stabilize new institutional and regulatory frameworks; encourage complementarities with other systems; phase out old system elements including compensation, retraining, and regional development.



Energy producers have become a significant component of the Canadian economy, providing jobs, export earnings, and investment opportunities—which is an important consideration for developing transition pathways.

3. An Energy Systems Perspective

Applying an energy systems perspective, which tracks energy and related material flows through the economy, casts important light on critical features of the net-zero challenge. Energy systems involve the harvest of renewable and non-renewable environmental resources (crude oil, uranium, wind, solar radiation, etc.), the conversion of energy into useful forms (gasoline, diesel, electricity), and transport to where it is needed (by rail, pipeline or electricity grids), in order to drive the devices (cars, furnaces, lights) which deliver services (transport, heat, light) to end users (individuals, households, businesses).[35]

Canada's energy system is large, diverse, and heavily fossil-fuel dependent. The largest sources of primary energy exploited in Canada today are fossil fuels (coal, oil and natural gas), uranium, and rivers that generate hydroelectricity, as well as some biomass, wind and solar.[36] Coal is used for electricity production, to provide industrial heat, and (as coke) as a reducing agent in metallurgy. Oil is refined into fuels for transport and industry (and some electricity generation) or for non-energy products (chemicals, plastics, lubricants, asphalt, etc.). Natural gas contributes to electricity production, heating for industrial processes and in commercial and residential settings, fertilizer production, and it is used within the energy sector itself (for example, in the oil sands).

Uranium is converted into fuel for nuclear power plants. Biomass is mainly used for electricity production in the pulp and paper sector and to make liquid biofuels for transport. Electricity generated from hydro, wind, solar, nuclear, gas or oil powers residential, commercial, and industrial end-uses such as lighting, cooling, heating, motors, and compressors.[37]

Ultimately, consumers value energy for the wide range of services it provides. At the same time, energy producers have become a significant component of the Canadian economy, providing jobs, export earnings, and investment opportunities—which is an important consideration for developing transition pathways.

Among the most important features of Canada's energy system are that:[38,39]

- The country is a large *net energy exporter*, producing far more energy than it uses. In 2025, Canada exported 87% of its oil production and 46% of natural gas production; the vast majority of these exports went to the United States (97% of natural gas and 90% of crude oil).[40,41] International exports of uranium, coal, and electricity are also significant (90%, 81% and 6% of Canadian production respectively).[42,43,44]
- *The greenhouse gas intensity of the Canadian economy is high* in comparison to that of many other developed countries. Exploiting Canada's comparative economic advantages (abundant land and natural resources) over the past century has led to great prosperity but has left legacy challenges as we move into a carbon constrained world.

- *Electricity supply systems are already substantially decarbonized*, with approximately 80% of generation coming from low carbon sources (principally hydro and nuclear).[45]
- The energy systems of Canadian provinces are highly diverse. Contrasting resource endowments and economic development trajectories, combined with decentralized constitutional arrangements, have led to different energy profiles. Provincial electricity systems have varied generation assets, ownership structures, and regulatory regimes. Electricity has served as a lever for regional economic development, and provinces are hesitant to integrate with neighbouring jurisdictions. Indeed, with the pull of markets to the south, north-south electricity trade is more developed than east-west connections.

This last point—regional variation—conditions the first three features of Canada's energy system described above, for exports differ by province, as do the GHG intensities per GDP and per capita (see Table 1).



Table 1. Diversity of Canadian provincial energy systems is illustrated through GHG emissions (per capita and per unit of GDP) and the economic value of key energy exports

Adapted from the National Inventory Report 1990-2023 and the Canadian International Merchandise Trade Web Application using annual export data for the year 2025[46,47]

Province or Territory	GHG Emissions (tonnes CO ₂ e)		Value of Energy Exports (millions of \$CAD)				
	Per capita	Per million \$ of GDP	Oil (Crude & Refined Petroleum Products)	Natural Gas (Gas & Liquids)	Coal	Electricity	Uranium
Newfoundland and Labrador	14.6	196	7,817	0	0	78	0
Prince Edward Island	9.1	158	0	0	0	0	0
Nova Scotia	13.2	231	19	2	0	0	0
New Brunswick	13.1	237	8,295	624	0	262	0
Quebec	8.9	136	3,959	52	0	580	0
Ontario	10.0	140	1,641	608	109	920	602
Manitoba	14.4	226	633	32	0	443	0
Saskatchewan	60.5	655	11,408	137	0	55	2,321
Alberta	55.3	583	122,232	11,711	732	42	0
British Columbia	10.8	145	3,426	5,143	6,766	671	0
Yukon	14.6	160	0	0	0	0	0
Northwest Territories	31.4	262	0	0	0	0	0
Nunavut	17.3	145	0	0	0	0	0
Canada	17.1	234	159,431	18,310	7,607	3,051	2,923

From the perspective of analysing the transition of the energy system in Canada (see Figure 4), the following features of the current system are worth bearing in mind:

- *The critical dependence of most sectors on end-use combustion of fossil fuels*, including almost the entire transportation system, much of the heating in residential and commercial buildings, and various major industries.[23]
- *The significant energy losses across the system*, including the energy consumed by the oil and gas industry itself, combustion losses (shed as heat in internal combustion engines and thermal power generation), and end use inefficiencies (for example, poorly insulated buildings).[39]
- *The relatively centralized nature of current fuel and electricity production*, where a few main nodes (oil refineries and electric power plants) feed energy through networks to millions of consumers.
- *The necessity for real-time balancing of supply and demand in electricity systems* which becomes an increasing challenge as more variable generation (wind and solar) is integrated onto the grid.[48,49]

- The significance of *spatial distribution*: oil or wind can only be harvested where they are found, which may be far from markets; and infrastructure constraints (pipeline and electricity grid congestion) matter.
- *There is no ideal form of energy*: all have a mix of costs and benefits (economic, social, and environmental) that must be assessed and balanced.[48]

Political-economic dimensions of Canada's energy system that pose challenges for the transition to net zero include:

- The weight of the oil and gas industry in the economy and public decision-making, especially in specific regions (jobs, investment portfolios, and political influence).
- Substantial (and constitutionally protected) provincial control over resources development which makes policy harmonization at the federal level difficult.
- Close economic integration with the United States (with its on-again/off-again climate policy) which must be a consideration in policymaking.



IMPORTS & EXPORTS

ENERGY SOURCES

ENERGY CARRIERS

ENERGY END-USE

Canada is a major net energy exporter.

- Roughly **70% of oil and gas** production is exported, almost entirely to the United States.
- Around **81% of uranium** is exported.
- Wood pellets** are a significant biomass export, primarily to Europe.
- Electricity imports and exports** occur at the margins, varying by province and season.

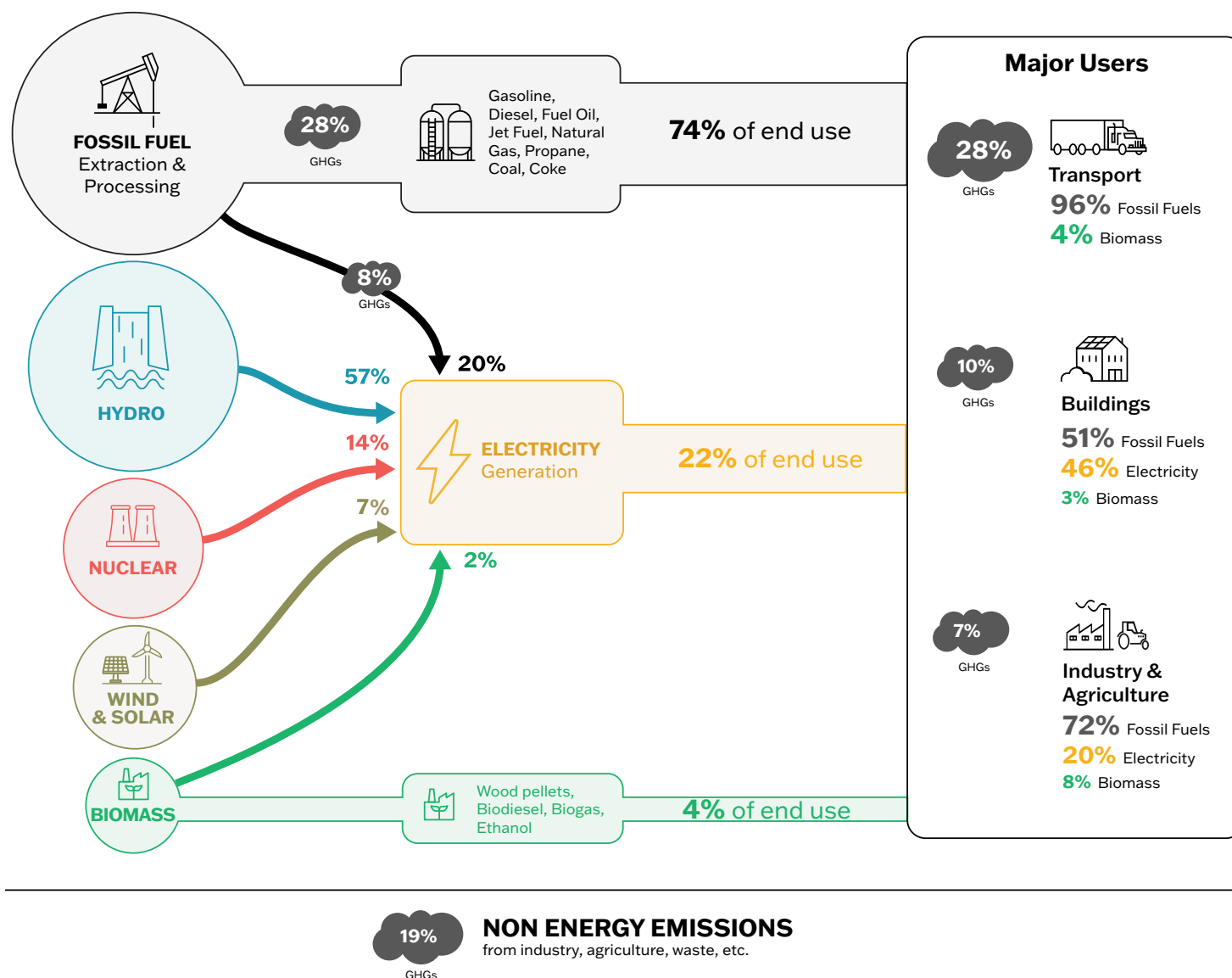


Figure 4 Schematic overview of Canada's current energy system.[43,57–61]

An energy system perspective can also tell us something about the net-zero energy systems of the future. We cannot anticipate every technological or economic development decades in advance, but some basic parameters are clear.[50-52] And knowing something about where we need to end up is important for defining pathways to get there.

A conceptual model of a net-zero energy system for Canada is presented in Figure 5. There are five essential elements of this system:

1. At its heart is a greatly enhanced role for decarbonized electricity in delivering end-use services, particularly for transport, building heating, and industrial operations.[50,53] Electricity is the most versatile of current energy forms and can be efficiently converted to a wide range of uses. Society is already wired up through the grid. In Canada, electricity is 80% decarbonized and we know multiple ways to generate more net-zero electricity, including hydro, wind, solar, biomass, geothermal and other renewables, nuclear, and fossil fuels with carbon capture and storage (CCS).
2. Hydrogen or zero-emission fuels serve as additional energy carriers in sectors where electrification is difficult or expensive (for example, heavy freight transport and industrial heat).[52,54]
3. Biofuels will have applications in industry, agri-food and perhaps some transport markets (for example aviation fuel). But issues with feedstocks and competition from other land uses may limit their contribution.
4. Residual domestic uses of fossil energy, including the fossil fuel extraction and processing industries, incorporate low carbon energy, CCS, and negative emissions to achieve net zero. Remaining fossil fuel exports and/or energy exports originally derived from fossil sources (for example, hydrogen or electricity) will have net-zero production profiles.
5. Dramatic changes in technologies, business models and social practices in end-use sectors—including substantial increases in energy efficiency[53]—will have allowed the essential phase-out of distributed fossil fuel end-use in transport, buildings, and industry.

It is not possible today to be precise about the relative importance of the elements in this conceptual schema. Technological developments, the evolution of relative costs, social acceptance, international circumstances, and political choices will influence future deployments. How much hydro versus nuclear, wind, solar, and so on will there be in the electricity mix? What proportion of energy needs in each end-use sector will be provided by electricity versus low-carbon fuels? What proportion of hydrogen will come from electrolysis, or from methane reforming with CCS and offsets? How centralized or decentralized will energy provision be? What scale of (production-emission-free) fossil energy exports will remain? Which negative emission approaches will prove viable? Answers to these and many other questions remain undetermined. The structure of existing systems places significant constraints on likely outcomes, and modelling can help explore the range of possibilities, but these issues will ultimately be resolved by technological, economic, social and political processes over multiple decades.

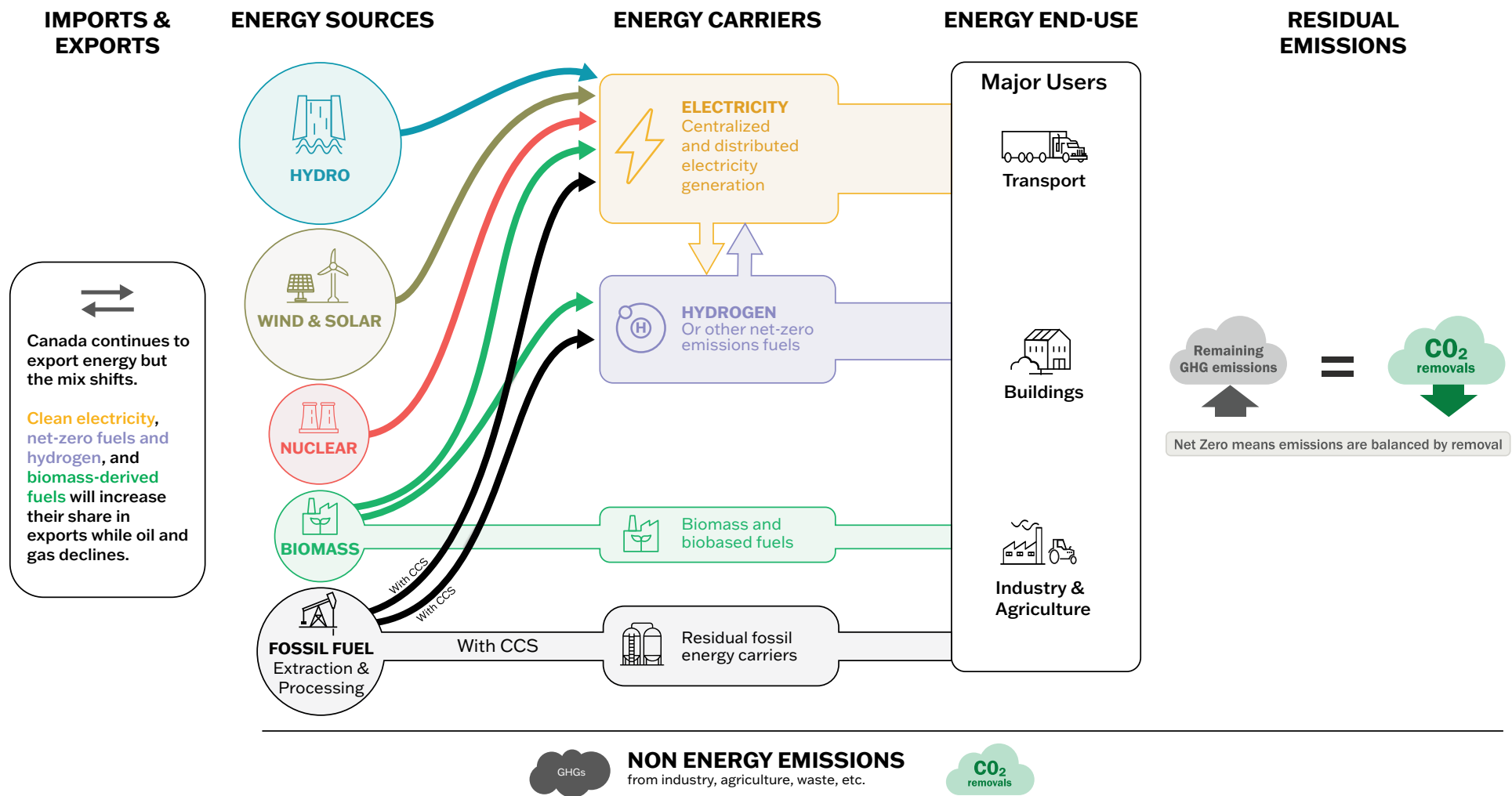


Figure 5 Schematic overview of Canada's future energy system.[43,57–61]

Despite these uncertainties, several things are clear:

- Since end-use energy requirements are to be shifted from fossil fuels to electricity, we will ultimately need greater electricity supply. Moreover, the growth of population and economic activity over several decades will leave us with more needs to service. Thus, moving towards net zero requires the phased buildout of the electricity system. The good news is that we do not need to replace the full energy content of the displaced fossil fuels (“joule for joule”) because of the inherent efficiency of electric end-use devices such as electric motors or heat pumps as compared to fossil fuel combustion. Nevertheless, Canada is looking at doubling or more its current electricity generation over coming decades.
- The relative significance of elements in the schema will vary across Canada, depending on the provincial resource base and economic trajectory, and there are opportunities for provinces to leverage their comparative advantages in developing distinctive low-carbon trajectories (hydro serves for energy storage in Quebec, hydrogen can be produced cheaply from methane in Alberta, Saskatchewan has important uranium reserves, etc.).[55]
- As new electricity generation capacity always imposes costs, be they economic, social, or environmental, further improving efficiency in many end-use sectors will be important.
- Since electrifying everything is not practical, we will need some other low-carbon energy carriers.[56] Enhancing research and development, demonstration projects, and infrastructure investment for hydrogen, ammonia, and low carbon fuels is therefore warranted.





Although the journey to net zero is primarily about building systems that avoid GHG emissions, it will also involve some application of “negative emission” approaches that remove carbon dioxide from the atmosphere.



4. Looking Beyond the Energy System

Some Canadian GHG emissions are not directly related to energy use, but stem from industrial processes and products (7.7%), agriculture (7.9%), and waste (3.3%).^[46] These emissions, which are entangled with a variety of existing systems of provisioning, may be particularly challenging to address. Industrial processes include the production of iron, steel, and cement (the critical structural materials of industrial society), and the manufacture of chemicals. Industrial products include fluorinated gases used in refrigeration, air conditioning and heat pumps, as well as other industrial and commercial applications. Agricultural emissions are generated by livestock operations (from enteric emissions and manure) and cropping practices (fertilizers, agricultural soils). Landfill and wastewater treatment facilities also generate substantial GHG emissions.

Moving towards net zero, system transformations must successfully address both energy and non-energy emissions, and these will be discussed together in subsequent sections of this report.^[39,46]

Although the journey to net zero is primarily about building systems that avoid GHG emissions, it will also involve some application of “negative emission” approaches that remove carbon dioxide from the atmosphere. This will be required to offset residual emissions that prove technically challenging or too expensive to eliminate. For example, if carbon capture and storage is applied to fossil energy production and use, or to control industrial process emissions, residual emissions of perhaps 10% will have to be offset by removals. And while accidental methane releases associated with fossil energy production and usage can in principle be reduced to low levels, negative emissions approaches may be required to deal with these.

Moreover, even if all fossil energy usage stops, or novel exploitation techniques completely avoid GHG releases, negative emissions approaches may ultimately be required to draw down

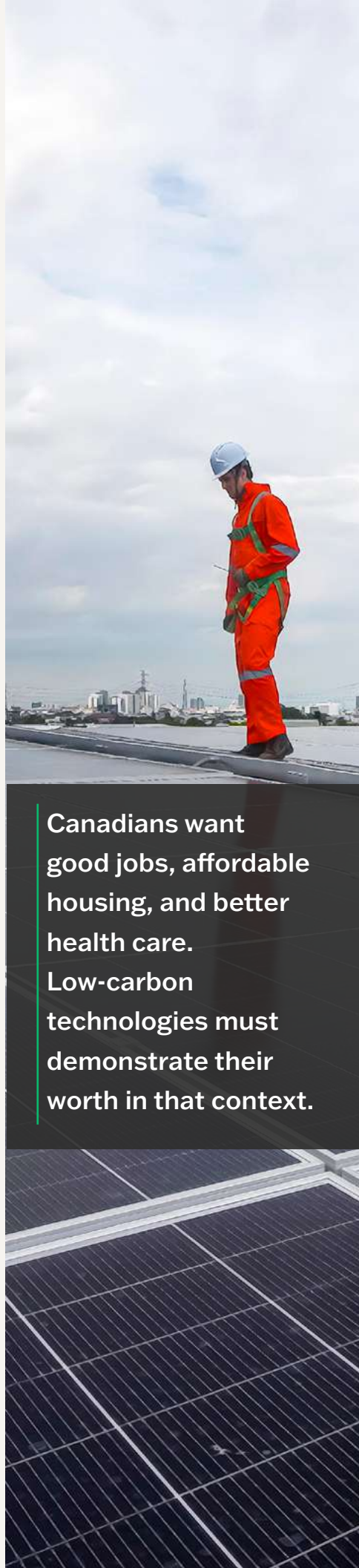
atmospheric GHG concentrations. Most integrated assessment models indicate these approaches will be needed in the second half of this century if the impacts of climate warming are to be kept within a manageable range.[10,11] Although some argue that these models have not accounted for more dramatic demand-led systems changes that might avoid the need for negative emissions, the longer climate action is delayed, the more potential significance they acquire.[62]

A wide array of negative emission approaches has been suggested, including:

- Large-scale reforestation and afforestation. As trees grow, they absorb carbon dioxide and convert it into standing biomass. If the forest remains undisturbed, the carbon is locked away from the atmosphere.[63]
- Increased retention of carbon in soils through changes to agricultural practices and/or the wide scale incorporation of biochar.[64,65]
- Bioenergy with carbon capture and storage (BECCS), where biomass energy facilities apply CCS to trap the carbon dioxide drawn down by plant growth underground.[66]
- Direct air capture (DAC), where CO₂ is extracted from ambient air and sequestered underground or used as an input for industrial processes.[67]

But there are many other potential approaches, including enhanced weathering (where geologic processes that absorb CO₂ are accelerated) or pyrolysis of organic waste and sequestration of the resultant oil.[68,69]

Each approach has different potential as well as difficulties or drawbacks. For afforestation and reforestation, concerns are with the vulnerability of sequestration to fires, pest and disease attack, or human activities, as well as the availability of land. The ultimate potential for organic carbon retention in soils remains uncertain, while there is still little systematic research on biochar. BECCS is currently expensive; energy is required to collect dispersed feedstocks; and there are doubts about the availability of bio-resource feedstocks without negative land use impacts. Air capture is currently very expensive and energy-intensive but could ultimately be linked to synthetic fuel production. Other approaches are possible, but there are persistent doubts about the funding of removal activities, the scale at which they could be undertaken, and possible negative environmental impacts. Several recent reports provide an overview of negative emission approaches and the frameworks required for their governance.[70-73]



Canadians want good jobs, affordable housing, and better health care. Low-carbon technologies must demonstrate their worth in that context.

5. Approaching Decarbonization Strategically

Societal decarbonization is a process that will extend across multiple decades. Over this time, political priorities, economic conditions, national concerns, and the geopolitical context will continuously evolve. Surprises and reverses are inevitable. It is therefore imperative that those interested in advancing progress towards a net-zero future adopt a strategic approach that focuses on the most important elements while adapting continuously to these changing circumstances. In the Canadian context it is particularly important to:

- **Ensure decarbonization is integrated with the pursuit of other societal objectives**, including enhanced prosperity, economic competitiveness, security, social welfare and Indigenous reconciliation. Canadians want good jobs, affordable housing, and better health care. Low-carbon technologies must demonstrate their worth in that context. Support for electricity system build out, value-added transformation of natural resources (mining and processing critical minerals), and manufacture of low-carbon technologies (EVs, heat pumps, electrical system components, etc.) creates a foundation for future affluence, gives us tools to decarbonize our domestic economy, and can strengthen political coalitions favoring more vigorous action.
- **Seize electrification as the central link by building out supply and electrifying end-uses in transport, buildings and industry.** With the costs of renewable technologies (especially solar and increasingly batteries) continuing to fall, rapid advances in end-use electric devices (vehicles and heat pumps), and increasing digitalization (including AI and robotics), some commentators have begun to talk of an “Electro-tech revolution”.[74] This extends the benefits of the earlier wave of 20th century electrification (lighting, industrial equipment, refrigeration and air conditioning, domestic appliances) to new areas of social life, enhancing the convenience,

reliability, cleanliness and efficiency of energy services. In coming decades, enhanced electrification will be both a key to industrial competitiveness and the cornerstone of the net-zero economy.

- **Focus on building the new rather than tearing down the old.** For decades activists have highlighted risks of climate change and decried the fossil-fuel-based energy system. Today, the priority should be implementing practical solutions. So long as oil and gas remain Canada's major export earner and world demand for fossil fuels is strong, the industry is unlikely to be constrained by domestic political action. Instead, the focus should be on rolling out the new, demonstrating the benefits of electric end-uses with higher performance and driving down their costs. As fossil fuel dependence is eroded on the demand side domestically and globally, the balance of forces between old and new energy systems and the associated political calculus will shift, and the transition can accelerate.
- **Embrace asymmetrical decarbonization.** Provinces and sectors will proceed down varied pathways towards net zero at rates appropriate to their circumstances. Policies should be adapted to these differentiated conditions and needs, and should reflect the transition readiness of specific sectors and regions. Enforcing a "one size fits all" approach sparks delays and division. Where solutions are ready, policy should accelerate mass deployment. Where solutions are not yet mature, policy can support R&D, experimentation, and measures to prepare eventual market transformation.
- **Prioritize practical steps needed to achieve decarbonization.** All too often government plans and strategies "float in the air", without realistic consideration of the material steps required to effect change.

Plans and targets should be operationalized in material terms (for example, the number of new homes to be fitted with electric heating) and identify the specific steps required to achieve a goal (regulatory changes, capital mobilization, supply chain development, work force training, and so on). Progress indicators should track the real state of market transformation (for example the proportion of new car sales that are electric) and not anticipated tons of emission reductions from a hypothetical business-as-usual scenario.

- **Pay attention to costs and prices.** Costs are critical to industrial competitiveness and prices matter to households. Today, low-carbon solutions are often more expensive than fossil-fuel-based alternatives. In the short term, prices are largely given, but over time they are influenced by investment. Learning rates (the price fall with doubling of deployment) and economies of scale can dramatically transform relative costs. Policy can help drive down the price of new technologies through public procurement, temporary production or consumption subsidies, regulations, and other mechanisms. Carbon pricing works in the opposite direction by raising the cost of carbon-intensive fuels. But, it remains politically divisive. So a cornerstone of decarbonization initiatives should be measures to drive down costs of low-carbon technologies to encourage market transformation. Moreover, if rising electricity prices are not to become an Achilles heel of decarbonization, careful attention must be paid to the systematic buildout of the grid, the mix of selected generation technologies, the phasing of the deployment of end-use electric technologies, and how electricity system improvements are financed.

Taken together, these priorities point toward a clear strategic logic: move fast where the economics are compelling, build the foundations that unlock broader transformation, and avoid diverting scarce political and investment capital into battles that cannot yet be won.

The sections of this report that follow translate this logic into sector-by-sector assessments. But before that analysis, Table 2 distills this report's overall strategic posture into a single view: which sectors warrant

priority action now, which require foundational investment to prepare for future deployment, and which are better served by provisional support and monitoring.

The ordering is deliberate. Electricity grid buildout sits at the top not because other sectors are unimportant, but because a decarbonized, expanded grid is the precondition for progress across almost everything else. Where the economics and technology are ready, the task is deployment at speed and scale.

Table 2. *Where to Move First: A Strategic Sequencing of Canada's Decarbonization Priorities*

Sectors	Priority Actions	Economic Competitiveness Advantage
Immediate Priorities for Strategic Decarbonization		
Electricity	Accelerate grid buildout and regional interties; scale wind, solar, hydro, and nuclear; invest in storage and demand management. Prioritize grid financing mechanisms that keep electricity affordable as the grid scales. The long-run cost benefits to households and industry depend on how infrastructure costs are structured and recovered.	High Canada's low-cost, reliable, low-carbon electricity is a significant competitive advantage in a world where energy price volatility and carbon intensity are becoming more important to industrial location decisions.
Personal Mobility (Light Duty Vehicles & Mass Transit)	Drive rapid EV adoption. Invest in charging infrastructure, procurement incentives, and electrified transit systems that reduce household transportation costs for urban commuters who don't own a vehicle.	High Canada can secure a competitive position in EV and battery supply chains, and manufacture of transit equipment, drawing on established manufacturing capacity, skilled labour and access to critical minerals.
Buildings	Deploy heat pumps widely, focusing on contexts where they are cost competitive, including households currently on expensive heating fuels such as oil, propane, and electric baseboard. Expand retrofit programs. Ensure new buildings are built to avoid the need for future retrofits.	High Supports large-scale skilled employment. Can develop export potential in low-carbon building materials, retrofit solutions, and construction expertise.

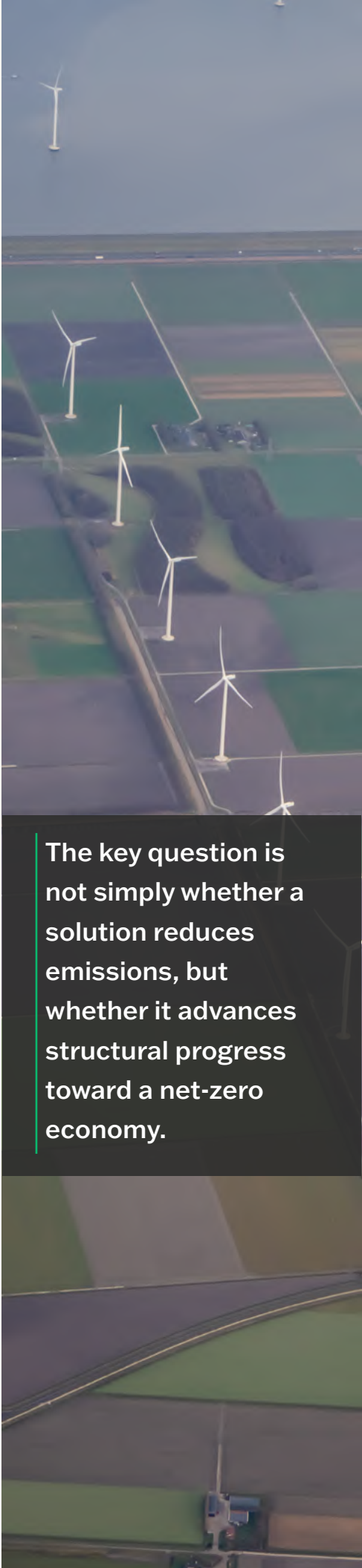
Sectors	Priority Actions	Economic Competitiveness Advantage
Medium-Term Opportunities for Accelerated Progress		
Aluminum	Electrify process heat; accelerate adoption of inert anode technology to eliminate process emissions; leverage Canada's low-carbon electricity advantage.	High One of Canada's strongest near-term industrial positions. Access to cheap, reliable hydro power gives Canadian aluminum producers a durable advantage on both cost and carbon intensity as global buyers place greater weight on supply chain resilience and embodied emissions.
Medium & Heavy-Duty Vehicles	Accelerate deployment of battery-electric MDVs through fleet procurement and depot charging investment, while supporting demonstration and early deployment of battery-electric and hydrogen fuel-cell HDVs. Invest in charging corridors and hydrogen fuelling infrastructure, with attention to bringing down costs over time in applications where total cost of ownership can become competitive.	Medium Canada already has manufacturing capacity and commercial vehicle supply chain relationships. The near-term advantage is to build domestic capability through fleet electrification, transit buses, drivetrain systems, and charging infrastructure, with the potential to translate domestic scale into export strength.
Alternative Fuels	Support R&D and pilot-scale production; develop regulatory frameworks; prioritize aviation and marine applications where electrification is not viable and where cost premiums can be absorbed or structured through long-term procurement agreements.	Medium Long-term opportunity in alternative fuels. Canada's agricultural and forestry base provides potential feedstock advantages. The competitive opportunity is to secure an early position in sustainable aviation fuel and other biofuel supply chains as global buyers begin locking in long-term procurement.
Hydrogen	Near-term action should focus on building up demand for strategic uses and on reducing production costs as scale increases. Fund demonstration projects; develop export strategy; prioritize applications where electrification is not viable such as industrial heat and heavy transport.	High Canada's abundant clean electricity, low-cost natural gas, and access to Atlantic and Pacific export routes give it a credible position as a future low-carbon hydrogen supplier. The opportunity is economic and strategic as allied economies look to diversify energy imports and build more secure supply relationships.
Steel & Iron	Support early electric arc furnace deployment and invest in R&D and pilot projects for hydrogen-based direct reduction. Technology is not yet cost-competitive; priority action should focus on demonstration, infrastructure and market development, rather than near-term cost savings.	Medium Canada is able to combine clean electricity with access to key upstream inputs—an advantage that is likely to become more important as procurement standards tighten and buyers become more conscious of embodied carbon.

Sectors	Priority Actions	Economic Competitiveness Advantage
Cement & Concrete	Support CCS pilot programs; promote low-carbon cement formulations and material efficiency in construction. The construction sector is highly price-sensitive, and low-carbon cement currently carries a cost premium that flows into building costs—policy support for adoption is essential to avoid passing costs to end users prematurely.	Medium A technical expertise opportunity to build globally transferable capabilities in CCS integration and low-carbon cement formulation. That creates potential to compete as a technology, investment, and project partner in the construction sector under growing pressure to decarbonize.
Mining	Electrify mining operations and pilot hydrogen equipment where appropriate. Remote electrification requires high upfront capital but can deliver long-run fuel cost savings and reduces exposure to diesel price volatility.	Medium Canada's critical mineral base is a major competitive asset. The opportunity is to secure and maximize its value as allied economies rebuild supply chains around more reliable, lower-carbon sources.
Long-Term Plays to Monitor and Prepare		
Chemicals & Plastics	Electrify process heat where feasible and support demonstration of electrified steam crackers and carbon capture at chemical facilities. Scale up mechanical and chemical recycling infrastructure, standardize plastics labelling and collection, and expand and improve extended producer responsibility (EPR) programs. Advance research into low-carbon feedstocks (low-carbon hydrogen, captured carbon, and biomass) to displace fossil-based inputs over the long term.	Low Longer-term, Canada's clean electricity and natural gas access could position it to compete in electrified chemical production and low-carbon hydrogen-based feedstocks, though most core decarbonization technologies remain in pilot or demonstration phase.
Agri-Food	Reduce nitrogen fertilizer emissions; improve livestock management practices; accelerate adoption of precision agriculture.	Medium With an existing strong export position in agri-food, the competitive opportunity is to stay ahead of tightening carbon and sustainability requirements in high-value markets, protecting access and strengthening its position in premium segments.
Oil & Gas	Drive methane emission reductions; electrify upstream operations; integrate CCS at major facilities.	Medium Canada's oil and gas sector remains a major economic asset with established infrastructure and market relationships. A competitiveness concern is to maintain access to markets where emissions intensity increasingly affects value.

The background features a large, faint, light-green geometric shape composed of many small dots and connected lines, resembling a stylized map or a complex network. A solid green rectangle is positioned on the left side of the image.

Part II

Pathway Assessments



The key question is not simply whether a solution reduces emissions, but whether it advances structural progress toward a net-zero economy.

6. Pathway Assessments

The following chapters provide an overview of possibilities for change in sectors central to Canada's decarbonized economy. Each section reviews the sector's current state, the key barriers to achieving net zero, decarbonization options, and short and long-term priorities. Not all sectors are examined in equal depth. Nor is every technological option assessed. The focus is rather on large systems and the most impactful and relevant opportunities for change.

Each section concludes with tables summarizing capsule assessments of potential net-zero pathways, including technologies, practices, and system approaches. In reviewing these tables, the following principles should be noted:[55,75,76]

1. The assessment does not develop fully elaborated transition pathways. Rather, it evaluates key pathway elements that could anchor and drive transformative progress toward net zero.
2. Since transition pathways link the present to a decarbonized future, pathway elements were assessed based on their contribution to system-wide transformation. Promising elements are those that either form part of a net-zero system, serve as necessary interim steps, or play a facilitating role in accelerating the transition. The key question is not simply whether a solution reduces emissions, but whether it advances structural progress toward a net-zero economy.
3. Even where a pathway element could play a meaningful role in the transition, its uptake depends on techno-socioeconomics.
4. Recognizing that climate change is not the only societal objective, pathway elements were also assessed for their potential to deliver broader benefits, including a more robust economy, improved services, healthier communities, and greater resilience.

6.1 CURRENT SECTORAL POSITIONS

The sectors assessed in the following chapters do not begin from the same place. Figure 6 positions each on the net-zero transition S-curve introduced in Chapter 2 (Figure 3), which distinguishes three phases: emergence, in which options are developed and tested at small scale; diffusion, in which net-zero options move beyond niche use and begin to displace incumbent systems at scale; and reconfiguration, in which the surrounding system reorganizes around them.

Each position reflects the sector as a whole rather than the progress of any single technology. Placement accounts for the full emissions profile of the sector and the full range of pathways available to address it, so a sector moves along the curve only as options capable of addressing the bulk of its emissions scale. The positions are a snapshot of where each sector stands today and are complementary to the in-depth review of each sector found in the following pages.

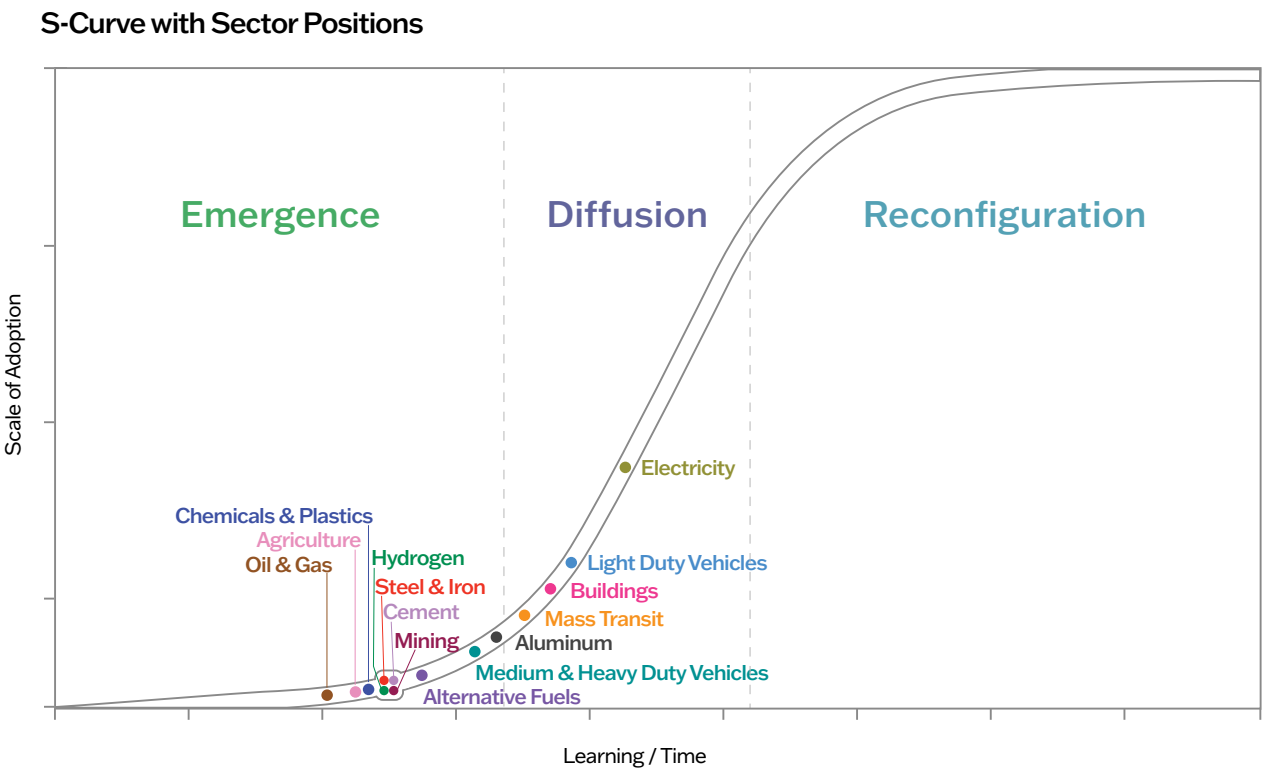


Figure 6. S curve of sectors as of 2026.[77]

6.2 PATHWAYS ASSESSMENTS METHODOLOGY

The assessment of pathway elements presented in the tables at the end of each of the following sections involved a structured evaluation of the technologies, fuels, practices, approaches, and system changes that could contribute to Canada’s transition to a net-zero economy. Each pathway

element was examined for its alignment with carbon neutrality and its economic, technical, and social performance.

Each of the nine criteria below was scored on a 1–5 scale, and an aggregate **Role in Net-Zero System** was assigned to each pathway. The resulting categories reflect the overall potential of each pathway in achieving net zero.

	Alignment with carbon neutrality: The degree to which the solution reduces GHG emissions and is ultimately compatible with a net-zero economy.
Economic Criteria	Economic Viability: Evaluates the solution’s current and projected cost-effectiveness, including capital and operating costs, and incentives relative to alternatives.
	Economic Development Opportunity: Assesses the potential for domestic economic growth through job creation, investment attraction, industrial competitiveness, or value-added regional activities.
Technical Criteria	Maturity: Examines the current stage of technological and commercial development, from research and pilots to proven, scaled deployment in relevant markets.
	Operational Fit: Evaluates the solution’s technical and operational compatibility, suitability, and practicality for delivering the required performance under Canadian conditions, including climate, geography, and infrastructure.
	Infrastructure and Supply Chain Suitability: Considers the degree to which the solution integrates with or requires adaptation of existing infrastructure and supply chains.
Social Criteria	Social Acceptability: Considers the likelihood of public and community support with attention to equity, trust, and perceived risk.
	Relevance to Stakeholders: Assesses how well the solution aligns with the objectives and strategies of key actors, including industry, utilities, and governments, along with the extent of their engagement.
	Related Benefits and Costs: Accounts for broader economic, social, and environmental impacts beyond direct financial metrics, such as avoided externalities, health impacts, or system-level efficiencies.

Role in Net-Zero System has **Core** and **Complementary** pathway categories as well as optional status descriptors.

Core Pathway Categories The four categories describe a pathway's fundamental compatibility with net zero.	 Decarbonization Pathway: The pathway can achieve net zero and has several other benefits.
	 Niche Pathway: The pathway can achieve net zero, but under specific regional or sectoral conditions.
	 Bridge Pathway: The pathway serves as an interim measure that supports but does not itself achieve net zero.
	 Dead-End: The pathway is incompatible with net zero.
Complementary Pathways Some solutions support core pathways rather than operating independently.	 Enabling : The pathway does not directly eliminate emissions itself but contributed to the successful deployment and performance of core pathways.
Status Descriptors Two descriptors may be appended to any of the categories above to further clarify a pathway's status.	Priority: Essential to net zero. Warrants immediate deployment and continued support.
	Potential: May grow into its assigned role but is currently limited by factors such as technological maturity or economics, preventing a definitive determination at this time.

Signal to Decision-Makers Beyond a pathway's role in the system, a timeliness element was identified in the column Signal to Decision-Makers . This criterion indicates what is needed today to progress a solution from its current technoeconomic state.	Deploy: Mature, cost-effective, ready today. Maximize deployment in relevant contexts with strong policy and capital.
	Enable: Promising but needs targeted support to unlock its potential. Invest in conditions, not just the technology.
	Incubate: Early-stage or niche. Fund R&D, pilots, and enabling conditions. Protect and develop.
	Don't Prioritize: Uncertain, limited applicability, or superseded. Watch, but don't lead with investment.
	Dismiss: Does not contribute meaningfully to net-zero transition at a relevant scale. Redirect investment and policy attention elsewhere.

ENERGY CARRIERS





The transition to net zero requires a dramatic transformation of this mix, with decarbonized electricity emerging as the main energy carrier.

7. Energy Carriers

Energy carriers link primary energy sources to end uses that provide the energy services we value. In Canada today the dominant energy carriers are fossil fuels. Petroleum moves people and goods. Natural gas heats buildings, meets the needs of industry, and contributes to electricity generation, while coal is now used primarily for industrial processes.

The transition to net zero requires a dramatic transformation of this mix, with decarbonized electricity emerging as the main energy carrier. Low-carbon hydrogen and alternative fuels will serve a complementary role, filling gaps in heavy industry and transport where direct electrification is not technically or economically viable. And to the extent that fossil fuels continue to serve as energy carriers in a net-zero world, their production and use will involve emissions abatement and carbon removals.

The technical and institutional systems for exploiting these four energy carriers are at different stages of maturity. Yet their future evolution is deeply interdependent. The pace at which electricity scales will influence the extent to which low-carbon hydrogen is economically viable, how long alternative fuels remain necessary, and how quickly fossil fuel demand contracts.

The four sections that follow examine the potential of each carrier as the world moves towards net zero. The electricity section focuses on decarbonizing the remaining fossil-dependent provincial grids and expanding generation across the country to meet demand that is expected to double by mid-century.[78,79]¹ The section on hydrogen explores its possible movement from an industrial feedstock to a carrier providing energy for high-temperature industrial heat, heavy transport, or seasonal energy storage. The section on alternative fuels examines which non-fossil liquid and gaseous fuels are most likely to serve residual demand given finite feedstocks and

¹ This estimate does not fully account for emerging electricity demand from AI data centres.

competition across applications. Finally, the section on oil and gas considers both the potential for near-term production emission reductions as well as the longer-term trajectory of a sector that currently contributes roughly 7% of national GDP and supports 200,000 direct jobs.[80]

The assessments that follow do not assume we can fully anticipate the energy carrier mix multiple decades in the future or define the pace at which change will take place. They do indicate the direction of probable advance, and are intended to help decision-makers

distinguish among the options that appear most promising, those that confront unresolved barriers, and those that are unlikely to deliver at the scale some anticipate. Readers should expect to encounter challenges and trade-offs without simple solutions, including how to build out the electricity system without driving up prices, whether hydrogen hubs can achieve the scale needed to break through current infrastructure and cost barriers, where finite biofuel feedstocks are best deployed, or how producing regions can prepare for an eventual weakening of fossil fuel demand.



7.1 ELECTRICITY

Function	Provides lighting, heating, cooling, and mobility, and powers motors, other machinery, and devices that underpin modern society; enables industrial processes.
GHG emissions	7.6% of national emissions in 2024, 49.6 Mt CO₂e.[61]
Options for decarbonization	Decarbonization Pathways: Wind power, utility-scale solar PV, hydro (reservoir), nuclear (conventional reactors) Bridge Pathways: Gas with CCS Niche Pathways: Building-integrated solar PV, hydro (run-of-river), geothermal power, biomass combustion Enabling Pathways: Grid improvements, interprovincial and international interties, power storage, demand-side management, energy efficiency
Stage of transition	Emerging: Gas with CCS, geothermal power, small modular reactors Diffusion: Wind power, utility-scale solar PV, building-integrated solar PV, hydro (reservoir and run-of-river), nuclear (conventional reactors), biomass combustion, grid improvements, interprovincial and international interties, power storage, demand-side management, energy efficiency
Nature of the problem today	Some provinces remain heavily reliant on fossil energy due to ageing infrastructure, slow permitting processes, lack of carbon-neutral-optimized utility structures, slow uptake of technology, rising cost concerns, and a reluctance to engage fully with the energy transition
Other systemic issues	Energy reliability/security; electricity costs and efficiency losses; centralized versus distributed control
Opportunities and concerns	Reduction in air pollution; clean electricity exports; economic opportunities
Priorities for action	Phaseout of coal; interprovincial transmission ties between carbon-intensive and clean provincial grids; support for renewables deployment; buildout and modernization of grid infrastructure; measures to manage electricity demand
Longer-term issues	Increased electricity supply and storage capabilities to reliably electrify transportation, buildings, and industry; integrating a large proportion of intermittent/variable renewables (wind, solar) on electricity grids; accommodating more distributed generation where appropriate
Indicators of progress	Percentage of electricity demand supplied by non-emitting sources. Percentage of final energy demand supplied by electricity; approximately 18% (1,990 petajoules) of Canada's final energy end-use is currently provided by electricity.[81].

7.1.1 Current Status

The electricity system provides power for lighting, heating and cooling, mobility, and the operation of machinery and electronic devices. Its energy services are vital to the health and welfare of Canadians, as well as to economic productivity and growth. In 2024 Canada generated 625.2 terawatt-hours of electricity (about 2% of the world total) and the country was the seventh-largest global producer. In 2023 the sector employed over 110,000 people[82] and contributed \$51 billion to Canada's GDP.[80] Net electricity exports to the United States in 2024 were about 2.6% of Canadian production.[83]

Canada's electricity sector is currently among the cleanest in the world, with more than 83% of power coming from emission-free sources (60% hydro, 6% wind, 14% nuclear, and 3% from other renewables). Most of the remainder comes from coal (5%) and natural gas (12%) (Figure 7). The generation mix varies widely from province to province (see Figure 9).

Provinces can today be divided into three groups: hydro provinces with more than 90% of the generation from hydro (Quebec, 94%; Manitoba, 96%; Newfoundland, 97%; and British Columbia, 89%); fossil provinces where two-thirds or more of power is derived from fossil fuels (Alberta, 85%; Saskatchewan, 85%; and Nova Scotia, 73%); and mixed-supply provinces (Ontario with 55% nuclear, 24% hydro, and 13% wind/solar; and New Brunswick with 40% nuclear, 23% hydro and 11% wind/other renewables). The remaining jurisdictions of Prince Edward Island (PEI), the Yukon and Northwest Territories, and Nunavut together account for less than 0.5% of Canadian production.

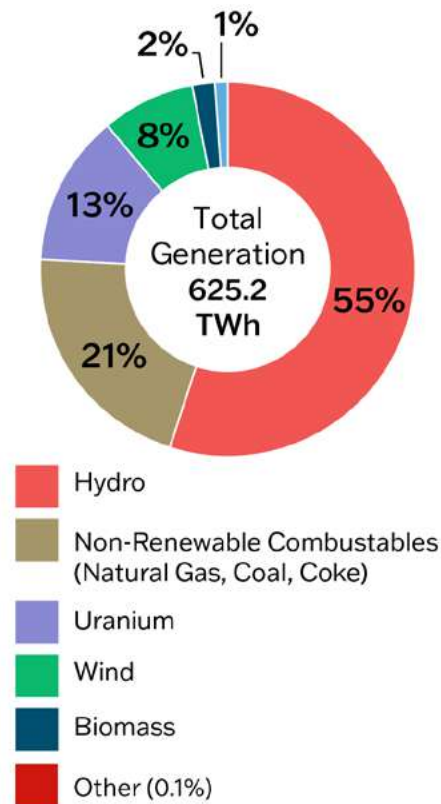


Figure 7. Canada, electricity generation by fuel type (2025)
Source: Statistics Canada Table: 25-10-0015-01, 2025

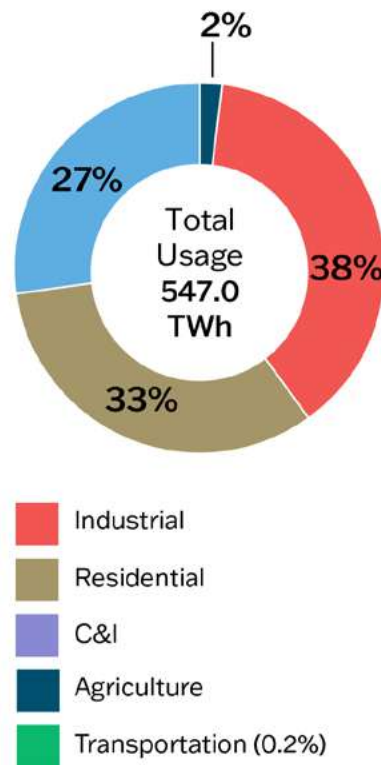


Figure 8. Canada, electricity usage by major sector (2023)
Source: NRCan, 2023 Comprehensive Energy Use Database.

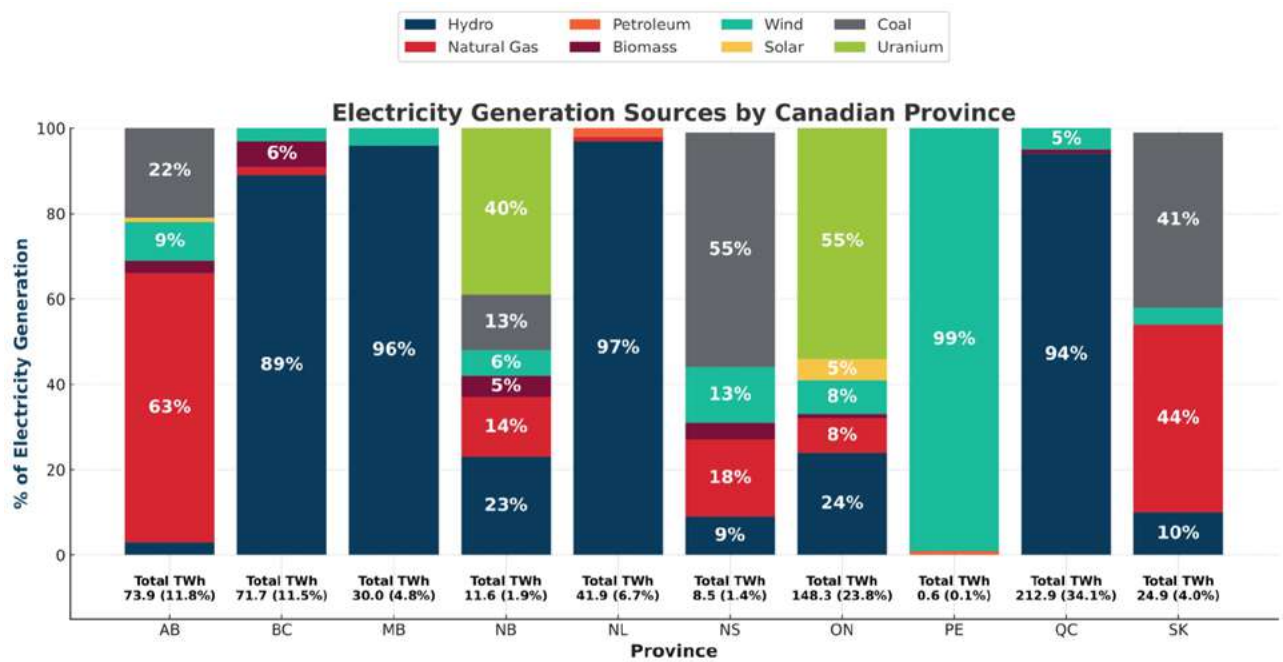


Figure 9. Electricity generation sources by Canadian province, 2021*

Source: Canadian Energy Regulator (CER), 2022

*The sum of individual percentages may not equal exactly 100% due to rounding by the CER.

The division of powers under Canada's constitution means that electricity systems are essentially under provincial control. However, the federal government retains regulatory oversight in several areas, including the nuclear industry, electricity exports, national and international environmental pollutants, inter-provincial transmission, and electricity metering, as explicitly provided for by the *Electricity and Gas Inspection Act*.^[84] Provinces have always viewed electricity policy as a critical lever for economic development, and jealously guard control over generation and transmission. North-south grid interties with U.S. markets are more developed than east-west interprovincial grid connections.^[55] The eight mainland Canadian provinces are integrated into the grid balancing areas of the North American Electric Reliability Corporation (NERC).

In most provinces, electrical utilities are vertically integrated Crown corporations. Deregulated wholesale electricity markets exist in Alberta and to some extent in Ontario. Industry accounts for the largest share of domestic consumption (39%), followed by residential buildings (32%), the commercial and institutional sectors (27%), agriculture (2%), and transport (0.2%), with variation across provinces (Figure 8).

Canadian electricity prices are among the lowest in the OECD but differ from province to province. There are arguments over how best to compare rates (at what level of monthly consumption, before or after taxes, and so on) but the basic pattern of variation is captured in Figure 10. Industrial bulk users receive significant discounts, and hydro provinces typically have the cheapest rates.^[85]

Average Large Industrial and Residential Electricity Prices* (as of April 2023) in cents/kWh

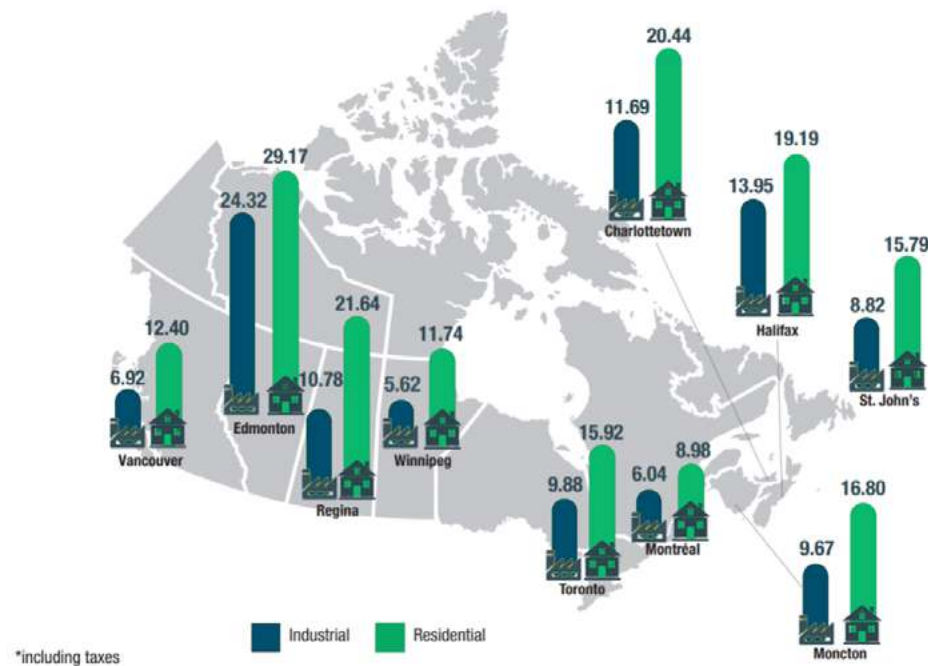


Figure 10. Average large industrial and residential electricity prices, April 2023

Source: NRCAN, 2023. Electricity Facts.

Climate change–related drought conditions in recent years have measurably strained Canada’s hydroelectric generation capacity. Hydropower typically provides around 60% of the nation’s electricity, so prolonged low precipitation and high temperatures can significantly constrain overall supply.[86] In 2021, Manitoba Hydro incurred an estimated \$248 million² revenue loss due to drought-driven hydropower shortfalls.[87] After a brief recovery in 2022, widespread drought returned by 2023, driving an 8.4% year-over-year drop in hydroelectric and pushing total generation to its lowest level since at least 2016.[86] This hydro shortfall has persisted into 2024, with national hydropower production remaining about 3.5% below the recent five-year average as drought conditions continued in parts of central and eastern Canada.[88]

These climate-driven deficits have also disrupted electricity trade and grid operations. With reduced water inflows, Canada’s exports

of electricity to the United States fell by roughly one-quarter in 2023—the lowest export volume in years—as utilities dialed back cross-border sales to preserve reservoir levels.[80] To maintain reliability, other sources were leveraged: domestic thermal generation was ramped up, and electricity imports from the U.S. surged by over 50% year-on-year.[89] Such drought-related stresses on the grid are expected to recur; federal climate assessments project that summer droughts will become more frequent and intense in key hydropower regions of southern Canada under warming scenarios.[90]

The recent hydroelectric shortfalls and trade imbalances of 2020–2024 are therefore seen as a preview of the challenges climate change poses to Canada’s electricity system, underscoring the need for adaptive measures to safeguard grid resilience.

² In 2021 Canadian dollars

Canada's Electricity Trade with the U.S.*



Figure 11. Canada's electricity trade with the United States, 2008-2024

Source: Natural Resources Canada, 2026. *Energy Fact Book 2025-2026*[91]

7.1.2 Nature of the Problem

Electricity systems have a pivotal role to play in decarbonization, as power can displace fossil fuel end-uses in transport, buildings and industry. At a global scale, the shift to low carbon electricity is well underway, with dramatic falls in the price of wind and solar generation encouraging ever wider deployment (see Figure 12).[92]

In this context, Canada enjoys three distinct advantages. First, our electricity supply is already substantially decarbonized.[93] Second, we have generous renewable resource endowments (including wind and

solar, but also tidal and geothermal), often located in areas where fossil energy dependence is highest today. Third, our abundant legacy hydro (the third largest installed capacity in the world[80]) can provide an energy storage solution to help balance grids and facilitate the large-scale integration of intermittent renewables.[94] Canada's ready access to low-carbon energy and potential to rapidly complete the decarbonization of electric supply is a competitive advantage to attract businesses seeking cheap net-zero emission power (for battery or EV manufacture, minerals processing, etc.).

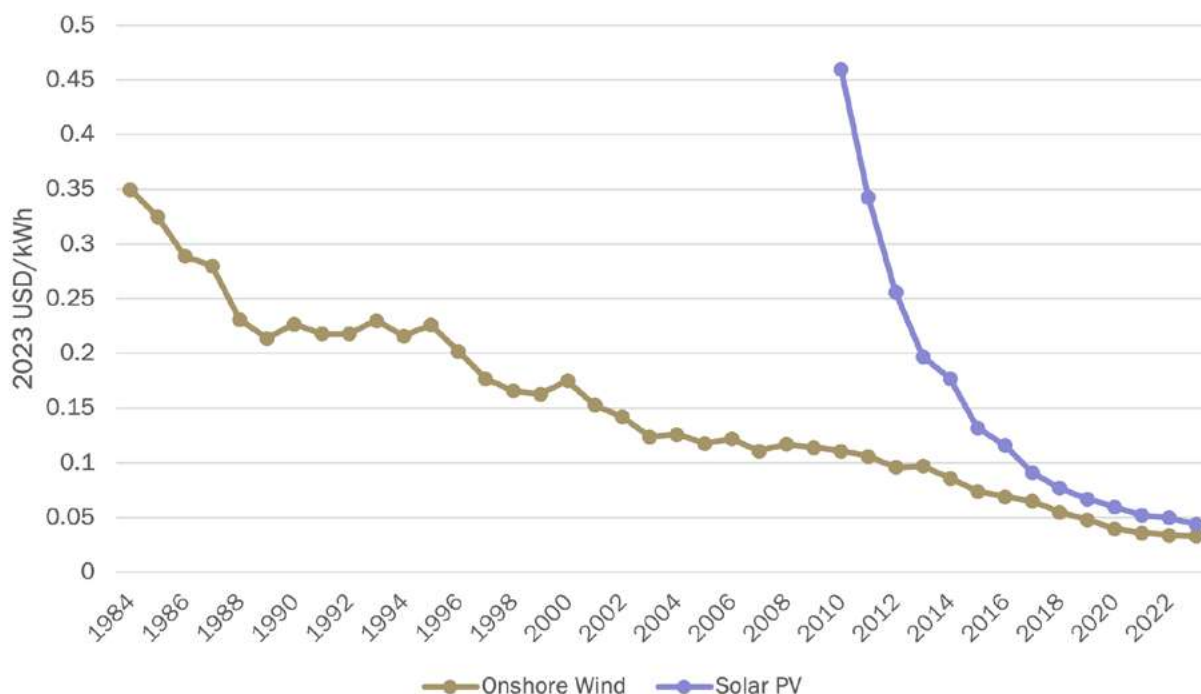


Figure 12. Global weighted average of levelized cost for onshore wind and solar PV, 1984-2023

Source: IRENA, 2023[95]

Nevertheless, the current split between low- and high-carbon provincial electricity systems poses challenges. The financial and political effort required to transform the fossil-dependent systems will be significant, requiring the construction of new generating capacity, retirement of fossil assets before their anticipated lifetime, and movement away from coal or gas produced within the province.

Most models suggest the cost of fully decarbonizing Canadian electricity systems could be lowered by closer inter-provincial coordination. While this flows against the tradition of provincial independence,[55,96] the federal government appears interested in encouraging such linkages.[97–99] More recently, eight provinces and territories signed a memorandum of understanding to build better-connected country-wide electrical transmission infrastructure.[100] In 2023, the federal government introduced Clean Electricity Regulations (CER) to establish a national framework for achieving a

net-zero electricity grid by 2035, signaling a stronger federal role in shaping long-term power system planning and emissions performance across provinces.

Other current challenges relate to public sensitivity over rising electricity costs, aging electricity infrastructure, electricity rate structures not aligned with the shift to net zero, and potential opposition to large scale energy projects (generating facilities, transmission lines). Over the past decade, average electricity costs in Canada have increased more rapidly than inflation.[101] The largest increase has been in Ontario, where prices rose by two thirds between 2007 and 2016. Although household energy spending averages only 2.6% of domestic budgets, increases hit lower-income families particularly hard. And electricity price increases are always politically salient. Drivers of this rise in Ontario included the costs of moving off coal, refurbishment of aging nuclear plants, grid modernization, and

decades of artificially suppressed prices and lack of investment. Although price rises in Alberta have been modest (because of exceptionally low natural gas prices), managing cost pressures will be an important consideration in advancing electricity decarbonization. Much of Canada's electricity infrastructure dates from the post-war period, requiring projected investments of nearly \$1.7 trillion³ by 2050, to meet clean electricity demands.[102] Public opposition to large energy infrastructure projects is not confined to pipelines, and resistance to the construction of generation assets (power plants, wind or solar developments) and transmission could raise costs, introduce delays or forestall potential projects.

7.1.3 Net-Zero Pathways

Moving Canada's electricity systems towards net zero involves two interrelated tasks: decarbonizing the existing electricity supply and expanding electricity systems so they can power sectors currently dependent on end-use fossil fuels. Both involve (a) building net-zero electricity generation; (b) adjusting electricity grids to make them more flexible, smart, and resilient; and (c) managing demand and encouraging energy efficiency to limit the need for additional generation. This will require a combination of centralized and decentralized energy solutions. Ultimately a net-zero electricity system may be integrated more closely with other parts of the energy system: for example, with hydrogen produced through electrolysis (or from fossil resources with CCS), which can serve as an electricity storage medium and meet demand in other sectors.

The first challenge—decarbonizing existing electricity supply—is most acute in fossil dominated provinces (Alberta, Saskatchewan,

Nova Scotia), but there is work to be done in New Brunswick and Ontario. The second challenge—expanding capacity to meet increased demand—is often assumed to be gradual, yet industrial demand can spike abruptly, particularly from sectors such as data centres, which require substantial capacity additions within short time frames. This rapid growth places pressure on electricity systems even in provinces like Alberta, Quebec, and Newfoundland, which currently have power surpluses.

Modelling suggests that electricity demand might double or more by mid-century in a decarbonized economy.[78,79] However, this estimate does not fully account for the recent emergence of AI data centres, whose significant electricity consumption could further accelerate the need for grid expansion. Increasing power production and distribution on this scale over coming decades represents an enormous task—especially in a context where energy projects today can stir substantial public opposition.

There are many ways to make relatively inexpensive net-zero emission electricity, but each approach has costs as well as benefits.[94] Hydro forms the backbone of most Canadian electricity systems, providing cheap and reliable legacy power. But sites close to demand centres have already been exploited, environmental impacts are substantial, capital costs and cost overruns (such as those at Muskrat Falls in Labrador and the Site C dam in British Columbia) are a significant concern, and there has been opposition from Indigenous communities. It is generally assumed that while new hydro generation will continue, most future capacity additions will come from other generation sources. Tremendous wind resources and falling prices mean that wind often represents the cheapest incremental addition to grids.

3 In 2011 Canadian dollars

Wind is intermittent in the short term, and its energy output varies by season, so a backup and/or storage is required when it does not blow. In the near to medium term, some jurisdictions may continue to rely on limited amounts of dispatchable thermal capacity (primarily natural gas-fired plants) to manage this intermittency. In these contexts, natural gas generation functions primarily as a system reliability and affordability backstop rather than a growth pathway for electricity supply, with utilization expected to decline with the expansion of wind energy storage, interties, and demand-side flexibility.

In some Canadian jurisdictions there is public opposition to further wind development. Offshore wind is attracting significant global investment and holds considerable promise for Canada's coastal provinces, including Ontario on the Great Lakes, as well as Nova Scotia, which is actively exploring major offshore wind projects. The costs of solar photovoltaic continue to fall.[103] Canada has substantial solar potential, but daily and seasonal variability pose significant challenges. Specifically, the mismatch between peak energy demand—driven primarily by electric heating and heat pumps during cold winter nights—and the lowest

availability periods for wind and solar generation highlights a critical obstacle. Addressing this seasonal imbalance will be central to integrating renewable energy successfully into Canada's electricity grid.

Other renewables (tidal, wave, geothermal) have promise but remain further from market and are limited geographically. Nuclear provides reliable, GHG-emission-free baseload power in Ontario and New Brunswick. Disadvantages include high capital costs, inflexibility (plants cannot be ramped up or down to follow intermittent renewables), security, waste disposal, and substantial public opposition to new build.[104] Small modular reactors (SMRs) are a possibility for the future, with Canada's first project underway in Ontario and expected to be operational by around 2030. However, the technology remains to be proven, and widespread deployment may be several decades away.[105] Fossil combustion with CCS (with removals to handle residual emissions) is possible. But coal with CCS appears expensive compared to renewables and emits many hazardous pollutants.[106,107] Gas with CCS could serve to back up variable renewables.



For now, wind presents the cost point for other technologies to beat, but solar continues to decline rapidly. Least-cost models of decarbonization in Canada currently suggest massive wind power additions even in hydro provinces.[96] Energy storage is an important consideration in building low-carbon generation capacity. Batteries continue to decline in price, and electricity/hydrogen linkages (where hydrogen serves as storage and a complementary energy carrier) could increase the overall flexibility of the energy system.

But it is not possible today to anticipate exactly how the low-carbon supply will develop. Choices in each province will be influenced by specific system attributes (sunk investments), capacities and decisions of neighboring jurisdictions, the evolution of technologies and comparative costs, public attitudes, market design, and political calculus.

Reliable and flexible grids will be essential to deliver decarbonized supply and expanded end-use electrification. Grids will accommodate variable and more widely distributed generation (e.g. wind and solar), support larger power flows (delivering more energy to end users), connect over longer distances (to balance loads), service more diverse end uses (electric vehicle charging) and allow more sophisticated demand management (to reduce peak usage). Investment in interprovincial and/or international interties, storage (battery, pumped hydro, compressed air, hydrogen, etc.), enhanced communications, and control systems (smart grids) will be important. So too will be adjustments to market design and regulatory mandates to accelerate needed investment.[79,108–111]

Energy efficiency and demand management can reduce the generation and transmission capacity required to deliver expanded energy services. Efficiencies can be sought on the supply side to enhance generator

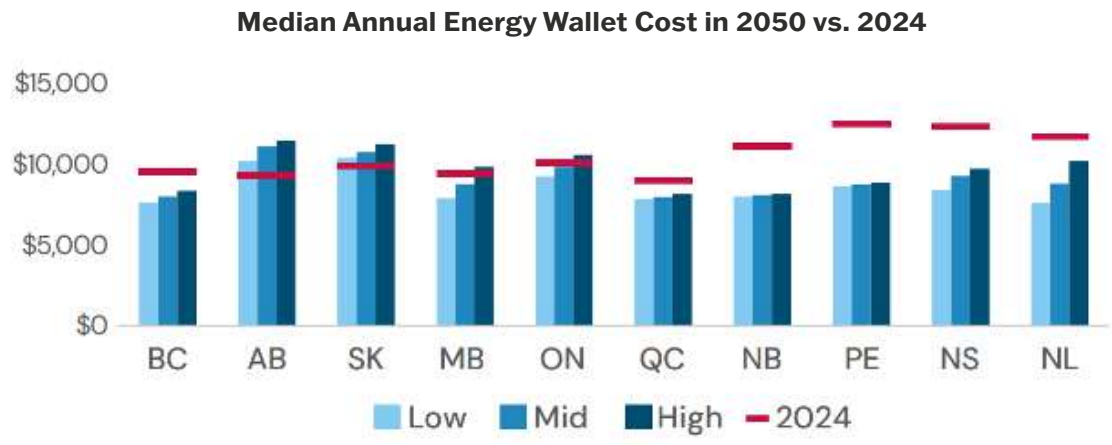
performance and reduce transmission and distribution losses, but more significantly on the demand side through improvements in technologies providing energy services (for example, space conditioning for buildings). Demand management programs that displace use over time (to off-peak hours) or allow customer loads to be curtailed during extreme weather events or other crises can reduce the need for peaking plants and transmission upgrades and contain costs.[112] These programs can involve new technologies, program designs, and institutions (energy efficiency utilities, “behind the meter” energy management companies). While efficiency gains and demand reduction strategies can contribute to managing electricity needs, investment in new generation and transmission capacity should be prioritized. The risks associated with inadequate electricity supply are substantial, whereas the downside of slightly overbuilding capacity is negligible. Moreover, prioritizing efficiency before expansion may hinder progress and limit the availability of essential new energy sources required to support growing industries and economic development.

An important but open question for long-term decarbonization is the extent to which the supply and management of power is centralized with the electrical utilities or decentralized to the customer level. Very different visions of net-zero energy systems co-exist today. On the one hand, there are highly centralized designs where power is produced in areas with maximal renewable resources and then moved across continents to load centres.[113] While existing long-distance transfers predominantly run north-south, emerging renewable energy emphasizes east-west transfers to align with solar availability across time zones. And on the other, highly decentralized models where electricity is produced and consumed locally (perhaps involving microgrids, or tens of millions of “prosumers” producing and

consuming their own power), with traditional grids serving backup and balancing functions.[114] Choices that would generate one or another alternative are political as well as being related to economics, technologies and resource availability. Yet there are many reasons for believing that real-world systems will involve a complex and nuanced mix of centralized and decentralized elements. There are advantages to local power production at the building or community level, such as reducing the need for large-scale projects, avoiding transmission losses and grid congestion, and promoting increased local control and resilience. And yet economies of scale and linkages between regions with different resources and load profiles are also attractive. So it makes sense to take a

pragmatic approach that combines centralized and decentralized elements to optimize overall benefits as net-zero-emission power systems are built out.

The two interrelated tasks of decarbonizing electricity supply and expanding systems must be done with affordability in mind. If done well, they will leave most Canadian households better off. In nearly every province, median energy wallet costs in 2050—defined as the total direct expenditure a household spends on energy—are expected to remain stable or fall compared to today, even under ambitious transition scenarios[115]. Clean electricity paired with smart grid investments and better efficiency isn't just good to reduce emissions; it's a cost-saving strategy for households across the country.



Note: All monetary values are expressed in 2024 Canadian dollars (CAD).

Figure 13. Median Annual Energy Wallet Cost between 2024 and 2050, according to three growth rates for electricity grids (low, mid, high).
Source: The Transition Accelerator, *Household Energy Affordability in a Net-Zero Future*, 2024

7.1.4 Provincial Initiatives

Critical decisions about the future of Canadian electricity systems will be made at the provincial level.

In making choices, the provinces face distinct geographic circumstances and resource endowments, legacy generation and transmission infrastructure, regulatory structures, and political economic realities.

Ontario

Ontario has a hybrid market design with substantial public ownership, complex lines of authority, and 60 local distribution companies. On May 1st, 2025, the province launched a major update to its electricity market to modernize the system and improve the way the market is scheduled and priced.[116] Electricity policy is highly politicized, with recent arguments about the roll out of renewables and the rise in energy prices. After the coal phase-out, Ontario has had a comparatively clean grid, dominated by nuclear power. But as nuclear units are taken out of service for refurbishment over the coming decade, increased emissions from natural gas plants are likely. To bolster supply and address these pressures, the province is undertaking major procurements of new electricity generation[117] and has completed its largest battery storage procurement to add grid flexibility.[118]

At present the province is firmly committed to a reinvestment in nuclear power. The stakes for the province and Canada's nuclear industry are high. Ontario's first Integrated Resource Plan (IRP) includes major nuclear investments in refurbishments and expansions including both conventional reactors and SMRs. Whether or not longer-term plans for nuclear expansion survive cost overruns and project delays which have often plagued earlier investment rounds, the province will eventually require additional wind and solar

capacity. Enhanced transmission interties with Quebec and aggressive energy efficiency programs could keep costs down and slow the speed at which new generation capacity must be built out.[119]

Alberta

Alberta completed its coal phase-out in 2024, marking a major milestone for decarbonizing its grid. Nevertheless, the province faces major challenges balancing continued decarbonization with affordability and reliability. Its deregulated electricity market remains heavily reliant on natural gas, raising concerns about locking in emissions-intensive infrastructure.

Wind and solar have grown quickly since 2019 but new policy restrictions on siting and reclamation have created regulatory uncertainty.[120] Still, given their cost advantages, renewables remain central to Alberta's energy future. Opportunities to expand grid interties with British Columbia and to develop geothermal and hydrogen offer further pathways to diversify supply.

A key uncertainty is the potential electrification of oil sands operations, which could drive major new electricity demand. Managing this shift while maintaining grid stability will require integrated long-term planning and coordination with federal infrastructure efforts.

Saskatchewan

Saskatchewan's electricity system is vertically integrated and primarily operated by a single public utility, SaskPower, with the exception of Saskatoon, which has an independent distribution utility. The system remains heavily reliant on coal and natural gas generation. Unlike provinces with large hydroelectric or nuclear fleets, the province has minimal non-emitting baseload capacity, giving it one of the longest decarbonization pathways in Canada. The province still

operates multiple coal-fired power units, including one with CCS (Boundary Dam 3), as well as gas-fired plants. The dependence on fossil fuels means that the province requires major new investments in generation and transmission infrastructure to transition to a low-carbon supply.

In 2023, the province signaled plans to extend the life of its coal-fired plants (which run on locally mined coal) even as current federal regulations mandate phasing out unabated coal by 2030. Saskatchewan has set a goal of net zero by 2050 and has asserted provincial jurisdiction over power generation.[121–123] In the meantime, SaskPower is pursuing a diversified transition strategy by expanding renewables, with plans to add up to 3,000 MW of wind and solar capacity by 2035, maximizing imports of hydroelectric power from Manitoba, and exploring nuclear energy.[121]

Manitoba

In Manitoba, hydroelectric dams produce most the province's power, and this hydro dominance keeps Manitoba's grid emissions among the lowest in Canada—though drought years can pose challenges.

The province's surplus of hydroelectricity is sold via interconnections, with export sales contributing to over one-fifth of Manitoba's electricity revenue. However, politically, the province has begun prioritizing domestic use of its hydro resources. In 2025, it declined the renewal of 500 MW of U.S. export contracts to reserve more power for regional economic development.[124] A major initiative in this regard is the proposed Kivalliq Hydro-Fibre Link, which is a combined transmission and broadband corridor that will send Manitoba's surplus power to Nunavut's Kivalliq region to displace diesel.[125]

Nova Scotia

Nova Scotia has long depended on coal-fired power, with coal generating over half of the province's electricity in 2021. In recent years, however, provincial law has mandated phasing out coal and reaching 80% renewable electricity by 2030.[126]

In 2024, the province enacted major reforms to modernize electricity regulation and drive its clean energy transition. The *Energy Reform Act* created a new Nova Scotia Energy Board and established an independent system operator to take over grid operations and planning from Nova Scotia Power to ensure more transparent, climate-aligned decision-making.[127] Nova Scotia also intends to add roughly 1,500 MW of onshore wind capacity by 2030[128] (including Indigenous-led projects like the 94 MW Mi'kmaq-owned Weavers Mountain wind farm[129]) and increasing imports of hydroelectricity via the Maritime Link from Labrador. As of 2025, the province has brought renewables to 43% while cutting coal's share down to 36%.[128]

New Brunswick

New Brunswick's generation is a mix of major hydroelectric facilities and the Point Lepreau nuclear station, which together provide almost two-thirds of the province's electricity.[130] The remaining third is sourced from emitting sources, such as coal, oil, and gas.[131] The province is now positioning its grid for decarbonization in line with current federal CER target of net zero by 2035. The province has committed to phase out coal by 2030 and is planning major clean energy investments. This includes a nearly fivefold expansion of wind power by 2035 (adding 1,400 MW of new wind power) and solar power (adding 200 MW)[130]. NB Power is also planning to build SMRs at Point Lepreau by 2035 (adding 600 MW), with a 100 MW unit scheduled for 2029.[130]

In 2024 the federal and provincial governments reached an understanding to allow flexibility under the new clean electricity rules, recognizing New Brunswick's need to balance decarbonization with affordability and reliability. Recent developments have focused on NB Power's financial health. The utility has faced rising rates (20% in two years) and \$5 billion⁴ in debt.[132]

British Columbia

A vertically integrated Crown corporation (BC Hydro) serves more than 90% of customers in B.C. Electricity demand is forecast to grow strongly over the coming decades. Further hydro development is politically contentious, as is the development of wind and run-of-the-river projects by independent power producers (under contract to BC Hydro). The completed Site C project on the Peace River attracted significant opposition from Indigenous communities and environmental groups. But the province has enormous wind potential. BC Hydro is beginning to harness this through regular calls for power: the utility launched its first competitive power procurement in 15 years in 2024 and is set to add about 5,000 GWh per year of new wind-based generation from that call.[133] Going forward, BC Hydro plans to hold such calls bi-annually to continuously bring new renewable energy online, primarily tapping the province's abundant wind resources.

Key areas of focus in the future include efficiency and demand management, continuing modernization and upgrades of transmission and existing hydro facilities, and incremental addition of renewables, especially wind. BC Hydro's expanded demand management programs emphasize energy efficiency and peak shaving, even piloting "virtual power plants" that aggregate distributed energy resources. For example, in 2025 the utility debuted a Peak Saver pilot project, installing 200 coordinated residential

batteries in two communities to improve grid resilience.[134] They are also investing in grid infrastructure by working to expand the transmission system in the northwestern part of the province to support electrification and economic development in that region.[135] British Columbia's ambition to become a major LNG exporter remains a critical issue, as does a commitment to electrify future liquefaction and associated upstream natural gas production infrastructure (compressors, pumps, etc.), with clean electricity, with obvious implications for electricity supply.[136]

Quebec

Quebec's electricity system is dominated by Hydro-Quebec, a publicly owned, vertically integrated utility known for its vast hydroelectric resources. This network ensures that Quebec has amongst the lowest grid emissions in North America, with over 99% of electricity generated from renewable sources. Nevertheless, anticipated growth in domestic electricity demand due to electrification goals, including transportation and industrial expansion, has prompted significant new infrastructure and generation investment. In 2024, Hydro-Quebec launched its 2035 Action Plan, aiming to meet rising demand through significant grid modernization and diversification of generation sources, notably investments in new wind generation capacity of over 10,000 MW.[137] In early 2024, the utility accepted eight bids from five developers to build 1,550 MW of new onshore wind under a call for tenders launched in 2023.[138]

The province is also ramping up solar generation by setting a target of 3,000 MW by 2035.[139] This marks a major shift for a province almost exclusively reliant on hydro power. Further, there has been a renegotiation of the utility's longstanding power agreement with Newfoundland and Labrador over Churchill Falls. Following a

4 In 2025 Canadian dollars

change of government in Newfoundland and Labrador, the 2024 agreement-in-principle was replaced by an enhanced agreement signed in August 2026 that guarantees supply from Churchill Falls until 2077. It also gives Hydro-Québec access to a total potential of more than 10,000 MW from Labrador, of which 6,915 MW is firm and 3,850 MW is tied to potential future projects, such as a Labrador wind farm and an additional hydroelectric facility at Churchill Falls.[140-142]

In all cases, provincial politics plays a significant role in the structure and design of electricity markets. If Canada is to meet long term decarbonization goals in a cost-effective manner there will need to be a concerted effort to break through parochial electricity market rules that prevent access and flexibility, and to enhance the potential for inter-jurisdictional coordination.

Competitiveness Implications

Canada's hydro provinces can make an offer most jurisdictions cannot: legacy reservoirs provide dispatchable clean electricity and the grid flexibility to integrate large volumes of wind without the dedicated storage costs that raise system prices elsewhere. The real competitive asset is hydro-wind complementarity, not clean generation on its own, and it functions as an industrial siting advantage at a moment when data centres, battery plants, and minerals processors are competing globally for firm, affordable, low-carbon power. Manitoba's 2025 decision to redirect 500 MW of export capacity toward domestic economic development suggests provinces are beginning to treat clean electricity as an economic development tool rather than an exportable surplus. But the window narrows as other jurisdictions build out their own clean supply. Whether Canada captures that investment depends less on generation endowment than on how fast provinces can connect strategic industrial loads to firm clean power.

7.1.5 Priorities for Action

Priorities for action differ by province. For the fossil-dependent jurisdictions, increasing energy efficiency, investing in renewable generation, building interties with neighboring hydro provinces, and phasing out coal are the most urgent tasks. Current federal regulations set 2030 as the deadline to end unmitigated coal generation, but decommissioning plants earlier will lower carbon intensity and secure immediate air quality gains. Simply replacing coal plants with new gas plants should be avoided. With the continuing fall in wind and solar costs, it makes more sense to build renewable resources steadily, particularly

since the fossil-based systems are well buffered with gas. As it is quite possible that emission abatement targets will be further tightened over coming decades, even "CCS ready" plants will pose a risk, so a straight switch to renewables is more prudent to prevent the further stranding of fossil assets.

For the hydro-rich provinces, incremental buildout of wind or solar can be timed to provide additional supply as needed. Large hydro facilities provide opportunities for storage to meet peak demand and balance intermittent resources. Active exploration of interties with neighboring provinces offers the possibility of more flexible and resilient

grids, and additional revenues or reduced power costs, through power transactions. At some point all jurisdictions should:

- Put greater effort into long-term power system planning by starting from the target of meeting anticipated needs while achieving net-zero GHG emissions by mid-century and modelling backwards. This involves first estimating the total electricity demand required to support full electrification of end uses at net-zero emissions. Once this endpoint is established, provinces can then work backwards to determine annual increments of generation, transmission, and distribution infrastructure needed. Scenarios should focus on system transformation, including radical shifts in supply and demand configurations, rather than incremental market-induced adjustments alone. Further, the planning should explore the implications of continued radical cost reductions in clean technologies, demand response, and efficiency measures, as well as collaboration with other jurisdictions.
- Introduce regulatory and/or market reforms to make system decarbonization and expansion a central preoccupation of all system entrants. Most provincial electricity markets are designed to limit access, limit flexible market participation, limit imports and exports, and facilitate central control. This historic approach to electricity system planning needs to shift to one of open access, flexibility, policy certainty, competition, and opportunities for market participants to operate in demand, response, efficiency, supply, storage, and financing. Governments must direct regulatory bodies to create regulated return models that incentivize achieving net zero and phase out rate structures based on sales volumes and capital expenditures.
- Ramp up incremental investments in transmission infrastructure (modernization, smart grids, distribution, renewables access, etc.) and storage to build flexible and resilient grids that can be adapted to shifting demand, and technological innovation.
- Involve electricity companies and regulators more directly in electrification of GHG emitting energy end-uses (such as transportation, space heating and cooling buildings, and industrial processes) to permit utilities to offer behind-the-meter load management systems and financial incentives to push load off peak.
- Support Indigenous power initiatives across the system, including northern and off-grid community supply projects, building efficiency, and building replacement, geothermal, skills training, and Indigenous-led finance mechanisms.
- Accelerate development and investment in new technologies, including geothermal, small modular reactors, hydrogen linkages, energy storage, and smart grid technologies.

Criteria Status

-
- Fails to meet criteria
-
- Meets in some respect
-
- Potentially meets criteria
-
- Meets criteria

7.1.6 Electricity Pathways Table

Not promising Potentially meets criteria Meets criteria			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Electricity Generation											
Wind (Onshore & Offshore)	<i>Priority</i> Decarbonization Pathway Expected to provide significant portion of power in a net-zero future. Canada has a vast wind resource on land and coastlines.	Deploy Support deployment with permissive regulatory environments. Educate public to reduce safety and environmental misconceptions.	 Clean power but needs storage to handle intermittent generation.	 One of the cheapest sources of new electricity, with low operating costs. Offshore wind costs remain higher. Intermittency may add costs.	 Drives jobs in manufacturing, construction, and maintenance. Boosts rural incomes through land leases and taxes. Positions Canada for export opportunities.	 Fully commercial — mature technology deployed widely. Offshore wind is less mature in Canada but proven in Europe.	 Integrates well with modern grids but challenges remain with regard to balancing and storage.	 Typically requires new transmission from wind areas to demand centres.	 Generally accepted but local opposition can be significant. Community involvement can improve acceptance. Offshore has higher acceptance.	 Aligned with federal and most provincial clean energy goals. Backed by utilities, provincial plans, the wind industry, and some landowners.	 No air pollution or water use during operation. Some issues with noise, migratory bird or bat deaths, and landscape impacts.
Utility-Scale Solar PV	<i>Priority</i> Decarbonization Pathway Costs now rival or beat new gas, and suitable land/rooftop area is ample.	Deploy Support deployment with permissive regulatory environments and R&D in cold-climate regions.	 Clean power (assuming panel lifecycle emissions are managed) but needs storage to handle intermittent generation.	 Cost-competitive with or cheaper than new natural gas generation in certain provinces. Intermittency may add costs.	 Construction and maintenance jobs. Draws private investment, boosts local tax revenues, and supports innovation and exports.	 Technology is proven. Multiple large solar farms operate in Canada. Performance in cold climates being demonstrated.	 Easy to connect at various scales, but high adoption needs better grid management.	 Most useful when paired with storage or hydro, but output varies seasonally.	 Strong support. Local concerns about land use can arise.	 Utilities for grid planning. Governments and regulators for meeting clean energy targets. Industry and communities through deployment.	 No direct emissions and improves air quality and health. Recycling of panels is immature.
Small-Scale & Residential Solar PV	<i>Potential</i> Niche Pathway Constrained by roof space and economics but still material.	Engage Upgrade local grid infrastructure to allow for smart metering. Provide financing options to assist in managing upfront costs.	 Clean power (assuming panel lifecycle emissions are managed).	 Costly without incentives but offers savings and local grid benefits. Costs are gradually declining.	 Local job creation in installation, sales, and manufacturing. Widespread adoption spurs investment within communities.	 Mature with numerous installations in Canada.	 Requires sunny, grid-connected areas or remote areas paired with batteries. Can require backup through winter.	 Integrates easily on rooftops with little land or new infrastructure needed. Some smart meters and local grid upgrades needed.	 Generally very high public acceptability with no notable opposition.	 Consumers and municipalities for cost savings and energy independence. Mixed views from utilities for grid impacts and revenue concerns.	 Clean, quiet energy source with reduced grid strain during peak times. Minimized land impact. Recycling of panels is immature.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Building-Integrated Solar PV	Niche Pathway Typically only used in showcase buildings.	Deploy Encourage interest from developers and building owners with financing mechanisms. Provide workforce training for installation. Work to integrate micro generation with the larger electricity grid.	 Clean power (assuming panel lifecycle emissions are managed).	 Costs have dramatically declined over time. Economics can depend on regional incentives. Return on investment occurs in solar panel lifespan.	 Industry is well established. Some opportunities for local installers and domestic material production.	 Commercially Mature.	 Best on sun-exposed surfaces in space-limited urban buildings. Must be integrated into building design and meet codes.	 Supply chain is early commercial.	 Widely accepted and non-disruptive.	 Niche interest among innovation-focused stakeholders, with limited utility impact due to small scale.	 When paired with storage they provide resilience in power outages and reduce peak demand. Can sell energy back to the grid. Immaturity of recycling panels and differing lifespan from building materials.
Hydro (Reservoir)	Decarbonization Pathway Forms the backbone of Canada's decarbonized baseload power. In the future, new generation will be challenging.	Deploy Support new builds where site conditions are economical and expansions where feasible. Collaborate with Indigenous communities. Expand and improve transmission infrastructure.	 Achieves net zero. Some GHG emissions associated with initial flooding and land changes, but these can be mitigated over time.	 New generation is likely to be capital-intensive, with long payback but low operating cost. Competes well on cost per MWh if sites are appropriate.	 Large projects spur employment. Limited new dam opportunities, but exporting hydro power can generate revenue.	 Mature technology with decades of operation.	 Compatible with grid needs. Some concerns about impact of changing climate on reservoir levels.	 Large dams require extensive transmission build-out to deliver power. New projects still face logistical challenges.	 Historically mixed — strong opposition from Indigenous groups and environmentalists for new large dams. Shared equity or co-governance with Indigenous communities can improve acceptability.	 Provincial utilities for reliable baseload and storage capacity. Relevant to Indigenous communities where there are equity stakes, co-governance, and early engagement.	 Delivers clean energy balancing other intermittent renewables (water reservoir storage). However, can lead to flooding of ecosystems and Indigenous lands.
Hydro (Run-of-River)	Niche Pathway Strong fit where geography allows, yet cannot scale to a large national share.	Deploy Support buildout where site conditions are favourable. Collaborate with Indigenous communities.	 Can supplement big hydro reservoirs.	 Cost per kWh can be competitive in favourable sites.	 Regional construction and contracting opportunities for smaller firms. In Indigenous or rural areas, can spur local economic activity.	 Proven technology and mature. Deployments in Canada are ongoing but site-specific.	 Particularly suitable for remote or smaller grids.	 Integration is simple, but remote projects need new transmission lines on a smaller scale.	 Generally more accepted than large dams. Local opposition still possible from environmental groups and Indigenous communities.	 Local and Indigenous communities looking for development. Provincial utilities looking for incremental additions to the grid.	 Avoids large reservoir flooding and has a lower ecological footprint. Can have a negative impact on river health.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Nuclear (Conventional Reactors)	Decarbonization Pathway Makes up a large share of non-emitting baseload. Development beyond current assets is limited.	Deploy Future support may be relevant in provinces with uranium supply chains or long-standing operational experience.	 Zero-emission, steady power. Requires decarbonized mining and waste management to handle upstream and downstream emissions.	 Costly and have a history of significant cost overruns and schedule delays. Interest where nuclear supply chains are being built out.	 Supports high-skilled jobs via refurbishments. Limited new builds constrain broader economic growth potential.	 Mature and reliable. Large reactors remain complex with limited recent innovation.	 Fits well but requires major scale, long timelines, and is less flexible for variable renewables.	 Strong nuclear supply chains and fuel security, but new builds require major infrastructure and could strain current capacity.	 Mixed and region-dependent. Strong backing in some areas (e.g., ON) but persistent concerns over safety and waste in others (e.g., BC, NS).	 Ontario and industry group interest. National momentum is building. Investment shifting away from large new builds.	 Waste product difficult to manage and some security and safety concerns. Waste heat can have negative impacts on water quality.
Nuclear (Small Modular Reactors)	Potential Decarbonization Pathway Successful deployment has not yet occurred in Canada. Cost and schedule overruns may pose significant barriers.	Incubate Support R&D, pilots, and demonstrations. Build out supply chains capable of manufacturing SMR fuel sources and modular parts.	 Zero-emission, steady power. Requires decarbonized mining and waste management to handle upstream and downstream emissions.	 Unclear — still in development. Capital costs per kW are not well established.	 Could drive major job creation, exports, and domestic industry growth.	 Research & prototype stage. No SMR is commercially deployed in Canada yet. Proven in small test reactors.	 Some SMR designs well-suited to smaller grids, industrial sites, and remote areas. More flexibility for grid operators.	 Strong nuclear supply chain foundations but suitability varies by reactor design. Some SMRs require new fuel sources, modular manufacturing capacity, and upfront supply-chain investment.	 Cautious but growing - strong near existing plants, mixed in remote areas, limited nationally.	 Backing from federal and some provincial governments, utilities, and heavy industry. Align with decarbonization and energy reliability goals.	 Waste product is difficult to manage and some security and safety concerns. Waste heat can have negative impacts on water quality.
Geothermal Power (Closed Loop, Conventional, and Deep)	Potential Decarbonization Pathway Geothermal has potential for generating net-zero electricity and heat.	Enable Support closed loop R&D as well as pilot and demonstration projects. Support longer-term development of deep geothermal.	 Conventional geothermal releases some carbon dioxide. Closed loop and deep geothermal are more promising for net zero.	 Not currently cost-competitive in Canada currently due to high drilling and capital costs. Potentially viable in remote areas.	 Potential dependent on cost-effectiveness. Can create jobs in drilling and operations, reduced fuel imports in remote communities, and exportable tech.	 Demonstration stage with one closed loop project under construction in Canada. Deep geothermal in early research.	 Site-dependent and best suited to regions with accessible heat at depth. Deep geothermal has wider geographical applicability.	 Can leverage oil & gas infrastructure and expertise with standard equipment and a ready supply chain.	 Significant concerns of seismic activity for conventional geothermal. Support from off-grid Indigenous communities with closed-loop systems.	 Western provinces, oilfield service firms, and federal innovation programs as a transition opportunity. Utilities are cautious.	 Small land footprint and co-benefits (usable heat, grid stability, consistent performance, etc.). Can affect water quality if conventional geothermal is used.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Biomass Power (Combustion)	Niche Pathway Feedstock supply is limited. Likely only economical and net-zero in very niche circumstances such as on-site power generation.	Don't Prioritize Unlikely to have a role in mainstream power generation. Watch for niche opportunities to support local or on-site power generation.	 Dependent on biomass carbon intensity, land change, and transport emissions. Likely requires CCS to achieve net zero.	 Costlier per kWh than wind or solar. Can be viable at small scale near cheap waste feedstock.	 Opportunities in rural and Indigenous communities through local jobs and valorization of forestry residues. Limited growth potential.	 Mature, proven technology widely used in Canada, especially at pulp mills.	 Baseload or on-demand power in biomass-rich regions. Requires developed fuel supply chains and consistent feedstock.	 Challenges around feedstock availability and industry competition.	 Mixed — higher when using waste feedstocks at small, clean facilities. Concerns of sustainability, traffic, and air pollution.	 Minimal interest from utilities, urban planners, and energy developers due to supply risks and higher costs.	 Total lifecycle emissions are variable. Air quality pollutants can be worse than burning natural gas. Land use changes can be negative.
Gas with CCS	Bridge Pathway Can be used as a backup power source while renewables are built out or marginal balancing in a net-zero system.	Don't Prioritize Watch for local or regional power reliability issues. Could be useful as backup power.	 Difficult to capture all emissions with CCS. Requires negative emissions to offset lifecycle emissions (extraction, transport, and combustion).	 Costly due to CCS. Needs subsidies but may become moderately competitive for baseload power.	 Protects existing energy jobs and supports regional CCS industries. Development depends on CCS demand and innovation.	 Demonstration stage. Technology for post-combustion capture from gas turbines is being tested.	 Best for steady-output roles. Can support flexible power with efficiency trade-offs in peaking or cycling applications.	 Benefits from existing infrastructure but requires new CO ₂ pipelines and strong methane management.	 Generally accepted if seen as a climate solution. Opposition remains over continued fossil fuel reliance and CO ₂ storage concerns.	 Relevant to gas producers and suppliers, Alberta, and industries needing firm power.	 Aids grid stability. Air quality and health issues with conventional combustion.
Coal with CCS	Dead-End Pathway Not required in Canada to reach net-zero.	Dismiss Difficult to fit with existing operations and infrastructure.	 Requires carbon offsets which can be limited. Perpetuates use of materials that will have little functionality in a net-zero economy.	 Very high cost and poor economics. can double the cost of electricity. More costly than renewables or gas + CCS.	 Apart from CCS, which has limited growth prospects, there are better opportunities in other clean energy sectors.	 Coal power plants are mature, but CCS is demonstration stage at scale, with one project in Saskatchewan.	 Frequent maintenance outages observed and requires suitable geology to store CO ₂ nearby. Coal phase-out makes this operationally irrelevant.	 Uses existing coal infrastructure with added capture units and CO ₂ pipelines. Coal fleet is being phased out.	 Negative due to coal but moderate CCS acceptability.	 Policies and utilities move to phase out coal entirely.	 Issues with air quality and health from exhaust. Water demand and upstream emissions (associated with mining) are high.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Grid Infrastructure and Electricity System Expansion and Improvements											
Inter-provincial Interties	Enabling Pathway Can reduce costs for decarbonization and increase grid resilience.	Deploy Encourage provincial collaboration and support interties that improve power reliability and security.	 Ensures reliability with renewable generation. Clean power can be available when local supply is limited.	 Economics can be positive depending on the projects. Funding is available but requires collaboration between parties.	 Reduces reliance on the U.S. and creates domestic jobs through infrastructure construction and maintenance. Generates domestic demand for electrical equipment manufacturing.	 Transmission technology is mature, but autarchical approach historically hampered progress.	 Provinces operate and plan resources individually. Some connections are geographically difficult with long timelines.	 New or larger transmission lines are required.	 Transmission lines often face local opposition. Shared ownership with Indigenous communities can help build support.	 Greater flexibility and reliability for users. Complexity with provincial collaboration and planning.	 Enhances power reliability in Canada and lowers decarbonization costs but requires new or expanded transmission corridors, leading to potential land disruptions.
International (U.S.) Interties	Enabling Pathway Not a priority for decarbonizing Canada. With political tensions and tariffs, economics have some risk.	Don't Prioritize Most connections and exports already established. Monitor for new export opportunities. Prioritize provincial interties.	 Offers an export opportunity for Canada's excess renewable power.	 Economics depend on the project and power demand within U.S. regions.	 Already a mature industry. Exports could grow with excess domestic power and increasing decarbonization requirements in the U.S.	 Already occurs in every province bordering the U.S.	 Requires strong collaboration between provinces and states, which can be difficult due to misalignment on goals, planning or regulations.	 Requires upgrades to existing transmission lines.	 Transmission lines often face opposition, as they require support across multiple jurisdictions. Additionally, international political tensions may heighten public scrutiny.	 Strong political tensions due to tariffs. Requires many parties to collaborate.	 Both countries benefit from increased reliability in the power grid and cleaner electricity. Some land use changes.
Grid Improvements	Priority Enabling Pathway Necessary to accommodate increased power demand. Raises grid efficiency, reliability, and resilience.	Deploy Support with stable financing. Support testing and piloting of new technologies and build out regulatory environment to include these.	 Integral to the net-zero future and its associated electrical demand across Canada.	 Cost structures vary by the type of improvement. Funding is available for some options.	 Installation and construction jobs in areas completing improvements.	 Depending on the technology, some are established (underground transmission lines) and some are emerging (smart grids).	 Proven technologies can integrate seamlessly whereas newer technologies can be complex with slow regulatory processes.	 Capacity and transmission will need to expand so that location specific needs are met.	 Improved grid reliability is seen positively but increased visible power lines may have opposition.	 Highly important to power companies for improving grid reliability, but viability depends on payment structures and government support to make business cases feasible.	 Improved reliability of electricity delivered to customers.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Power Storage	Enabling Pathway Necessary to reach net zero where power supply is primarily supported by intermittent renewables.	Enable Support R&D so economics improve and demonstration or deployment where contexts are economically positive. Reduce regulatory hurdles for new technologies.	Prevents excess generation going to waste and mitigates issues related to the intermittency of renewable energy sources.	Costs vary by technology but are falling. Currently and only cost-competitive in certain contexts (remote locations or peak shaving).	Vary by technology but opportunities and projects are emerging associated with domestic jobs.	Some technologies (hydro reservoirs) well developed where others (grid batteries or pumped storage hydropower) at varying levels of commercialization and deployment.	Improved grid operations, Can help with diurnal peaks. Seasonal battery storage not yet feasible or economic.	Will require some changes to connect to the grid but should reduce the burden on infrastructure.	Depends on technology, location and size of projects not widely implemented yet.	Aligns with objectives to improve grid reliability, counteract peaking, and work with intermittent renewable generation.	Counteracts the intermittency of renewable generation.
Demand Side Management	Enabling Pathway Required to reduce and manage overall power demand.	Deploy Support regional and local testing and piloting to determine the best methods and subsequent deployment.	Reduces need for new power generation.	Often cheaper for governments than adding additional electrical infrastructure.	Frees electricity for industry, export, and trade.	Implemented in some locations in Canada with mild success compared to other locations.	Is mainly implemented through policy and regulations which may have downstream effects on operations.	Functions with existing infrastructure and can reduce burden on the existing system.	Resistance to utility-controlled demand. Programs need to be communicated clearly to the public.	Can offer large savings. Seen as very favourable to utilities and large electricity users.	Reduces environmental burden through avoided power generation and grid peak loads. Lowers energy costs.
Energy Efficiency	Enabling Pathway Required to reduce end demand for power.	Deploy Provide education to manufacturers, installers, retrofitters, and purchasers on the benefits of high-efficiency assets. Offer financing mechanisms to help with up-front costs where relevant (i.e. low-income and cold-climates).	Reduces need for new power generation.	Often cheaper than adding additional electrical infrastructure. Funding can vary widely by application and region.	Job growth in many end-use sectors with retrofits and technology installations or upgrades.	Maturity of high efficiency technologies vary by sector and application.	Typically requires purchase of new assets.	Can require import of new end-use technologies. Reduces burden on existing infrastructure.	Understanding and perceptions of efficient equipment can vary widely. Higher-efficiency appliances may also carry higher up-front costs, raising equity concerns.	Inconsistent information leads to limited understanding, causing many stakeholders to undervalue the effectiveness and deprioritize adoption.	Cost savings for consumers and providers. Reduces environmental burden through avoided power generation and grid peak loads. Lowers energy costs.

7.2 HYDROGEN

Function	Today: Used as a feedstock for the chemical industry, fertilizer production, bitumen upgrading, and oil refining. Future: Could play an expanded role as a clean energy carrier in transportation, and industrial heating, alongside emerging roles in energy storage, grid balancing, and in the production of biofuels and steel.
GHG emissions	Currently, Canada lacks a hydrogen-specific national accounting system for production volumes, pathways, and associated emissions. Production methods vary in carbon intensity, and most hydrogen produced today is higher-emission “grey” hydrogen, with only limited low- or net-zero-emissions hydrogen deployed. A rough estimate suggests emissions from Canadian hydrogen production could be 38 Mt of CO₂e in 2024 (already reflected in our inventory, largely under oil and gas and refining categories—not additional to reported totals).⁵
Options for decarbonization	Decarbonization Pathways: Autothermal reforming with carbon capture and storage, electrolysis with low-emission electricity. As an emerging but highly uncertain opportunity, some companies are exploring natural hydrogen, which should have very low carbon intensity. Bridge Pathways: Steam methane reforming with carbon capture storage. Niche Pathways: Methane pyrolysis, biowaste gasification, byproduct of industrial processes.
Stage of transition	Emerging: Methane autothermal reforming and pyrolysis, hydrogen derived from carriers (i.e., ammonia, methanol, liquid organic hydrogen carriers, etc.) Early Diffusion: CCS applied to methane reforming and electrolysis supported by low-emission electricity.
Nature of the problem today	There is currently limited demand and production for hydrogen as a fuel, and very limited distribution infrastructure. Very little low-carbon-emission hydrogen is now being produced. Substantial investment risk with the uncertainty in infrastructure development and downstream demand. High production, storage, and delivery costs.
Other systemic issues	Fugitive emissions from natural gas extraction. Requirements of high volumes of decarbonized electricity and water availability for electrolysis. Hydrogen leaks could elevate levels in the atmosphere and increase the half-life of atmospheric methane. In this way, hydrogen is an indirect greenhouse gas, so leaks must be managed.
Strategic opportunities and concerns	Opportunities: Hydrogen is a decarbonization energy option for hard-to-abate sectors. Potential for societal and economic benefits from development of a new industry. Co-located demand and production hubs offer high economic potential. Concerns: Infrastructure/demand feedback loop stalls investment and growth. Decarbonization of existing production methods requires expensive retrofits or new market demand. Hydrogen leakage across production, storage, and transport infrastructure could undermine climate benefits if not effectively managed.
Priorities for action	Use policy to encourage production and demand and co-location of production with demand. Establish carbon intensity thresholds and reduction schedules to ensure a clear pathway to zero emissions. Additional research and demonstration for compatibility with existing infrastructure, equipment, and safety requirements.

⁵ National production: 4 Mt of hydrogen
 Energy density: 120 GJ/t
 Carbon intensity of grey hydrogen: ~80 kg CO₂e/GJ
 $4,000,000 \text{ t} * 120 \text{ GJ/t} * 0.08 \text{ t CO}_2\text{e/GJ} = 38,400,000 \text{ t CO}_2\text{e} = 38.4 \text{ Mt CO}_2\text{e}$

Longer-term issues	Buildout of infrastructure to meet broader applications. Address fugitive methane and hydrogen emissions and data gaps. Demand on water.
Indicators of progress	Total emissions from hydrogen production, carbon intensity of hydrogen, production and retail costs, deployment of fuel cell vehicles and other technologies that efficiently convert hydrogen into energy services, proportion of energy use for which low-carbon hydrogen, ammonia or methanol displace fossil fuels in end-use sector.

7.2.1 Current Status

Hydrogen is light, abundant, and highly reactive, and bonds with elements like oxygen to form water or carbon to form hydrocarbons. Releasing hydrogen from oxygen bonds (as in water) requires significant energy input; releasing it from hydrocarbon bonds generates energy. Some industries, like the chlor-alkali sector, produce hydrogen as a byproduct.

Hydrogen is currently used mostly as a chemical feedstock for hydrocarbon refining, ammonia and methanol production, and fertilizer production. Additionally, it can be used as an energy carrier that can generate electricity in a fuel cell, be combusted to generate heat, added to improve the energy density of carbon in biomass, or leveraged to reduce iron oxide in the production of green steel.

Several factors make hydrogen attractive:

- Zero-emissions Potential:** Hydrogen combustion or electrochemical conversion in a fuel cell emits no greenhouse gases. It is technically feasible to produce hydrogen with zero emissions.⁶
- Flexibility:** Hydrogen is a versatile molecule that can be stored or transported as a gas or cryogenic liquid. It can be used to make energy-rich chemicals (e.g. ammonia) for transportation or heating, generate electricity, make steel, or produce drop-in biofuels.
- Complementarity to Electricity:** Hydrogen can fill gaps where electrification is difficult, such as with rail and heavy-duty vehicle transport, and can store renewable electricity as chemical energy. A hydrogen “grid” of pipelines and salt cavern storage could improve the economic viability of large-scale, low-carbon electricity deployment (wind, solar, nuclear), since the production of hydrogen would add value to surplus electricity generation while creating a zero-emission fuel that can be stored for long periods. As a northern country, Canada’s surplus power generation in the summer could be stored as hydrogen for use as a zero-emission heat source in the winter.
- Regional Benefits:** Hydrogen could support regional transitions away from fossil fuels. Areas with abundant natural gas or renewable energy could have a future role as hydrogen producers. Some argue the Canadian Shield is a promising geology for the discovery of natural hydrogen sources.

Canada has many advantages when it comes to hydrogen production. There are abundant feedstocks, including natural gas, clean electricity, fresh water, as well as space for geological carbon storage. Canada is already established in the hydrogen fuel cell sector with more than 100 companies and 2,400 employees in the value chain.[143,144] Today, Canada produces roughly 4 Mt of hydrogen annually, ranking among the top 10 global producers.[145]

⁶ Although hydrogen combustion does not produce direct greenhouse gas emissions, it does produce NO_x as the air is heated to high temperatures during the combustion process. NO_x is not considered a direct greenhouse gas, but it does contribute indirectly to greenhouse gas emissions through the formation of ozone. Additionally, NO_x leads to local air quality concerns and is associated with human health impacts.

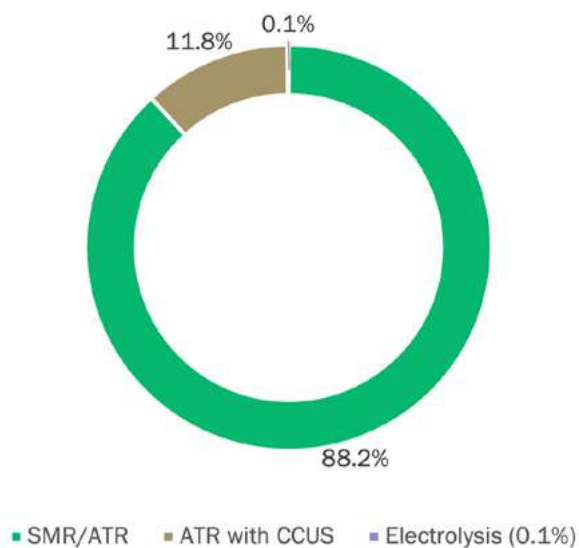


Figure 14. Canadian hydrogen production by method (2024)

Source: CER and AER[146–148]

Virtually all the hydrogen produced in Canada in 2020 was consumed by industrial processes, chiefly oil upgrading and refining, ammonia, and methanol production. Western Canada produces and consumes Canada's hydrogen. Alberta consumes the largest share of hydrogen produced in Canada, about 61%.[149] Alberta also produces 65% of the hydrogen in Canada.[146] Hydrogen-based steelmaking remains a future pathway rather than a current source of demand, with existing direct reduction of iron (DRI) facilities operating on natural gas and only limited pilot-scale hydrogen-use tests conducted to date.

There is consensus that hydrogen will be required to reach net zero, but uncertainty in the required quantities and its use cases. Canada's hydrogen strategy, updated in 2024, envisions hydrogen providing between 3% and 18% of the country's end-use energy by 2050.[148]

7.2.2 Nature of the Problem

The hydrogen economy is confronted with a “chicken and egg” dilemma: infrastructure depends on demand, and demand depends on infrastructure. This mutual dependency fuels market instability and deters investment. Hydrogen has potential as a net-zero fuel, but low-emission hydrogen supply in Canada is extremely limited, distribution networks are fragmented and mostly reliant on trucking, and end-use equipment is only available in niche, early-market applications.

Currently, around 3.5 Mt of hydrogen is generated from unabated natural gas, while only 0.5 Mt is confirmed to employ low-carbon methods.[146–148] According to Canada's updated hydrogen strategy, between 6 Mt and 20 Mt of low-carbon hydrogen will be needed for net zero in 2050.[148] This highlights the need to scale production and shift to lower-emitting methods. However, widespread adoption of hydrogen is constrained by several infrastructure-related barriers.

Infrastructure

Production: Hydrogen's emerging role as an energy carrier requires significant investment in production infrastructure. Achieving low-carbon hydrogen at scale requires retrofitting existing facilities with CCS and building new facilities with either natural gas and CCS or electrolysis. Both options are associated with significant costs and planning. Natural or geological hydrogen is an additional longer-term alternative that, if proven at scale, could bypass some of these production costs entirely.

Transport: Governments and natural gas utilities are exploring repurposing natural gas networks for hydrogen transport, as this minimizes the need for new infrastructure and enables the continued use of gas networks. The picture varies by network type: lower-pressure distribution pipelines are generally more

compatible with hydrogen, while high-pressure transmission pipelines made of high-carbon steel are prone to hydrogen embrittlement and would likely need to be replaced for pure hydrogen service. End-use equipment such as meters, appliances, and industrial burners would also require modification or replacement in either case.⁷ Only newer polyethylene (PE) networks might accommodate pure hydrogen, but such a transition would likely still require the replacement of end-use equipment. Where pipelines are not available, hydrogen must be compressed or liquefied for transport on trucks or trains. This can be expensive, energy-intensive and safety-sensitive.[150]

Storage: Unlike electricity, hydrogen can be stored as a physical fuel, making it a valuable complement to variable renewable generation. However, hydrogen is challenging to store due to its low density and small molecular size. It can be compressed at moderate pressure (i.e., 350 bar) or high pressure (i.e., 700 bar), or liquefied to reduce volume, but these options involve trade-offs in cost, energy use, and safety similar to those in transport. Hydrogen can also be converted into ammonia for easier handling, but this has not yet proven to be cost-effective at scale. Storing hydrogen underground in geological formations shows promise as a low-cost option. Salt cavern storage in particular has been demonstrated commercially, though it is only economical at large scale, reinforcing the need for substantial demand before this alternative is viable.[150]

Distribution: Canada currently has only a handful of accessible hydrogen fuelling stations, leaving most of the country without refuelling options for hydrogen vehicles.[151] High capital costs per station, low utilization, and no self-reinforcing demand cycle yet in

place create a financing gap that private operators are unlikely to bridge without targeted government support.

In all cases infrastructure safety remains a foundational concern. Hydrogen is non-toxic and disperses quickly, reducing some risks. However, its high flammability and low ignition-point demand specialized safety protocols that are currently limited to a few industrial settings. To the extent that hydrogen expands into sectors like transport, the need for broader expertise, standardized guidelines, and public education will grow significantly.

Market size and cost competitiveness

Infrastructure challenges contribute directly to uncertainty in market size and cost competitiveness. Without clear infrastructure pathways, the scale of hydrogen adoption in Canada remains unclear. Hydrogen will continue to serve as an essential feedstock for the chemical and fertilizer sectors and may support difficult-to-electrify applications. However, its potential beyond this, including its role in building heating and transportation, remains less certain. Until infrastructure policies, funding, and plans are in place, investment at scale will remain a challenge.

Hydrogen is currently expensive, largely due to high capital and operating costs and limited end uses. Today it is not cost-competitive with most other fuel types. Cost would go down with infrastructure buildout and greater demand. Ongoing development of multiple technologies will influence its evolving cost competitiveness. While natural gas-based hydrogen is generally cheaper today, electrolysis is expected to become cheaper as technology improves and scales.

⁷ The specific threshold will vary according to the characteristics of the system in question, but 20% hydrogen by volume is often cited as an upper limit for typical natural gas networks. Hydrogen is less energy dense per unit volume than methane, meaning a 20% blend of hydrogen could be expected to reduce emissions by approximately 6-7% over natural gas alone.

7.2.3 Net-Zero Pathways

Hydrogen can be produced by steam methane reformation, autothermal reforming or pyrolysis using natural gas as a feedstock, or electrolysis using water as a feedstock. This section explores decarbonizing these technological pathways. Hydrogen can in principle also be derived from alternative sources, such as biomass. However, due to the limited availability of biomass feedstocks and their likely small role in the market, this is not explored further in this report. Hydrogen generated as a byproduct from industrial processes, like chlor-alkali processes, was also excluded as the supply is limited.

Steam Methane Reforming (SMR)

SMR is the most common method of hydrogen production by reacting methane with steam and air, generating both hydrogen and CO₂. To reach net zero, CO₂ must be captured. Current capture systems typically address only about 60% of process emissions. The remaining emissions are found in flue gas, and there is currently no commercial-scale capture of these. While 90% capture rates have been demonstrated in pilots, no commercial plants exist. It is, however, very difficult to achieve net zero with SMR and carbon capture, as flue gas is very dilute.

Autothermal Reforming (ATR)

ATR is a commercial methane reforming process similar to SMR except that it uses pure oxygen in place of air and carries out the reaction in a closed vessel. This produces a concentrated CO₂ stream, making carbon capture more efficient. There are ATR's commissioned in the United States and facilities planned for Canada; all have target capture rates of 95%.^[152–154] The absence of flue gas simplifies capture, making ATR a more viable near-term pathway for low-carbon hydrogen compared to SMR.

Methane Pyrolysis

Pyrolysis is less developed than SMR and ATR, and has a higher natural gas consumption rate, but recent commercial projects have been announced in Canada.^[155] This method decomposes methane without oxygen to yield hydrogen and solid carbon (carbon black), eliminating the need for carbon capture from process emissions. While carbon black is a valuable product, the development of supply chains would be necessary as its market potential is believed to be limited.⁸

To fully meet net-zero requirements, methane-based hydrogen production pathways (SMR, ATR and pyrolysis) might require negative-emissions technologies to negate fugitive methane emissions, while those involving carbon capture would require such technologies to account for the residual carbon emissions.

Electrolysis

Electrolysis is a process that uses electricity to split water into hydrogen and oxygen. This method produces no direct emissions and does not require carbon capture. The emissions associated with electrolysis are from the source of electricity. Electrolyzers can be found in various sizes, enabling both small-scale distributed units and larger centralized facilities to be deployed as needed. Electrolysis projects are planned in British Columbia, and Canadian Pacific Kansas City has deployed a retrofitted hydrogen-electric locomotive, complete with on-site electrolysis-based hydrogen refuelling facilities, that is reported to be cost-competitive with purchasing a new Tier 4 diesel-electric locomotive.^[144,156,157]

Energy decarbonization across pathways

Regardless of production method, hydrogen pathways rely heavily on energy inputs for heat, processing, or other facility operations. SMR,

⁸ Carbon black is manufactured today for use in various industries such as the production of pigments, and manufacture of tires and other rubber goods.

ATR, and pyrolysis require industrial-scale heat either directly or in the form of steam, while electrolysis requires substantial electricity for processing. To achieve net zero, these energy-related emissions must also be addressed through electrified heating, clean electricity sources, or the use of low-emission fuels.

Hydrogen production methods may be more viable in some regions than others. Alberta's abundant natural gas may favour thermal methods, while British Columbia's clean electricity makes electrolysis more suitable. This highlights the need for location-specific strategies.

Storage and transportation

Storage and transport methods are critical in determining hydrogen's carbon intensity and net-zero compatibility. The most suitable option depends on transport distance, volume, and infrastructure availability. Compressed gas trucks are typically used for short hauls and small volumes, while liquefied hydrogen

becomes more cost-effective at longer distances and larger loads. Pipelines are the lowest-cost option for high-volume regional transport once demand is established, though they require the highest upfront investment. For overseas transport, conversion to ammonia, methanol or liquid organic hydrogen carriers is only economical at large scale due to higher capital requirements. In some cases, it may be more cost-effective to produce hydrogen at the point of use where local natural gas or clean electricity is available, though this should be weighed against the economics of dedicated hydrogen infrastructure, which can be significantly cheaper per unit of energy at scale. Techno-economic analyses that compare capital and operating costs, alongside existing infrastructure and location-specific energy prices, are needed to evaluate trade-offs between these options. Table 3 outlines the main hydrogen transport methods and the distance and volume ranges where each becomes economically viable.

Table 3. *Hydrogen transport method distance and amount requirements for economic viability*

Transport Method	Distances	Amount
Compressed Gas Truck	<320 km	500 kg
Liquefied Hydrogen (Truck/Train)	320 km – 960 km	4 tonnes
Transmission Pipeline	Regional (inter-city or province)	1-2 tonnes/day per km of pipeline
Ammonia (Marine)	>4000 km	Substantial demand required for economy

Competitiveness Implications

The harder problem in Canada's hydrogen export ambitions is market-formation timing. The architecture of international hydrogen trade (carbon-intensity certification thresholds, bilateral offtake commitments, port and carrier infrastructure) is being built now by jurisdictions furthest ahead in deploying certified supply. Producers who lock in these frameworks will set the terms of access others must accept.

Canada has not yet resolved a prior question: whether its export value lies in the hydrogen molecule itself, in derived carriers like ammonia, or in production technology and equipment. These are three different strategies requiring different infrastructure, different partnerships, and different certification pathways.

This is compounded by the divergence between Canada's two regional production tracks: western natural-gas-based hydrogen must demonstrate verified CCS capture rates sufficient to meet emerging carbon-intensity thresholds; eastern electrolytic hydrogen must demonstrate additionality of clean electricity supply. Neither certification pathway is resolved. The risk is not production capability; it is that bilateral offtake relationships and carbon-intensity benchmarks may be substantially set before Canada's export proposition is defined.



7.2.4 Priorities for Action

Identifying viable, no-regrets applications

To accelerate hydrogen deployment and reduce investment risk, decision-makers should start by identifying the most viable and impactful use cases in their jurisdictions—applications where hydrogen is already close to being cost-effective, technically compatible, and operationally necessary. These “no-regrets” opportunities are typically found in sectors where hydrogen has few substitutes, such as heavy industry, refining, and long-haul or high-utilization transport fleets. In regions with clean electricity and surplus grid capacity, electrolytic hydrogen may also be viable for local energy storage or the displacement of high-emissions fuels.

Once these priority applications are identified, policy frameworks can be structured to support them. Focusing early investment and policy effort on these foundational use cases enables capacity building across the value chain, reduces uncertainty for infrastructure development, and establishes the institutional expertise needed to scale hydrogen more broadly in the future. These early steps are not just about technology readiness; they are about creating credible pathways for growth that align with local strengths and decarbonization needs.

Developing viable hydrogen hubs and corridors

A key solution to hydrogen infrastructure challenges is co-locating hydrogen production and demand in a hub, where production, storage, distribution, and end-use are all in one place. These hubs reduce the need to transport hydrogen over long distances and allow the sharing of costs. Offtake agreements, which commit buyers to purchase goods from suppliers in advance of their production, can provide producers with demand certainty and can help to diversify end-use applications. Even

so, it's expected that governments will need to support the initial buildout of infrastructure to get the hubs started. That support should be focused on a limited number of hubs where potential exists to reach commercial scale, delivering hydrogen to end users at a reasonable price for multiple years.

Hydrogen hub development is already underway in Alberta, where strong industrial demand aligns with production potential. Both Edmonton and Calgary host active coordination hubs that focus on connecting hydrogen producers with demand centres and facilitating project development. While these early ventures serve coordination and development functions, fully integrated physical infrastructure hubs with co-located production, storage, distribution, and end-use facilities are still in development. Future clusters are likely to emerge near existing hydrogen demand centres (e.g., refineries, chemical plants), emerging demand (e.g., steelmaking), or transportation nodes (e.g., ports, railyards).

Demand-side support

Demand-side support is vital to the development of the hydrogen ecosystem. Measures that encourage hydrogen demand could include:

- Market development tools and projects for potential key end users, with piloting, testing, and awareness-building around hydrogen technologies.
- Clean fuel standards (such as Canada's Clean Fuel Regulations) to create demand-pull for hydrogen by allowing it to generate compliance credits when substituted for higher-carbon fuels.
- Offtake agreements and contracts of difference to de-risk investment by securing long-term prices and demand.

- End-use incentives to reduce upfront costs for fuel switching and equipment adoption.
- Carbon pricing to increase the cost-competitiveness of hydrogen as fossil fuel costs rise. The exact carbon price needed to make hydrogen cost-effective varies by end use and industry.
- Mandates and procurement requirements for low-carbon fuels like hydrogen in key sectors (e.g., transport, industry).
- Supply chain coordination, including OEM engagement to ensure equipment availability.
- Targeted subsidies or production incentives for electrolytic hydrogen producers.
- Tax credits and financial incentives to offset capital investment and support the whole value chain including transport and storage.
- Carbon intensity thresholds and reduction schedules to ensure hydrogen decarbonizes over time.
- Streamlined regulations and standards to ensure safe deployment and industry clarity.
- Continued decarbonization of electricity grids.

Supply-side support

In addition to co-locating production and demand, coordinated supply-side and demand-side policies are required. Supply side policies to encourage hydrogen production can include:

- Government investment in enabling infrastructure including storage and distribution systems.
- Support for pilot and demonstration projects that improve production technologies and reduce costs, as well as validate the technical compatibility of hydrogen with various end uses.

Canada's hydrogen strategy envisions Canada becoming an exporter of hydrogen and hydrogen-related technologies. However, the specifics of where and how this export will happen are not clear, nor is Canada's comparative advantage as compared to production in other jurisdictions evident.[158] Based on current potential, it is anticipated that eastern Canada will primarily produce hydrogen from electricity, while western Canada will focus on hydrogen from natural gas. Further analysis is required to determine the size of the opportunity and the specifics regarding the return on investment that can be expected for Canadians.

ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Significant GHG reductions. Very high capture feasible via pure O₂ feed. May require removals for residual emissions. Requires upstream methane capture.	Moderate premiums from incumbent. More efficient capture process than steam methane reformation + CCS.	Drives oxygen and CCS services. Regional job growth.	Demonstration phase.	High capture efficiency with simplified CO₂ capture. Requires oxygen production and integration.	Requires hydrogen pipelines and storage or nearby industrial users. Needs O₂ supply, CO₂ compression hubs and storage.	Generally accepted but public concern over hydrogen safety and CCS leakage.	Hydrogen producers and natural gas industry as a longer-term net-zero hydrogen production strategy.	Some concerns about CO₂ and hydrogen leakage and continued upstream methane emissions.
Offers moderate emissions reduction but cannot reach net zero without combination with negative emissions due to dilute flue gas.	Moderate premiums from incumbent. High capital costs for retrofit with CCS infrastructure and ongoing operational complexity.	Maintains existing industrial base and jobs in regions with natural gas resources. Drives CCS services.	Mature and deployed in Canada.	Compatible with existing SMR plants, but flue gas capture retrofit is complex.	Requires hydrogen pipelines and storage or nearby industrial users. Needs CO₂ compression hubs and storage.	Generally accepted but public concern over hydrogen safety and CCS leakage.	Hydrogen producers and natural gas industry as near-term emissions reduction strategy.	Air pollution concerns. Some concerns about CO₂ and hydrogen leakage and continued upstream methane emissions.
Enables net-zero hydrogen with solid carbon byproduct. May require removals for residual emissions. Requires upstream methane capture.	Moderate premiums from incumbent. Higher gas consumption. Emerging tech with pilot costs.	Potential market for carbon black. New manufacturing opportunities.	Pilot/ demonstration stage.	Operates similarly to SMR but yields solid carbon. Requires reactor modifications.	Requires solid carbon- handling supply chain. Nascent support. Requires hydrogen transport and storage or nearby users.	No particular concerns. Public is unfamiliar with carbon black products.	Hydrogen producers. Maturity and markets for products limiting uptake.	Avoids flue gas emissions. Produces marketable carbon black product. Risk of continued upstream methane emissions.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electrolysis with Clean Power	Decarbonization Pathway Can produce net-zero hydrogen.	Enable Invest in electrolyzer supply chains and grid interconnections. Support deployment in regions with surplus clean electricity.	 Fully decarbonizes when powered by clean electricity.	 High premiums compared to SMR. Cost declines with renewables.	 Stimulates electrolyzer manufacturing and grid integration.	 Mature but limited commercialization.	 Compatible with existing water and power infrastructures with minor adjustments. Flexible scaling.	 Requires grid upgrades, high-voltage interconnects, electrolyzer supply chain. Requires hydrogen transport and storage or nearby users.	 Highly favourable where clean power exists.	 Hydrogen producers and utilities have begun developing some commercial projects.	 Complements renewable electricity generation. Integration as storage and transportation option. Supports grid balancing.
Biowaste Gasification	Potential Niche Pathway Likely only economical and net-zero in very niche circumstances.	Don't Prioritize Watch for improvements in feedstock costs and conversion efficiency. Prioritize investments if site-specific conditions demonstrate viability.	 Moderate GHG reduction. Dependent on sustainable feedstock availability.	 High operation, maintenance, and feedstock costs.	 Creates rural jobs. Supports waste management and circular economy.	 Demonstration stage.	 Requires biomass pre-processing. Fits waste-to-energy sites.	 Needs certified biomass supply chains. Limited scalability. Requires hydrogen transport and storage or nearby users.	 Waste management supportive. Public views mixed.	 Waste operators and municipalities.	 Reduces landfill emissions. Provides local feedstock management. Competition with other sectors for feedstocks.
Byproduct of Industrial Processes	Niche Pathway Only available from limited chemical production pathways.	Deploy Support capture and utilization of existing byproduct hydrogen streams where economical.	 Moderate GHG reduction. Leverages concentrated process streams.	 Highly viable where hydrogen concentrated. Minimal incremental cost depending on purity of hydrogen byproduct.	 Very limited opportunity to expand as hydrogen supply is dependent on other industries and finite.	 Fully commercial.	 Direct integration into existing process off-gas capture systems.	 Uses on-site infrastructure.	 Broadly accepted as efficient waste valorization.	 Supported by chlor-alkali and petrochemical industries.	 Cost-effective hydrogen supply. Reduces flaring. Improves overall plant efficiency.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Natural or Geological Hydrogen	<i>Potential Decarbonization Pathway</i> Potential for large GHG reductions but maturity is currently too low to determine overall role.	Don't Prioritize Track geological exploration results and early research. Commit capital when resource potential and extraction methods are clear.	 Fully decarbonized hydrogen.	 Potential to be very low cost, but still speculative.	 Opportunity to develop hydrogen production in regions that find geological potential.	 Research phase; no real-world applications.	 Some geological hydrogen production methods fit with existing utility systems; others would require modification.	 Requires build out and supply of new facilities and technologies.	 Similar concerns to other resource extraction operations	 Some research and early geological exploration are occurring in Canada.	 Some concerns with water pollution depending on the method of production.

7.3 ALTERNATIVE FUELS

Function	Low-carbon substitutes for conventional fossil fuels ideal for hard-to-abate sectors (aviation, heavy freight, and industrial applications). Alternative fuels include blended fuels that require mixing with conventional fuels at specific ratios and drop-in fuels that can directly replace petroleum fuels without engine or infrastructure modifications.
GHG emissions	Production of alternative fuels currently contributes relatively small greenhouse gas emissions with no formal, comprehensive system to track these emissions separately. Canada's National Inventory Report appears to under-represent the growth of clean fuels mandated under federal regulations, with recent analysis suggesting renewable fuel consumption is undercounted by a factor of more than two at the national level compared with compliance-program data.
Options for decarbonization	Decarbonization Pathways: Sustainable Aviation Fuel (SAF). Niche Pathways: Hydroprocessed Esters and Fatty Acids (HEFA) SAF, renewable diesel, renewable natural gas (RNG), advanced biofuel, bio-synthetic and synthetic fuels (e-fuels). Dead-End Pathways: Biodiesel, ethanol (as transport fuels).
Stage of transition	Mature: Biodiesel, ethanol. Emergence: Renewable diesel, sustainable aviation fuel, renewable natural gas. Early emergence (R&D): Synthetic e-fuels
Nature of the problem today	Limited domestic production of biofuels, feedstock constraints, and higher production costs compared to fossil fuels.
Other systemic issues	Sustainability and land-use concerns, dependence on imports, infrastructure limitations, and competition with electrification strategies.
Strategic opportunities and concerns	Canada has abundant biomass resources, renewable electricity, and innovation capacity, but faces competition from international incentives and sustainability challenges.
Priorities for action	Scale domestic advanced biofuel production for selected applications, strengthen policy mandates, ensure sustainable feedstock, support infrastructure upgrades, and incentivize innovation.
Longer-term issues	Long-term feedstock and technology constraints require balancing hydroprocessed esters and fatty acids deployment with scaling advanced residue-based biofuels, while carefully assessing the role of higher-cost synthetic e-fuels (likely focused on export) and coordinating this transition with the managed decline of fossil fuel infrastructure and evolving global market conditions
Indicators of progress	Blending rates, production capacity, greenhouse gas intensity, sustainability metrics, market signals, and investment/cost trends.

7.3.1 Current Status

Canada’s alternative fuels encompass several non-fossil energy carriers that can be used in place of conventional petroleum fuels and natural gas, including bio-based liquids (ethanol, biodiesel, renewable diesel, biocrude oils), synthetic liquids (power-to-liquid e-fuels), renewable gaseous fuels like biomethane/RNG, and others. Renewable propane, produced from non-fossil feedstocks and commonly emerging as a byproduct of renewable diesel and sustainable aviation fuel refining, is also beginning to enter the Canadian market as a low-carbon drop-in fuel.[159] Deploying these fuels is a strategy to cut emissions in sectors that cannot be easily electrified. Transportation is a prime example with an estimated contribution of 22% of Canada’s GHG emissions.[160] While electrification will reduce emissions from light- and medium-duty vehicles, many heavier or long-range transport applications and some industrial heating will likely continue to need high-density liquid or some form of gaseous fuel. Alternative fuels offer a way to decarbonize these fuel demands through drop-in low-carbon alternatives with lower lifecycle carbon intensities.

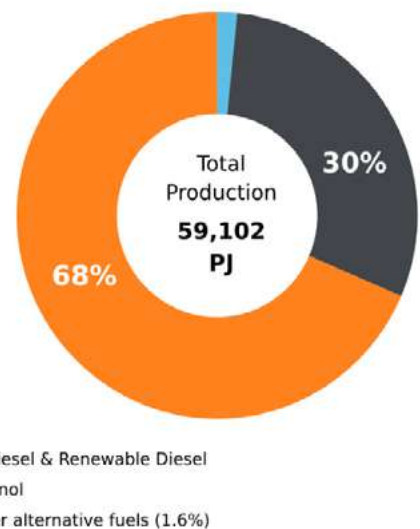


Figure 15. Canada, Alternative fuel production (2023)

Source: Statistics Canada, 2025. Renewable fuel plant statistics, supply and disposition, monthly.[161]

Source: Natural Resources Canada, 2025. Energy Fact Book 2025-26.[162]

Energy density of “Other alternative fuels” was assumed to be 36.67 MJ/L, an average of fossil diesel and gasoline. In 2023, all co-processed fuels were produced in Burnaby refinery and Tidewater Renewables and were primarily a blend of gasoline or diesel.



Figure 16. Renewable fuel content in gasoline by province (2024)

Source: Advanced Biofuels Canada & Navius Research, 2025[163]

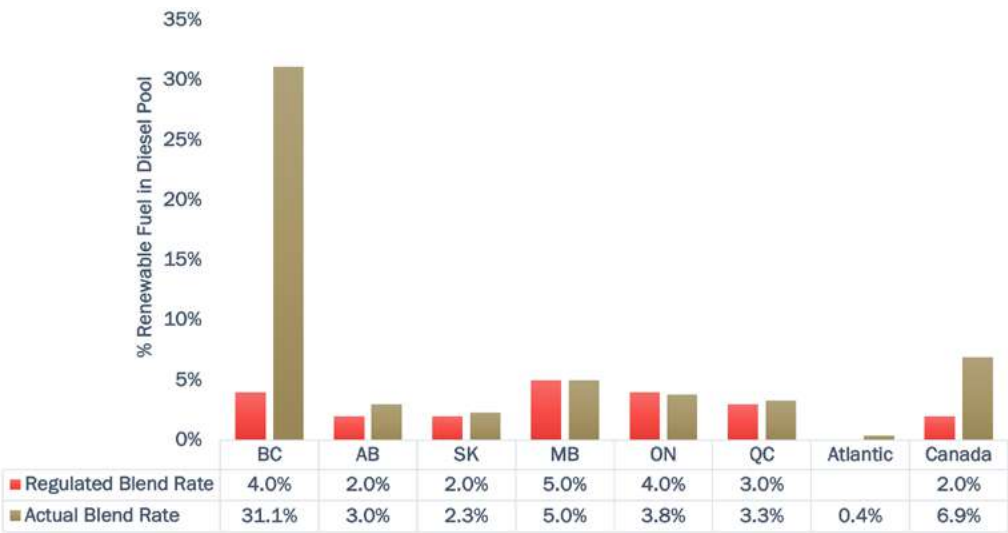


Figure 17. Renewable fuel content in diesel by province (2024)
Source: Advanced Biofuels Canada & Navius Research, 2025[163]

7.3.2 Nature of the Problem

Ethanol

Ethanol represents Canada’s most established alternative fuel, with a history of blending into gasoline dating back decades. Federal renewable fuel regulations have set baseline requirements of 5% ethanol in gasoline, while several provinces have mandated their own standards—Ontario and Manitoba require 10% ethanol, Saskatchewan 7.5%, and all provinces have met or exceeded their standards.[160,164] In 2023, ethanol consumption reached four billion litres, representing 9.44% of the gasoline pool, while production of 1,756 ML fell short of domestic demand of 4,072 ML in 2024 (Figure 18).

Despite its maturity, the niche for ethanol is increasingly narrow. While ethanol can reduce emissions, demonstrating 55% lower carbon emissions than gasoline in 2023 (or about 5% emissions reduction for a 10% ethanol/90% gasoline blend), its application faces fundamental limitations that make it unsuitable as a long-term solution for achieving net zero. [163] Ethanol suffers from inherent technical constraints, including higher oxygen content, corrosivity, and lower energy density, that prevent it from being transported in existing

pipelines and limit conventional vehicles to blend levels of 10–20%.[165] Higher blends like E85 require flex-fuel vehicles and dedicated fuelling infrastructure, which are costly and limited in Canada.

More critically, ethanol’s reliance on food-grade commodities raises sustainability concerns and intensifies the food versus fuel debate. Currently, approximately 400,000 tonnes of corn and wheat are used monthly for ethanol production, creating direct competition with food supply and contributing to potential land-use changes that can result in higher emissions than fossil fuels.[166]

For light-duty vehicles specifically, ethanol presents a dead-end pathway. As electrification becomes more viable for passenger cars and light trucks, ethanol makes an increasingly poor investment compared to BEV infrastructure. The modest but persistent 3% energy loss in E10 blends, infrastructure and blend-wall limitations that prevent higher concentrations, together with competition from other uses for bio-based feedstocks positions ethanol as fundamentally incompatible with deep decarbonization goals for LDVs.[167]

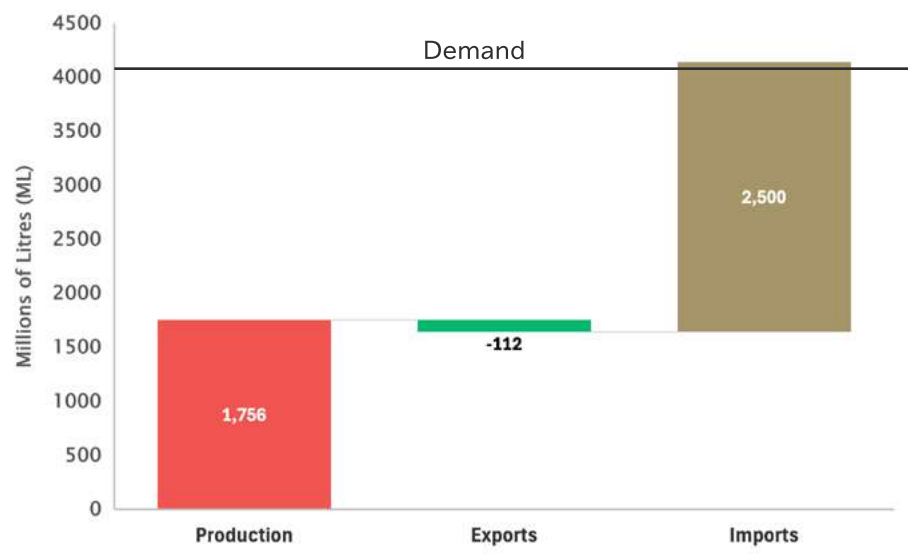


Figure 18. Canada's ethanol supply balance, 2024: Domestic production, trade, and total demand (ML)

Source: NRCan, 2024. Energy Fact Book 2025-26.[162]

Biodiesel and Renewable Diesel

Biodiesel and renewable diesel present a more promising pathway than ethanol, though they carry their own challenges and occupy different market niches. Canada's production of biodiesel and renewable diesel totalled 1,119 ML in 2024, while demand reached 1,005 ML, the first time Canada has filled the substantial supply gap previously filled by imports primarily from the U.S (Figure 19). Renewable diesel consumption more than doubled to 1.2 billion litres in 2023 relative to previous years—surpassing biodiesel for the first time in 2019—and was 2.2 times greater than biodiesel consumption (530 ML, up 14%).[163] Renewable diesel's compatibility with existing diesel infrastructure gives it a logistical advantage. Biodiesel and renewable diesel differ fundamentally in their production processes. Biodiesel is produced through transesterification of vegetable oils and fats, creating a blend-limited product (typically 5–20% with petroleum diesel), while renewable diesel undergoes hydrotreating to become almost chemically identical to conventional petroleum diesel, enabling 100% replacement without blend limits. Although renewable diesel's additional processing can

result in a higher carbon intensity than biodiesel, the chemical similarity of renewable diesel to conventional diesel provides better cold-flow properties and storage stability, enabling higher deployment volumes. The unrestricted blend limits allow renewable diesel to be deployed to meet overall carbon-intensity requirements set by the Canadian Clean Fuel Standard (CFS).

The niche for these fuels lies primarily in heavy-duty applications where their high energy density and compatibility with existing diesel infrastructure provide current advantages over electrification. In 2023, biomass-based diesel demonstrated 87% lower lifecycle carbon intensity than conventional diesel, making it valuable to sectors like long-haul trucking, marine shipping, and industrial heating where today battery electric alternatives remain technically and/or economically challenging.[163]

However, significant obstacles constrain their expansion. Biodiesel faces poor cold-weather performance challenges—blends above 5% have shown persistent gelling unless treated for cold flow and can cause engine challenges

unless properly tuned. Feedstock constraints represent another limitation with volatile prices and competition between food and fuel leading to price instability. Renewable diesel offers better characteristics compared to biodiesel by eliminating cold-weather and engine compatibility problems, but Canada's first standalone renewable diesel facility, owned by Tidewater Midstream, has encountered difficulties. While renewable diesel can be produced from various feedstocks, Tidewater relies on canola oil, tallow from meat processing, and tall oil from pulp and paper production—feedstocks chosen to leverage Canada's agricultural and forestry byproduct streams. But their limited availability constrains overall production capacity and increases processing costs. A second Canadian facility, Braya Renewable

Fuels in Come by Chance, Newfoundland and Labrador, was forced to shut down in January 2025 citing inability to compete with U.S. production tax credits and loss of blender's tax credits, but has since reopened under improved market conditions.[168] Meanwhile, provincial policy is tightening with B.C.'s updated LCFS now requiring renewable diesel and biodiesel be produced in Canada as of April 2025, with a similar requirement for ethanol as of January 2026.[169] At the same time, Imperial Oil's Strathcona Renewable Diesel facility in Alberta is now online and expected to produce up to 1 billion litres per year at full capacity, making it the largest renewable diesel facility in Canada and a major new source of low-carbon diesel for western Canadian markets.

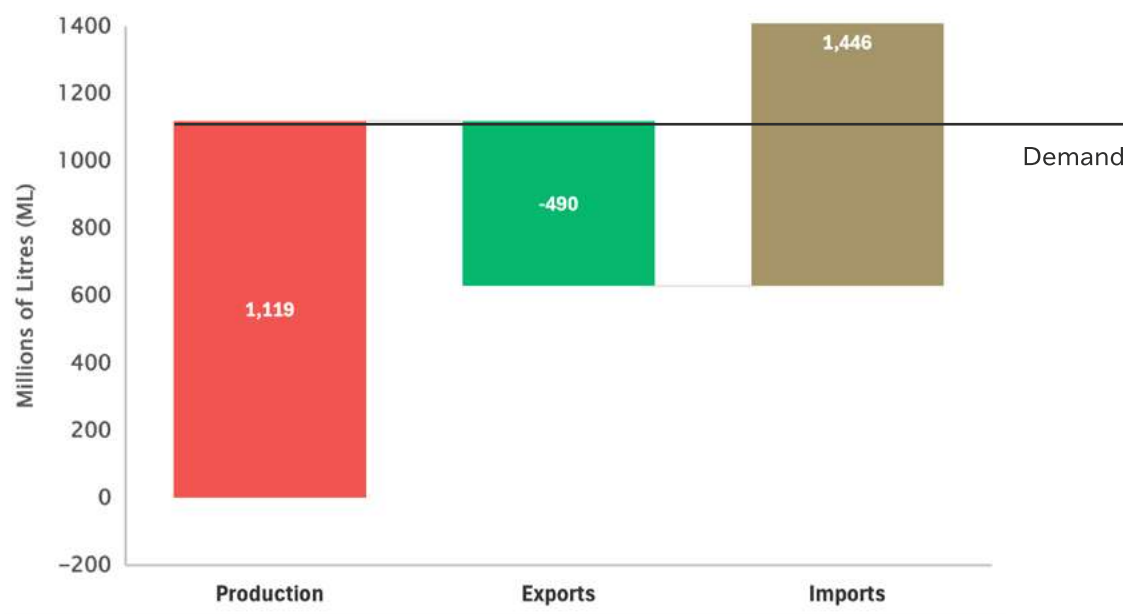


Figure 19. Production, imports, exports, and total demand of biodiesel and renewable diesel, Canada, 2024
Source: NRCan, 2024. Energy Fact Book 2025-26.[162]

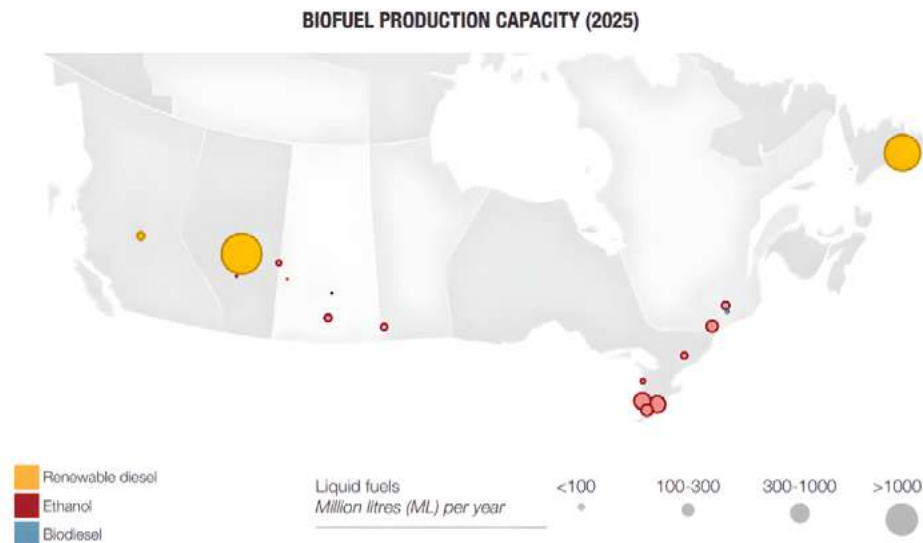


Figure 20. Biofuels production facilities and capacities in Canada, 2025

Source: NRCan, 2024. *Energy Fact Book 2025-26*. [162]

Sustainable Aviation Fuels (SAF)

Sustainable aviation fuels represent the most critical alternative fuel for achieving net-zero emissions given aviation's unique requirements.

The niche for SAF is clear: commercial aviation currently has no reasonable alternative for long-haul flights. Unlike light-duty transport, which can transition to electrification, or short-haul shipping, which may use hydrogen, aviation's energy density requirements and safety considerations make liquid fuels indispensable for the foreseeable future.

However, SAF faces economic and production constraints. SAF is in the emerging phase of transition with current production representing less than 1% of aviation fuel demand globally and remaining virtually absent commercially in Canada, where volumes are still limited to imported SAF and pilot-scale projects and assessments. [170,171] Air Canada's recent purchase of approximately 78 million litres of unblended SAF from Neste constitutes the airline's first commercial import of SAF into Canada and highlights the country's current reliance on overseas production. [172] Economic barriers are also

present with costs two to seven times more than conventional jet fuel. [171]

Most SAF today relies on the Hydroprocessed Esters and Fatty Acids (HEFA) process, accounting for 86% of global SAF production. [171] HEFA draws on waste oils, animal fats, and used cooking oil, as well as virgin vegetable oils — principally canola in the Canadian context — the same feedstocks competing with biodiesel and renewable diesel production. [173] Concerns about indirect land-use change have historically weighed on the carbon credentials of crop-oil HEFA, but emerging evidence suggests those impacts may be overstated for Canadian canola with a stable cropland base. Additionally, Canadian canola is already exported for overseas crushing — so redirecting supply to domestic fuel production largely replaces an existing commodity flow rather than creating new demand. Even with a more favourable outlook, sustainable feedstock supply limits HEFA to a minority of Canadian SAF demand, positioning it as a viable near-term niche pathway within its feedstock scope rather than a full-system solution. As SAF demand scales toward the estimated 24 million tonnes (30 billion litres)

globally required by 2030, feedstock availability will become further constrained,[174] making Fischer-Tropsch routes based on residues and waste—covered below under Advanced Biofuels—essential to meet the balance of aviation fuel demand.

Canada's SAF ecosystem is at an early but pivotal stage. According to a roadmap produced by the Canadian Council for Sustainable Aviation Fuels (C-SAF), the Transition Accelerator, and the Energy Futures Lab, Canada could produce up to 1.2 billion litres annually by 2030, meeting the 10% target.[175] However, unlocking this potential requires mobilizing sustainable feedstocks, investing in at least 10 commercial-scale plants, and putting in place strong policy incentives and offtake agreements.

In Europe, regulatory measures are driving uptake with the EU's ReFuelEU Aviation regulation legally mandating escalation of SAF and e-SAF (synthetic aviation fuel produced from renewable electricity and captured CO₂) shares in fuel pools through 2050. Canada, as a participant in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), is pursuing a federal target of 10% SAF in domestic jet fuel by 2030, while British Columbia has introduced its own 2030 requirement of 3% SAF and a 10% reduction in carbon intensity.

Renewable Natural Gas (RNG)

RNG is produced by upgrading biogas from organic waste sources—including landfills, wastewater treatment plants, agricultural operations, and municipal solid waste—to pipeline-quality gas with a methane content of 90% or greater.[176]

The niche for RNG lies in applications where existing natural gas infrastructure provides distribution advantages and where direct electrification faces technical or economic barriers. This includes industrial heating

processes and residential heating in regions with established gas networks. RNG can be injected directly into existing natural gas pipelines without infrastructure modifications, making it immediately compatible with current systems. However, RNG remains in early stages of deployment, comprising only 0.36% of gas delivered by Canadian utilities in 2021. Moreover, Canada's full realistic biomethane potential (estimated at 91-160 PJ/year) represents only 2-4% of national gas demand, limiting RNG's role to a supplementary blending strategy.[177] Some provinces are also exploring RNG as a tool for peak demand management. In Quebec, dual-energy heating systems are being deployed to manage winter grid peaks, while gas distributors are being pushed to reduce fossil gas use and increase renewable gas within a broader plan to reach 100% renewable energy in buildings by 2040.[178]

The obstacles to RNG expansion include limited feedstock availability relative to total natural gas demand, collection and processing costs, and competition with direct electrification strategies. Production requires either anaerobic digestion systems for wet organic waste or gasification systems for dry biomass, both requiring significant capital investment. The Canadian gas industry has so far failed to meet its 2016 target of a 5% RNG blend nationally by 2025—national RNG capacity reached only about 17.1 PJ in 2025, against the roughly 184 PJ a 5% blend would require—while British Columbia's CleanBC strategy mandates 15% renewable gas content by 2030.[177,179,180]

Advanced bio- and synthetic fuels

Along with hydrogen (explored in section 7.2), advanced biofuels and synthetic fuels are widely viewed as the main scalable options for decarbonizing sectors that will remain difficult to electrify, particularly long-haul aviation and portions of marine shipping. Both advanced biofuels and synthetic fuels

are designed to produce drop-in, energy-dense fuels compatible with existing aircraft and fuel infrastructure, but they differ fundamentally in their primary inputs and near-term readiness.

Synthetic Fuels (Power-to-Liquids / Power-to-X)

Synthetic fuels (often called e-fuels) are produced by combining electrolytic hydrogen (from water electrolysis powered by low-carbon electricity) with captured CO₂ to synthesize hydrocarbons or other energy carriers through Power-to-Liquids (PtL) or broader Power-to-X (PtX) routes. In principle, these fuels can approach very low lifecycle emissions when electricity is near-zero carbon and the carbon feedstock is sourced from the atmosphere (i.e., direct air capture) or other eligible non-fossil streams.

The primary strategic niche for synthetic fuels is hard-to-abate demand where liquid fuels remain indispensable, long-haul aviation, some marine applications, select industrial uses, and, in some systems, as a form of long-duration or seasonal energy storage when clean electricity is abundant.

However, the dominant constraints are electricity intensity and thermodynamic efficiency. Current PtL pathways convert only a fraction of input electricity into usable liquid fuel energy, making costs highly sensitive to the availability of abundant, ultra-low-cost clean power. Synthetic fuel production is also tightly coupled to the cost and performance of enabling technologies (green hydrogen production, CO₂ capture including Direct Air Capture, and advanced fuel synthesis systems) which remain capital-intensive and complex. As a result, synthetic fuels are unlikely to contribute at large scale in the near term but may become important by mid-century for residual emissions in sectors with limited alternatives.

Advanced Biofuels (Biomass-to-Liquids /FT Fuels)

Advanced biofuels provide a nearer-term pathway to drop-in fuels by converting sustainably sourced biomass residues, such as forest or agricultural residues, into liquid hydrocarbons. A key route is Biomass-to-Liquids (BtL), in which biomass is gasified into syngas and upgraded through Fischer-Tropsch (FT) synthesis to produce renewable diesel and SAF. Relative to first-generation biofuels derived from crop oils, residue-based pathways can reduce food-versus-fuel concerns and may leverage established forestry and agricultural supply chains, though they remain constrained by sustainable feedstock availability, transport logistics and costs, and project economics.

Canada has emerging examples of this approach. Expander Energy's Carseland Bio-Synfuels facility (25 ML/y) is positioned as a first-of-a-kind bio-synthetic diesel and SAF project with stated ambitions for near-zero carbon intensity fuel performance with the addition of carbon capture and storage (CCS) for the concentrated bio-CO₂ produced in the gasification-plus-FT process. Highbury Energy's Fort Frances planned biorefinery (20 ML/y) is expected to produce drop-in SAF and renewable diesel with an explicit longer-term objective of reaching near-zero fuel carbon intensity through CCS as well.[181]

Overall, advanced biofuels represent the more credible near-term route to scaling next-generation drop-in fuels from residues, while synthetic fuels are the longer-term option that becomes compelling primarily under conditions of very low-cost, near-zero-carbon electricity and scalable, low-cost CO₂ capture and hydrogen supply.

7.3.3 Net-Zero Pathways

Achieving Canada's net-zero emissions target by 2050 requires a fundamental reorientation of alternative fuel strategy away from the current piecemeal approach toward a comprehensive, technology-specific deployment framework. Strategic prioritization and resource allocation are essential to advancing beyond the Clean Fuel Regulations and provincial policies. To reach net zero by mid-century requires transition of all applications to fully zero- or near-zero-carbon fuels.

Several key pathways can be identified, each with distinct sectoral roles and uncertainty about ultimate market shares. Given deep uncertainty about technology costs, fuel availability, and adoption rates—for example, how rapidly electrification could overtake slower hydrogen and renewable diesel development—the information should be treated as a portfolio of pathways.

Sustainable biofuels from non-food feedstocks

The pathway requires expanding sustainable biofuels produced from non-food feedstocks and waste streams. Second-generation biofuels derived from cellulosic materials (agricultural residues, wood waste, and forest biomass) can avoid food competition challenges while leveraging Canada's significant biomass potential. Advanced processing facilities that convert cellulose and waste into fuels through gasification and Fischer-Tropsch and other thermochemical pathways must be developed, coupled with carbon capture and storage systems to achieve net-negative-emission fuels.[160,182] That said, sustainable biofuels should be prioritized for applications where high energy density and drop-in compatibility with existing infrastructure provide the greatest value.

Synthetic hydrocarbon E-fuels

Synthetic hydrocarbon production using clean electricity and recycled carbon represents a longer-term and potentially necessary complement to advanced biofuels, particularly for aviation applications where bio-feedstock availability will prove insufficient. E-fuel development should focus on applications where electrification is technically infeasible and where the energy storage characteristics of liquid fuels provide system value. However, realistic deployment timelines place e-fuels as post-2035 solutions requiring sustained research and development investment and early deployment in niche, high-value markets, notably aviation and potentially long-distance marine shipping.

Sectoral fuel allocation and primacy of electrification

Strategic fuel allocation becomes critical given finite resources. Light-duty transport should transition primarily to electrification, reserving liquid biofuels—including renewable diesel and other advanced fuels—for heavy-duty trucking, aviation, marine shipping, and industrial heating where alternatives are limited. This requires explicit policy frameworks that prevent alternative fuels from competing with electrification in sectors where batteries provide greater solutions, while acknowledging that the eventual balance between electrification, hydrogen, and renewable fuels in freight and off-road applications continues to be uncertain. Economically, capital for alternative liquid and gaseous fuels is best directed toward long-haul freight, aviation, marine, and industrial heat markets, rather than light-duty road transport.

Renewable Natural Gas as a targeted bridge

Renewable natural gas expansion should focus on waste methane capture and industrial applications where gas provides processing advantages, while recognizing its bridging role rather than permanent solution status. The development of regional biomethane networks can provide near-term emissions reductions while supporting agricultural waste management. In a systematic view, RNG plays a time-limited, niche role: targeting high-leverage waste streams and specific industrial users rather than broad, system-wide gas substitution.

Cross-cutting CCUS and infrastructure integration

The integration of carbon capture utilization and storage technologies across fuel production pathways offers potential for bio-CO₂ as feedstock and net-negative emissions. This will be particularly important for offsetting residual emissions in sectors where complete decarbonization is elusive. The coordinated development of CO₂ transport and storage infrastructure alongside fuel production facilities will be critical.

Taken together, these pathways represent a systematic map of uses based on alternative fuel type. Policy design and investment strategy should therefore emphasize flexibility and periodic review, scaling up those pathways that prove most compatible with rapid electrification and cost-effective emissions reductions.

Competitiveness Implications

When Braya Renewable Fuels shut its Newfoundland facility in early 2025, it cited a specific cause: inability to compete with U.S. production tax credits. When Air Canada made its first commercial SAF purchase (78 million litres from Finland's Neste), it did so because no Canadian producer could supply the volume. Canada's SAF production is virtually zero at commercial scale. The pattern is consistent: feedstock leaves, refined product returns, and the conversion-stage value where margin and industrial capability concentrate accrues elsewhere. Imperial Oil's Strathcona renewable diesel facility and B.C.'s new domestic production mandate show this can be reversed when investment or regulation intervenes. But the gap that matters most now is fiscal: absent a federal framework competitive with U.S. and EU regimes, refining capital will keep flowing to jurisdictions that offer producers greater certainty, and offtake relationships will form around non-Canadian supply. Canada continues to be the only G7 nation without a federal bioeconomy strategy.

7.3.4 Priorities for Action

Secure and stabilize feedstock through regional bio-hubs

A key priority must be establishing regional bio-hubs—sub-provincial clusters organized around an anchor conversion facility—that aggregate and preprocess feedstocks such as wood residues, agricultural wastes, and CO₂ streams before conversion. In this context, regional refers to feedstock catchment areas rather than entire provinces or single cities. Each hub may focus on a subset of compatible feedstocks and products, with modular expansion around the anchor facility rather than attempting to integrate all possible streams from the outset. While more complex than single-molecule hubs (i.e., hydrogen hubs), this can reduce risk by diversifying feedstocks and end-markets within a defined geography.

These hubs ensure reliable, stable supplies and lower costs by co-locating:

- Feedstock collection and preprocessing facilities;
- An anchor biorefinery (either dedicated biorefineries or retrofit support for existing petroleum refineries) to handle bio-crude, bio-oils, and Fischer-Tropsch (FT) intermediates, with capacity that can be expanded as additional feedstock becomes available;
- Logistics coordination and shared infrastructure (including storage and CO₂ handling) to minimize transport emissions and costs.
- Federal incentives for refitting existing refinery infrastructure or deploying new biorefineries will catalyze early adoption and unlock domestic value addition.

Build integrated regional fuel hubs

Once feedstock security is in place from bio-hubs, develop integrated regional fuel hubs that co-locate conversion technologies (i.e., pyrolysis, gasification, electrolysis) alongside end-users. This approach captures value domestically while minimizing transport costs and embedded emissions from larger feedstocks. Strategic positioning near biomass or CO₂ sources can dramatically reduce the cost and logistical barriers that constrain deployment.

Align alternative fuels with hard-to-electrify sectors

Given the finite sustainable feedstock resources, alternative fuels should be prioritized where the most value is added and directed toward sectors where electrification is currently not possible and may remain out of reach, including some heavy-duty trucking, aviation, marine shipping, and certain types of industrial heating.

Accelerate commercial-scale RD&D and demonstration

Accelerated RD&D should move beyond pilot projects toward first-of-a-kind (FOAK) commercial facilities demonstrating scalability and economic viability. Priority should focus on cellulosic pathways for SAFs, advanced biomass conversion technologies, and integration of CCS to achieve net-negative emissions.

Develop early-stage hydrogen and CO₂ infrastructure

The development of hydrogen and CO₂ supply hubs underpins both e-fuel production and broader decarbonization of hard-to-abate sectors. There should be a focus on early infrastructure development to break investment chicken-and-egg cycles while supporting multiple industrial applications concurrently.

Strengthen policy, procurement, and strategic coordination

Policy frameworks require strengthening and refinement to create predictable demand signals supporting long-term investment. While Canada's Clean Fuel Regulations provide a foundation, achieving net zero may need more aggressive carbon intensity requirements. Public and private procurement by government fleets, military operations, and crown corporations can provide necessary early demand signals. Canada remains the only G7 nation without a federal bioeconomy strategy tying biomass use to emission-reduction targets. A national policy framework should:

- Link climate goals explicitly to sustainable biomass deployment;
- Tighten carbon intensity requirements under the Clean Fuel Regulations;
- Leverage government, military, and crown-corporation procurement to provide early, predictable demand signals.

Standardize carbon accounting and life-cycle assessment

Common emissions accounting standards and verification systems should also address the fundamental gap undermining investor confidence. Current LCA methodologies create uncertainty—both from absent indirect land use change accounting, which can overstate benefits, and from reliance on legal global economic models whose indirect land-use change assumptions may overstate impacts for feedstocks like Canadian canola. Standardized systems provide credibility needed for large-scale investment.

Incentivize domestic value-add production

Finally, policy frameworks should incentivize value-added processing within Canada to create economic benefit while reducing costs through shorter supply chains. Fostering domestic capabilities must address Canada's position as a raw material exporter importing refined products.

 Fails to meet criteria Meets in some respect
 Not promising Potentially meets criteria
 Meets criteria

ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Deep lifecycle emission reductions with forestry and other organic residues.	Higher direct production cost than HEFA but cheaper per tonne of CO₂ abated. Still requires policy support and offtake certainty.	Strong domestic potential. Integrated biorefineries, forest and agricultural residue value chains, and Canadian opportunities in gasification and FT.	Integrated FT-SAF at commercial scale is pilot/demo. Limited Canadian deployment.	Drop-in replacement for jet fuel. No aircraft or fuelling infrastructure changes required.	Biomass and residue supply chains emerging. FT synthesis and low-carbon H₂ infrastructure not yet at scale. Aviation blending infrastructure is in place.	Generally positive. Waste valorization and residue use are supported by communities.	Forest sector and waste managers for waste valorization. Federal government funding R&D.	Multiple co-benefits: waste diversion, forest management support, co-production of renewable diesel. No food competition or land use change concerns.
Moderate to deep lifecycle reductions depending on feedstock/crop chosen and associated land use changes. Crop-oil HEFA can exceed some fossil fuel intensities. Would require removals for net zero.	High costs relative to fossil jet fuel. Viability depends on policy support.	Moderate opportunity for domestic production in crop oil (i.e. canola) regions. Limited Canadian IP. Technology is imported.	Commercial globally. Canadian facilities are emerging.	Drop-in replacement for jet fuel. No aircraft or fuelling infrastructure changes required.	Compatible with existing blending and distribution infrastructure. Sustainable feedstock supply is the main constraint on domestic scale.	Virgin crop oils face growing food-vs-fuel and land-use concerns. Concerns less acute for Canadian canola given its stable cropland base.	Some airlines and airports actively purchasing fuel, limited by cost and supply. Federal regulations in progress; some provinces are further ahead.	Waste-oil and tallow feedstocks provide waste valorization option. Risks from indirect land-use change and pressure on food/feed markets.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Heavy Duty Diesel End Users											
Renewable Diesel	Niche Pathway Drop-in fuel compatibility and strong lifecycle reductions. Supports hard to electrify end users. Long term net-zero alignment requires sustainable feedstocks and removals.	Deploy Continue support to ensure cost parity. Provide education to end-users on drop-in capabilities.	 Drop-in fuel, delivering significant lifecycle CO ₂ cuts. Net zero requires sustainable feedstocks and complementary carbon removal.	 Currently requires support for price parity.	 Potential for domestic production and associated jobs.	 Commercial and rapidly scaling.	 Fits existing diesel engines and distribution networks without retrofit. Better cold-weather performance than some alternatives.	 Uses existing storage and pipelines but can be difficult to procure.	 Concerns of competition with food crops.	 Interest from hard hard-to-electrify industrial end users (i.e. trucking fleets). Developing interest from fuel producers to supply emerging markets, but confusion remains with properties of other alternative fuels.	 Improves air quality while retaining energy density. Risk of locking in diesel dependency for end users who could otherwise electrify.
Biodiesel	Potential Dead-End Pathway Provides near-term emission reductions using existing engines and infrastructure. Blending limits and feedstock availability limit uptake.	Don't Prioritize Not drop-in. Provide information on the quality differences between renewable diesel and biodiesel.	 Can cut tail-pipe CO ₂ significantly, but blending limitations exist with unmodified engines. Net zero requires sustainable feedstocks and complementary carbon removal.	 Costs greater than fossil fuel diesel.	 Creates domestic demand for used cooking oil and canola oil, boosting farm and refining sectors. Competes with food.	 Commercial, but climate-grade quality still improving.	 Compatible with diesel engines to B20. Cold weather performance and material sedimentation limit higher blends.	 Separate heated tanks are needed in winter. Logistics become complex above the B20 blend.	 Generally positive when made from wastes. Land-use change for virgin crops draws scrutiny.	 Can be less relevant than renewable diesel.	 Improves lubricity and reduces particulate matter. Offers a practical bridge until zero-emission drivetrains dominate.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Heat and Power Production											
Renewable Natural Gas (RNG)	<i>Potential Niche Pathway</i> Complements hard-to-electrify end uses and applications. Limited feedstocks constrain scale.	Enable Support projects that reduce methane emissions from waste. Focus funding on projects with secured long-term end users.	 Moderate GHG reduction. Methane capture benefits. Net-zero requires sustainable feedstocks and complementary carbon removal.	 Viable with support. Cost competitive under supportive policy environment.	 Creates jobs in waste management and valorizes agricultural residues.	 Emerging commercial.	 Compatible with existing pipelines and end-use equipment.	 Fully compatible with gas networks. Limited by feedstock availability and interconnection.	 Varying acceptance. Issues with increased traffic and odours. Seen as waste valorization.	 Seen as economic addition for agricultural and waste management. Gas utilities to leverage existing networks.	 Reduces fugitive methane. Potential for fertilizer production.
 Light Duty Vehicles											
Ethanol	Dead-End Pathway Limited lifecycle emissions reductions and sustainability concerns make ethanol unlikely to have a meaningful role in net zero.	Dismiss Not net-zero in its primary use of light duty vehicle decarbonization. Support transition to other pathways.	 Limited GHG reductions. Food-vs-fuel controversies over land use and feedstocks.	 Affordable and viable with support.	 Low value-add. Small rural jobs. Competes with food.	 Fully commercial.	 Compatible with gasoline blending up to E10. Higher blends need flex-fuel vehicles.	 Incompatible with existing pipelines beyond 10% blends. Requires new infrastructure.	 Mixed: accepted historically but declining due to sustainability concerns.	 Provincial regulators and oil refiners. Limited OEM engagement.	 Reduces gasoline emissions modestly. Supports legacy ethanol plants.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Advanced Bio and Synthetic Fuel Pathways											
Advanced Biofuel (Biomass-to-liquids)	Niche Pathway Delivers deep emissions reductions where sustainable feedstocks/ biogenic CO ₂ and low-carbon electricity exist, but restricted by localized and limited ability to obtain feedstocks.	Incubate Support R&D projects.	 Achieves high emissions reductions but requires substantial biomass feedstocks/biogenic CO ₂ and clean power. Feedstocks used must be decarbonized. May still require removals.	 High production costs due to complex multi-step conversion. Requires supportive policy environment.	 Creates integrated biorefineries and supports biogenic carbon capture build-out. Some provinces developing demonstration projects.	 Pilot/ demonstration.	 Drop-in compatibility with all diesel engines and aviation turbines.	 Requires biomass or biogenic carbon supply chains, gasification plants, and synthesis facilities. Forestry residue supply chain exists.	 No particular concern.	 Forest sector and waste managers for waste valorization. Federal government funding R&D.	 Multiple co-benefits: waste diversion, forest management support, co-production of renewable diesel and SAF. No food competition or land use change concerns.
Synthetic / E-Fuel	<i>Potential Niche Pathway</i> Potential for net-zero compatibility with offset or directly captured CO ₂ and low-carbon hydrogen.	Don't Prioritize Watch to see if economics or maturity improve; support if progress is made.	 Potential for deep lifecycle reductions. Carbon intensity depends directly on the H ₂ source and how CO ₂ is captured or offset.	 Not viable. High electricity input and low conversion efficiencies. Costs hinge on low-carbon H ₂ and CO ₂ capture/offset maturing at scale.	 Long-term manufacturing potential. Requires new industrial clusters.	 R&D/Concept.	 Drop-in compatibility with all diesel engines and aviation turbines.	 Requires low-carbon hydrogen, captured or offset CO ₂ (i.e. from direct air capture), and synthesis plants. No existing supply chain.	 Public awareness is low. Acceptance will depend on framing. Conceptually attractive as a “drop-in” net-zero fuel.	 Research institutions, energy ministries as a long-term feedstock-secure fuel production pathway.	 Unaffected by biomass supply chain instabilities.

7.4 OIL AND GAS

Function	Fuels for transportation, power generation, space heating, industrial processes, and feedstock for multiple industries including chemicals and fertilizers.
GHG emissions	190–200 Mt CO ₂ e annually, representing about 28–31% of Canada's emissions (208 Mt or 30% in 2024).[74] Emissions from the sector have increased over recent decades, driven by production growth, and are concentrated in upstream production and processing.
Options for decarbonization	Decarbonization Pathways: Methane abatement, electrification of upstream operations. Niche Pathways: Carbon Capture and Storage, blue hydrogen. Enabling Pathways: on-site clean power, lithium extraction from oilfield brines, geothermal power. Reduce production-related emissions to the lowest level possible through methane abatement, carbon capture, and efficiency improvements.
Stage of transition	Emerging: Blue hydrogen, lithium extraction from oilfield brines, geothermal power Diffusion: Methane abatement, electrification of upstream operations, carbon capture and storage, on-site clean power
Nature of the problem today	Emissions and emission intensity are high, and long-lived infrastructure and capital stock create transition complexity. Policy signals on decarbonization have strengthened since 2021 but remain subject to political uncertainty.
Other systemic issues	Deep economic dependence on oil and gas revenues in producing regions; environmental liabilities including abandoned wells and tailings ponds.
Opportunities and concerns	Leverage existing labour skills, industrial expertise, and infrastructure to support energy transitions; develop and export emissions-reducing technologies; avoid stranding assets prematurely through a managed and predictable transition.
Priorities for action	Reduce production emissions through methane abatement, efficiency improvements, and electrification of upstream operations. Strengthen industrial carbon pricing to provide a durable signal for carbon capture utilization and storage and other longer-term abatement investments.
Longer-term issues	Managing demand decline and macroeconomic impacts as electrification accelerates domestically and globally; reclamation liabilities; workforce and community transition in producing regions.
Indicators of progress	Sector production emissions and emissions intensity; upstream methane emissions.

7.4.1 Current Status

Canada's oil and gas sector is one of the country's most significant industries. Canada is the world's fourth-largest oil producer and fifth-largest natural gas producer. The sector directly contributed roughly 6% of national GDP in 2024, and supports approximately 200,000 direct jobs, with considerably more employment across supply chains and service industries.[154] In 2024, 93% of Canadian crude oil exports were directed to the United States, down from 97% the previous year due to the completion of the Trans Mountain Expansion Project.[183] The sector's economic weight is particularly concentrated in Alberta, Saskatchewan, British Columbia, and Newfoundland and Labrador, where it shapes provincial fiscal positions, investment patterns, and community livelihoods.

Since the 2021 edition of this report, the sector's operating context has shifted considerably. The collapse in global demand through 2020 and early 2021 caused widespread financial losses, asset write-downs, and accelerated consolidation across the industry.[184] Conditions reversed sharply with the post-pandemic recovery and the energy price shock following foreign conflicts, and Canadian producers recorded operating profits of \$66.6 billion in 2022.[185] Prices and

margins have since moderated from those highs, though oil sands production has continued to grow, supported in part by the Trans Mountain pipeline expansion. At the same time, global energy markets are being reshaped by accelerating electrification, tightening environmental standards in importing countries, and intensifying geopolitical competition over energy supply chains. The policy landscape in Canada has also evolved, with strengthened methane regulations, investment tax credits for carbon capture and clean hydrogen production and the introduction and subsequent withdrawal of a proposed federal oil and gas emissions cap in favour of a negotiated carbon pricing framework.

These developments underscore a fundamental reality: the oil and gas sector will continue to generate revenue and employment for Canada in the coming years, but the terms on which it does so are changing. How Canada manages this transition, which involves reducing production emissions, positioning for evolving global markets, and rolling out end-use alternatives (such as electric vehicles and heat pumps) that will ultimately reshape demand, will have significant consequences for national prosperity and regional economic stability.



7.4.2 Nature of the Problem

The oil and gas sector is Canada’s largest source of greenhouse gas emissions. According to the most recent national inventory data, the sector accounted for approximately 208 Mt CO₂e in 2024, representing roughly 30% of Canada’s total emissions.[61,186] Within the sector, oil sands production is the dominant source (approximately 44% of sector emissions), followed by natural gas production and processing, conventional oil production, and petroleum refining.[61,187]⁹ Production growth has been the primary driver of emissions increases: total crude oil output has roughly tripled since 1990, with oil sands production increasing more than eightfold over that period.[187]¹⁰

Of course, production-related emissions represent only a fraction of the total climate impact of oil and gas. When the end-use combustion of oil and gas products is included (in vehicles, furnaces, industrial equipment, and power generation), the full lifecycle emissions are roughly five times greater than production emissions alone.[188]

In a net-zero framework, this distinction matters. Reducing production emissions is necessary, but the larger prize, in emissions terms, lies in displacing the end-use combustion of fossil fuels through electrification and the deployment of alternative energy carriers. This is the central argument of this report: the most effective long-term strategy for reducing the emissions associated with oil and gas is to electrify demand.

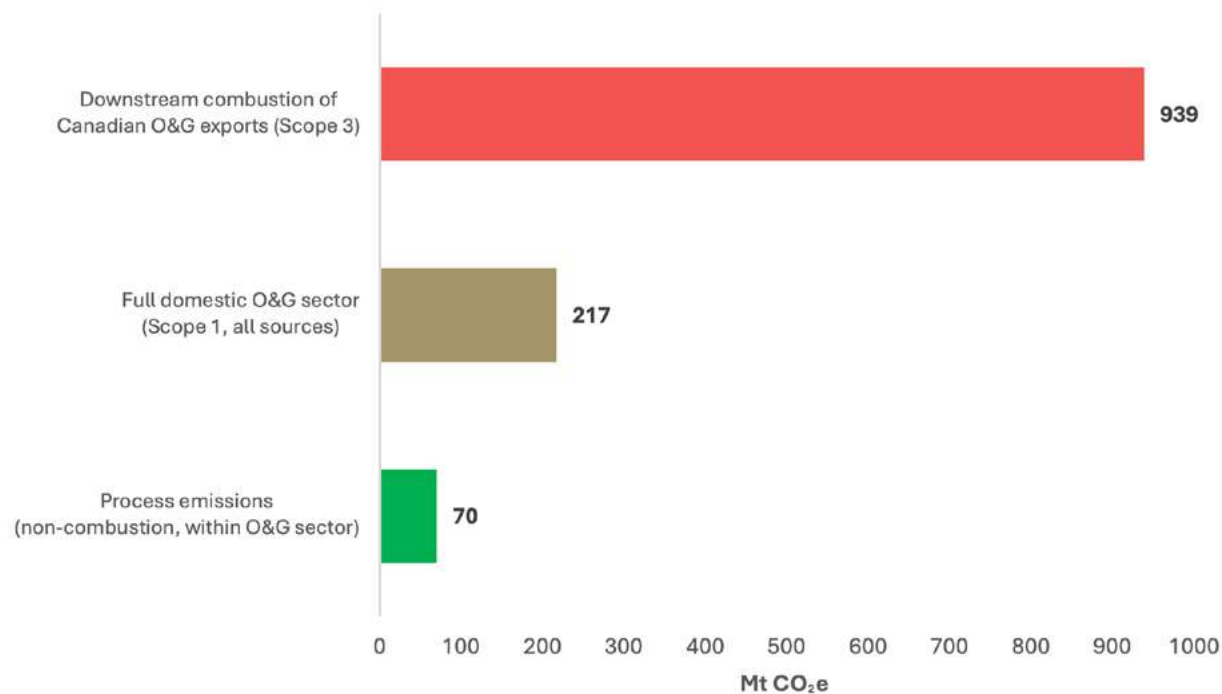


Figure 21. 2022 Process vs. Downstream Combustion (Mt CO₂e)
Source(s): Environment and Climate Change Canada, *Greenhouse Gas Sources and Sinks in Canada: Executive Summary 2026 (2025)*[46]. *Climate Action Tracker, Canada’s Uncounted Emissions (2024)*. [189] International Energy Agency, *Energy Balance (2024)*. [190]

9 ECCC, 2024 National Inventory Report (data for 2022). Oil sands: 87 Mt (40%); natural gas production and processing: 54.5 Mt; conventional oil: 39 Mt; petroleum refining: 17 Mt.
10 From 1990 to 2022, total crude oil production increased by 193%.

The scale of those downstream combustion emissions also reflects a structural feature of Canada's export position. The vast majority of Canadian crude oil exports flow to the United States, and the bulk of production- and transmission-related emissions from the sector are tied to supplying that single market. The United States is itself on an electrification trajectory, likely slower than Canada's, but directionally the same.[191] As U.S. end-use demand for oil and gas gradually contracts, Canadian producers will face pressure to redirect volumes. The obvious alternative is Asian markets, and Canada is positioning itself as a stable and reliable supplier to the Indo-Pacific. But those markets are simultaneously pursuing strategies to reduce their own hydrocarbon dependence, driven not primarily by climate policy but by energy security concerns: a lesson reinforced by recurring supply disruptions, price volatility, and the 2026 closure of the Strait of Hormuz.[192] The practical implication is that the long-run market environment for Canadian oil and gas is structurally more constrained and more competitive than near-term prices suggest, and that this dynamic compounds the challenge of justifying long-lived capital investment in conventional production.

Beyond greenhouse gas emissions, the sector carries significant environmental liabilities. These include multi-billion-dollar reclamation obligations from inactive and orphaned wells, unfunded liabilities associated with oil sands tailings ponds, and widespread landscape fragmentation.[193] These obligations represent fiscal and environmental risks that grow with the continued expansion of conventional operations and require proactive management regardless of the pace of the energy transition. In this sense, they are not simply legacy issues; ensuring adequate financial provisioning for these liabilities and not deferring costs to future taxpayers is a governance issue that grows more urgent with time.

The transition challenge is not only environmental or technological, but also economic and institutional. The most significant obstacle to the sector's transition is the gap between the long-term direction of the global energy system and the near-term economic incentives facing producers. Oil and gas remain highly profitable, and current commodity prices reward continued production expansion. In this context, investment in deep decarbonization competes directly with returns from conventional operations. While record profitability provides the financial capacity to invest in transition, the commercial pressure to deploy capital toward production growth is strong.

Infrastructure lock-in compounds this dynamic. Canada's oil and gas asset base (wells, pipelines, upgraders, processing plants) was built for a fossil-fuel economy and represents hundreds of billions of dollars in sunk capital. Retrofitting or repurposing this infrastructure for lower-emission operations requires significant additional investment, and in some cases is technically infeasible. Continued investment in conventional long-lived assets further strengthens this lock-in and raises the risk of future stranded assets.

Policy signals have become more directional, and federal-provincial friction has eased since the November 2025 Canada-Alberta MOU and its May 2026 Implementation Agreement, which replaced the contested emissions cap with a negotiated carbon pricing framework and streamlined project assessment processes. Whether these commitments prove durable remains to be seen, and international factors — including the evolving U.S. regulatory and trade landscape — add further uncertainty for long-term capital allocation decisions.

The political difficulty of imposing greater stringency on production emissions is real, but it will diminish as international markets increasingly differentiate on emissions

intensity. As carbon border mechanisms and importer standards take hold, the market case for low-intensity production aligns with the regulatory case. Over time, this could shift the balance of leverage between governments and industry, making stronger production-side requirements more politically and economically defensible.

In the long term, global demand for oil and gas is projected to plateau and eventually decline as electrification advances across major economies, though the pace and timing continue to be uncertain and are subject to geopolitical, technological, and policy variables. How quickly this demand contraction reaches Canadian producers will be shaped by the competitiveness of Canadian production, the success of carbon border mechanisms in importing countries, and the availability of lower-cost alternatives. This creates a difficult planning environment, whereby near-term market conditions still support expansion, even as the longer-term direction of travel points toward a more competitive and constrained market.

So long as domestic and international demand for oil and gas products remains robust, the economic case for supply-side transformation is harder to make. This reinforces the strategic priority of accelerating demand-side electrification while preparing for a more uncertain long-term market environment.

7.4.3 Net-Zero Pathways

In a net-zero world, fossil fuels will still have a role, but a significantly diminished and different one. Residual uses may include feedstock for petrochemicals, liquid fuels for aviation, specialty products such as lubricants, asphalt, and waxes that lack near-term substitutes, and fuel supply for remote and off-grid communities where infrastructure alternatives are uneconomical.

Beyond these residual uses, it is worth noting that even absent a global policy commitment to net zero, structural pressures on fossil fuel demand are already intensifying. The world's largest energy-importing regions—Europe and Asia—have powerful and durable incentives to electrify and reduce their dependence on imported hydrocarbons. Those incentives are not primarily climate-driven: they are strategic. Recurring supply disruptions, price volatility, and the concentration of critical transit routes in geopolitically unstable regions have consistently demonstrated the systemic vulnerabilities of fossil fuel import dependence. The 2026 closure of the Strait of Hormuz, which the IEA described as the largest oil supply disruption in the history of the global oil market, is only the most recent, and most dramatic, illustration of this dynamic.^[194] For major importers, the energy security case for electrification is increasingly entangled with the climate case, and both are pointing in the same direction.

These pressures reinforce a central conclusion of this report: the trajectory of Canada's oil and gas sector toward net zero involves action on two distinct fronts: reducing emissions from production operations and managing the structural decline in fossil fuel demand as end-use sectors electrify. The following pathways describe the principal options available to the sector. They are not mutually exclusive; a realistic trajectory will combine elements of each, with the balance shifting over time as technologies mature and markets evolve.

Reduce production emissions while continuing to produce oil and gas.

This pathway focuses on driving production-related emissions toward the lowest achievable levels through a suite of technologies: methane abatement (leak detection and repair, elimination of routine venting and flaring), electrification of

upstream operations, carbon capture and storage at major facilities, process efficiency improvements, and the use of lower-emission extraction technologies. This is the pathway most directly aligned with the current industry trajectory, and it has received significant policy and investment attention.

Canada has made measurable progress on this front. Methane emissions from the oil and gas sector fell approximately 40% between 2014 and 2023, even as production continued to grow.[195] The federal government finalized enhanced methane regulations in December 2025, targeting a 72% reduction from 2012 levels by 2030.[196]

These developments have unfolded alongside a broader federal-provincial realignment. The November 2025 Canada-Alberta Memorandum of Understanding set aside the proposed federal emissions cap in exchange for Alberta's commitment to strengthen industrial carbon pricing and advance carbon capture investment. This led to an agreement-in-principle in March 2026 on methane equivalency,[197] an April Co-operation Agreement streamlining environmental and impact assessments for major projects,[198] and a May 2026 Implementation Agreement that formalized the MOU's commitments on carbon pricing and the Pathways CCS project.[199]

However, aside from methane abatement, the policy environment around decarbonizing production emissions is in flux. In late 2024, the Trudeau government published proposed regulations to cap upstream oil and gas emissions through a cap-and-trade system. [192] The proposal drew strong opposition from industry and producing provinces, and the November 2025 Canada-Alberta MOU effectively set it aside. The federal government agreed to forgo the cap in exchange for Alberta's commitment to

strengthen industrial carbon pricing and invest in carbon capture.[201]

With the emissions cap off the table, industrial carbon pricing is now the primary regulatory signal for decarbonization investment in the sector. But that signal is itself weakened. Alberta froze its Technology Innovation and Emissions Reduction (TIER) carbon price at \$95 per tonne in 2025,[202] and the market price collapsed to between \$17 and \$40 per tonne, due to a surplus of banked credits and weak demand.[203] The May 2026 Implementation Agreement attempts to address both problems, establishing a rising headline price schedule and a credit price floor reaching \$130 per tonne by 2040.[199], At these prices, there is little economic incentive for producers to invest in deep emissions reductions.

This matters directly for the viability of carbon capture at scale. The flagship initiative, the Pathways Project, a proposed \$16.5 billion CO₂ pipeline and storage hub in northern Alberta backed by the five major oil sands producers now organized as the Oil Sands Alliance,[204] depends on robust carbon credit revenue to close its business case. The May 2026 Implementation Agreement commits both governments to completing a trilateral MOU with the Oil Sands Alliance and extends the Alberta Carbon Capture Incentive Program to support it.[199] The project also faces structural cost challenges: CCS in remote oil sands operations is expensive relative to other abatement options, and independent analyses have raised doubts about whether it can break even under current cost trajectories.[205] Even at full scale, the project would address only a portion of production emissions.

The economic logic of this approach is straightforward: as global markets increasingly differentiate between higher- and

lower-emission sources of energy, Canadian producers with lower production-emission profiles will be better positioned to retain market access and command premium pricing. The EU's incoming methane intensity standards for imported fuels, and similar signals from Asian importers, reinforce this competitive case.[206]

Nevertheless, this faces real constraints. Reducing production emissions to near zero is technically demanding and capital intensive, particularly for in-situ oil sands operations. It would raise production costs, reducing economic competitiveness. And while the carbon intensity of barrels could theoretically be a market differentiator, this signal has not yet materialized into a market advantage, making long-term decarbonization investments harder to secure absent strong regulatory signals.

Develop net-zero energy products and alternative uses for hydrocarbon resources.

Rather than producing oil and gas exclusively for combustion, some segments of the industry could shift toward net-zero energy carriers, principally hydrogen produced from natural gas with carbon capture (so-called blue hydrogen), or potentially electricity generated from natural gas with CCS. Alberta's geological advantages for carbon storage, existing pipeline infrastructure, and established gas processing expertise give the province a cost advantage in blue hydrogen production.

Interest in hydrogen as an energy carrier has grown substantially since 2021, driven by industrial decarbonization needs in sectors like steel, cement, and heavy transport, as well as by emerging export opportunities. Canada's federal hydrogen strategy and provincial strategies in Alberta and British Columbia have established frameworks for development.[207] However, low-carbon hydrogen production at

scale remains in early stages, and the business case depends on sustained demand growth, infrastructure buildout, and continued cost reductions. More details about hydrogen's role in a net-zero energy system are available in the hydrogen section of this report.

Beyond energy carriers, hydrocarbon resources can serve as feedstock for non-combustion products: petrochemicals, carbon fibre, activated carbon, and other advanced materials. Bitumen-beyond-combustion concepts such as these have received research attention in Canada.[207] These applications could generate value from hydrocarbon resources without the associated combustion emissions, though most are at early commercial stages and none would match the economic scale of existing oil and gas operations.

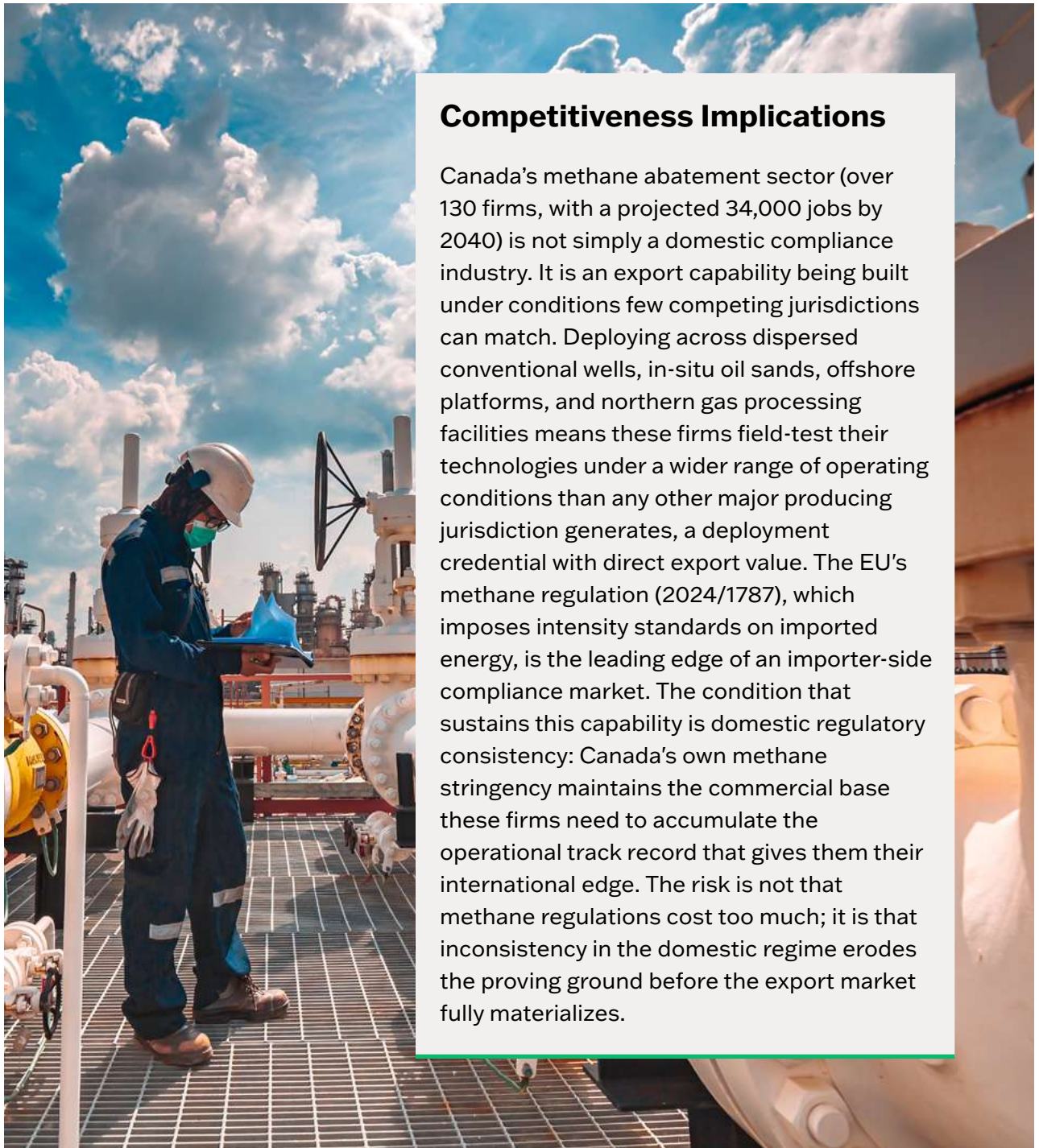
Diversify into adjacent energy and resource sectors.

Some oil and gas companies are already diversifying into adjacent areas, such as renewable electricity generation, geothermal energy, critical minerals, and carbon management services. Lithium extraction from oilfield brines is being actively explored in Western Canada.[208] Alberta and Saskatchewan have significant solar and wind resources. CCUS is itself becoming a commercial service industry, with the sector's geological and engineering capabilities directly transferable.

Geothermal energy serves as an interesting example to repurpose existing expertise to support renewable energy development since it can leverage subsurface expertise, drilling technologies, and geological data from the oil and gas sector.[209,210] Emerging advanced geothermal systems including closed-loop technologies developed by Calgary-based Eavor, which require no fracking or water and can be deployed across a much wider range of geological settings than conventional

geothermal, are drawing international interest. [211] Canada's first co-produced geothermal power plant is already operating at Swan Hills, Alberta, using legacy oil and gas well infrastructure.[212] Alberta established a formal regulatory framework for geothermal development in 2022, including provisions for converting existing oil and gas wells to geothermal use.

This approach is best understood not as a direct replacement for oil and gas activity but as part of a portfolio strategy that builds resilience and captures emerging opportunities. Its relevance will grow as the energy transition progresses, global demand patterns shift, and new revenue streams mature.



Competitiveness Implications

Canada's methane abatement sector (over 130 firms, with a projected 34,000 jobs by 2040) is not simply a domestic compliance industry. It is an export capability being built under conditions few competing jurisdictions can match. Deploying across dispersed conventional wells, in-situ oil sands, offshore platforms, and northern gas processing facilities means these firms field-test their technologies under a wider range of operating conditions than any other major producing jurisdiction generates, a deployment credential with direct export value. The EU's methane regulation (2024/1787), which imposes intensity standards on imported energy, is the leading edge of an importer-side compliance market. The condition that sustains this capability is domestic regulatory consistency: Canada's own methane stringency maintains the commercial base these firms need to accumulate the operational track record that gives them their international edge. The risk is not that methane regulations cost too much; it is that inconsistency in the domestic regime erodes the proving ground before the export market fully materializes.

7.4.4 Priorities for Action

Focus on end-use electrification as the highest-impact use of limited government capital. As this report argues throughout, the most consequential reductions in emissions associated with oil and gas will come not from within the sector itself, but from displacing the combustion of fossil fuels in transportation, buildings, and industry. These end-use emissions represent roughly 80% of the lifecycle total.[213] Governments face real constraints on fiscal and political capital, and directing that capital toward grid buildout, EV adoption, heat pump deployment, and industrial electrification delivers the largest structural impact. As these transitions advance, they reduce domestic fossil fuel consumption and, over time, reshape global demand patterns, and provide a timeline for diversification strategies to develop.

Implement and maintain strong methane regulations. Methane abatement is the most cost-effective near-term emissions reduction available in the sector, with abatement costs estimated at \$48 per tonne CO₂e or less. Canada's enhanced methane regulations, finalized in December 2025, provide a clear framework, though a March 2026 Alberta-Ottawa agreement-in-principle on provincial implementation timelines has introduced some uncertainty of its consistent application.[197,214] Maintaining regulatory consistency and supporting the growth of Canada's methane abatement technology sector, which already includes over 130 firms and has the potential to create 34,000 jobs by 2040, strengthens both the climate and competitiveness case.[195]

Employ regulations and fiscal measures to encourage sector emission abatement through electrification, efficiency and CCUS approaches. If an industrial pricing regime is to be maintained, its architecture should be sufficiently robust to encourage incremental change from a business-as-usual scenario.

Support hydrogen development and net-zero fuels where the economics and demand warrant. Blue hydrogen production leverages Canada's natural gas resources, CCS expertise, and geological storage capacity. Federal and provincial hydrogen strategies should focus on building demand in hard-to-electrify sectors (e.g., industrial heat, heavy freight) and on the infrastructure needed to connect supply and demand.

Prepare for regional economic adjustment. As the energy transition progresses, producing regions will face adjustment pressures. Proactive investment in economic diversification, workforce development, and community transition planning done well in advance of acute economic disruption is essential. This includes supporting the development of new industries and value chains that can absorb the transferable skills concentrated in oil and gas regions, including engineering, project management, geosciences, and skilled trades. Because these capabilities and communities are geographically concentrated, transition planning must be place-based and proactive, rather than generic. It should be designed to ensure that producing regions participate in the economic upside of the energy transition rather than simply bearing its adjustment costs. This is both an economic and a political imperative.

 Fails to meet criteria Meets in some respect
 Not promising Potentially meets criteria
 Meets criteria

ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Targets one element of oil and gas production emissions. Reduces significant near-term GHG emissions. Would require complementary measures including carbon removals to get to net zero.	Low cost compared to other direct GHG management measures. Potential to recover saleable gas, partially offsetting costs.	Growing market for specialized oil and gas equipment. Canada has many technology firms and can export tech and expertise.	Many technologies mature and used across Canada.	Integrates with existing processes.	Relies entirely on existing upstream infrastructure. Well-established domestic supply chain of equipment manufacturers, service companies, and measurement technology providers.	Reduces pollution. Broadly accepted.	Relevant to governments and producers as frequently lowest cost abatement option.	Can improve air quality around operations.
Can eliminate meaningful share of emissions from specific facilities. Does not address very dilute upstream sources or end-use combustion. Will require additional removals.	Adds operating cost without revenue generation. Requires strong policy signals.	Potential for CCS expertise as an export.	Mature for some applications. Used internationally and in Alberta.	Retrofits feasible at large point sources. More complex at distributed upstream facilities.	Requires CO₂ pipelines and storage hubs. Alberta geology is well-characterized but transport network is limited.	Public concern around long-term leakage and liability. Mixed Indigenous perspective.	Strong industry interest. Weak regulatory signals.	Co-benefits through CO₂ feedstock for industrial uses. Continued environmental concerns from oil and gas production.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electrification of upstream operations electric drives, grid-tied facilities, co-gen displacement, vehicle fleet and equipment electrification	Decarbonization Pathway Essential to decarbonizing the energy used in oil and gas production. Requires decarbonized electricity.	Deploy Prioritize transmission build-out into oil sands basins. Requires supportive policy environment.	Can decarbonize many upstream operations, equipment and process heat, but dependent on decarbonized electricity.	Economics currently challenged and would require significant policy intervention.	Stimulates demand for clean power, transmission, and electrical trades. Retains regional employment.	Deployed at Canadian sites, including some oil sands in-situ operations.	Requires facility redesign and reliable grid access or substantial decarbonized on-site generation.	Requires significant transmission build-out and generation capacity additions.	Generally supported. Transmission corridor siting can attract opposition.	Limited stakeholder engagement.	Reduces local air pollution and noise. Risk of stranding existing assets.
Hydrogen Fuel Switching Cogeneration and gas turbines, process boilers, compression drives, vehicles and equipment	<i>Potential Niche Pathway</i> Viable decarbonization lever for combustion assets where electrification is difficult. Dependent on low-carbon hydrogen supply.	Enable Advance where low-carbon hydrogen supply is credible and off-take is firm. Prioritize turbine hydrogen-readiness in new cogeneration builds.	Can achieve significant CO ₂ reductions. Net zero only achievable with near-zero upstream methane leakage and high-capture rate CCS and removals.	Economics currently challenged and would require significant policy intervention.	Leverages Alberta's existing gas processing expertise and CCS-ready geology for hydrogen production.	Maturity varies by technology.	Existing cogeneration units can blend hydrogen. Sole use of hydrogen will require substantial upgrades or equipment replacement and NOx control systems.	No dedicated hydrogen supply infrastructure exists at O&G production sites. Requires new production facilities, compression, pipelines or on-site storage.	Safety concerns around hydrogen flammability and storage.	Alignment with government hydrogen strategies. Active investment by some producers and OEMs in hydrogen-ready turbine upgrades.	Repurposes sector expertise. Produces NOx emissions but better overall air quality.
Low-Energy Extraction Technologies Solvent-assisted steam-assisted gravity drainage (SAGD), radio-frequency and electro-magnetic heating	<i>Potential Enabling Pathway</i> Could be part of a net-zero system provided decarbonized production. May reduce the energy intensity — and potentially emissions — of in-situ oil sands extraction.	Incubate Support R&D, field pilots, and transparent reporting of real-world performance data before commercial scaling.	Reduces energy intensity and associated emission but does not eliminate emissions. Requires decarbonized production.	Potential operational cost savings from lower steam and energy use. High capital costs.	Canadian-led R&D ecosystem with IP and service industry potential.	Pre-commercial. A few pilots and demonstrations exist with limited long-term field data.	Can retrofit some SAGD assets. Requires process changes and operator training.	Largely uses existing oil sands infrastructure and well pads.	Mixed perception. Performance claims are held primarily by industry. Limited independent verification.	Relevant to government and academia with pilots. Important to industry if cost savings occur.	Energy and water savings. Reduced steam-to-oil ratio. Land-use impacts persist.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
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On-Site Clean Power Generation (Small modular reactors, solar and wind)	Enabling Pathway Provides low-carbon electricity and/or heat directly to remote upstream facilities where grid access is absent or unreliable. Enables electrification of operations.	Incubate Avoid scaling investment ahead of proven economics. With improvement continue R&D and pilot funding for SMRs and electrothermal storage. Advance regulatory frameworks for nuclear deployment in Alberta.	 Can fully decarbonize on-site power and heat when powered by zero-emission sources.	 Solar and wind cost-competitive in some contexts but intermittency requires storage investment. Small modular reactors uneconomic for oil sands applications under current conditions.	 Small modular reactor development would leverage Alberta's engineering and supply chain base and create high-skilled jobs.	 Solar and wind mature but limited application in remote northern sites. Small modular reactors are not commercially available in Canada and are not proven at remote sites.	 Small modular reactors co-location with SAGD facilities creates new regulatory and safety challenges. Solar/wind requires storage and backup to match continuous 24/7 steam demand.	 No nuclear supply chain established for remote locations. SMR components require new manufacturing pathways. Renewable on-site power supply chains more developed.	 Public awareness of nuclear energy in Alberta is low. Opposition exists from communities near proposed sites and some Indigenous groups. Renewable opposition also exists.	 Alberta and federal governments actively exploring small modular reactors. Some interest from producers but economics are the limiting factor. Renewables have a low-level of interest.	 Improved air quality from zero-emission power generation. Potential to export power surplus to the grid. Timelines may create significant stranded asset risk if oil sands demand declines faster than anticipated.
 Net-Zero Products from Hydrocarbon Resources											
Blue Hydrogen (Natural gas Reforming with CCS, methane pyrolysis, autothermal reformation with CCS)	Niche Pathway Leverages Canada's gas resources and geological storage to generate net-zero energy. Contingent on very low upstream methane leakage.	Enable Advance where end-use demand is firm. See hydrogen section for detail.	 Can approach net zero only at high capture rates and with near-zero upstream methane emissions. May require carbon removals for residual emissions.	 More cost-competitive than green hydrogen. Contingent on gas prices, capture costs, and durable policy signals.	 Leverages existing gas processing expertise and subsurface storage. Export potential through Western corridors.	 Steam methane reforming with CCS is commercial internationally. Other technologies are in demonstration and pre-commercial.	 Builds on existing gas-processing practices. Integrates with proposed CCS hubs.	 Requires hydrogen demand, new hydrogen distribution, storage, and CCS network build-out.	 Concerns of upstream methane leakage. Safety concerns related to hydrogen handling.	 Some investment by major producers. Interest from some provincial governments.	 Repositions gas assets for a decarbonized economy. Extends fossil fuel production.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electricity Production from Natural Gas with CCS	<i>Potential Niche Pathway</i> Can be used as a backup power source while renewables are built out or for marginal balancing in a net-zero system. Potential export opportunity.	Incubate Support R&D for carbon capture from existing natural gas assets. Watch for local or regional power reliability issues.	 Difficult to capture all emissions with CCS. Requires negative emissions, which can be limited, to offset lifecycle emissions.	 Costly due to CCS. Needs subsidies but may become moderately competitive for baseload power.	 Electricity export potential in limited regional circumstances.	 Demonstration stage. Technology for post-combustion capture from gas turbines is being tested.	 Best suited to baseload or steady-output roles, cycling and peaking operation reduces capture efficiency. Retrofitting existing plants is feasible but requires significant site engineering.	 Benefits from existing infrastructure but requires new CO ₂ pipelines and strong methane management.	 Opposition remains over continued fossil fuel reliance and CO ₂ storage concerns.	 Relevant to gas producers and suppliers, Alberta, and industries needing firm power.	 Offers reliable low-carbon power and aids grid stability. Air quality and health issues with conventional combustion.
Non-Combustion Uses for Bitumen (i.e. Carbon fibre, asphalt binder, energy storage devices)	<i>Potential Niche Pathway</i> Extracts value from bitumen, avoiding combustion emissions.	Incubate Continue targeted R&D and build market linkages into carbon-constrained value chains.	 Avoids combustion emissions from bitumen. Requires up-stream abatement of methane and CO ₂ . May require removals.	 Long-term outlook unclear and varies by product. Competition from cheaper feedstocks.	Diversification opportunity for Alberta. Demand for carbon materials is growing.	 Mostly laboratory and early pilot stage.	 Requires new processing facilities separate from conventional refining.	 Requires new supply chains, manufacturing capacity, and networks. Asphalt binder faces specific transportation difficulties.	 Concerns about tailings, land disturbance, and reclamation.	 Active government-funded ecosystem. Producers supportive as feedstock suppliers, end use commitments limited.	 New markets and reduced reliance on combustion revenue. Continued upstream environmental liabilities.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Resource Diversification											
Lithium Extraction from Oilfield Brines (Direct Lithium Extraction)	Enabling Pathway Repurposes sector capital, infrastructure, and workforce to supply critical minerals for the broader energy transition. Does not directly reduce oil and gas emissions.	Incubate Support piloting, validation, and integration with existing oilfield infrastructure; align with federal and provincial critical minerals strategies.	 Supports the broader net-zero transition rather than abating sector emissions directly.	 High capital costs. Costs expected to fall as technology matures. Price exposed to global lithium markets.	 Diversification opportunity. Builds on subsurface and brine-handling expertise. Battery supply chain opportunities.	 Pilot and demonstration stage. Provincial projects advancing, but no commercial operations to date.	 Uses existing wells, brine handling, and operational know-how. Minimal disruption from operations.	 Leverages existing facilities and well pads. Downstream critical mineral supply chain is nascent in Alberta.	 No particular concerns.	 Strong alignment with federal critical minerals strategies. Active industry participation.	 Low land disturbance. Regional diversification. Workforce transition pathway for oilfield service firms.
Geothermal Power (Closed loop, Conventional, and Deep)	Enabling Pathway Geothermal has potential for generating net-zero electricity and heat. Can transition oil and gas expertise to a net-zero industry.	Enable Build up regulatory frameworks. Support transitioning expertise. Support closed loop R&D as well as pilot and demonstration projects.	 Conventional geothermal releases some carbon dioxide. Closed loop geothermal is more promising for net zero.	 Not cost-competitive in Canada due to high drilling and capital costs. Potentially viable in remote locations.	 Established Canadian leadership in advanced geothermal. Drilling and subsurface, expertise transferable from oil and gas. Strong technology export potential.	 Demonstration stage with one closed loop project under construction in Canada. Deep geothermal in early research. Conventional geothermal is mature.	 Drilling, subsurface knowledge, and brine management map directly from oil and gas operations. Alberta regulatory framework includes provisions for well conversion. Site-dependent and best suited to regions with accessible heat at depth.	 Can leverage oil & gas infrastructure and expertise with standard equipment and a ready supply chain. Closed-loop systems require specialized tools not yet in domestic supply chains.	 Significant concerns of seismic activity for conventional geothermal. Support from off-grid Indigenous communities with closed-loop systems.	 Western provinces, oilfield service firms, and federal innovation programs as a transition opportunity. Utilities are cautious. Active investment in Canadian technologies.	 Baseload zero-emissions power —addresses intermittency of other renewables. Low land and water footprint. Can affect water quality if conventional geothermal is used.

TRANSPORTATION





Canada's advantage in electric vehicles lies in its potential to develop an integrated battery and automotive value chain anchored in critical minerals, clean electricity, and existing automotive manufacturing capacity.



8. Transportation

Few things shape daily life in Canada more than the movement of people and goods. Transportation gets people to work, to school, and to one another. It carries the food, fuel, and materials that keep the economy moving. Today most transport still runs on fossil fuels, and this constitutes Canada's second-largest source of greenhouse gas emissions.

The majority of passenger journeys are made in personal vehicles: the cars and light trucks found in driveways across the country, which convey more than 80% of Canadian commuters. Most of the country's freight travels by truck, from the delivery vans threading through cities to the long-haul rigs on highways. Beyond the road, rail carries bulk freight and people over long distances; ships move cargo through ports and along the coasts and inland waterways; aircraft connect a country too large to cross easily any other way; and off-road machinery is at work in mines, farms, forests, and construction sites. All operate almost exclusively on petroleum-based fuels.

The clearest route away from fossil fuel dependence is electrification. Battery-electric vehicles already offer a mature alternative for cars and light trucks, and the technology is moving steadily into delivery vans and heavier trucks. But electrification cannot reach every mode with equal ease. Long-haul trucking, marine shipping, and aviation face distance and energy demands that batteries cannot yet meet—and here low-carbon fuels and hydrogen can close the gap. Decarbonizing transportation means electrifying wherever it is practical, turning to alternative fuels where it is not, and alongside both, reducing how much vehicle travel is required.

The discussion that follows concentrates on three elements of road transport where emissions and abatement opportunities are largest: light-duty vehicles, medium- and heavy-duty trucks, and the mass transit systems that serve commuters in Canada's larger metropolitan regions. Aviation, marine, rail, and off-road transport each raise distinct challenges that will not be examined further here but have been analyzed in other work from The Transition Accelerator.

As the following analysis will make clear, transitions in transport confront real challenges and trade-offs. Vehicle lifetimes of a decade or more mean that purchases made this decade will shape emissions into the 2040s. Progress in market segments where electrification is difficult will depend on low-carbon fuels and hydrogen. And questions remain as to whether Canada can retain a place in vehicle and battery manufacturing as global production reorganizes around electric drivetrains.

The assessments that follow do not attempt to predict how quickly the vehicle fleet will turn over or which technologies will prevail in every case. They do indicate the direction of probable advance and are intended to help decisionmakers distinguish options that appear most promising, those that face unresolved barriers, and those unlikely to deliver at the scale some anticipate.

8.1 LIGHT-DUTY VEHICLES (LDVs)

Function	Mobility for work, shopping, social activities, recreation.
GHG emissions	11.4% of Canadian emissions in 2023 (78.2 Mt CO ₂ e)[215]. Represents 41% of transportation emissions; additional emissions associated with production of gasoline.
Options for decarbonization	Decarbonization pathway: Battery electric vehicles. Bridge pathway: Plug-in hybrid vehicles. Potential niche pathway: Hydrogen fuel cell vehicles. Enabling pathways: Modal shift, shared mobility models, vehicle right-sizing.
Stage of transition	Diffusion: Battery electric vehicles. Emergence: Fuel cell.
Nature of the problem today	Structural dependence of the transportation system on private vehicle ownership; uneven charging/refuelling infrastructure; slow fleet turnover with long vehicle lifetimes (10-15 years); policy and market uncertainty; supply side challenges in scaling electric vehicle production.
Other systemic issues	Air and noise pollution; traffic congestion; car-dependent land-use patterns; automotive industry manufacturing, workforce and service ecosystem transition.
Strategic opportunities and concerns	Opportunities: Electric vehicles (EVs) offer lower fuel and maintenance costs and total cost of ownership; reduced air pollution; Canada holds strategic advantages in critical minerals, clean electricity, and existing manufacturing capacity that could anchor a domestic battery and EV value chain. Concerns: Without sufficient investment in EV manufacturing and supply chains, existing Canadian auto sector jobs and industrial capacity are at risk; loss of competitiveness to global leaders; range anxiety, cold-weather performance, charging times, high voltage and fire risks, and increased dependence on original equipment manufacturers for maintenance and servicing.

Priorities for action	Subsidies and incentives for EV purchases; infrastructure investment for home, depot, and corridor charging including in multi-unit residential buildings; government fleet and procurement standards; support for domestic EV and battery manufacturing and value chain development; enable shared mobility and modal shift; consumer education on EV costs and performance; workforce training and reskilling for mechanics and service technicians.
Longer-term issues	Managing grid integration, complementary technologies, smart charging, and vehicle-to-grid; integration with connected and autonomous vehicles; end-of-life recycling/disposal; EV and battery supply chain concentration risk.
Indicators of progress	Share of zero-emissions vehicle sales and fleet; rate of fleet turnover; availability and accessibility of charging infrastructure; domestic EV and battery production capacity and value chain development; and growth of independent aftermarket service ecosystem.

8.1.1 Current Status

The global auto industry has been a pillar of economic development for more than a century and plays two distinct but interrelated roles in Canada's economy. First, it is the backbone of personal mobility, with roughly 89% of Canadian households relying on at least one car or light-duty truck (SUVs, pickups, vans)[216]. Second, it is a major industrial sector, directly employing more than 125,000 workers and contributing \$16.8 billion to GDP.[217] Its role in mobility has evolved gradually with the expansion of mass transit and changing travel patterns, but its role as an economic engine is poised for a fundamental transformation in the coming decades.

On the mobility front, light-duty vehicles (LDVs) play a major role in Canada's transportation system. Between 2008 and 2024, the vehicle population grew by 37% (from 19.6 million to 26.8 million), with light-duty trucks making up the fastest-growing segment.[218,219] Today, more than 80% of Canadian commuters rely on a personal vehicle to get to work, underscoring the central role of LDVs in Canada's transportation system.[220]

In addition to its large share of personal transport, Canada has a substantial auto manufacturing sector that is a major economic driver. Five multinational companies (Stellantis, Ford, GM, Honda and Toyota) operate vehicle assembly plants, supported by a network of parts suppliers, machine tool and electronics firms, and testing and R&D facilities.

The fundamentals of this industry have changed drastically over the past two decades. In the early 2000s, production was dominated by a relatively stable cohort of North American, European, and Japanese manufacturers competing primarily on brand, features, and incremental improvements within an internal combustion engine (ICE) system. Back then, Canada was assembling roughly 2.9 million vehicles per year, accounting for about 17% of North American output.[221]

Canada's position in the global market has been in steady decline since then. By 2024, assembly had fallen to approximately 1.3 million units—a decline of more than half. Over the same period, Canada's share of North American production dropped by more than eight percentage points, as Mexico overtook Canada as the continent's lowest-cost producer.[222] The shift to electric

powertrains is moving the centre of industrial value to battery supply chains which Chinese firms now dominate. In fact, China went from producing roughly 2 million vehicles in 2000 to over 31 million by 2024.[223]

This decline in manufacturing comes at a time when supply chains are reorganizing around electrification of LDVs. The five Canadian assemblers are all legacy ICE-oriented manufacturers, and incumbent automakers across North America and Europe have struggled with this transition. U.S.-based automakers have been particularly hard hit in recent years. They belatedly began to invest heavily in EV production under the Biden administration, which provided subsidies for EV purchases and generous support for battery plants and EV assembly facilities. With the election of President Trump, the policy environment was reversed. The removal of production and consumption incentives for electrification, as well as the tariff and trade-related disruptions to the integrated North American auto market, caused billions of dollars in losses for legacy automakers.[224]

For the Canadian industry, the trade issue is existential, with the U.S. threatening to end or dramatically re-write the Canada-U.S.-Mexico free trade agreement (CUSMA), potentially robbing the export-oriented Canadian industry of access to its critical market.[225] The automotive industry provides the country's second-largest export. Most motor vehicles and parts go to the United States (94% in 2024).[226] This leaves the sector highly exposed to shifts in U.S. trade policy, continental industrial strategy, and cross-border supply chain dynamics at precisely the moment when the global industry is being reorganized around electrification and new centres of competitive advantage.[227]

In Canada, zero-emission vehicles (ZEVs) reached 18.3% of new vehicle registrations in 2024, falling back to 11.2% in 2025. These dynamics—the pace of electrification, the concentration of battery supply chains, and the repositioning of major producers—are increasingly shaping vehicle availability, costs, and competitiveness in the Canadian market.

8.1.2 Nature of the Problem

GHG emissions from LDVs are a central decarbonization challenge in Canada as they make up 11.4% of the national emissions (78.2 Mt). 41% of Canadian transportation emissions overall are from LDVs.[215] Almost all LDVs run on gasoline (95% of LDV energy consumption); the remaining 5% run on diesel, propane, electricity and natural gas.[228]

Over time, the fuel efficiency of internal combustion engine (ICE) vehicles has improved, mainly due to strict air pollution regulations.[229] Though these measures have lowered GHG emissions per vehicle, total annual LDV emissions have not declined significantly.[230] This reflects both growth in the vehicle fleet and a shift toward larger, less efficient vehicles—particularly SUVs and pickup trucks, which now dominate the market.[231,232]

The core challenge is therefore structural. Canada's transportation system is highly dependent on personal vehicles, and the existing vehicle population is overwhelmingly powered by ICEs. Vehicles also have long lifetimes, often 10–15 years or more, meaning that emissions reductions depend not only on new vehicle sales, but on the gradual turnover of the existing fleet.

Decarbonizing the LDV sector requires a system-wide transition to ZEVs, alongside supporting infrastructure and policy. Several key challenges remain:

- **Charging:** Infrastructure is expanding but remains uneven, especially in rural and remote areas and for residents of multistory buildings; access, cost, and charging time remain barriers.[233]
- **Grid capacity and infrastructure readiness:** Large-scale electrification will require significant expansion and coordination of electricity systems.
- **Affordability of ZEVs:** Higher upfront costs remain a barrier, particularly for high-demand vehicle segments such as pickup trucks and SUVs.[234]
- **Technology perceptions:** Concerns about range, cold-weather performance, and safety persist, though they are diminishing.
- **Policy and market uncertainty:** Changing ZEV sales mandates, consumer incentives, and trade measures create uncertainty for consumers and investors.
- **Workforce and service ecosystem transition:** Electrification reduces mechanical complexity and shifts maintenance needs, increasing dependence on original equipment manufacturers (OEMs) and requiring reskilling of mechanics and service workers.

The battery supply chain that underpins the new industrial architecture is concentrated in China, not North America. The window for Canada to build a meaningful position in EV and battery production is narrowing. If it closes, the long-running erosion of Canada's auto sector will accelerate as the global transition gathers pace. The problem is particularly acute in the absence of a home-grown OEM.

8.1.3 Net-Zero Pathways

Decarbonizing Canada's LDV sector requires transforming both vehicle technologies and the broader transportation system.

LDV decarbonization

There are two main technological routes to decarbonize power trains in vehicles: electrification or the use of alternative fuels. Electric vehicles are largely seen as the better solution and, therefore, the focus of this section. For an evaluation of the difficulties with alternative fuel approaches—such as blending ethanol with gasoline, switching to renewable natural gas, biofuel vehicles, or synthetic (non-fossil-derived) gasoline—see the assessment table below.

The movement to net-zero GHG emissions requires a fundamental shift in vehicle design away from ICEs. Battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs, which have auxiliary gasoline motors), hybrid-electric vehicles (HEVs, with gasoline engines and battery storage charged from regenerative braking), or hydrogen fuel cell electric vehicles (FCEVs) are alternatives. BEVs offer lower lifetime vehicle costs (reduced operating and maintenance costs), improved performance, and elimination of tailpipe air pollutants (i.e. particulate matter, nitrogen oxides, VOCs). HEVs, without plug-in capabilities, are not discussed further, as they are a dead-end pathway, not a bridge between gasoline and electric vehicles. They require gasoline to operate and do not drive the buildout of charging infrastructure required by BEVs.

BEVs are in the diffusion phase and are the dominant ZEV design. Vehicle functionality has improved, and producers are benefiting from improved economies of scale, infrastructure rollout, complementary innovations, and favourable regulatory and policy frameworks.[77] PHEVs are also in diffusion, offering a bridge pathway between

ICE and fully electric powertrains. FCEVs remain in the emergence phase with limited infrastructure and niche applications.

The total cost of ownership for BEVs is now often lower than that of ICE vehicles, driven in part by global battery pack prices dropping 25% compared to 2023 levels. [235] While EVs experience only slightly greater range reductions in cold weather than ICE vehicles (14%–39% versus 12%–28%), performance in low temperatures can

be a concern. That said, cold-weather performance and overall vehicle range (both major consumer concerns) have steadily improved over time.[236–238]

The deployment of charging infrastructure has expanded significantly across Canada, from 313 chargers in 2019 to close to 40,000 in 2024, but remains uneven across regions, particularly in rural and remote areas (Figure 22).[151,233]

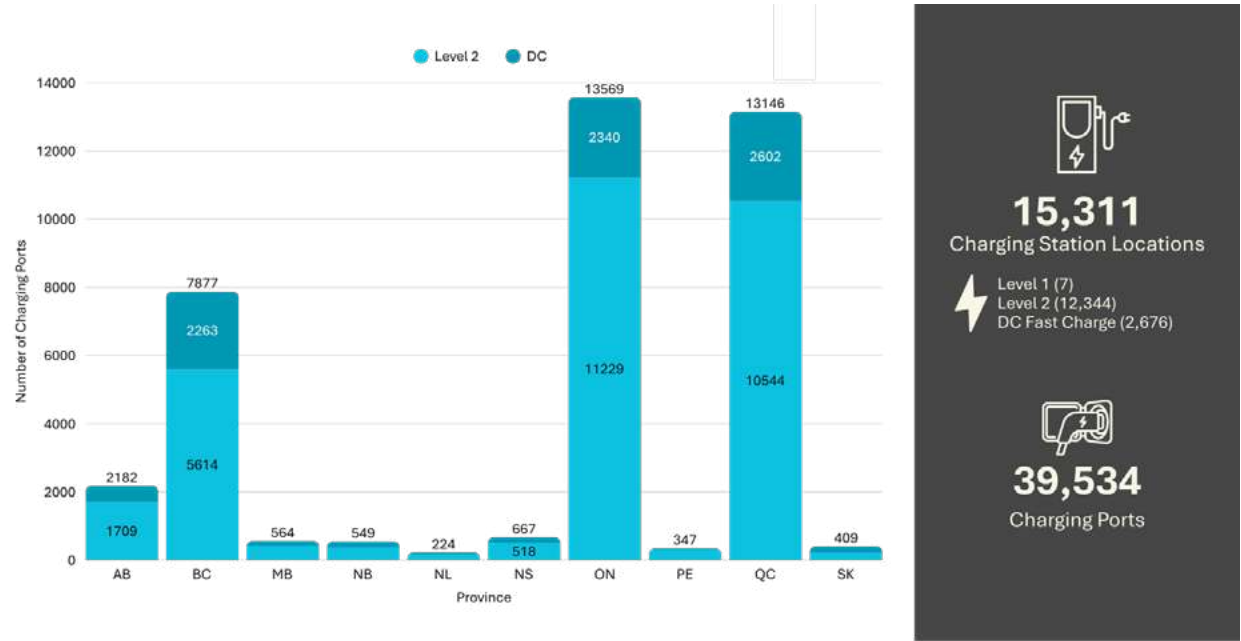


Figure 22. Total number of EV charging station locations and charging ports by province and charger type
Source: Natural Resources Canada, 2024. Electric Charging and Alternative Fuelling Stations Locator.[151]

Broader transportation system changes

Electrification alone will not achieve net-zero emissions. Reducing demand and shifting travel behaviour are also essential.

Modal shift: Increasing the share of trips made by public transit, active transportation (walking and cycling), and shared mobility (carpooling) can significantly reduce per-capita emissions, particularly in urban areas.[239]

Shared mobility services: The growth of car-sharing platforms, ride-hailing, micromobility and other mobility-as-a-service models can reduce vehicle ownership and increase utilization rates, lowering total vehicle numbers over time.[240–242]

Vehicle efficiency and right-sizing: Encouraging smaller, more efficient vehicles (particularly in urban contexts) can reduce energy demand even as electrification progresses.[243]

Efficient land-use planning: Compact, transit-oriented development can reduce reliance on personal vehicles, shorten or consolidate trip distances, and support lower-emission travel behaviours.[243]

Automotive industry transformation

Over the past decade, international EV production has ramped up to exceed 17 million in 2024, with over 70% of that production taking place in China.[244] Globally, EVs make up about 22% of car sales but have taken a larger share in a few lead markets (Norway 92%, Sweden 58%, Denmark 56%, Finland 50%, and China and the Netherlands 48%).[245] The balance of sales between types of EVs in 2024 was dominated by BEVs with 86% of sales. PHEVs made up 14%, and FCEVs remained negligible.[245]

While early innovation in modern electric vehicles was driven by new entrants such as Tesla, the current phase is characterized by the rise of Chinese manufacturers.[246] Firms such as BYD, SAIC, and Geely now lead in scale, cost competitiveness, and speed of innovation, supported by deep integration across battery supply chains, critical minerals processing, and manufacturing ecosystems. China accounts for the majority of global EV production and sales, and in 2025, BYD overtook Tesla as the world's largest EV manufacturer.[247]

In North America, the pace and structure of the transition to electric vehicles have been increasingly shaped by trade and industrial policy disruption. U.S. tariffs on vehicles, steel, and auto parts have placed significant pressure on Canada's auto industry. In response, Canada has adjusted elements of its regulatory approach, reducing the EV sales target to 75% in 2035, and developing new vehicle emissions standards. Canada has also recently announced strategic partnerships with South Korea and China that aim to strengthen domestic EV manufacturing and position Canada within a more diversified global market.[248–250] EV adoption is proceeding gradually in Canada reflecting a smaller market scale, less mature supply chains, and evolving policy and trade conditions.

Automobile production in Ontario is today based almost entirely around ICE vehicles. As the global transition in this sector gathers pace, existing manufacturing jobs face growing long-term uncertainty. Expanding EV market share and strengthening domestic industrial capacity are essential to a competitive Canadian auto industry.

While the direction of travel with vehicle electrification is clear, the pace of change remains very much in question. Breakthrough technologies rarely progress in a smooth line. The automobile's original century-long rise was punctuated by plateaus and dips that, with hindsight, look like minor ripples. The message for EVs is clear: short-term setbacks in cost, infrastructure, or supply chains are normal features of the diffusion curve—not signs that the transition is stalling.

Canada's advantage in electric vehicles lies in its potential to develop an integrated battery and automotive value chain anchored in critical minerals, clean electricity, and existing automotive manufacturing capacity. Canada holds significant reserves of key battery inputs (i.e. nickel, cobalt, lithium, and graphite) and has an established mining sector, but current analysis shows that much of the value in global supply chains is captured downstream in refining, battery materials, and cell production. Federal benchmarking highlights that while Canada has activity across the battery ecosystem, midstream capacity—such as battery-grade chemicals, cathode and anode materials, and cell manufacturing—remains limited, representing both a gap and a strategic opportunity.[251]

Canada cannot expect to be a first-rank player in the global automotive industry (like Germany, China, or the United States), but even a second-tier position with a strong presence in particular niches could generate substantial economic value. Attracting foreign partners can speed up development. It is not clear that incumbent auto makers will dominate EV production in the future. New entrants are joining the sector, and battery and drive-chain technologies are still at the beginning of their development curves. If Canada is to have a place in this future, governments must take an active role to chart a path forward, build capacity, attract capital, and support training and R&D.

8.1.4 Priorities for Action

Ensure affordability and broaden access to EVs

Currently, federal and provincial governments offer a range of incentives to encourage light-duty EV purchases, and initial investments have been made in vehicle charging networks. As of the beginning of 2026, the federal government has launched a five-year EV affordability program with purchase or lease incentives up to \$5,000 for BEVs and \$2,500 for PHEVs. This incentive prioritizes vehicles under \$50,000 and Canadian-made EVs.[248] Provincial incentives for light-duty EVs are additive to federal incentives, constantly evolving, and vary considerably by province or territory.

Purchase incentives will remain necessary in the near term but should evolve to become more targeted and efficient. Policy actions include:

- Maintaining time-limited, declining purchase incentives to bridge the upfront cost gap until parity is reached.
- Expanding support for used EV markets (i.e. tax credits, financing tools, and certification programs).
- Targeting incentives toward segments with high emissions or financial need (i.e. high-mileage drivers, fleets, rural or remote users, low and middle-income households, small business operators).
- Expanding access to lower-cost ZEV models (i.e. the recent allowance of Chinese EVs in the Canadian market).[249]

Build a targeted charging ecosystem

Infrastructure remains a major barrier, but the issue is not simply the total number of chargers. Canadian and international experience point to the need to be strategic in charging build-out. Most charging happens at home, but future adoption will increasingly depend on access in multi-unit residential buildings (MURB) and along inter-city corridors. A recent Canadian infrastructure analysis found that meeting future demand will require major retrofits in multifamily buildings and policy changes to ensure new housing is EV-ready.[252] Though the government is investing \$1.5 billion into building out charging and hydrogen fuelling infrastructure, Canada still lacks a clear roadmap for infrastructure expansion. [248,253,254]

Priority actions, therefore, include:

- Prioritizing **home and depot charging**, where most charging occurs.
- Accelerating deployment in **MURBs** through building codes, retrofit incentives, and regulatory changes.[255,256]
- Building out **fast-charging corridors** to support inter-city travel and reduce range anxiety.
- Targeting **rural, remote, and underserved regions** where private investment is less likely.
- Enabling **private-sector investment models** (utilities, charging networks, real estate developers).
- Integrating charging rollout with **grid planning and demand management** (smart charging, time-of-use pricing, “vehicle to grid” energy storage applications) to ensure sufficient grid capacity.

Provide stable policy signals and align supply with demand

A coherent and durable policy framework is essential to support both consumer adoption and industry investment. Though ZEV sales are growing, Canada lacks a time-phased roadmap that coordinates vehicle, infrastructure, and market policies. Providing long-term emissions standards, charging investments, procurement signals, aligned provincial and federal policies, and consumer incentives while avoiding abrupt stop-start changes will ensure consumer confidence and manufacturer investment. Public procurement and government fleet commitments can also play a useful anchoring role by creating predictable demand.[248,257–259]

Link consumer transition to industrial strategy and battery value chains

For Canada, the LDV transition is not only about reducing emissions from vehicles already on the road; it is also about whether the country captures economic value from the shift to electrification. The 2026 federal auto strategy explicitly links EV adoption to a broader industrial agenda, including investment support for manufacturing, tax incentives for zero-emission technology manufacturers, worker reskilling, and efforts to diversify trade relationships.[248] Priority actions should therefore support the buildout of battery and EV value chains in ways that move Canada beyond the role of raw materials supplier. This includes refining and processing capacity, battery materials, cell production, pack assembly, electric and autonomous vehicle manufacturing, and second-life battery applications and battery recycling, along with research, commercialization, and workforce development.[260,261]

Enable system-level shifts in mobility and vehicle use

Electrification alone will not fully offset emissions growth driven by increasing vehicle numbers, larger vehicles, and car-dependent land-use patterns. Actions should focus on encouraging modal shift to public transit or active transport, promoting vehicle right-sizing particularly in urban areas, enabling shared mobility models (carsharing, ridesharing, mobility-as-a-service), and integrating transportation with land-use planning to reduce travel demand and private vehicle dependence.

Build public awareness, confidence, and market readiness

Consumer perceptions remain a significant barrier, particularly around cost, range, charging access, and performance in Canadian conditions. Priority actions include:

- Implementing public information campaigns on EV costs, performance, and benefits.
- Working with dealerships, utilities, and municipalities to improve consumer education and engagement.

Prepare the workforce

Priority actions should include training for mechanics and technicians to work safely with high-voltage systems, support for independent repair and aftermarket service capacity, and measures to reduce overdependence on OEM-controlled servicing. A stronger local maintenance and repair ecosystem would improve consumer confidence, support employment, and help ensure that EV adoption does not create new service bottlenecks.



 Fails to meet criteria Meets in some respect
 Not promising Potentially meets criteria
 Meets criteria

8.1.5 LDVs Pathways Table

				Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Battery Electric	Priority Decarbonization Pathway Backbone of LDV decarbonization.	Deploy Mass deployment now. Scale charging infrastructure.	Zero tailpipe emissions. Dependent on decarbonizing grid electricity and supply chain (net-zero lifecycle vehicles).	Purchase cost still higher than ICE vehicles but improving. Total cost of ownership often at or below ICE with lower fuel/maintenance.	Strategic opportunity: batteries/critical minerals and assembly. Links to autonomous vehicle development.	Mass market deployment, battery range continues to increase as costs fall. Future technological improvements possible.	Works across Canada. Winter range and multi unit home charging remain serious operational constraints.	Rapidly expanding public charging. Grid planning underway. Some regional disparities in grid readiness and charger deployment.	No particular concern.	Compelling to emerging producers. Alignment among governments and utilities with sales targets. Some opposition from incumbents.	Air quality and health gains. Vehicle-to-to-grid energy storage potential. Prepared for connection with autonomous technologies. Lifecycle emissions and pollution associated with battery production and disposal.
Plug-in Hybrid Electric	Bridge Pathway Useful in the near term to facilitate transition to battery electric. Good for long trips/cold regions when charged frequently. Not a fully decarbonized solution.	Deploy Deploy PHEVs. as a complementary option for BEVs. Scale charging infrastructure.	Meaningful reductions only with high electric miles share. Complements transition to BEVs but not compatible with net zero.	Competitive total cost of ownership in some use cases. Lower upfront cost than BEVs but higher than ICE.	Targeted value in engineering, dealerships, and service. Limited incremental manufacturing advantage vs. BEVs.	Fully commercial across segments. Extensive Canadian availability.	Works with today's fuelling plus home/workplace charging. Ideal for rural/long distance drivers who can plug in.	Compatible with existing retail fuel network and Level 2 charging. Minimal new infrastructure required.	Pragmatic. Acceptance drops when real world emissions underperform. Helps accustom consumers to vehicle charging and eases range anxieties.	Automakers and some provinces use PHEVs to meet near term ZEV targets. Crediting is bounded in the federal standard.	Mixed: benefits depend on charging behaviour. Fewer local air quality gains if driven mostly on gasoline. Lifecycle emissions and pollution associated with battery production and disposal.
Hybrid Electric (gasoline engine with battery and regenerative braking)	Dead-End Pathway Small GHG cuts but retains gasoline lock in. Absent from credible net-zero LDV end state.	Dismiss End support. Prioritize support for BEVs and PHEVs.	Limited emissions reduction and slows transition to better alternatives. perpetuates fossil fuel use.	Competitive with ICE vehicles.	Not relevant in a decarbonizing world.	Fully commercial.	Works with today's fuelling and improves vehicle acceleration.	Compatible with existing retail fuel network.	No particular concerns.	Less relevant to government and producers than BEVs and PHEVs as they are not compatible with net zero.	Continued reliance on fossil fuels. Doesn't address air quality concerns. Slows transition to better alternatives.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Hydrogen Fuel Cell	<i>Potential Niche Pathway</i> Applicable in regions or remote areas where very long range is required, or local hydrogen infrastructure is well established.	Don't Prioritize Very niche applications (remote or robust hydrogen infrastructure).	Achieves zero emissions when supplied with low- carbon hydrogen.	Vehicles and hydrogen costs are high in most locations. Dependent on hydrogen cost reduction and policy support.	Could help drive local hydrogen economy growth and spur jobs in hydrogen production, refuelling, and fuel-cell manufacturing.	Some models exist. Focus is on developing medium- and heavy-duty vehicles.	Good for long-range vehicles or where hydrogen infrastructure is present. Most LDV applications are better suited for BEVs.	Need new, large-scale hydrogen fuelling network which must be built alongside vehicle adoption to overcome infrastructure and supply challenges.	Supported in regions with hydrogen build out or remote areas. Broad acceptance hinges on fuelling infrastructure, costs, and safety.	Most stakeholders backing BEVs and PHEVs for LDVs. Some interest from provincial or municipal governments where hydrogen is present or electrical infrastructure is lacking.	No air pollution. Supports renewable integration, and enables broader hydrogen use across sectors.
FUELS											
Ethanol-Blended Gasoline	Dead-End Pathway Small lifecycle GHG cuts but retains combustion lock in. Absent from credible net zero LDV end state.	Dismiss Phase out. Focus efforts on other solutions with net-zero alignment and more economic opportunity.	Delivers modest GHG reductions via blending but can't fully decarbonize LDVs.	Low incremental cost increase for E10. Viability tied to feedstock prices.	Targeted gains for farm regions and existing biorefineries. Limited growth vs. ZEV supply chains. Not relevant in a decarbonizing world.	Fully commercial and ubiquitous in Canada.	Drop in up to E10 across existing vehicle fleet. Higher blends need engine compatibility.	Uses current storage, pipelines, and retail fuelling. No new networks required.	Mixed. seen as lower carbon but concerns persist on land use and air toxins. Acceptance is context specific.	Supported by fuel producers and some provinces. Peripheral for long term LDV decarbonization.	Continued air pollution. Limited co benefits. Upstream land/water impacts can offset gains unless strong safeguards are applied.
Synthetic gasoline	<i>Potential Dead-End Pathway</i> No Canadian deployments, and outcomes hinge on scarce, costly clean power and captured CO ₂ .	Don't Prioritize May be relevant in the future in very remote applications. No action currently until maturity and economics improve.	Can be very low carbon when produced with clean hydrogen, electricity, and CO ₂ , suited for remote niches.	Production costs much higher than conventional gasoline with viability dependent on high, long-term subsidies and very cheap renewable power.	Could generate niche projects but scale is very uncertain.	Novel solution in R&D phases, no commercial supply.	Works in all current gasoline vehicles with no retrofits. Fuelling, maintenance, and driver practices remain unchanged.	Downstream distribution is compatible. Upstream supply chains are nascent and require significant new investment and coordination.	Public awareness is low. Acceptance will depend on framing. Conceptually attractive as a “drop-in” net-zero fuel.	Refineries, fuel suppliers, and some OEMs to preserve combustion assets.	Benefits are offset by large energy losses. Net benefits materialize only in narrow circumstances (i.e., no electrification option).

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
TRANSPORTATION SYSTEMS											
Modal Shift (to public transit or active mobility)	Enabling Pathway Reduces car dependence and associated emissions, applicable mostly to urban areas.	Deploy Continue to improve and build out well-designed transit systems. Provide education, incentives, and policy support to encourage modal shift.									
			Proven to reduce car trips and emissions when paired with better service.	Urban infrastructure construction and operational funding for transit poses financing challenges.	Supports service expansion and economic productivity.	Mature.	Strongest in dense cores with viable transit alternatives.	Mass transit and bicycle infrastructure investments required for urban centres.	Acceptance grows post-implementation as benefits materialize.	Cities, provinces and utilities use these to meet goals.	Traffic, safety, air-quality gains. Equity improves with targeted discounts.
Shared Mobility Models	Enabling Pathway Reduces vehicle ownership; associated with significant life-cycle emissions reductions, especially when integrated with autonomous vehicles.	Deploy Integrate with existing transit systems. Provide education on use of digital platforms.									
			Reductions depend on methods chosen, vehicles used, and integration with automation.	Reduced necessity for personal car ownership comes with significant household savings.	Growth in service-based economy. Increases transit efficiency. Benefits concentrated to urban regions.	Commercial. Ride-hailing, car-sharing, and micro mobility used today. Profitability and integration with public transit still evolving.	Strong fit in urban contexts with some changes to transit coordination, use of digital platforms, and travel behaviours. Operations more difficult in rural or low-demand areas.	Largely compatibility with existing infrastructure with modest digital, fleet, or road upgrades.	Generally accepted due to convenience and cost saving. Access and equity issues in smaller communities.	Relevant to urban locations, transit providers, and private stakeholders. Automakers have taken note. Engagement strongest in cities.	Reduced vehicle ownership, congestion, and parking demand. Can improve transportation accessibility. Some concerns with transit replacement if not integrated.

8.2 MEDIUM- AND HEAVY-DUTY VEHICLES (MHDVs)

Function of the Sector	Transport of goods, people, and services by road.
GHG emissions	9.6% of Canada's total emissions or 64.5 Mt CO ₂ e in 2023.[262]
Options for decarbonization	Decarbonization Pathways: Battery electric vehicles, hydrogen fuel cell electric vehicles, hydrogen combustion. Bridge Pathways: Renewable diesel. Niche Pathways: Renewable natural gas.
Stage of transition	Emergence: Hydrogen combustion, hydrogen fuel-cell electric vehicles. Diffusion: Battery-electric vehicles, renewable diesel, renewable natural gas.
Nature of the problem today	High costs of zero-emission vehicles, low availability and technological readiness of MHDV zero emission vehicles, fleets require operational changes to accommodate zero-emission vehicles, and insufficient energy capacity and infrastructure.
Other systemic issues	Negative health impacts and premature deaths are linked to poor air quality from diesel and gasoline vehicles.[263]
Strategic opportunities and concerns	Potential to reduce operational costs, improve air quality, and decarbonize multiple sectors through shared pathways such as electrification and hydrogen. Opportunities to lead in heavy-duty vehicles innovation and early hydrogen market development, despite lagging other countries in MHDV zero-emission vehicle deployment.
Priorities for action	Focusing on easier to decarbonize market segments, align supply and demand policies to boost adoption, build the charging and grid infrastructure, support innovation and commercialization, and raise awareness.
Longer-term issues	Stepwise buildout of clean electricity and hydrogen supply and infrastructure.
Indicators of progress	Percent of zero-emission vehicle sales in each market segment, scale of infrastructure build out, carbon intensity of grid electricity or hydrogen used for MHDVs.

8.2.1 Current Status

In Canada, roads are the arteries of commerce, and medium- and heavy-duty vehicles (MHDVs) are its lifeblood. They deliver goods, provide public services, and move passengers.[219]

MHDVs include passenger transit, multi-purpose vehicles, heavy pickup trucks, vans, service vehicles, and large trucks.[264] They fall into three main on-road categories: medium duty, heavy duty, and buses.

Medium-duty vehicles (MDVs) are typically used for services and shorter or regional delivery routes. MDVs are defined by their

weight, ranging from 4,535 kg to 11,793 kg (class 2B to 6). Heavy-duty vehicles (HDVs) typically travel greater distances and are used to carry very heavy loads. They are defined as any vehicle weighing more than 11,793 kg (class 7 and 8).[264,265] Buses can be classes 6-8 and are mainly used to transport people.[264,265]

Beyond weight classes, there are other ways to categorize MHDVs by features such as distance driven, load weight, operational characteristics, driving patterns, or nights away from home. This report breaks down MHDV fleets into five functional segments:[266–268]

Table 4 Categorization of MHDVs by functional segment

Functional Segment	Vehicle Class	Purpose	Typical Distance	Route Pattern and Operations
Passenger Transit	School buses, public buses, private coaches	Moving passengers	Varied	Fixed routes, returns to base
Urban Delivery	Class 2B–6 trucks and vans	Delivery of cargo within urban areas	<100 km/day	Typically returns to base with long overnight dwell times
Service	Class 2B–8 vehicles	Government, light construction, refuse removal, utilities, surveying, towing, snow removal, emergency response	Mostly short distances	Returns to base, high idle times
Regional Haul	Class 2B–8 vehicles	Cargo transport (e.g., moving, industrial, agricultural)	<400 km/day	Urban and interurban routes
Long Haul	Class 7–8 trucks	Large cargo movement across wide regions	>400 km/day	Urban, interurban, provincial, international

Only on-road vehicles are examined for this report, as off-road vehicles have different decarbonization challenges and solutions.

In 2023 there were 681,500 MDVs. Of these, 34% ran on gasoline, 65% on diesel, and less than 1% were battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), or

hydrogen fuel cell electric vehicles (FCEVs). In the same year, there were 576,300 HDVs on the road, with 4% running on gasoline and 96% running on diesel. There were also 65,100 buses, which typically run on diesel.[232] Figure 23 displays MHDV and bus registrations by fuel type in 2023.

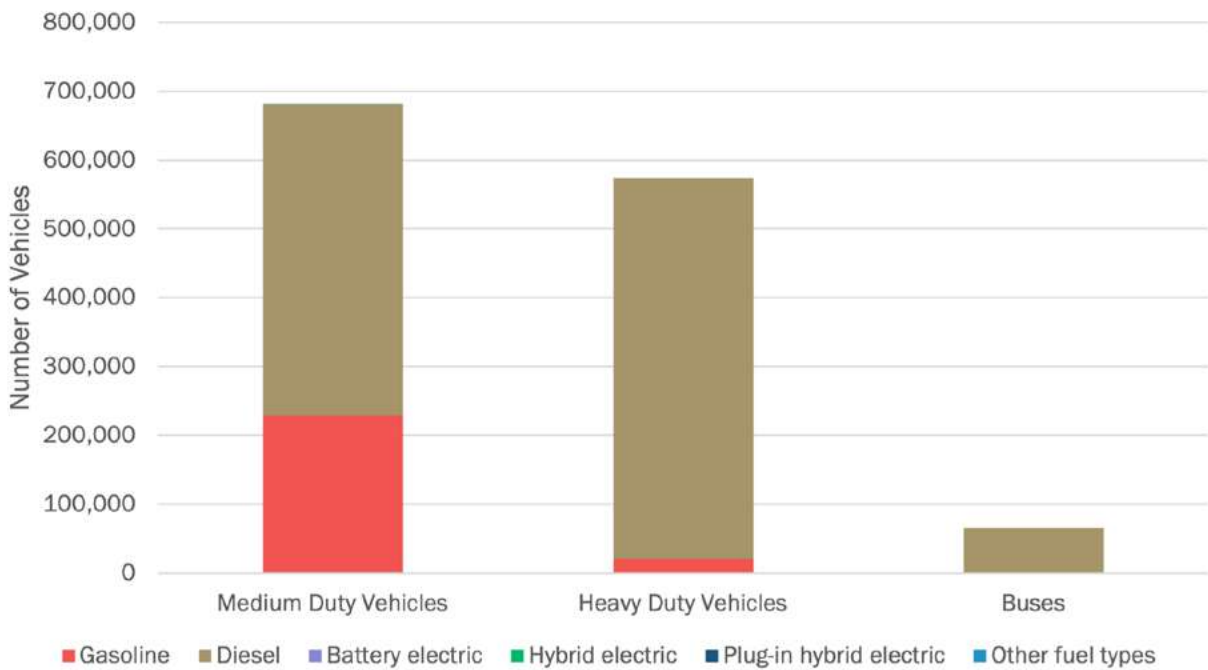


Figure 23. MHDV and bus vehicle registrations by fuel type, Canada 2023[219]

Overall, the MHDV sector is large and highly fragmented. Haulage companies often struggle with labour shortages, small profit margins, and poor load factors. Digital technologies have impacted trucking through tighter supply chain management and logistics. E-commerce has increased traffic movements in urban areas with direct-to-home delivery. Emerging technologies, including software analytics, applications of AI, and connected and autonomous vehicles, are expected to disrupt the sector, and may lead to greater ownership concentration in the future.

8.2.2 Nature of the Problem

The MHDV sector is considered one of the more difficult sectors to decarbonize given its size and complexity. Nearly all MHDVs on the road in Canada run on diesel or gasoline. The sector accounts for 9.6% (64.5 Mt) of Canada’s total emissions and 39% of transport sector emissions.

Managing MHDV emissions is complicated by many factors including the different vocations and distances traveled, whether vehicles return to a base each day, and how often they stop or idle.[262] The sector cannot be decarbonized using one solution that can be implemented simultaneously across the sector.

Switching to zero-emission fuels and vehicles is challenging because of:

- **Large energy demands:** The challenge to decarbonize vehicles varies greatly by their vocation and weight. Heavier vehicles often travel longer distances and have higher energy demands making meeting the energy requirements to decarbonize MHDVs difficult.
- **Energy system and infrastructure:** The supply and capacity of net-zero energy, either electricity or hydrogen, is emerging and struggles with regulation, market education and awareness, and direction on infrastructure location.
- **High costs for zero-emission vehicles (ZEVs):** There is an ongoing need for subsidies to achieve cost parity with diesel vehicles. Operational costs of BEVs specifically are lower than ICEVs but currently parts are more expensive.
- **Technological concerns:** The technological readiness of ZEVs for MHDVs is lower than for passenger vehicles and there are fewer pilots and demonstrations.
- **Vehicle availability:** Manufacturers prioritize larger markets than Canada. Canada also has larger freight trucks than the U.S. and we are not yet catered to in product offerings.
- **Changes to operation and maintenance:** Not all companies have the ability or ownership over assets needed for change. Maintenance and operation of ZEVs may also require reskilling of labour.
- **Operational constraints:** Longer charging and fuelling times can affect duty cycles and create challenges for hours-of-service compliance, especially for long-haul and time-sensitive operations.

- **Insurance availability and cost:** In some regions, such as Alberta, fleets are reporting challenges securing insurance for ZEV MHDVs and uncertainty around potential cost increases. This adds another layer of financial risk to early adoption.

Canada is behind the rest of the world in ZEV adoption in this sector with only 1.9% of MHDVs sold in 2023 being electric, compared to the global average of 9%.[263] Supporting infrastructure remains nascent: as of 2025, 128 MHDV chargers were open nationwide, with a further 518 planned.[269]

8.2.3 Net-Zero Pathways

The road to net zero in the MHDV sector runs along two main technological routes: battery electric vehicles (BEVs) and hydrogen fuel cell electric vehicles (FCEVs). Both eliminate tailpipe emissions through electric motors, delivering high torque, lower maintenance, and quieter operations. Both technologies will play a role, but their advantages vary by use case.

BEVs: A Core Decarbonization Solution

BEVs are already suitable for some MHDV applications, particularly for smaller vehicles and those that return to a base (most delivery and service vehicles), or do not travel long distances (regional-haul vehicles or public and school buses). These applications are more amenable to overnight- or slow-charging and the lower energy densities of batteries.

Studies suggest that more than 80% of MDVs and 50% of HDVs travel less than 240 km per day. So BEVs operationally make sense for the majority of MHDVs on road today.[263] BEVs have the added benefit of lower fuel costs, as electricity is cheaper than gasoline or diesel. [263] As compared to hydrogen, battery technologies are relatively mature, and the electricity distribution system is extensive.

However, BEVs are not currently practical in all applications. For long-haul operations, charging times, battery weight, and energy density constraints start to bite. For the heaviest vehicles, batteries contribute significant weight, which reduces available payload.

FCEVs: The Long-Haul Play

Hydrogen fuel cell electric vehicles (FCEVs) are best suited to long-haul and heavy-duty applications where vehicle range and fast refuelling are critical. In Canada, this is particularly relevant for freight corridors in Western provinces and other routes with long distances between stops and limited grid capacity for high-power charging. Hydrogen could also play a role in intercity bus services and long-distance coach services, particularly for rural routes, and operations in challenging weather where range demands exceed what current batteries can deliver. In these contexts, hydrogen could offer a more practical decarbonization pathway than BEVs. FCEVs also offer faster refuelling times compared to BEVs, along with longer range and less payload impact, since fuel-cell systems are generally lighter than large battery packs. These attributes support high vehicle utilization rates essential to freight operations.

The biggest challenges with hydrogen FCEVs are the availability and cost of fuel and vehicles. Low-cost, low-carbon hydrogen is not currently available. Increased production requires the stepwise development of demand (consumption) and supply so that economies of scale can kick in and hydrogen production and distribution costs can come down. In principle, long-haul trucking could be an “anchor tenant” for the hydrogen economy, as the fuelling infrastructure would be built along major transport corridors. Coordinated deployment along road-rail freight corridors in Western Canada could further accelerate infrastructure build-out, particularly as Canadian Pacific Kansas City (CPKC) advances its fuel-cell locomotive program. The availability of cheap hydrogen can in turn facilitate decarbonization in other sectors (rail, heavy construction, cement, steel, chemicals, and in some cases building heating).

Table 5 shows the number of vehicle models available in Canada for BEVs and FCEVs by vehicle class.

Table 5. Available Electric MHDVs by Class Size[270]

Vehicle Class	Unique Models Available	
	BEV	FCEV
2B: Cargo van, chassis cab, cutaway, pickup truck	9	0
3: Cargo van, shuttle, ambulance, minivan, chassis cab	12	0
4: Step van, minivan, cutaway minivan, chassis cab, shuttle, box truck	14	0
5: Step van, straight truck, chassis cab	9	0
6: Ambulance, chassis cab, shuttle, refuse, straight, sweeper, bucket, delivery, flat bed, or terminal truck, and step van	24	0
7: Attenuator, bucket, refuse, straight, flat bed, tractor and terminal truck, chassis cab, coach, and shuttle	16	0
8: Beverage, bucket, dump, fire, refuse, roll-off, straight, sweeper, terminal, and tractor truck, chassis cab, coach, and shuttle	46	3
Total	130	3

Other Proposed Solutions for MHDVs

Other potential net-zero solutions include catenary trucks, hydrogen combustion engine vehicles, hydrogen-diesel co-combustion retrofits, renewable natural gas vehicles, and drop-in-capable fuels. Catenary systems power large trucks on overhead electrical cables, similar to the arrangements for electrified commuter trains or trolley busses. This system resolves weight and battery size issues as HDVs only need small batteries for road operation without the overhead network. These systems work best for applications that travel the same routes (refuse or snow removal, sweeper trucks, public buses, or school buses) or along high-trafficked corridors, such as inter-city highways. The difficulty here is the cost of installing the overhead network, which is particularly acute in a country like Canada with its vast distances and multiple jurisdictions.

Hydrogen combustion engines represent one pathway for long-haul and heavy-payload applications, using purpose-built engines that run on hydrogen to deliver diesel-like performance and fast refuelling with no payload penalty. While lower in energy efficiency than FCEVs (more hydrogen is consumed per km) and requiring aftertreatment to manage NOx emissions, they offer a lower-cost entry point and faster deployment. Still in the on-road testing phase, their full climate benefit depends on access to low-carbon hydrogen, but they can seed hydrogen demand and complement FCEVs as part of a broader hydrogen corridor buildout.[271,272]

Hydrogen-diesel co-combustion retrofits offer a related but nearer-term option, allowing existing long-haul diesel fleets to reduce emissions by up to 40% without replacing

vehicles or sacrificing payload and range.[273] While not a net-zero end state, retrofits can lower the cost of entry into hydrogen use and help build out hydrogen demand corridors alongside other zero-emission solutions.

Investment in natural gas as a vehicle fuel should be discontinued, as it is a dead-end pathway, slowing the transition to a decarbonized economy. Renewable diesel and renewable natural gas (RNG) may play some role but are not viable as broad solution for MHDV. Both are associated with deployment challenges related to the availability of biomass feedstocks, impacts on land use, costs, and questions around the real emissions reductions once upstream impacts have been factored in.

Service or regional-haul vehicles with a combination of limiting factors, including heavy vehicle or load weights, lack of access to clean power or viable hydrogen fuel-cell solutions, extended periods away from a base, and travel along remote or variable routes, are good candidates for renewable fuels. Examples of these vehicles include class 6-8 vehicles used in applications such as powerline service, some industrial or agricultural uses and surveying.

Electrofuels are produced using hydrogen and carbon sourced from CO₂ rather than biomass. This is still an emerging technology. In the medium term, high production costs are expected to limit widespread deployment.

Competitiveness Implications

Global OEMs are building their MHDV zero-emission platforms now, and the specifications being locked in reflect the jurisdictions generating the strongest demand signals, not Canada's. With only 130 BEV and 3 FCEV models currently available in the Canadian market and no binding national sales mandate, Canada's operating conditions remain a low priority in global product planning. The result is a specification gap that grows more consequential with each platform generation: gross vehicle weight limits exceed U.S. standards, winter performance requirements are among the most demanding in any major freight market, and corridor distances in Western Canada push the boundaries of current battery range. These are solvable engineering problems, but OEMs solve them for markets that pay for the solution through regulation, procurement, and infrastructure commitment. The longer that signal is absent, the more Canadian freight operators become price-takers for vehicles optimized elsewhere, absorbing performance penalties in a sector where margins leave little room to absorb them.

8.2.4 Priorities for Action

Canada's stated goal is for 35% of new MHDV vehicle sales to be zero-emission by 2030 and 100% by 2040.[274] Achieving this 2030 milestone would require a dramatic change from current deployment rates: approximately 414,000 zero-emission MHDVs on the road and 41,000 MHDV charging ports nationwide by 2030.[275] At the current pace, these targets remain out of reach. Progress will depend on strategic sequencing of vehicle deployment, rapid infrastructure expansion, and coordinated policy action across governments, utilities and industry.[263]

Develop a strategic transition plan

An MHDV transition plan should sequence adoption phases. Focus first on the vehicle segments that are most ready to electrify, such as school and transit buses, urban delivery, refuse/municipal service, utility/service fleets, and regional hauls under 400 km/day that return to base. Follow with regional-haul and end with long-haul as

hydrogen and megawatt charging mature. Link infrastructure planning to this sequencing, prioritizing depot and hub charging initially before expanding to corridors. Align infrastructure, regulation, and procurement timelines by coordinating actions across federal, provincial, and municipal governments. Sequencing should also reflect the financial capacity of different fleet types, as large carriers and public agencies typically have more ability to invest early than smaller operators.

Ensure an adequate supply of vehicles

Move beyond relying solely on U.S. heavy-duty emissions standards by adopting a Canadian MHDV ZEV sales regulation with early, segment-specific sub-targets (buses, urban delivery, refuse), and later-phase targets for long-haul. Provide compliance flexibilities by vocation and weight class; expedite type approvals; pre-qualify models/specs suited to Canadian conditions (gross weight variants, cold-weather packages); and align public procurement to pull supply into the priority niches.



Boost demand and reduce upfront costs

Accelerate adoption by directly reducing the total cost of ownership. Cut both upfront and operating costs with:

- Rebates tied to vehicle weight and proven use,
- Bonuses for scrapping older diesels,
- Zero- or low-interest financing with guarantees,
- Faster tax write-offs, and
- Predictable off-peak charging rates or relief from high demand charges at depots.

Enable pooled purchasing power (i.e., school districts and municipalities) to secure lower prices and reduce risk with battery leasing and resale-value guarantees. Above all, design programs around the real total cost to own and operate, not just sticker price, to directly clear the main cost barrier to zero-emission adoption. Program design should also minimize the administrative burden, particularly for smaller operators with limited capacity to navigate complex rebate and grant requirements.

Fill innovation and commercialization gaps

Target RD&D and commercialization support where readiness lags: cold-weather battery performance and depot energy management for buses/MDVs; megawatt-class charging and cost-optimized packs for Class 8; hydrogen fuel cells and storage for select long-haul corridors; zero-emission vocational body integration (refuse, utility); and high-throughput charging. Fund lighthouse demonstrations — large-scale, high-visibility pilots to prove feasibility and de-risk follow-on investment — at ports/rail hubs and along specific corridors with clear procurement pathways to scale.

Build industry awareness and capacity

Deploy segment-specific transition playbooks and work with industry associations and anchor fleets in targeted industries. Disseminate case studies, training, and operations/maintenance guidance for fleet managers, technicians, and planners. Establish a pipeline of fleet projects so manufacturers and infrastructure providers can respond to visible demand.

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

8.2.5 MHDVs Pathways Table

Not promising Potentially meets criteria Meets criteria			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Vehicles											
Battery Electric	<i>Priority</i> Decarbonization Pathway Can decarbonize most MD and some HD vehicles.	Deploy Accelerate fleet adoption and charging infrastructure buildout for MHDV applications. Prioritize return-to-base and short-haul segments first.	 Runs on clean electricity with no tailpipe emissions. Requires decarbonized electricity and supply chain.	 Higher upfront costs but dropping. Cost parity in many segments expected soon as battery prices fall. Total cost of ownership can be positive, especially for medium duty, urban delivery, or passenger transit.	 Promotes battery, charger, and truck manufacturing. OEM activity and government support can allow leadership in clean transport tech and exports.	 Commercially mature for MDVs and buses. Long-haul HDVs are in early adoption, with range and weight challenges. Advances in battery chemistries may be required for the heaviest duty vehicles.	 Ideal for short-haul, return-to-base operations where daily travel is local or regional. Strong performance for most MDVs but limits in long-haul or heavy-load use. Improves driving (torque).	 Needs major charging and grid upgrades. Depot, highway chargers, and utility coordination to handle the added load.	 Acceptance growing. Range and charging concerns remain.	 Fleet interest to cut diesel and maintenance costs. Governments, utilities, manufacturers for new markets and climate goals.	 Cuts emissions, reduces noise, eliminates air pollution, and lowers maintenance costs. Supports a cleaner, smarter grid with vehicle to grid charging.
Hydrogen Fuel Cell Electric	<i>Potential</i> Decarbonization Pathway Covers long-haul/payload use cases where BEVs hit range and weight limits.	Enable Invest in hydrogen refuelling corridors and support demonstration fleets for long-haul and heavy-payload applications.	 Achieves zero emissions when supplied with low-carbon hydrogen.	 Expensive vehicles and high hydrogen prices. Competitiveness dependent on lower hydrogen cost, larger-scale production, and policy support.	 Could drive hydrogen economy growth and spur jobs in hydrogen production, fuelling, and fuel-cell and vehicle manufacturing.	 In a late-demonstration, early commercial stage—mostly in pilot use.	 Enables zero-emission operations with diesel-like range. Ideal for long-haul, heavy-duty use with high range and fast refuelling needs. Improves driving (torque).	 Need new hydrogen fuelling networks along major freight corridors which must be built alongside vehicle adoption to overcome infrastructure and supply challenges.	 Cautiously supported. Broad acceptance hinges on fuelling infrastructure, costs, and safety.	 Draws interest from energy firms, truck manufacturers, and trucking companies. Serves governments and broader hydrogen economy.	 Cuts emissions, reduces noise, eliminates air pollution, lowers maintenance costs, and preserves payload. Some concerns with fuel cell recycling.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Hydrogen Combustion	<i>Potential Decarbonization Pathway</i> Covers long-haul/payload use cases where BEVs hit range and weight limits. Less efficient than FCEVs.	Enable Support demonstration fleets and investment in hydrogen fuelling corridors alongside FCEV development. Treat as a complement to FCEVs, not a replacement.	Achieves near-zero emissions when supplied with low-carbon hydrogen.	Lower base cost than FCEVs; avoids reliance on expensive minerals and catalysts, but lower efficiency overall. Competitiveness is still dependent on lower hydrogen cost, larger-scale production, and policy support.	Could drive hydrogen economy growth and spur jobs in hydrogen production and refuelling. Narrower supply chain opportunity than FCEVs as it doesn't require fuel cell components.	On-road testing has begun. Underlying high-pressure direct injection technology is commercial with many units sold globally.	Ideal for long-haul, heavy-duty use with high range and fast refuelling needs. Less suited for short urban hauls.	Need new hydrogen fuelling networks along major freight corridors which must be built alongside vehicle adoption to overcome infrastructure and supply challenges.	Cautiously supported. Broad acceptance hinges on fuelling infrastructure, costs, and safety.	Draws interest from energy firms and OEMs. Serves governments and broader hydrogen economy.	Near-zero tailpipe CO ₂ and diesel-like performance with no payload penalty. NO _x emissions require aftertreatment. Less energy-efficient than FCEVs, meaning higher hydrogen consumption per km.
Renewable Natural Gas (RNG)	<i>Potential Niche Pathway</i> Leverages existing compressed and liquified natural gas fleets and waste gas but remains niche and supply constrained.	Enable Support RNG projects tied to hauling (i.e. waste management) with secured end users.	Can be net zero with decarbonized feedstocks.	Without incentives, high production costs can make it less viable than diesel or fossil gas.	Create jobs in waste management and rural areas, but the total market is modest and capped by feedstock availability.	Drop-in fuel for compressed and liquified natural gas vehicles.	Best for transit and refuse trucks with centralized fuelling. Requires new assets with natural gas engines.	Can flow through existing gas pipelines and stations, but fuelling infrastructure for NG trucks is sparse and feedstock collection/supply chains are still developing.	Broadly accepted and seen as a practical waste-to-fuel solution when sourced from genuine waste.	Utilities, waste managers, farmers, and certain fleets view RNG as valuable.	Avoids direct methane emissions from wastes. Impact is constrained by feedstock and questions about life-cycle reductions once upstream impacts are counted. Does not address air pollution from combustion.
Natural Gas (NG)	Dead-End Pathway Does not facilitate transition to net zero. Provides limited emissions reductions relative to diesel.	Dismiss Redirect support to initiatives focused on electrification and building out production and use of renewable fuels.	Incompatible with net zero. Limited emissions reduction. Investment into assets that lengthen the timeline to decarbonization.	Natural gas is currently inexpensive. Costs can be higher where new or upgraded distribution lines, high compression, or liquification are required.	Short-term expansion of natural gas markets. Longer term prospects limited.	Technologically mature.	Best for transit and refuse trucks with centralized fuelling. Requires new assets with natural gas engines. Worse performance with lower torque.	Can flow through existing gas pipelines and stations, but fuelling infrastructure for NG trucks is sparse and feedstock collection/supply chains are still developing.	Perceived similarly to all fossil fuel use in vehicles.	Some interest from fleet operators to reduce emissions and costs. Strong relevance to existing gas suppliers.	Lowers but does not eliminate air quality concerns with cleaner combustion compared to diesel. Increases long-term reliance on natural gas, slowing the transition to electrification or clean fuels.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Drop-in Fuels											
Renewable Diesel (RD)	Bridge Pathway Provides immediate, drop-in cuts while zero-emission trucks and charging build out. Feedstocks limit scalability.	Deploy Maximize drop-in renewable diesel use across existing fleets now while zero-emission vehicles scale up. Ensure feedstock sustainability governance is in place.									
E-Fuels	Potential Dead-End Pathway No Canadian deployments and outcomes hinge on scarce, costly clean power and captured CO ₂ .	Don't Prioritize Track international developments in e-fuel production costs and efficiency. Invest if economics fundamentally improve.									

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
∞ Complementary Technologies											
Hydrogen-Diesel Co-Combustion Retrofits	<i>Potential Bridge Pathway</i> Simultaneously helps build out hydrogen economy and lower emissions on diesel assets until they can be retired. Not a net-zero end state.	Incubate Support retrofit for existing long-haul fleets in near-term, particularly where BEV adoption faces constraints. Invest in hydrogen fuelling corridors.	 Reduces diesel use and lowers emissions but not a net-zero end state. Compatible with low-hydrogen supply buildout.	 Low-cost retrofit. Competitiveness dependent on lower hydrogen cost and policy support.	 Could drive hydrogen economy growth and spur jobs in hydrogen production and refuelling.	 Proven at scale but with limited applications. Some development still needed to adapt to broader range of makes and models.	 Requires retrofit of existing diesel vehicles. Reversible and does not void OEM warranties. Seamlessly switches back to diesel if hydrogen runs out.	 Hydrogen supply remains the primary infrastructure constraint. Retrofit kits can be installed through local fleet dealerships and mechanic shops, reducing deployment barriers compared to new vehicle purchases.	 Some concerns with hydrogen cost and safety.	 Draws interest from energy firms and OEMs. Enables operators to meet near term emission targets and build familiarity with hydrogen.	 Lowers air quality impacts but does not eliminate emissions. No loss to payload.
Catenary Electric Systems	<i>Potential Niche Pathway</i> Potentially viable on fixed, high-throughput corridors.	Don't Prioritize Redirect resources toward battery-electric and hydrogen solutions with broader applicability.	 Electrifies at point of use, but corridor-bound infrastructure limits national scalability.	 Demands high upfront investment and only becomes viable with heavy, continuous use. Depends on public or consortium funding.	 May generate localized economic activity in construction and electrical equipment.	 Proven in demos, with reliable operation on short highway stretches. Lacks large-scale integration, standardization, and commercial deployment.	 Suits fixed, high-traffic routes like freight corridors or industrial loops. Poorly matched to flexible, irregular trucking.	 Demands major infrastructure along roads, grid upgrades, and regulatory coordination. Low applicability in Canada with low population density and long transportation distances.	 Uncertain. Concerns about visual impact, cost, and relevance.	 No clear stakeholder advocates in Canada at this time.	 Cuts tailpipe emissions and noise, reduces battery mineral demand, and lessens road wear. Concerns about impacts on other road users.

8.3 MASS TRANSIT

Function of the Sector	Transport of people in urban settings.
GHG emissions	Approximately 0.2% of national emissions in 2022, 1.7 Mt CO ₂ e (1.5 Mt CO ₂ e from buses[276], 0.2 Mt CO ₂ e from trains).
Options for decarbonization	Decarbonization Pathways: Electric rail transit, battery-electric buses. Bridge Pathways: Renewable diesel for existing commuter rail. Niche Pathways: Hydrogen fuel-cell buses. Enabling Pathways: Transit-oriented urban planning, modal-shift levers.
Stage of transition	Emergence: Hydrogen fuel-cell buses. Diffusion: Electric rail transit, battery-electric buses, renewable diesel for existing commuter rail, transit-oriented urban planning, modal-shift levers.
Nature of the problem today	Emissions generated from fossil-fuel-powered rail transit and buses. Absence of convenient, accessible, affordable, frequent and safe mass transit in many locales.
Other systemic issues	Equity (mass transit more affordable than personal vehicles, but less accessible). Mass transit's ability to relieve costs related to congestion, road maintenance and infrastructure, parking, and the livability of cities. Limitations in the layout of cities and urban sprawl. Climate change stressors and the impact of flooding and fires on transit.[277]
Strategic opportunities and concerns	Opportunities: Reduced commuting times, pollution healthcare costs, and household expenses; improved quality of life; economic development leveraging Canada's leadership in manufacturing electric/hydrogen buses; infrastructure utilizes Canadian materials (steel and aluminum) and creates more jobs per dollar than highway spending.[278,279] Concerns: Poor reliability and comfort due to overcrowding and long commutes; weak transit systems limit productivity; attitudinal or cultural shifts away from car dependency are difficult to achieve.
Priorities for action	Invest in reliable, comfortable, and safe mass transit that encourages mode shifting; support decarbonizing and expansion of public transit; implement policies to ensure smart city planning with well thought out transit corridors.
Longer-term issues	Urban planning for smarter, more livable cities must include mass transit in original design.
Indicators of progress	Proportion of regular commuters using mass transit. Number of riders expressing satisfaction with service standards. Sector-wide emissions. Falling construction delays and cost overruns for major transit projects.

8.3.1 Current Status

Mass transit can play a significant role in building resilient carbon-neutral cities in Canada. By moving large numbers of people efficiently, transit systems reduce greenhouse gas (GHG) emissions, ease urban congestion, and improve access to services.

Mass transit in Canada includes public transit infrastructure such as buses, urban and commuter rail, subways, and streetcars. It is complementary to active transport (biking and walking) and operates primarily on fixed routes with regular schedules in and between urban areas. While active transport is important, the emphasis of this section will be on the public transit systems and their opportunities to reduce existing emissions and contribute to further GHG reductions across the transport sector.

Canada's public transit systems comprise a suite of well-established and often integrated services, such as:[280]

- Subway systems: Toronto and Montreal subways
- Light rail and urban trains: Vancouver's SkyTrain, Ottawa's O-Train, Calgary's CTrain, Montreal's REM, and Edmonton's LRT
- Commuter rail: GO Train (Ontario), EXO (Quebec), West Coast Express (British Columbia)
- Buses: Virtually every Canadian city
- Water-based transit: Halifax Transit Ferry Service, BC Ferries

Canada's urban structure is dominated by a small number of very large metropolitan areas and a long tail of mid-sized and smaller urban

regions.[281]¹¹ This distribution matters because feasible transit technologies, service designs, and funding models differ markedly by city size and concentration.

Public transit ridership is strongest in Canada's largest and most densely populated cities. As of May 2024, 11.4% of commuters across Canada use public transit, approaching the 12.6% pre-pandemic peak in May 2016. [282] However, in Toronto, Vancouver, and Montreal, over 20% of commuters use public transit.[283] In fact, in 2016, 75% of Toronto commuters living within 5 km of downtown used transit, walked, or cycled, compared to 28% in Winnipeg.[284] Outside urban cores, ridership declines rapidly with increasing distance, lower density, and greater reliance on personal vehicles. A breakdown of commuting by mode for Canadians in 2021 can be seen in Figure 24.

Canada has a strong industrial base in public transit manufacturing. Companies such as New Flyer, Nova Bus, and Alstom design and produce buses and rail vehicles domestically and create thousands of jobs.

In addition to contributing to a strategic economic opportunity for Canada, mass transit provides critical social benefits. It helps reduce transportation-related emissions, improve mobility for underserved populations, and support more livable, vibrant urban environments.[286]

While the zero-emission technologies for transit are relatively clear—battery-electric and, in some contexts, hydrogen fuel cell—the path to expand or redesign transit systems is highly city-specific, reflecting each metro's size, density, geography, and the configuration of its existing network. Planning starts from what already exists, not from a clean slate. Federal programs such as the Zero Emission

¹¹ Using 2021 Census metropolitan area (CMA) populations as a proxy for urban scale: 6 CMAs have 1,000,000+ residents; 3 CMAs have 750,000-999,999; 2 CMAs fall between 500,000-749,999; 6 CMAs are 250,000-499,999; and 24 CMAs are 100,000-249,999

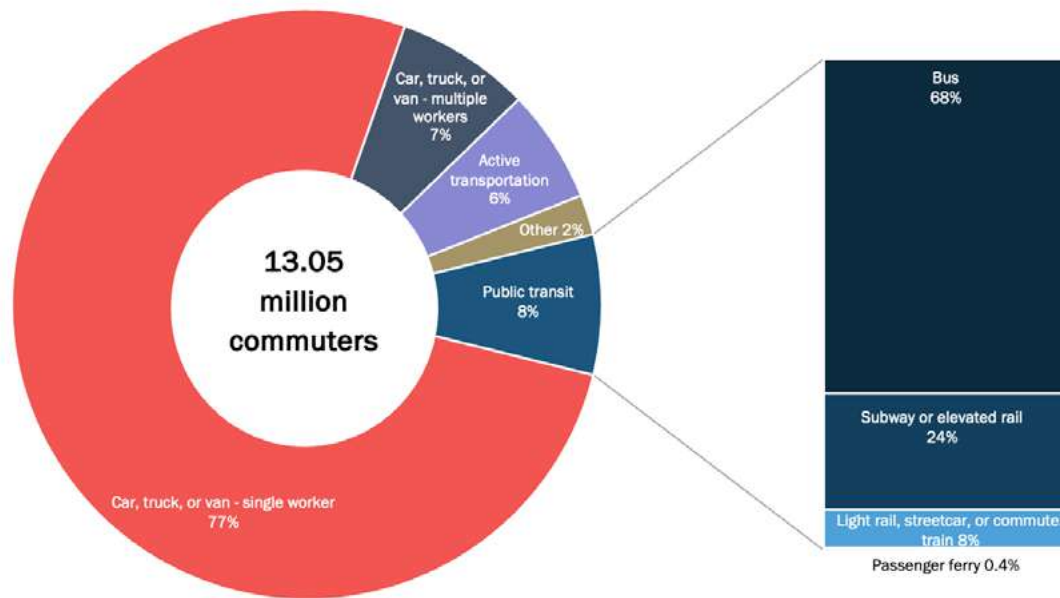


Figure 24. Main mode of commuting for the employed labour force aged 15 years and over in private households, Canada 2021[285]

Transit Fund (ZETF) explicitly support both battery-electric and hydrogen fuel cell deployments, and Canadian agencies are piloting both options (i.e., Mississauga's hydrogen bus initiative), underscoring that technology selection is contextual.

Municipal budgets alone are generally insufficient to fund major transit initiatives, and Canadian cities have historically relied on provincial and federal contributions to deliver large projects. Municipalities manage about 60% of core public infrastructure but collect only 8-10 cents of every tax dollar, constraining their ability to self-finance major expansions.[287] Senior-government tools such as the Investing in Canada Infrastructure Program, the forthcoming Permanent Public Transit Fund, Zero Emission Transit Fund, and flexible Canada Infrastructure Bank financing are necessary to deliver fleet electrification and capacity expansions across city sizes.

Ferries are not discussed further as they impact a very small portion of commuters and have very different decarbonization problems and solutions better addressed with future analysis of the marine sector.

8.3.2 Nature of the Problem

Despite offering a sustainable alternative to private vehicles, several interrelated barriers continue to limit mass transit decarbonization and its role in addressing broader transport-related problems.

Moving to low-emissions transit

To fully realize the climate benefits of mass transit, the systems themselves must be decarbonized. While public transit produces significantly lower emissions per rider than personal vehicles, diesel-powered buses and commuter rail still emit 1.5 Mt CO₂e and 0.2 Mt CO₂e respectively.[280,288,289]

Cities like Montreal, Vancouver, and Toronto have committed to providing 100% zero-emission transit by 2040, but progress is slow.[290–292] This is due to structural, financial, and political factors. For example, Toronto's Metrolinx plans to electrify 600 km of GO Train routes and add 200 km by 2032, yet faces delays due to land disputes, environmental pushback, funding gaps, and political instability.[293,294] Additionally, although Montreal's Exo plans to electrify 10

trains in its fleet, and Vancouver's Translink now uses renewable diesel for the West Coast Express, both operators lack clear timelines and detailed plans for fully decarbonizing commuter rail services.[295–297] Despite progress, vague planning and execution risks threaten the ability of all three commuter rail operators to meet their climate goals.

Bus electrification also lags, with only 2% of bus and truck sales in 2023 being electric, compared to 9% globally.[298] Canada is home to four electric bus manufacturers: Lion Electric, New Flyer, Girardin Blue Bird, and Nova Bus / Prevost.[299] A prominent barrier is the high upfront cost of battery-electric buses and the depot/on-route charging infrastructure required to operate them at scale. Currently, electric buses can be more than double the cost of diesel buses, and most Canadian-made electric buses are sold to other jurisdictions.[299,300] Upgrading charging infrastructure, installing charging along routes, and the availability of low-carbon electricity remain additional adoption barriers.[301]

Cold-weather performance is also a significant operational consideration. Transit agencies in Edmonton and Vancouver report the need for auxiliary diesel heaters to maintain interior temperatures during winter, reducing the net GHG benefit of Battery Electric Buses (BEBs). Cold temperatures also reduce vehicle range, requiring additional vehicles or on-route charging to maintain service levels.

Canada is a global leader in hydrogen fuel cell buses, with Mercedes-Benz's fuel cell manufacturing facility in Vancouver and New Flyer's in Winnipeg. In Alberta, hydrogen fuel cells are being deployed for trucks, buses, and light-duty vehicles.[302] The Alberta Zero Emission Hydrogen Transit (AZEHT) demonstration, launched in 2021, has two hydrogen fuel cell electric buses operating in Edmonton and Strathcona County since 2023. [302] Despite insights from AZEHT, Canada

still has relatively limited experience with the large-scale deployment of hydrogen fuel cell buses. Yet proponents highlight Canada's competitive advantages in hydrogen supply and the bus manufacturing value chain and believe costs will fall as supply chains mature and scale increases.[303]

Barriers to modal shift

Encouraging modal shift from personal vehicles to mass transit remains a challenge for many municipal governments. A 2018 literature review on the trends of Canadian transit ridership found that a variety of factors related to the built environment (e.g., proximity to downtown), socioeconomic conditions (e.g., household income), and external variables (e.g., weather) impact Canadians' transportation choices. Among the strongest levers are service frequency and reliability. These are areas where policy and investment can have an immediate impact. [304] Fare levels are important—especially for equity—but, on average, service quality has a larger influence on ridership; moreover, fare reductions typically require ongoing public subsidies to replace lost fare revenue.

Urban design and equity

How cities are built shapes how people move. In Canada, sprawling urban development makes it harder for transit to succeed. Cities that integrate housing, schools, workplaces, and shops within neighbourhoods have a positive impact on transit use as they generally promote shorter transit-accessible trips. Availability of affordable properties (for both renters and buyers) decreases near transit corridors. This poses issues from an equity perspective as lower-income households may face longer (and in some cases unmanageable) walking distances to access their desired routes.

Congestion in metropolitan areas and associated idling vehicles contribute to lost productivity, worsen air quality, increase GHG

emissions, and impact the health, safety, and personal finances of Canadians. It is estimated that traffic congestion in the Greater Toronto Area alone costs the economy over \$11 billion¹² annually in lost productivity.[305]

The negative effects of congestion continue to put demands on public infrastructure funds to expand road networks instead of transit modes.

Systematic constraints and policy gaps

Access to transit or safe active transport is also limited by planning and policy decisions which favour roads. Government spending on roads is historically more than double that of public transit.[306] Laws that restrict high-density housing or mixed-use neighborhoods negatively impact ridership.[279] In many regions, personal vehicles remain the only viable transportation option. Addressing these systemic issues requires substantial, ongoing public investment.

8.3.3 Net-Zero Pathways

Ensure reliable, comfortable, and safe transit services

The most effective way for governments to encourage people to choose mass transit over personal vehicle use is to ensure systems are reliable, safe, comfortable, and accessible.

Adequate operation and maintenance (O&M) funding is critical to uphold service quality. This includes not only punctuality and cleanliness, but also infrastructure upgrades, security features, and accessibility improvements that allow Canadians to depend on transit for commuting and leisure activities.

Decarbonize public transit

Decarbonizing public transit will eliminate the GHG emissions and air pollution currently associated with mass transit.

For buses, electric and hydrogen fuel cell buses present scalable options. However, these options require investment in related

infrastructure (i.e., charging stations) and training programs to ensure proper maintenance and operation of newer technologies. Future transit development should include smart grids, route optimization, and charging schedules to minimize grid strain and operational inefficiencies.[301]

Most light rail and subway systems are already low-carbon. Public investment should target light rail and subways that can replace congested or slow bus routes in cities with a population greater than 100,000.

Canada also has a strategic opportunity to meet rising transit demand with made-in-Canada solutions.[278] Bus manufacturing is already concentrated in Quebec and Manitoba, and train production facilities exist in several provinces. Rather than exporting most of this output, governments could prioritize domestic procurement—using Canadian-built vehicles to support transit buildout nationwide.

Encourage modal shift away from solo car use

Shifting Canadians from personal vehicles to transit requires a combination of incentives and disincentives:

- **Incentives:** Fare discounts, passes, and promotional campaigns (e.g., municipal transit challenges with prizes).
- **Disincentives:** Fuel taxes, congestion pricing, or limited parking to raise the relative cost of car travel compared to mass transit.
- In general, the public value of mass transit goes beyond emission reduction. It also reduces congestion, cuts pollution, improves public health, and lowers household transportation costs. These positive spillovers justify strong public investment and ongoing operational subsidies.

12 2024 Canadian dollars

Design Smart Cities with well-thought-out transit networks

Urban sprawl is a pattern of metropolitan expansion onto previously undeveloped land, characterized by low-density, discontinuous growth; single-use zoning; car-oriented design; fragmented open space; and high per-capita land consumption that makes infrastructure and public services less efficient. Sprawling neighbourhoods are generally unsuitable for mass transit because of their low population densities and lack of specific hubs of activity.

By contrast, compact, mixed-use neighbourhoods—the inverse of urban sprawl—enable mass transit and active transportation to meet most daily needs and provide a viable alternative to driving.[299] Municipalities and urban planners can design cities that have:[279]

- Dense, mixed-use developments near transit corridors,
- Integrated walking and cycling infrastructure,
- Reduced dependence on road infrastructure, and
- Vibrant urban cores with accessible green and public spaces.

Well-thought-out transit networks improve access to jobs, reduce emissions, enhance health, and raise urban livability. They also support businesses by increasing access to labour markets.[279,308,309] Municipalities and urban planners can make net zero more tangible and smart by pairing compact, mixed-use growth with smart transit operations. Using data and automation can help coordinate routes, manage service in real time with data sharing, and simplify trip planning and payment. These improvements can make transit more reliable and convenient, encouraging people to shift from private vehicles and cutting per-trip emissions.



Competitiveness Implications

Canadian-built zero-emission buses are already exported across North America, but the domestic fleet that validates them is thin. As of 2023, only 2% of Canadian bus and truck sales were electric, less than a quarter of the global rate. The transit electrification procurement wave is well underway and will lock agencies into supplier ecosystems for a fleet generation. Canadian OEMs like New Flyer and Nova Bus hold credible positions today, but that credibility erodes when the home market is visibly not buying at scale. Canada's cold-climate operating conditions add a second dimension: agencies in Edmonton and Vancouver are already navigating range loss and auxiliary heating challenges that Nordic, northern U.S., and Northeast Asian buyers will face as they electrify. Solving those problems through domestic fleet-scale deployment would give Canadian manufacturers a validated cold-climate credential that warm-weather competitors cannot replicate. But fleet-cycle lock-in sets the timeline, and fragmented municipal procurement is not moving at the pace the window demands.

8.3.4 Priorities for Action

Investing in transit and enabling infrastructure

Funding should be directed toward both infrastructure and operational needs, including safety, cleanliness, and inclusive access to balance system growth (transit access, rates, routes, and reliability) and user experience (comfort and safety on board). [306] Innovative financing models that cover operational costs—such as payment per kilometre for certified ZEVs (e.g. U.K. Bus Service Operators Grant)—or public-private partnerships that leverage private financing, can support stable long-term funding for transit systems. Careful planning and evidence-based policy are essential to ensure that investments deliver the greatest benefits in emissions reduction, accessibility and ridership growth.[310]

Moreover, incentives like the Zero Emissions Transit Fund that support the deployment of zero-emission buses and rail can be expanded and aligned to also cover the necessary charging and maintenance infrastructure.[311]

Strategic urban design

Policies for urban planning should be developed to support higher-density cities as well as mixed-use neighbourhoods, affordable housing near transit hubs, removal of municipal parking mandates, and accessible and safe active transport.[279] These will ensure that cities are designed to provide incentives for the use of existing public transit infrastructure, but also that new projects are strategically located to maximize their use.

Supporting domestic low-carbon manufacturing

Finally, Canada already has a strategic manufacturing advantage in public transit. Scaling up domestic deployment creates local jobs and strengthens Canadian manufacturing while positioning the country to export the technologies and expertise a carbon-neutral world will require.

Criteria Status

-
- Fails to meet criteria
-
- Meets in some respect
-
- Potentially meets criteria
-
- Meets criteria
-
- Not promising

8.3.5 Mass Transit Pathways Table

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Transit Technologies											
Electric Rail Transit (subways, LRT/trams, commuter rail)	Decarbonization Pathway Already the low-carbon backbone in cities. Expanding/modernizing electrified rail displaces diesel services and high-GHG road travel.	Deploy Support deployment of electrified rail with policy, financing, and investment. Enable growth of Canadian electric rail manufacturing capacity.	 Zero tailpipe emissions when running on clean power systems.	 Capital-intensive but justified on high-demand corridors. Viability rises with ridership and public co-funding.	 Strong Canadian rail manufacturing base (i.e., Alstom) and project delivery supply chains.	 Commercially mature.	 Best fit on dense, fixed routes. Replaces congested/slow bus routes in larger cities.	 Requires major capital works and grid connection but draws on established suppliers.	 Generally popular and accepted where it improves speed/reliability.	 Cities, provinces and federal funders see it as core to mobility.	 Cuts air pollution, eases congestion, improves urban livability.
Battery-Electric Buses (BEBs)	Decarbonization Pathway Scalable option for bus decarbonization.	Deploy Scale fleet procurement and depot charging infrastructure. Coordinate with utilities to ensure grid readiness for full fleet transition.	 Zero tailpipe emissions when running on clean-power systems.	 Today higher upfront cost vs. diesel. Viability improves with public support and charging optimization.	 Canadian OEM strength (New Flyer, Nova Bus) and supply-chain jobs.	 Deployment scaling from pilots to fleets.	 Strong fit for urban routes and return-to-depot operations.	 Needs depot/on-route chargers and utility coordination. Smart charging to manage grid impacts.	 Positive where reliability and comfort improve	 Transit agencies slowly adopting. Requires strong coordination from utilities. Larger cities starting to incorporate into planning.	 Better air quality, less noise.
Hydrogen Fuel-Cell Buses	Niche Pathway Complementary option where range/uptime needs challenge BEBs. Canada has H ₂ /fuel-cell industrial strengths.	Enable Support targeted pilots in corridors where range or uptime needs exceed battery-electric capability. Invest in refuelling infrastructure alongside vehicle trials.	 Zero tailpipe emissions when supplied by low-carbon H ₂ .	 Vehicle and fuel costs are much higher. Viability hinges on H ₂ price/infrastructure.	 Domestic capabilities in fuel cells and buses. Potential to anchor H ₂ value chains.	 Some pilots underway to validate technology.	 Useful for longer uninterrupted routes/high uptime and quick refuelling.	 Requires new H ₂ production, storage and refuelling networks.	 Mixed. Interest exists, but costs, safety, and infrastructure questions remain.	 Agencies and OEMs piloting. Supported in federal programs alongside BEBs.	 Air-quality gains. Operational flexibility in cold climates and long duty cycles.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Renewable Diesel for Existing Commuter Rail	Bridge Pathway A stop-gap to cut emissions where rail electrification isn't yet possible.	Deploy Procure renewable diesel as an immediate drop-in measure for diesel commuter rail while electrification is built out. Support scaling of RD production.	Drop-in fuel, with lifecycle CO ₂ cuts. Net zero requires carbon removal. Combustion persists and sustainable feedstocks are finite.	Not competitive with incumbent, except areas where policy supports offsets fuel premiums.	Supports refinery jobs, rural economies, and feedstock markets. Growth is limited by feedstock constraints.	Fully commercial, drop-in fuel. Dominant production processes (i.e. hydrotreated vegetable oil) mature, with several large-scale facilities operating globally. Established technology licensors.	Drop-in fuel ideal for reducing near-term fleet emissions without new equipment or operational changes.	Existing fuel storage, pipelines, and retail networks work for RD. Main gaps are upstream (sustainable feedstock availability and refining capacity scale-up).	Accepted when made from sustainable waste feedstocks and used as a bridge. Concerns for forestry and food competition remain.	Fleets seeking fast GHG cuts. Fuel producers and farmers benefiting from new markets. Policymakers aiming for near-term climate progress and rural investment.	Delivers reduced particulate matter and NO _x emissions in existing fleets. Benefits are tempered by feedstock limits and land-use change concerns.
Transportation Systems											
Transit-Oriented Urban Planning	Priority Enabling Pathway Dense, mixed-use development near corridors to boost transit use and cut car dependence.	Deploy Implement and strengthen transit-oriented zoning and density policies at all levels of government now. Align housing and climate goals.	Locks in low-carbon travel by design.	Infrastructure requires significant upfront investment but can yield strong long-term economic returns including increased productivity, higher tax revenues, and reduced household transportation costs.	Infill, housing, and jobs around stations.	Mature planning tools	Works across climates. Depends on zoning and political will.	Starts from existing networks with targeted upgrades.	Support rises with affordability and good urban design. There could be some opposition to densification from local residents.	Important to city/provincial climate and housing goals. Implementation faces governance fragmentation and local opposition.	Health, safety, walkability, and affordability gains.
Modal-Shift Levers (e.g. congestion pricing, fare integration)	Enabling Pathway Reduces car dependence and associated emissions, applicable mostly to urban areas.	Deploy Advance congestion pricing, fare integration, and service improvements now. Reinvest revenues into transit expansion and equity measures.	Proven to reduce car trips and emissions when paired with better service.	Revenues can recycle into transit. Distributional design matters.	Supports service expansion and economic productivity.	Many global precedents with robust evaluations.	Strongest in dense cores with viable transit alternatives.	No major new physical Infrastructure. Enforcement/IT back-end needed.	Acceptance grows post-implementation as benefits materialize.	Cities, provinces and utilities use these to meet goals.	Traffic, safety, air-quality gains. Equity improves with targeted discounts.

BUILDINGS



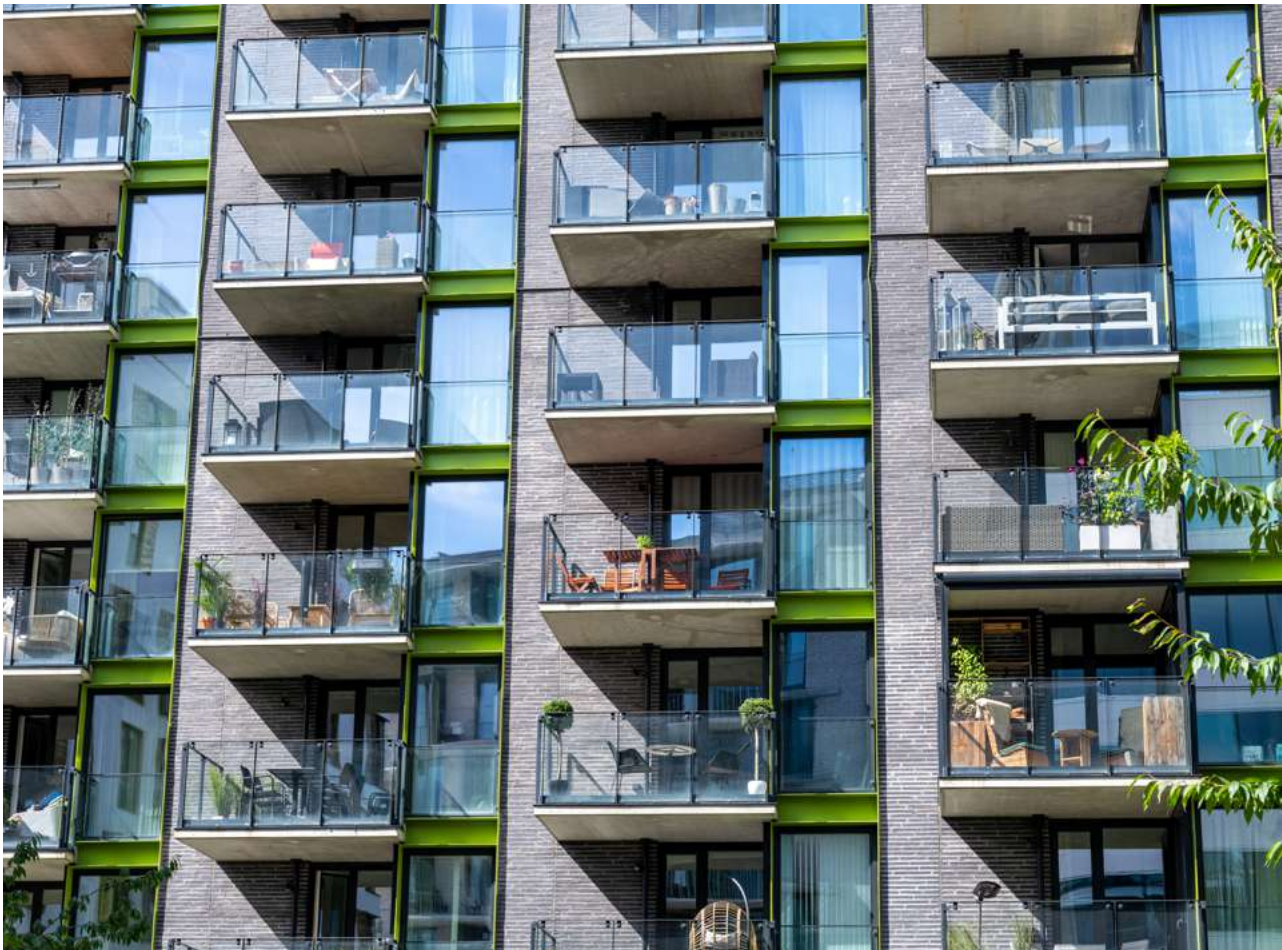


Buildings are essential to the comfort, health, and economic productivity of Canadians. As climate change intensifies, the importance of building cooling and ventilation during heat waves and wildfire season is growing.

9. Buildings

Function	Structures including residences, places of business, schools, hospitals and other public facilities.
GHG emissions	81 Mt CO ₂ e (2024); 12% of total national emissions. 38 Mt CO ₂ e residential; 43 Mt CO ₂ e commercial and institutional buildings.[61]
Options for decarbonization	Decarbonization Pathways: Air and ground source heat pumps. Bridge Pathways: Dual fuel (hybrid) heat pumps. Niche Pathways: Electric furnace heating, hydrogen, renewable natural gas, biomass. Enabling Pathways: Net-zero design, retrofitting for energy efficiency, district energy systems, solar panels on buildings.
Stage of transition	Emergence: Design, construction and retrofitting of net-zero buildings. Early diffusion: Individual technologies such as heat pumps.
Current obstacles	Cheap natural gas; capital cost of low-carbon equipment and building renovations; shortage of trained workforce; insufficient incentives and coordinated standards driving innovation; entrenched industry practices.
Other systemic issues	Affordability of housing; lack of public housing; electricity options for remote communities; construction-related waste; developer-dominated urban planning; little real estate industry interest in energy performance.

Opportunities and concerns	Opportunities: For consumers, lower long-term energy costs and improved indoor air quality and comfort. For economic development, jobs in low-carbon construction and retrofits; domestic manufacturing of net-zero equipment, growth in green real estate and low-carbon materials. Concerns: For consumers, high upfront costs, affordability challenges for low-income and households. For economic system, workforce shortages, financing barriers, slow industry adoption, electricity system constraints, stranded gas asset risks, and limited scalability of some alternatives.
Priorities for action	Raise standards for new construction through progressive adoption of net-zero building codes; accelerate electrification and retrofits in existing buildings through heat pump deployment, district heating, and energy efficiency upgrades; promote heat pumps over other heating and cooling systems through incentives, regulation, education and training; mandate building emissions performance standards and labelling; build financing capacity and drive innovation to mobilize private capital and scale emerging clean technologies; train Canada's labour force for low-carbon building design, construction, retrofit and maintenance.
Longer-term issues	Affordable net-zero housing; managed phase-out of fossil fuel infrastructure; reduced embodied emissions in construction and retrofitting; construction waste reduction and circular material use.
Indicators of progress	Share of electricity in building energy consumption; share of the building stock using heat pumps for heating and cooling; annual retrofit rate; transparency around embodied carbon in building materials.



9.1.1 Current Status

Buildings are essential to the comfort, health, and economic productivity of Canadians. As climate change intensifies, the importance of building cooling and ventilation during heat waves and wildfire season is growing. This isn't just a matter of comfort. In 2021, 619 heat-related deaths were reported in B.C. during a one-week extreme heat event, and those affected were largely vulnerable populations without access to cooling.[312]

The building sector contributes to GDP directly through real estate, rental, and leasing income (13% of Canada's GDP) and indirectly through the construction industry (7% of Canada's GDP, although this figure includes infrastructure construction as well as buildings).[305] Real estate, rental, and leasing markets are concentrated in key metropolitan areas. The construction industry employed 1.2 million people in 2024, or 6.5% of the workforce.[314]

It is useful to distinguish residential properties from commercial and institutional premises at the outset, as the two sectors differ in ownership structure, financing, energy use patterns, and the social pressures they face. However, when it comes to decarbonization, the two share many of the same challenges, solutions, and policy levers.

Residential buildings

There were 16.4 million dwellings in Canada in 2022.[307] Over 200,000 new homes are built each year as the population continues to grow, the majority of which are apartments.[316,317] In 2021, more than 66% of Canadian families owned their own home, and more than half of those households (60% in 2021) were paying off a mortgage.[318] Single detached houses represented 53% of all dwelling types in 2022,[307] but with the rise of apartment-based households, this share has been declining for decades. Figure 25 displays the breakdown of residential buildings by type in 2022.

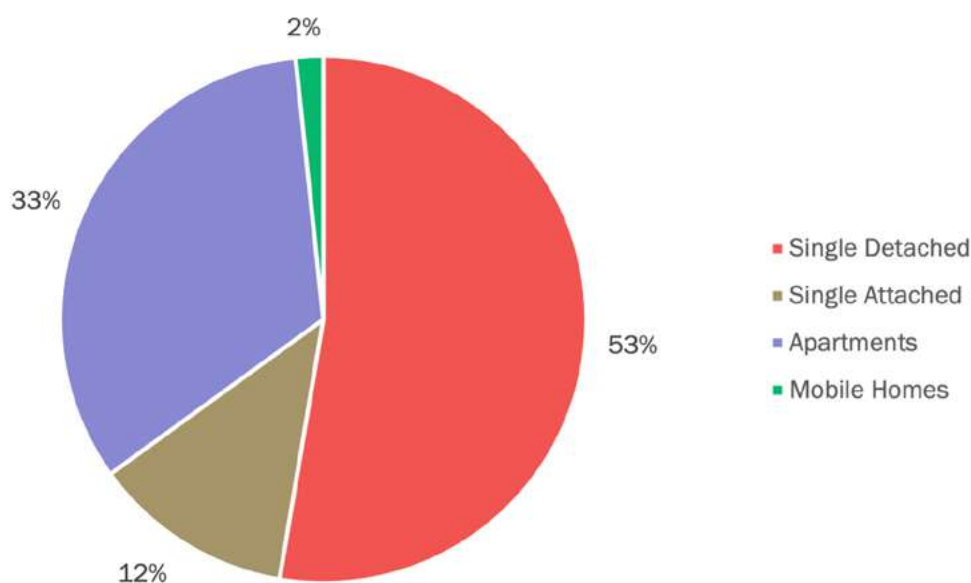


Figure 25. Residential buildings by type, Canada 2022[315]

For low-income households, renting is often the only affordable housing option, and large investment firms and property management organizations own a significant share of rental properties. These large firms are shown to charge premiums compared to other types of landlords. In Toronto, these premiums are most extreme for lower-income and racially marginalized areas.[319] Across the country, 45% of Canadians are concerned about the affordability of housing.[320]

In recent years, house prices have risen faster than household income. While the median after-tax Canadian family income increased by 4.5% between 2019 and 2023,[321] house prices grew by 17%.[322] According to the OECD, Canada's house price-to-income ratio was the second highest among the reported countries in 2024. Shelter was the largest item on household expenditures in 2023, accounting for 32% of the total consumption,[323] and mortgage debt is responsible for three-quarters of the debt burden on Canadian families.[324]

Although household energy costs such as water, fuel, and electricity account for less than 3% of total annual expenditures on average, they still pose a significant burden for many.[323] Studies estimate that nearly 2 million Canadian households struggle with high energy costs.[325] Nevertheless, Canada has some of the lowest residential electricity pricing in the world. Modelling by Electrifying Canada showed that adopting heat pumps and electric vehicles will be better for most Canadian households in the long term. Their analysis found that roughly 70% of households

will spend less on energy by 2050 because efficiency gains will more than compensate for electricity rate increases as grids expand, with electric vehicles being a key driver of those savings.[115]

There are significant regional differences in the fuels used for residential space and water heating. Most Quebec homes use electric resistance heating and Atlantic provinces primarily rely on electric resistance or heating oil. Meanwhile, lower cost natural gas is a dominant source of home heating in Ontario, the Prairies, and British Columbia.[326] Energy use in the residential sector increased by only 5.5% from 2000-2022 (despite a 32% increase in the number of households). This indicates steady improvements in energy efficiency, which can be attributed to modernization of building codes in some jurisdictions, the adoption of LED lighting across Canada, and improvements in the efficiency of air conditioners, furnaces, and appliances.[327,328]

Commercial and institutional buildings

There were more than 560,000 commercial and institutional buildings in Canada in 2019.[329] The floor space of commercial and institutional buildings has risen by 27% since 2000 as Canada's economy has grown, and international companies continue to expand in Canadian cities.[320] Office buildings, non-food retail stores, and mixed-use buildings made up the biggest shares of non-residential buildings in 2019, accounting for 18%, 14%, and 11%, respectively.[329] Figure 26 displays the share of commercial and institutional buildings by primary activity.

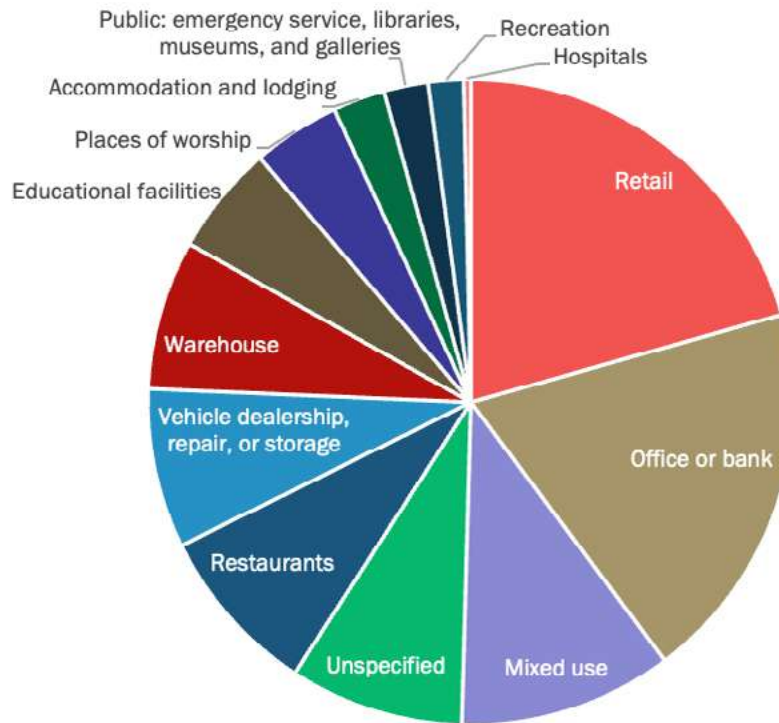


Figure 26. Commercial and institutional buildings by use, Canada 2019[322]

Commercial buildings are generally owned by private investors, and office and retail rents have surged by about 20% across Canada between 2018 and 2024, even as occupancy has continued to fall. One explanation is that tenants increasingly demand premium features, allowing landlords to maintain high rents to recover costs despite vacancies. [321] At the same time, the push for return-to-office policies and the high cost of new construction are expected to increase demand for existing spaces, reinforcing the trend of high prices.[331]

Commercial real estate financing comes from a variety of institutional sources including banks, insurance companies, investment firms, pension funds and credit unions, with some larger players holding significant market share. There are few restrictions on foreign ownership, and major players include firms from Europe, the U.S. and China.[332]

Natural gas is the dominant fuel for commercial and industrial space heating across Canada, but there are regional differences. Just over half of space heating energy comes from light fuel oil and electricity in Atlantic Canada, while electricity provides nearly a third of space heating in Quebec. Alternatives to natural gas are minor contributors to commercial and industrial space heating in all provinces west of Quebec.

9.1.2 Nature of the Problem

Buildings accounted for 12% of Canada's total GHG emissions in 2024 (81 Mt of CO₂e).[186] Approximately half of this came from the residential sector (38 Mt), and half from the commercial and institutional sector (43 Mt). Since 1990, residential emissions have decreased by 15%, realized through measures such as building envelope upgrades, adoption of higher efficiency appliances, and fuel

switching. Emissions from the commercial and institutional sector have increased by 57% since 1990.[186] Building sector emissions arise from onsite burning of fossil fuels such as natural gas and heating oil, primarily for space and water heating.

In addition to direct combustion-related emissions, buildings are associated with other sources. Emissions can arise from electricity generated to power buildings and from the hydrofluorocarbons (HFCs) used in air conditioners, fridges and heat pumps. Emissions produced during the construction phase and production of building materials (steel, concrete, plastic and so on) are considered embodied carbon. As operational emissions from buildings decline, embodied carbon in construction materials (for new builds and retrofits) becomes an increasing share of lifecycle emissions from buildings.[333]

Low-cost natural gas

The relatively cheap cost of natural gas in Canada discourages investment in energy efficiency (building insulation, more efficient heating units) and fuel switching to electricity. Energy efficiency is not a high priority for consumers when they choose a home or consider value-added renovation to an existing property. Similarly, commercial and institutional building owners and managers have paid relatively little attention to monitoring energy performance. Natural gas and electricity prices vary from province to province, but the relatively low gas prices in Ontario and Western Canada make displacing gas a challenge.

Since Canada is a large natural gas producer, this issue is also politically charged. In some provinces, decisions to expand gas infrastructure risk creating stranded assets whose costs will ultimately fall on ratepayers as the transition to a low-carbon economy proceeds.

Financing challenges

Financing the upfront costs for energy retrofits and fuel switching is challenging, even when payback periods are short, largely due to high household debt levels and a lack of dedicated financing mechanisms. In buildings that are rented or leased and where tenants pay utilities, there are few or no financial benefits to investing in energy retrofits or fuel switching even when these are cost effective. This can exacerbate the affordability challenges for renters. In 2022, 34% of renters in market rental housing were paying more than 30% of household income on shelter costs.[334]

Additionally, the financial benefits of residential electrification are less accessible for households without vehicles, who are disproportionately lower income, as they cannot realize the significant cost savings associated with electric vehicles. As a result, their overall energy savings from electrification are more limited.[115]

Upfront costs are also a problem for the commercial and institutional sectors, who often do not prioritize the sometimes-significant capital investments needed to decarbonize their buildings. Unlike residential property owners who often rely on individual mortgages or home energy grants, commercial project developers must engage institutional actors to fund retrofits or new low-carbon construction. The scale and timeline of these investments, along with risk aversion among capital providers, create additional financing barriers.

Slow retrofit schedules and turnover of building heating systems

Building decarbonization is also constrained by the slow turnover of building stock and heating equipment. In the residential sector, the pace of deep energy retrofits remains far below what would be required to decarbonize the existing stock. For example, the Greener Homes Grant

supported only 29,000 deep energy retrofits over five years,[335] while more than 6.5 million homes built before 1984 and 2.5 million before 1960 will require major upgrades.[336] In the commercial and institutional sector, where heating systems often have longer lifespans (often 15-25 years), buildings may already be locked into high-carbon equipment beyond 2050. Since low-carbon heating systems are most cost-effectively installed when older systems are at end-of-life, slow replacement cycles can delay the transition unless action is taken well in advance.

Other issues

The construction sector plays a significant role in building emissions through material choices, construction practices, and the specification of appliances. However, decarbonization is complicated by the sector's structure: although some large firms operate in the market, much of the industry consists of small firms and independent contractors. This fragmentation makes it harder to coordinate and adopt new approaches at scale, contributing to a general hesitancy to take risks on unfamiliar technologies or practices. There is also a growing skilled trades shortage, with an estimated 56,900 new green construction workers needed between 2023-2032 to meet Canada's emissions targets in the residential sector.[337]

Overall, in the past few decades, building energy efficiency and GHG emissions have been a secondary concern in the commercial, institutional, and residential sectors. Given today's relatively inexpensive energy prices and permissive regulatory environment, there has been little incentive for change.

9.1.3 Net-Zero Pathways

A transition to a net-zero building sector requires the elimination of end-use combustion of natural gas and heating oil and

efforts to mitigate the electricity grid peak impacts that result from electrifying those end uses (e.g., via energy efficiency, demand response, etc.). Efforts in the building sector can also reduce industrial emissions by advancing the phase-out of high global warming potential refrigerants and planning new construction to minimize the embodied carbon of construction materials. There are two critical strategies to achieve this transformation: replace fossil fuel end uses in buildings with net-zero energy and improve building efficiency.

Replace fossil fuel end uses in buildings with net-zero energy

Natural gas and oil supplied about half of residential energy requirements in 2022 (46% and 3%, respectively), and a little more in the commercial and institutional sector (51% and 2%).[327] Most is used for space and water heating, although some goes for appliances (cooling systems, stoves, dryers) and backup power systems. Net-zero energy options for the future mainly run through electricity, but other niches might be supplied through biofuels or even hydrogen.[329]

Electrification as the primary pathway

Electricity is typically the most straightforward alternative for building energy needs. It already supplies about 44% of commercial, institutional, and residential building energy use and is widely used for both space and water heating. Although electric heating has traditionally taken the form of resistance devices (baseboard heaters or furnaces), ground or air source heat pumps can dramatically reduce electricity requirements and fuel cost.

Heat pumps use refrigerants to transfer outside heat into a building for heating in the winter and reverse this process for cooling in the summer. They can be several times more efficient than electric resistance. But this is not always sufficient to enable them to

compete successfully with gas appliances, given their higher upfront costs, especially for ground source heat pumps.[338]

The cost-competitiveness of heat pumps depends on several factors, including local electricity and natural gas prices, and climate conditions.[339] As demand for electric heating rises, concerns also grow around ensuring adequate electrical capacity and access to low-cost, clean power.

Heat pump performance has improved in both standard and cold-climate models to the point that replacing electric resistance heating, oil, or natural gas furnaces can deliver substantial cost savings over time in most provinces. In colder regions or where electrical capacity is limited, dual-fuel systems offer a practical transition by pairing a heat pump with a natural gas, propane or fuel oil furnace for backup. One analysis shows that using a heat pump in place of a central air conditioner while retaining existing heating as backup results in cost savings across every province. Overall, heat pumps are now the lowest-cost heating option for a majority of Canadian households.[339,340]

Heat pump uptake has risen in Canadian residential buildings over the last 20 years (see Figure 27). Heat pumps now provide 3.5% of the residential space heating energy mix. [341] Commercial uptake of heat pumps is not substantial to date.

Supplementary low-carbon energy sources

Buildings can also generate their own electricity. Rooftop solar panels are already a familiar sight in Canadian cities. When combined with passive energy design elements and building envelope improvements that reduce heating requirements, these technologies may be able to displace a large fraction of the annual electricity load for many buildings. This could relieve pressure for electrical grid expansions.[342]

Biomass currently supplies about 5.5% of residential building energy needs, mainly in the form of wood or wood pellets.[327] Biomass is typically considered carbon neutral, but the actual emission footprint includes greenhouse gases such as nitrogen oxides, as well as sulphur dioxide and soot. [343] Biomass also has fossil inputs

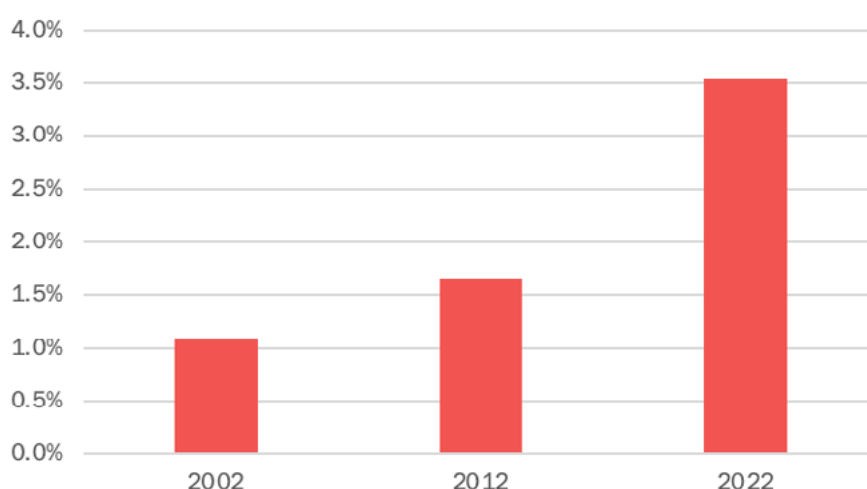


Figure 27. Heat pump share of residential space heating, Canada 2002, 2012, and 2022

associated with harvesting, processing and transport. Improved practices could significantly reduce these emissions, but biomass is unlikely to become a major source of building heat because of concerns over air quality, scalability, logistics and alternative feedstock demand.

Another option is to exploit the existing natural gas distribution network, but substitute a net-zero gaseous fuel. This could be “renewable natural gas” made by anaerobic digestion of organic wastes or eventually “synthetic natural gas” made by using low-carbon feedstocks and electricity.

Problems with renewable natural gas include cost, residual emissions, and scalability. Although the carbon dioxide generated when renewable natural gas is burned is considered part of the natural carbon cycle, methane leaks across the supply chain could be significant. Marginal emissions reductions are achieved today by blending renewable natural gas with conventional natural gas, but opportunities to extend this approach are limited. Torchlight Bioresources estimates that the feasible renewable natural gas supply from all feedstocks could only generate up to 3.3% of Canada's 2029 natural gas consumption.[344] On the other hand, synthetic natural gas is far from ready for market and would require significant low-carbon electricity that may be better used for direct electrification.

Finally, hydrogen could be distributed through a modernized gas grid and used as a form of stored energy. This would require investments in low-carbon hydrogen production and replacement or upgrading of gas transmission and distribution networks, meters and end-use appliances.[345] Additional challenges include increased fire and explosion risks from hydrogen[346] and projected high costs for delivered

low-carbon hydrogen. A meta-analysis of 54 studies from around the world concluded that hydrogen was not generally a cost-effective pathway to building decarbonization.[347] Hydrogen fuel cells could contribute to the management of building electrical supply (serving as storage for building-integrated renewable generation) or for back-up power. The deployment of a hydrogen building heating option at scale could be made more viable in specific regions by demand development in other sectors (heavy freight, industrial users, and so on).[348] However, it is not expected that hydrogen will play a significant role to heat buildings in Canada, especially in provinces where electrification could supply heating at scale. Further details on these alternative low carbon fuels can be found in chapter 7.3.

Improve building energy efficiency

A critical supporting element for building decarbonization is the promotion of energy efficiency, which can reduce demand pressure on the supply system and keep costs down for consumers. Energy efficiency measures can lower building heating loads, reduce demand on the electricity grid for new generation or transmission, help control electricity costs and reduce the price differential with gas. [349,350] New buildings can be built to higher energy performance standards using:

- Improved building envelopes (better insulation and air sealing),
- Passive design principles,
- Energy-efficient HVAC and lighting systems,
- Smart controls, and
- New materials (low-carbon cement or steel).

Retrofits are important for older structures, particularly for the large stock of buildings with poor energy efficiency built before 1960.[351] Better windows, doors, exterior siding and caulking, additional insulation, and improved envelope air sealing and roof structures can all significantly lower energy requirements, particularly when coupled with energy-efficient equipment.[351] This will have the greatest energy, emissions, and cost impacts when applied to older buildings.[352] Nevertheless, building envelope retrofits can be very expensive and disruptive with long payback times, and should be synchronized with the building lifecycle where possible.

These two foundational elements—replacing fossil fuel end uses and dramatically raising building energy efficiency—form the foundation for transition pathways in this sector and can be pursued in an integrated manner in new builds and retrofits of the existing building stock.

Cross-cutting and long-term system changes

Additional elements which connect buildings to wider systems, such as electricity, industry, transport, and community design, include:

- Grid expansion and decarbonization, ensuring that increased electricity demand from buildings is met with clean power (discussed in chapter 7.1).

- Replacement of high-global-warming-potential refrigerants used in building cooling systems and heat pumps with climate-benign refrigerants and technologies.
- Transition to net-zero-emission building construction by decarbonizing steel and concrete production, using low-carbon alternatives like engineered wood, and eliminating emissions from construction, manufacturing, and transport.
- Management of construction and demolition waste streams to reduce landfill use and material-related emissions.
- Promotion of sustainable urban design to enhance well-being while encouraging climate-friendly patterns of living. Changes here could include:
 - » Mixed-use community design with district energy schemes,
 - » Urban densification with accessible mass transit and lower energy demand than suburban housing, and
 - » Shared green spaces and local work hubs that may encourage a trend towards smaller homes or teleworking.

Competitiveness Implications

Canada needs to retrofit over 6.5 million homes built before 1984, yet the Greener Homes Grant delivered only 29,000 deep retrofits over five years. That gap reflects a market-formation problem more than a technology one. The retrofit industry remains fragmented across small firms and independent contractors, without a standardized project pipeline large enough to attract sustained private capital or support workforce specialization. This decade's equipment replacement cycle, the last full cycle before 2050 given 15-to-25-year system lifespans, is the window that determines whether Canada industrializes cold-climate retrofit delivery or enters the 2030s still treating deep retrofits as bespoke projects. If replacement decisions continue to default to gas and procurement remains fragmented, the volume needed to drive cost reduction and workforce formation will not materialize. Jurisdictions that industrialize during this window will set the terms for a market that late movers enter at a disadvantage.



9.1.4 Priorities for Action

Achieving a net-zero building sector requires action on four fronts: raising standards for new construction; electrifying, retrofitting, and decarbonizing existing buildings; mandating stronger performance standards; and building the financing and innovation capacity to deliver change at scale.

Raise standards for new construction

Each new structure built without low-carbon standards locks in years of greenhouse gas emissions, making decarbonizing new construction an urgent priority.[335] A central goal is the universal adoption of Canada's Net-Zero Energy Ready Code, with continued support to accelerate progress beyond minimum requirements. Recent updates to national model building codes, introducing operational GHG emissions limits alongside enhanced energy efficiency requirements, are already raising the bar for new residential, commercial, and institutional buildings.[353] Natural gas phase-outs for new buildings, already underway in some jurisdictions, should be more broadly considered. Eventually, building standards should evolve to address embodied carbon by promoting low-carbon material choices and reducing emissions from construction, manufacturing, and transportation.

Building codes should preserve flexibility in heating, cooling, and envelope design strategies while progressively escalating toward net-zero emission standards. In the residential sector, higher standards must be carefully coupled with industry support to avoid compounding affordability concerns.

Accelerate electrification, low-carbon energy, and retrofits in existing buildings

Because most of the 2050 building stock already exists, and heating equipment is replaced only periodically, electrification and

retrofit efforts need to accelerate now to avoid locking in fossil fuel use for decades.

For existing buildings, electrification and fuel switching should be the priority. A simple near-term strategy is to ensure that all newly installed cooling systems are heat pumps with heating capability, normalizing the technology while building workforce capacity in installation and servicing. Dedicated efforts may be required to ensure the switch is economically attractive to building owners through incentives, regulations, and public education. Although heat pumps can already be cheaper to operate than natural gas or oil-based heating, high upfront capital costs and ongoing concerns about electricity prices remain barriers to adoption. Programs should ensure that clean alternative technologies become more attractive than those powered by natural gas. Transitioning to low-GWP refrigerants in heating and cooling equipment should also accompany the broader shift to heat pumps.

District heating can be an efficient and cost-effective way to heat buildings by distributing heat from centralized sources (waste heat from industry, data centres, and sewers) to clusters of buildings. Coordinated planning among the private sector, utilities, and multiple levels of government is crucial for scaling these systems. Enabling these projects can require changes to utility rate structures, zoning, and urban planning.

Efforts to scale up energy efficiency retrofits should focus on older buildings where energy, emissions, and cost savings are greatest. These retrofits can be pursued independently of electrification or fuel switching but yield greater benefits when combined. Key enablers for the retrofit ecosystem are investing in skilled labour training and stimulating consumer demand. Expanding training and professional certifications in integrated design principles and heat pump installation

will support the workforce needed for wide-scale deployment of clean heating technologies. At the same time, as the transition proceeds, natural gas infrastructure risks becoming stranded assets with costs that can disproportionately affect lower-income households—reinforcing the importance of making retrofit pathways accessible and affordable.

Mandate performance standards and labelling

Mandatory building emissions performance standards and labelling can help buyers or tenants choose better-performing spaces with lower operating costs and encourage existing building owners to invest in fuel-switching technologies and energy efficiency measures. Standards should be augmented with minimum emission performance requirements that increase over time and systematically target the worst-performing buildings. To be successful, energy and emissions disclosure must be mandatory at the point of sale, rent, or lease for both commercial and residential buildings. Regular updating and harmonizing of minimum performance standards for appliances and equipment will ensure that low-carbon options are chosen during construction and retrofits.

Build financing capacity and drive innovation

A core objective is to create institutional structures for a functioning private market for fuel switching and building retrofits. This requires developing common underwriting standards, aggregating small retrofit projects into larger financial portfolios, and demonstrating investment opportunities to the private sector through de-risking, co-investing, and information sharing. A publicly supported investment vehicle can accelerate this process. Public sector procurement across all levels of government can also drive demand for net-zero new builds and retrofits.

Targeted R&D and market development can support emerging technologies, including cold-climate heat pumps, prefabricated wall assemblies, digital tools for virtual energy audits and building energy management systems, and hydrogen heating, where regionally viable.

Together, these strategies can establish a foundation for a net-zero building sector that is efficient, affordable, and equitable.



 Fails to meet criteria Meets in some respect
 Not promising Potentially meets criteria
 Meets criteria

ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Net zero with a decarbonized electrical grid.	Cost competitiveness varies by region and building type. Residential single units most often achieve parity, but economics weaken for multi-unit and commercial buildings, in cold climates, and where gas is cheap.	Some potential for domestic assembly, installation, and distribution jobs. Manufacturing is typically international.	Commercially mature for residential applications across Canada. Well-established and growing for commercial and institutional buildings.	Used across Canada in buildings. Less efficient in very low temperatures.	Upgrades to grid and generation may be needed to accommodate increased demand.	No particular concern.	Increasing interest from utilities and HVAC companies as the need to decarbonize becomes clearer. Interest from some building owners in terms of savings. Some hesitancy from contractors to recommend newer technologies, preferring to stick with incumbents.	Reduced grid demand compared to other electric alternatives. Some concerns with emissions from refrigerants.
Net zero with a decarbonized electrical grid.	Installation significantly more expensive than ASHP but efficiency and operational savings are greater. Payback periods lengthy.	Some potential for domestic assembly, drilling, installation, and distribution jobs. Manufacturing is typically international.	Mature for residential, and commercially available for commercial and institutional buildings.	Site suitability is a constraint; not all buildings have suitable land area or soil conditions. More efficient than ASHP overall and in cold climates specifically.	Upgrades to grid and generation may be needed to accommodate increased demand. Specialized drilling equipment may not be available in remote/rural areas. Community and district applications face gaps in standards.	No particular concern.	Growing interest from institutional building owners, developers, and utilities for large scale and district projects. Limited residential interest and more niche than air source heat pumps. Some hesitancy from contractors to recommend newer technologies, favouring to stick with incumbents.	Reduced grid demand compared to other electric alternatives. Some concerns with emissions from refrigerants.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Dual Fuel (Hybrid) Heat Pump Systems (Heat pump & natural gas or fuel oil furnace as a back-up)	Bridge Pathway Applicable until clean electricity is widely affordable, available, and reliable.	Deploy Support deployment where electricity is expensive or climates are very cold through education, incentives, building codes, and subsidies that assist with capital costs. Provide workforce upskilling.	 Significant GHG reductions but still some GHGs associated with fossil fuel combustion.	 Similar economics to ASHP. Can be cost competitive in some regions.	 Some potential for domestic assembly, installation, and distribution jobs. Manufacturing is typically international.	 Mature for residential, and commercially available for commercial and institutional buildings.	 Used across Canada in buildings. Dual fuel can compensate when temperatures are very low.	 Requires electricity and incumbent heating source (i.e. natural gas, fuel oil), which are available in almost all locations in Canada.	 Well accepted. Viewed positively in terms of cost savings.	 Increasing interest from utilities as need to decarbonize becomes clearer. Interest from building owners in terms of savings. Some hesitancy from contractors to recommend newer technologies, favouring to stick with incumbents.	 Reduced grid demand compared to other electric alternatives. Some concerns with emissions from refrigerants.
Dual Fuel (Hybrid) Heat Pump Systems (Heat pump & renewable natural gas or hydrogen furnace as a back-up)	Potential Niche Pathway Applicable where clean electricity access is limited, clean fuels are accessible, and where a back-up furnace may be required (i.e. extreme cold or remote regions)	Incubate Support development of hydrogen and RNG supply chains as well as R&D projects using clean fuels as heat pump back-ups.	 Significant GHG reductions but may require removals. Can be net-zero with sustainable feedstocks.	 Worse economics than dual fuel with fossil fuels as clean fuels carry premiums. Hydrogen furnaces have very high capital costs.	 Some potential for domestic assembly, installation, and distribution jobs. Manufacturing is typically international. Can support RNG and hydrogen production.	 RNG is a drop-in fuel and mature, with some utilities offering purchase. Hydrogen furnaces have lower maturity in early-stage demonstration.	 RNG is a drop-in fuel and requires no modifications. Hydrogen requires replacement of existing furnace and appliances.	 Requires RNG or hydrogen, which have limited supply and require substantial infrastructure build out to connect generation to broader consumption. Additionally, electricity is needed.	 Well accepted. Viewed positively in terms of cost savings. Some concerns around safety of hydrogen.	 Some interest from utilities as need to decarbonize becomes clearer. Some hesitancy from contractors to recommend newer technologies, preferring to stick with incumbents.	 Reduced grid demand compared to other electric alternatives. Some concerns with emissions from refrigerants. RNG has indoor air quality concerns.
Baseboard or Electric Furnace	Niche Pathway Relevant for some buildings where heat pumps are not practical.	Deploy Support in contexts where heat pumps are not viable (i.e. as a back-up to heat pumps and/or in very cold regions).	 Net zero with a decarbonized electrical grid.	 More expensive in regions with low-cost natural gas, but widely used.	 Already a mature industry, supports existing jobs.	 Commercially mature.	 Used across Canada in buildings.	 Requires upgrades to the electrical grid and generation to accommodate new demand.	 Widely accepted and used in many households across Canada.	 Established market alternative.	 Very low overall environmental impact. High electricity demand, inefficient compared to heat pumps.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Hydrogen in Place of Natural Gas	<i>Potential Niche Pathway</i> Could be relevant in specific geographies where the availability and price of net-zero hydrogen are positive.	Don't Prioritize Support if niches emerge in locations with substantial hydrogen infrastructure buildout.	 Can eliminate heating emissions if hydrogen is net zero. Some concerns around hydrogen leakage and associated GHGs.	 Potential for high costs for net-zero hydrogen. Viability is location specific.	 Domestic potential to produce net-zero hydrogen and build up a surrounding industry.	 Low blends currently piloted in some locations in Canada.	 New appliances and modified furnaces are required.	 Gas infrastructure requires substantial upgrading. Supply of net-zero hydrogen as an energy source is currently very limited.	 Concerns around safety may cause mixed views in communities.	 Limited interest. Some relevance from existing natural gas producers and utilities to continue use of gas networks.	 Some concerns around safety due to leakage and high flammability. Substantially reduces indoor air quality concerns.
Natural Gas	Dead-End Pathway GHG emissions occur at point of use, cannot achieve net zero.	Dismiss Phase out use of natural gas in buildings using building codes and other policy instruments.	 Produces emissions during combustion, transport, and production. Methane leakage remains a concern.	 Low cost compared to other heating alternatives.	 Already a mature industry, supports existing jobs.	 Commercially Mature.	 Used currently across Canada in many locations and types of equipment.	 Incumbent technology in many locations. Some regions are difficult to reach with pipelines.	 Generally, widely accepted and used in many households across Canada.	 Important to industry and utilities.	 Increasing concern with indoor air quality issues.
Renewable Natural Gas	<i>Niche Pathway</i> Applies in specific contexts such as a facility or community. Not applicable at large scale given limited feedstock.	Don't Prioritize Support development of feedstock including biogas capture and biomethane in appropriate contexts.	 Only net zero if RNG fully displaces fossil natural gas. Requires low-carbon feedstocks. Methane leakage remains a concern.	 Costs vary by geography and can be very high depending on availability of feedstocks.	 Some local opportunities especially for waste or organics management facilities.	 Some small-scale or local deployment and use. Not used frequently for building heat beyond blending with conventional NG.	 As a drop-in fuel for natural gas.	 Uses incumbent technology. Can be difficult to connect some RNG suppliers to the existing NG network.	 Should receive the same level of acceptance as conventional NG.	 Interest and some investment in various regions in Canada from utilities and feedstock suppliers.	 Increasing concern with indoor air quality issues. Waste valorization.
Synthetic Natural Gas	<i>Potential Dead-End Pathway</i> Supply cannot meet demand with current maturity and costs. Prolongs use of dead-end assets.	Dismiss Economics and maturity limit viability.	 Net zero in principle but requires net-zero hydrogen and biomass or direct air capture. Methane leakage remains a concern.	 Very high cost. Depends on reliable and low-cost supply of net-zero feedstocks or offtake of carbon.	 Limited by feedstock or carbon storage availability.	 In early research phase.	 Is a drop-in fuel for NG which is used currently across Canada in many locations and types of equipment.	 Uses incumbent infrastructure. Can be difficult to connect supply to NG network. Major buildout of feedstock supply chains required.	 Likely to be socially acceptable.	 Still in research, so not relevant to many stakeholders at this time.	 Indoor air quality issues. Methane leakage during transport and production.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Biomass Combustion	Niche Pathway Could be used in remote locations where electricity isn't available, in district energy systems, and/or as a back-up heating system.	Don't Prioritize Relevant where other options are not applicable.	Can be net-zero when feedstocks are decarbonized.	Viability depends on location.	Largely developed. Potential for local economic development in remote or Indigenous communities.	Commercially mature.	Used mainly in residential buildings in some areas of Canada.	Supply chains exist today but are unlikely to scale. Difficult logistics in moving feedstocks.	Some concerns about indoor air quality but widely accepted and used in many residences.	Unlikely to expand beyond current measures.	Can use forestry residues. Air quality and health concerns.
Building Design and Energy Systems											
Net-Zero Design for New Builds	Priority Enabling Pathway Buildings need to be built so that they will not require future net-zero retrofits.	Deploy Implement and accelerate net-zero building codes now at the municipal, provincial, and federal level. Support training programs to certify the workforce.	Net zero with a decarbonized electrical grid. Further decarbonization can be achieved when low-carbon materials are used for building.	Upfront costs may be higher. Can be cost competitive over the lifecycle of a building.	Large opportunity for job creation. Housing deficit and building for climate resilience provide opportunity for net-zero building industry to grow. Anchor tenant for low-carbon building materials.	Emerging industry. Some buildings exist in Canada.	Requires training for builders to learn new codes and technologies.	Relies on access to or production of clean electricity and heat pump technologies. Infrastructure and maturing supply chains are available in most locations.	Viewed positively as it can improve air quality, comfort, noise, lighting and operational costs. Some wariness around efficacy and upfront cost.	Some builders are adopting practice as a competitive advantage. Wariness around upfront cost premium.	Improvements to health and comfort of people living or using the buildings. Air quality improves.
Retrofitting for Existing Builds	Priority Enabling Pathway Retrofits are required to reduce emissions from the current building stock.	Deploy Support retrofits with financing mechanisms, especially where affordability is a concern or deep retrofits are required. Provide consumer education. Support training programs to certify the workforce.	Net zero with a decarbonized electrical grid. Further decarbonization can be achieved when low-carbon materials are used for building.	Many investments pay for themselves through energy savings over time. Deep retrofits are more challenging.	Large opportunity for job creation. Housing deficit and building for climate resilience provide ample opportunity for net-zero buildings industry to grow.	Building technologies relatively mature but finance mechanisms and approaches to mass retrofits are still emerging.	Requires builders to learn new codes. Installation of newer technologies requires training. Deep retrofits can cause significant disruption to building operations and are best timed with lifecycle of assets.	Relies on access to or production of clean electricity and heat pump technologies. Infrastructure and maturing supply chains are available in most locations.	Viewed positively as it can improve air quality, comfort, noise, lighting, and operational costs. Some wariness around efficacy and upfront cost.	Undervalued by building owners who rent or lease, especially where tenants pay utilities.	Improvements to health, air quality, and comfort of people living in or using buildings.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
District Energy Systems (Powered by Net-Zero Energy)	Enabling Pathway Reuses waste heat and can reduce costs for building heating where applicable.	Deploy Support buildout where waste heat is available and buildings are clustered.	 Aligned if powered by net-zero energy. Emissions reductions from increased efficiency but only applicable where buildings are clustered.	 High upfront cost but return on investment occurs from reduced energy costs.	 Municipalities or private companies will have major design and installation work.	 Commercially mature. Limited deployment currently.	 Can be integrated into buildings and communities at design stage. More challenging to retrofit existing urban infrastructure.	 New infrastructure required. Challenging for planning systems, coordination of multiple owners and stakeholders. Project execution and management difficult.	 Viewed positively for new builds but may be some controversy with retrofits.	 Some relevance to gas utilities as an alternative business model as decarbonization proceeds.	 Reduces air pollution and burden on the energy system.
Solar Panels on Buildings	Enabling Pathway Relevant to regions and buildings with good sun exposure.	Deploy Deploy financing mechanisms for developers and building owners. Provide workforce training for installation. Pilot programs to integrate micro-generation with the larger electricity grid, working collaboratively with utilities.	 Can be part of net-zero buildings (assuming panel lifecycle emissions are managed).	 Costs have declined dramatically over time. Economics can depend on regional incentives. Return on investment occurs over solar panel lifespan.	 Industry is well established. Some opportunities for local installers.	 Commercially mature.	 Power output likely not high enough to meet all needs in conventional buildings.	 Supply chain is mature.	 Widely accepted and non-disruptive. Some pushback over aesthetics.	 Some interest from building firms and owners. Recognized in federal net-zero strategy for transforming Canada's buildings.	 When paired with storage, provides resilience in power outages and reduces daily peak demand. Can sell energy back to the grid. Issues with disposal and differing lifespan from building materials.
Building-Integrated Solar PV	Enabling Pathway Relevant to regions and buildings with good sun exposure.	Deploy Technologies and materials maturing. Support further development of materials, approaches, standards, and demonstration.	 Can be part of net-zero buildings (assuming material lifecycle emissions are managed).	 Costs have declined dramatically over time. Economics can depend on regional incentives. Return on investment occurs over solar panel lifespan.	 Industry still emerging. Opportunities for materials and construction will expand with maturity.	 Commercially available with demonstrated projects in Canada. Not a mainstream solution.	 Requires retrofit (new roofs, facades, windows etc.). Better suited for new build construction. Must be integrated into building design codes.	 Supply chain is emerging.	 Widely accepted and non-disruptive.	 Niche interest among innovation-focused stakeholders, with limited utility impact due to small scale.	 When paired with storage, provides resilience in power outages and reduces peak demand. Can sell energy back to the grid. Immaturity of recycling panels and differing lifespan from building materials.

INDUSTRY





The mining sector in Canada has begun to re-position itself as a supplier of metals and minerals that are critical not only to a low-carbon economy but also to national sovereignty and defence.

10. Industry

Heavy industry produces primary materials from which much of the rest of the economy is built. In Canada, four sectors account for much of this output. Cement goes into buildings and civil infrastructure; steel supplies the structural metal for grids, turbines, vehicles, and buildings; aluminum provides conductors and lightweight material for aerospace and automobiles; and mining yields the mineral and metallurgical feedstocks on which batteries, electronics, and primary manufacturing depend.

Together these four sectors accounted for roughly 42 Mt CO₂e of emissions in 2022–23, on the order of 6% of the national total.^[61]¹³ The emissions profile of heavy industry is distinctive. Much of it comes from high-temperature process heat in kilns, furnaces, and smelters, which are long-lived, capital-intensive assets. Coal and coke are used in ironmaking; natural gas and petcoke for cement production; and natural gas in calcination and alumina refining. The remaining emissions result from the chemistry of production, with the calcination of limestone, the consumption of carbon anodes in aluminum electrolysis, and the coal-based reduction of iron ore all releasing CO₂.

The transition to net zero requires a reconfiguration of how these sectors operate. Electrification is emerging where temperatures and economics permit, with hydrogen, biomass, and waste-derived fuels filling gaps at higher heat grades. On the process side, alternative chemistries, carbon capture and storage, greater circularity through scrap recovery, and material efficiency can each contribute. The pace at which enabling inputs become available (including low-carbon electricity at scale, hydrogen supply, CO₂ transport and storage, and higher-quality scrap) determines when viable pathways become practical, how long interim fuels remain necessary, and where near-term investment is likely to concentrate.

¹³ This source provides mining (11 Mt CO₂e, 2022), cement (11 Mt CO₂e, 2023), and steel (14.5 Mt CO₂e, 2023) emissions. Aggregate is approximate.

In the following sections, we examine each sector in turn. The section on cement focuses on calcination and downstream product specification, where process chemistry and the codes governing material use together shape emissions abatement. The section on steel examines primary-route conversion, which depends on the availability of hydrogen and clean electricity, and on the economics of scrap-based production. The section on aluminum considers the commercial maturity of inert-anode technology against the backdrop of a sector already benefiting from a carbon-intensity advantage from hydropower in Quebec and British Columbia. And the section on mining explores electrification of mobile fleets and grid access at remote operations. The assessments that follow do

not attempt to predict which configurations will ultimately prevail or how quickly they will mature. They do indicate the direction of probable advance and can help decisionmakers distinguish between more and less promising alternatives.

As the following analysis will make clear, heavy industry confronts many challenges and trade-offs, including reinvestment windows opening this decade while enabling infrastructure remains absent, trade exposure in sectors where tariff conditions have tightened sharply,[354–356] and the question of whether inert-anode technology and hydrogen-based ironmaking can mature in time to meet ongoing capital cycles.



10.1 MINING

Function	Extraction of minerals used for multiple purposes across all sectors.
GHG emissions	10 Mt CO ₂ e (2024), 1.5% of total national emissions.[61]
Options for decarbonization	Decarbonization Pathways: Battery-electric and trolley-assist mining equipment. Enabling Pathways: On-site renewables and storage microgrids, transform extraction and processing, metal recycling and recovery.
Stage of transition	Emergence/diffusion boundary: Transform extraction and processing, metal recycling and recovery. Diffusion: Battery-electric and trolley-assist mining equipment, on-site renewables and storage microgrids.
Nature of the problem today	Legacy infrastructure, high up-front costs, lack of regulatory framework (metal recycling and recovery).
Other systemic issues	Pollution; worker health and safety; remediation of abandoned sites; relations with Indigenous peoples.
Strategic opportunities and concerns	Potential to reduce operational costs, improve air quality and worker health, and create new revenue streams (metal recycling and recovery). Design, build and test new electric mining technologies in Canadian labs and mines, export technology. Markets for minerals critical to a low carbon transition (eg, batteries). Indigenous land claims and opportunities for partnership. Competitiveness. Issues: Need for international collaboration.
Priorities for action	Incentivize use of electric mining equipment and on-site renewable energy production and storage; regulatory framework and funding of pilots to encourage metal recovery/recycling.
Longer-term issues	Lifecycle management of batteries, mine site reclamation, production of metallurgical coal.
Indicators of progress	Proportion of mining equipment that is electric or fuel cell; volume and value of recycled metals.

10.1.1 Current Status

Canada has a significant and well-established mining sector with over 200 active mines and 6,500 quarries.[357] The direct contribution of the mining sector to Canada's 2023 GDP was \$117 billion¹⁴. [358] The sector directly employs about 213,000 people in extraction, services, and primary manufacturing.[359] These numbers do not include oil sands operations. Mining is a major source of export earnings.

Global demand for battery and defence-critical minerals means Canada's mining footprint is poised to grow quickly. Natural Resources Canada's 2024 Major Projects Inventory lists 35 new or expanded mines that are approved, 31 announced, 46 in review, and 26 under construction.[360] Capturing the economic upside while meeting net-zero and Indigenous-partnership goals will require

front-loaded deployment of low-carbon power, electric mobile equipment, and ESG safeguards.

In 2024, the total value of Canada's domestic mineral exports was \$125.0 billion. The top five mineral exports that year were gold (\$40.2 billion), iron and steel (\$20.6 billion), aluminum (\$17.4 billion), copper (\$10.7 billion), and metallurgical coal (\$10.2 billion)¹⁵. [361]

Many Canadian mining companies operate abroad. Of the sector's \$343.2 billion¹⁶ in assets (2023), 68.1% were located outside the country. In 2023, the Toronto Stock Exchange was the top exchange in the world for global mining equity financing. Compared to most industrial sectors, Canada's mining industry has a moderately high level of foreign ownership. In 2023, 31.9% of total mining industry assets were controlled by foreign entities, 2.2 times the private sector average.[362]



Figure 28. Canada, Major planned and under-construction mining projects

Source: Natural Resources Canada, 2025. Major Project Inventory[360]

¹⁴ In chained (2017) Canadian dollars

¹⁵ In 2024 Canadian dollars

¹⁶ In 2023 Canadian dollars

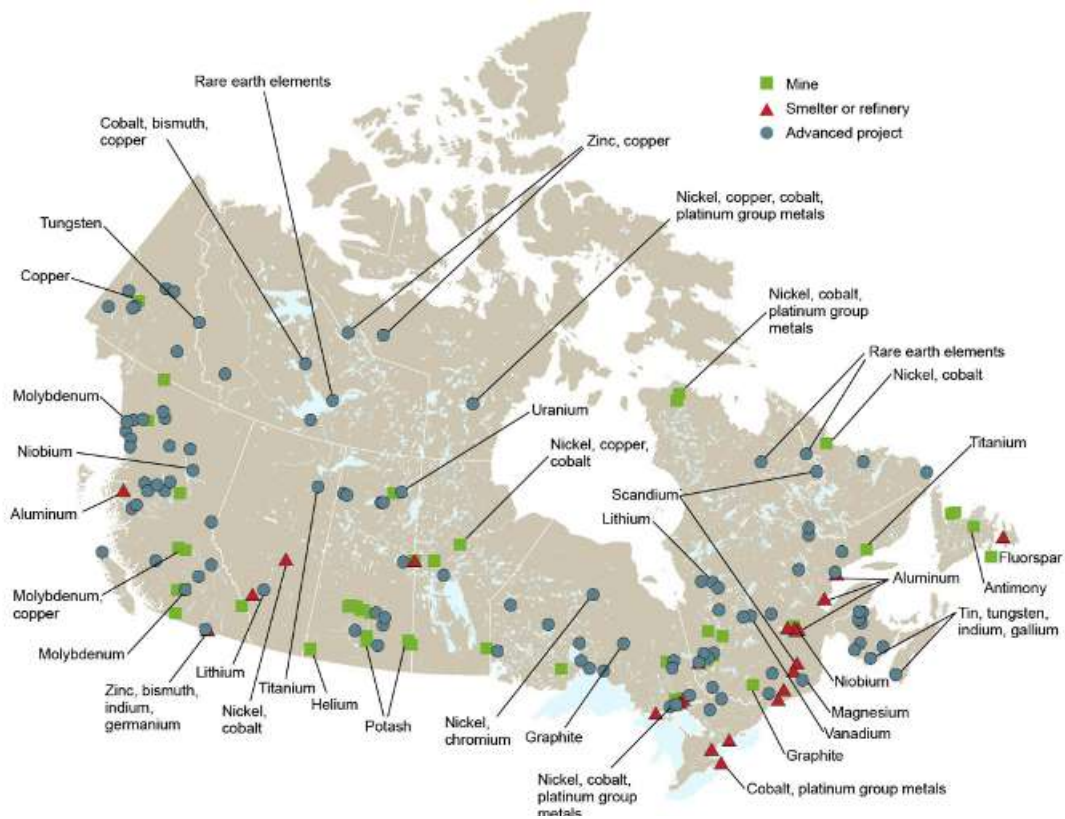


Figure 29. Canada, Critical mineral project locations (2022)

Source: Natural Resources Canada, 2023. *The Canadian Critical Minerals Strategy*[363]

10.1.2 Nature of the Problem

The main challenge to decarbonizing this sector is the remote location of most mines, sunk investments in existing mining infrastructure, high capital costs for new equipment (for example, electric vehicles, processing equipment, net-zero energy supplies) and competitiveness concerns in this globally integrated industry. Mobile equipment is a key source of emissions in mining; however, because this equipment is routinely replaced every 10 to 15 years, these regular procurement cycles provide cost-effective opportunities to transition to electrified alternatives, mitigating some of the challenges posed by high initial capital costs. In 2022, Canada's mining sector emitted 10 Mt of CO₂e or approximately 1.5% of Canada's

total emissions. At the mine site, stationary emissions come from electricity generation (needed for ventilation, lighting, ore processing, etc.).[186] Diesel trucks are the largest source of mobile emissions. Since 1990, emissions have remained flat while the sector has grown significantly. Many remote mines rely on expensive and polluting diesel generators to power operations. Mining companies face increasing environmental and economic pressures from local and Indigenous communities and are subject to more stringent regulation. Unsettled Indigenous land claims in some regions complicate mine development. Some decarbonization activities, such as renewable power generation, can provide helpful partnership opportunities with Indigenous and local communities.

The mining sector in Canada has begun to re-position itself as a supplier of metals and minerals that are critical not only to a low-carbon economy but also to national sovereignty and defence. Reflecting this broader priority, the federal government now lists 34 critical minerals that it considers essential for economic security and the energy transition[364] such as lithium, cobalt, nickel, and copper, as well as for rare-earth elements used in permanent magnets, copper for grid and transportation electrification, and specialized metals required for wind turbines, semiconductors and defence systems. On the other hand, demand for thermal coal will fall as Canada phases out coal-fired generation. Metallurgical coal (which makes up 97% of Canada's coal exports) will continue to be needed by the steel industry until alternative foundry technologies are developed and diffuse internationally over coming decades.[365]

10.1.3 Net-Zero Pathways

The fundamental approach to achieving net-zero emissions in mining is electrification of mine operations, supply of renewable electricity, and the modernization of extraction and processing techniques—for example for comminution (crushing and grinding of ore). Promotion of resource efficiency in mineral-consuming industries, reuse, and recycling (embracing the circular economy) provides a complementary track. Given the established global leadership of Canada's mining sector, and existing public and private sector activities currently underway, Canada is well-positioned to lead on both paths.

Table 6. Decarbonization opportunities by mine type and grid connectivity mine area

	Grid-Connected Opportunities	Additional Off-Grid Considerations
Site-wide Power and Storage	Stationary batteries can help overcome grid peak-demand limitations as operations electrify. Greening the grid is generally more practical than adding on-site renewable generation, unless supply reliability is a concern.	On-site renewable generation (wind, solar) can displace diesel, though energy storage is needed to smooth intermittent supply. Large-scale storage may be required to bridge extended periods of low renewable availability. Establishing a grid connection should be evaluated where feasible.
Underground Mining (material movement and ventilation)	Hoisting and conveyance systems are typically already electrified; further gains come from optimizing these systems. Battery-electric or trolley-assisted mobile equipment (loaders, haul trucks) can replace diesel fleets, also reducing ventilation energy requirements. Electrification and optimization of ventilation air heating offer additional energy savings.	Expansion of local generating capacity (renewables, diesel, or hybrid systems) is needed to support the additional electrical load from fleet and ventilation electrification.

	Grid-Connected Opportunities	Additional Off-Grid Considerations
Open Pit Mining (haulage and conveying)	Diesel haul trucks are the dominant source of emissions; trolley-assist systems augmented by on-board batteries, or fully battery-electric trucks, can substantially reduce fuel use. In-pit crushing and conveying (IPCC) systems can replace truck haulage on suitable haul profiles. Hydrogen-powered haul trucks are an emerging alternative for long-haul routes.	Significant expansion of local generating capacity is required to support trolley, battery, or conveyor electrification. Hydrogen-powered trucks may be better suited than trolley-assist in remote settings where electrical infrastructure is limited.
Mineral Processing (comminution and concentration)	Energy efficiency improvements through ore-sorting and grade-control technologies can reduce the volume of material processed. Optimizing comminution and processing parameters (i.e., grinding circuits) lowers energy intensity per tonne.	Higher cost of locally generated electricity can shorten payback periods for efficiency investments. Reducing energy intensity per tonne is especially valuable where power supply is constrained.
Metallurgical Processing (smelting, hydrometallurgy, refining)	Most mines do not operate their own smelters or refineries. Concentrate is typically shipped to centralized metallurgical facilities located near low-cost power, water, and transport infrastructure, often operated by separate companies. Where on-site hydrometallurgy exists (i.e., solvent extraction-electrowinning for copper), process electrification and efficiency gains can be pursued directly.	On-site metallurgical processing at off-grid mines is rare. Gold operations are the main exception, with leaching and smelting of doré bars routinely carried out at remote sites. SX-EW circuits, which produce finished metal at the mine, are generally feasible only at grid-connected operations due to their high electricity demand.

Electrify all that is possible. Energy is one of the largest and most volatile operating costs for mines—typically around a quarter to a third of total operating costs—and in some deep or remote operations it can be the single largest.[366,367] Many of Canada's remote mines are off-grid and rely on diesel for power generation and operational equipment. For underground mines, this means additional costs for ventilation and increased health risks for workers from air and noise pollution. Mine electrification can reduce operational costs. Electric (or hydrogen fuel-cell) mining

equipment eliminates the need for diesel, improves air quality in underground mines, eliminates tailpipe emissions, and reduces ventilation costs and noise. Newmont Goldcorp's Borden gold mine in Ontario, which opened in 2018, is the first all-electric underground mine in Canada.[368]

Major equipment manufacturers like Sandvik, Epiroc, Komatsu, Hitachi, and Caterpillar as well as several Canadian firms (e.g., Maclean Engineering) already sell battery electric mining equipment. Hydrogen fuel cell electric

technology is currently under development for mining applications, providing torque, size and weight advantages over batteries. But this equipment is not yet in commercial production. In March 2020, the federal government introduced a temporary 100% first-year capital cost allowance (CCA) for eligible zero-emission vehicles and automotive equipment (under new CCA Class 56), with a full write-off available if put into use by 2023, phasing down to 75% in 2024–25 and 55% in 2026–27. However, industry stakeholders have pointed out that the write-off under Class 56 only applies to fully electric or hydrogen-powered self-propelled equipment (i.e., battery or fuel-cell vehicles). The inclusion of tethered or trolley-powered equipment is unclear as these retain a diesel engine. This has led to calls for extending eligibility to these systems.

Renewable diesel would offer a drop-in and bridge decarbonization pathway for remote-site generators and legacy diesel fleets, cutting a portion of lifecycle emissions without engine modifications while electrification builds out.

On-site wind and solar-PV power generation, when combined with energy storage technologies, can reduce carbon emissions for off-grid mine sites or those connected to emission-intensive electricity grids. Glencore's Raglan mine in Quebec has two wind turbines and an energy storage system, which includes a small hydrogen generator. [369] Between 2014 and 2019, the mine's new power system displaced 10 million litres of diesel fuel. Small modular nuclear reactors have also been proposed as a longer-term option for power generation at mines, but the technology remains far from market, and it is uncertain how cost, safety, and security concerns will be overcome.

Transform extraction and processing technologies. Achieving full electrification will require major advances in mining and mineral processing systems for upgrading, integrating

continuous mining with already-continuous processing circuits, reducing material brought to the surface, and increasing sorting efficiency. Such platform improvements could dramatically increase energy efficiency and reduce water use and tailing discharges, raising operational efficiencies. Modernizing mining processes (which in some respects have remained remarkably stable) to eliminate inherent energy inefficiencies can also help address the long-standing problem of declining ore quality, where more material must be processed to extract a given quantity of mineral. It will require continued research and development and significant capital expenditures.

Block caving. This is an emerging option for deep or mature deposits and a gravity-assisted underground method that lets ore break and flow to draw-points, slashing waste-rock movement and diesel haulage. Canada's only operating block-cave mine is New Afton (B.C.), but several projects, including KSM (B.C.), Red Chris extension (B.C.), and Galore Creek (B.C./YT), have advanced block-cave designs. Studies by WSP and recent case reviews link the technique to smaller surface disturbance, potential reductions in GHG emissions, and improved worker safety, making it a credible component of Canada's critical-minerals strategy.[370,371]

Recycle and reduce usage. Greater demand for metals and minerals needed to decarbonize the economy could increase the cumulative environmental impacts of mining. Encouraging materials efficiencies in industries that consume mine products and promoting recycling (keeping materials in circulation and postponing final waste disposal) can limit primary extraction. This potentially decouples economic growth from increasing natural resource consumption and complements electrification. Re-processing legacy mine tailings—which often contain economically

recoverable critical minerals—presents an additional source of supply while turning an environmental liability into value. Action Canada's Waste Not report (2025) estimates that re-mining Canadian tailings could unlock substantial volumes of copper, nickel and rare-earth elements.[372] Recycling is well developed for some metals (steel, aluminum) but immature for others. The global e-waste recycling market is expected to increase six-fold by 2050, providing a valuable source of metals such as gold, copper, and aluminum. This could create new economic opportunities.

Some ultramafic-hosted nickel deposits go a step further, using their magnesium-rich tailings to mineralize and permanently store CO₂. Pilot initiatives at Canada Nickel's Crawford project in Ontario, Giga Metals' Turnagain deposit, and FPX Nickel's Baptiste project in British Columbia suggest such sites could sequester hundreds of thousands of tonnes of CO₂ each year, creating opportunities for genuinely net-negative mining operations.

These approaches to net-zero emissions face significant obstacles. While high up-front

capital costs for non-diesel power generation and for electric- or fuel-cell-powered trucks and equipment can deter investment, mobile equipment is normally replaced on roughly a 10-year cycle. This creates recurring, lower-cost opportunities to adopt these technologies as part of the regular capital-replacement program. Even so, the sunk costs of existing infrastructure and the substantial upgrades it may require continue to make full decarbonization financially challenging for many mining companies. Recycling initiatives can appear to threaten primary producers. Canada currently lacks a policy and regulatory framework to incentivize metal recovery and recycling.

Although absolute production emissions are not high, coal mining poses a distinct challenge. While thermal coal extraction is expected to decline as coal is eliminated from the power sector, demand for metallurgical coal will remain for some time. Fugitive methane emissions will therefore require offset provisions, and policies to ease the burden for impacted workers and communities will be required.

Competitiveness Implications

Mine electrification in Canada is not solely a decarbonization play; it is a trade-competitiveness investment. The EU's Carbon Border Adjustment Mechanism already covers aluminum, iron, and steel, worth over \$38 billion of Canada's \$125 billion in annual mineral exports, and the trajectory is clear: embedded production emissions are becoming a direct input to the landed cost of traded minerals through border adjustments, procurement screening, and ESG-conditioned financing. Canada's clean hydroelectric grids in Quebec, British Columbia, Manitoba, and Ontario make mine electrification structurally cheaper here than in most competing jurisdictions, where mining runs on coal-fired or diesel-generated power, a cost-formation advantage few mineral-exporting nations can replicate at comparable speed. But the advantage only materializes if mines electrify during the current round of new and expanded mine development. With 138 new or expanded projects underway and equipment replacement cycles of roughly 10 years, every procurement round that defaults to diesel locks in a decade of competitive exposure across export markets that increasingly price embedded carbon.

10.1.4 Priorities for Action

Transition in this sector can be accelerated by incentives to lower capital costs for electric mining equipment and on-site renewable production and storage, and measures to promote retirement of diesel generators and mining equipment. These could be linked to industrial policy measures to (a) support Canadian companies that can provide net-zero mining technologies and power supplies, and (b) expand mining of materials required for society-wide electrification. A regulatory framework for metal recycling and recovery would lower uncertainty and speed market development. Some mining companies have already begun to process recycled materials

at their smelters and refineries, and government support for pilot or demonstration projects could help.

Several longer-term issues await attention. The increased use of batteries and fuel cells, both at the mine site and by consumers, creates concerns about end-of-life disposal. Improved lifecycle management will be needed to minimize the potentially toxic legacy of these zero-GHG emission technologies. Increased demand for metals and minerals may exacerbate existing reclamation liabilities for the sector. Measures to address remaining metallurgical coal production will ultimately be required.



Criteria Status

-
- Fails to meet criteria
-
- Meets in some respect
-
- Potentially meets criteria
-
- Meets criteria

10.1.5 Mining Pathways Table

Fails to meet criteria Meets in some respect Potentially meets criteria Meets criteria			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Mining Equipment and Processes											
Battery Electric & Trolley Assist Mining Equipment	Priority Decarbonization Pathway Can fully displace mobile diesel, which is the largest source of mine site emissions.	Deploy Invest in site electrification, charging infrastructure, and workforce training.	 Zero tailpipe emissions. Enables net-zero operations when powered by clean electricity.	 Higher capital costs offset by lower fuel and ventilation reducing operating costs. Tax incentives can improve payback.	 Canada can design, test, and assemble equipment. Exportable know-how from labs and operating mines. Could be combined with autonomous and connected vehicle technology.	 Commercial for many underground loaders/trucks. Open-pit ultra-class battery electric haulage still emerging.	 Strong fit, especially underground. Needs charging/trolley integration and upskilled maintenance and labour.	 Requires site charging power, batteries and/or trolley. Off grid mines need microgrid upgrades.	 Cleaner air and lower noise improve worker health/safety.	 Seen as a solution to reduce emissions and costs where appropriate, less relevant to open pit or legacy operations.	 Air quality and safety gains. Less heat/ventilation energy. Lower local pollution.
Hydrogen Fuel-Cell Mobile Equipment (haul & utility)	Potential Niche Pathway Useful where long duty cycles, heavy haul or fast refuelling challenge batteries.	Incubate Fund demonstrations for heavy-haul and long-cycle mining applications where batteries face limitations. Develop on-site hydrogen production	 Zero tailpipe emissions when supplied with low-carbon H ₂ .	 Vehicle and fuel costs are high. Viability hinges on H ₂ price and on site production/logistics.	 Targeted opportunities across H ₂ value chains (electrolyzers, storage, service), but unclear near-term scale.	 Demonstrations only. Not in commercial production for mining fleets.	 Operationally attractive for long blocks/quick refuelling. Requires new fuelling protocols and training.	 New H ₂ production, storage, and dispensing must be built at remote sites.	 Generally positive where safety is robustly managed. Air quality benefits valued.	 OEMs and a few miners are piloting. Interest is real but not universal.	 Air quality and ventilation reductions in underground settings.
Transform Extraction & Processing	Enabling Pathway Cuts energy use and diesel haulage. Complementary to clean power and offsets declining ore grades. Block caving reduces surface disturbance and GHGs in suitable deposits.	Enable Invest in process redesign and electrified material movement where productivity and emissions benefits align.	 Significant energy reductions from efficiency gains.	 Often attractive on operational savings and throughput. Capital costs vary by site/process.	 Canadian engineering/R&D has global export potential.	 Mixed maturity: some technologies proven. Others at pre-scale.	 Broadly applicable with process redesign. May require stoppages or staged retrofits.	 Uses/optimizes existing plants with targeted upgrades.	 Fewer tailings/water impacts and safer operations raise acceptance.	 Strong operator interest when productivity improves.	 Less water use/tailings and noise. Smaller surface footprint in some methods.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Renewable Diesel (RD)	Bridge Pathway Can help reduce emissions from diesel equipment while electric options are being commercialized.	Deploy Maximize drop-in renewable diesel use across existing fleets while electrification scales.	Drop-in fuel, with some lifecycle CO ₂ cuts. Combustion emissions persist and sustainable feedstocks are finite.	Higher production cost than diesel. Viable where policy support offsets fuel premiums.	Supports refinery jobs, rural economies, and feedstock markets. Growth is limited by feedstock constraints.	Fully commercial, drop-in fuel. Dominant production processes (i.e. hydrotreated vegetable oil) mature, with several large-scale facilities operating globally. Established technology licensors.	Drop-in fuel ideal for near-term fleet decarbonization without new equipment or operational changes.	Existing fuel storage, pipelines, and retail networks work for RD. Main gaps are upstream (sustainable feedstock availability and refining capacity scale-up).	Accepted when made from sustainable waste feedstocks and used as a bridge. Concerns over land-use competition.	Fleets seeking fast GHG cuts. Fuel producers and farmers benefiting from new markets. Policymakers aiming for near-term climate progress and rural investment.	Delivers reduced particulate matter and NO _x emissions in existing fleets. Benefits are tempered by feedstock limits and land-use change concerns.
On-Site Energy Generation											
On-site Renewables & Storage Microgrids (Solar, Wind, and Battery Storage)	Priority Enabling Pathway Off-grid mines rely on diesel. Hybrid microgrids cut fuel, cost, and GHGs.	Deploy Support hybrid microgrid deployment at off-grid and remote mine sites. Build enabling frameworks for grid interconnection.	Enables low carbon electricity for mine loads and electric fleets. Key to decarbonizing remote sites.	Site specific economics. High upfront costs. Some operational offsets with avoided diesel and reliability gains but today largely reliant on subsidies.	Room for Canadian suppliers/ integrators.	Commercial components with multi-year field results in Canada. Current deployments custom designed, widespread deployment is challenging.	Works across various geographies with adequate storage/controls. Adds microgrid complexity and requires upskilling.	Integrates with existing diesel systems. Grid connection added where feasible.	Strong community support when it reduces noise, spills and local pollution.	High priority for miners seeking cost stability, power resilience and sustainability outcomes.	Health/air quality gains and energy security benefits for nearby communities. Improves reliability of power supplies.
Small Modular Reactors (SMRs) for Mine Power	Potential Niche Pathway Zero-carbon heat/power is attractive for remote sites, but SMRs are pre-commercial with cost and waste concerns. High potential if delivered.	Don't Prioritize Track SMR development timelines and costs but do not anchor plans to this technology. Prioritize proven electrification and renewable alternatives.	Enables net-zero electricity for mine loads and electric fleets.	Costs and financing are uncertain. Decommissioning and waste obligations weigh on viability.	Could leverage Canada's nuclear ecosystem, but near-term market is unclear.	Pre-commercial. No mine deployments.	Conditionally applicable. Matching unit size to load and siting is complex.	New fuel, logistics, and regulatory systems required.	Public concerns about safety and waste reduce acceptance.	Emerging interest from nuclear fuel suppliers. No clear interest from mining.	Potential community co-benefits such as reliable power and use of waste heat in buildings, but long-term waste and decommissioning challenges. Improved air quality.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Waste and Recycling											
CO₂ Mineralization in Ultramafic Tailings	<i>Potential Niche Pathway</i> Potential storage solution for CO ₂ . Permanently captures and stores CO ₂ in magnesium rich tailings. Optional in sector-wide pathways.	Incubate Fund pilot, monitoring, and process optimization at sites with suitable geology.	 Could be a direct CO ₂ capture and storage method or negative emissions option.	 Business case depends on process cost and carbon credit revenue.	 Emerging niche service or carbon credit production method. Domestic IP and technology development. Potential branding as “net negative” metals.	 Pilots underway. Sustained field data still developing.	 Integrates with tailings management. Process control and monitoring needed.	 May need grid connection or another source of renewable energy. Equipment supply chain is nascent as technology is maturing.	 Converts tailings ponds into environmental assets.	 Growing interest from government and academia with ongoing studies and pilots.	 Stabilizes tailings, reduces dust and long term risks while sequestering CO ₂ .
Metal Recycling & Recovery	<i>Enabling Pathway</i> Limits primary extraction needs and creates new revenue streams. Complements—not replaces—primary mining.	Enable Strengthen regulatory frameworks for recycled content and e-waste recovery. Invest in collection, sorting, and quality assurance infrastructure.	 Net-zero metal production when powered by clean energy.	 Economics vary by metal and collection/ sorting costs. Mature for some streams, nascent for others.	 Expanding e-waste and tailings re processing can grow domestic jobs and IP.	 Many processes already commercial. Others emerging.	 Uses existing smelters/ refineries. Requires new feedstock logistics.	 Collection and quality assurance systems are the constraint, not technology.	 Public support for waste reduction and circularity.	 Miners and smelters are beginning to integrate recycled inputs.	 Cuts land/water impacts and community exposures. Reduces biodiversity pressure.

10.2 CEMENT

Function	A binding agent in concrete (a mix of cement, aggregates and water) that is a basic construction material.
GHG emissions	10 Mt of CO ₂ e in 2024 (Process emissions about 60% , energy-use emissions about 30% , with the remainder from transport and operations). Approximately 1.5% of Canadian emissions.[61]
Options for decarbonization	Decarbonization Pathways: Electrification, hydrogen, hybrid energy mix, CCUS. Bridge Pathways: Alternative fuels (biomass and waste). Niche Pathways: Alternative chemistries. Enabling Pathways: Supplementary cementitious materials, optimizing design, recycling.
Stage of transition	Emergence: Electrification, hydrogen, alternative chemistries. Emergence / diffusion: CCUS. Diffusion: Hybrid energy mix, alternative fuels (biomass and waste), supplementary cementitious materials, optimizing design, recycling.
Current obstacles:	Decarbonization technologies are capital intensive; some are immature, while others face regulatory policy barriers. Weak demand for low carbon cement and high building sector sensitivity to material prices; cumbersome codes and standards process slow to adopt innovations; competitiveness concerns.
Economic/social opportunities:	Job creation while developing and implementing new technologies, reduction in air pollution and associated health risks; climate adaptation/resilience applications.
Industrial policy/competitiveness	Cement production in Canada is dominated by multinational parent companies; international collaboration can accelerate decarbonization.
Priorities for action	Public investment in demonstration and commercial applications of viable low-carbon cement technologies; government procurement of low-carbon cement and support for material-efficient design; movement to performance-based codes and standards; research and development on novel technologies.
Longer-term issues	Alternative cement chemistries; alternative building materials.
Indicators of progress	Percent change in GHG emissions from cement manufacture; market penetration of low-carbon cement.

10.2.1 Current Status

Cement is manufactured by heating limestone, clay, and sand to form an intermediate product called clinker, which is then ground into cement. As the second-most consumed material globally after water,[373] cement acts as a binder in concrete—a fundamental construction material used across commercial and industrial buildings, housing, roads, schools, hospitals, dams, airports and ports.

Canada produces 13 to 14 million tonnes of cement per year.[374] With 16 domestic cement manufacturing plants (15 integrated, one grinding plant) that ship cement to more than 1,100 concrete facilities, the industry directly employed more than 27,000 people in Canada in 2023 (Figure 30), with a GDP of \$5.0 billion¹⁷. [359,375] Cement production is concentrated in central and Western Canada, and financial impact is provided primarily by Ontario (34%), Alberta (21%), Quebec (17%), and British Columbia (14%), with exports going to the United States.[373]

Cement and Clinker Production in Canada

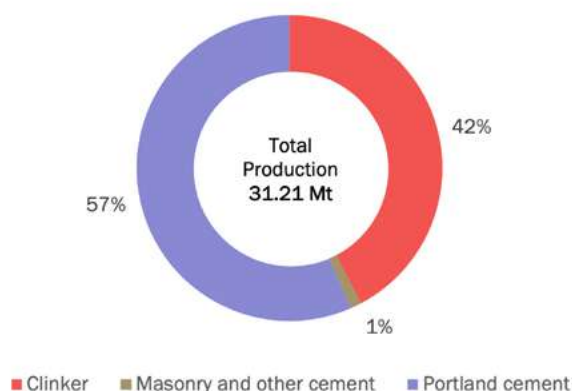


Figure 30. Cement and Clinker Production in Canada

Source: Annual Survey of Cement, production and exports – 2023 Dataset[376]

10.2.2 Nature of the Problem

The cement industry is energy, material, and emissions intensive. Historically, cement production in Canada relied primarily on coal and petroleum coke products (82%); electricity (13%); natural gas, liquid petroleum products and waste oil products (4%); and tire-derived fuels and other alternative energy sources (2%).[377] However, over the past decade there has been movement towards gas and alternative fuels as energy sources.

Most carbon emissions are produced during clinker production: approximately 60% from process emissions associated with calcination, and 40% from fuel combustion to provide kiln heat.[378] As the dominant energy user, 90% of total energy consumption comes from clinker production while the remaining 10% of energy is used in activities related to fuel and raw material preparation, grinding of clinker, and the blending to produce finished cement.

In 2024, the cement industry emitted 10 Mt of CO₂e. This represents approximately 14% of heavy industry emissions and 1.5% of Canada's total emissions.[61] Of these, 7.3 Mt CO₂ (66%) are process emissions associated with clinker production and the remainder are energy-related.[186]

Cement production is highly capital intensive, requiring large upfront investments in facilities that are expected to operate for decades. In Canada, production is concentrated among six companies, most of which are multinational firms. As a result, the sectors are shaped not only by domestic conditions but also by competitive pressures in global markets, particularly from the U.S.[379]

¹⁷ Chained (2017) Canadian dollars

10.2.3 Net-Zero Pathways

Shifting cement production towards net zero will require a variety of approaches. While energy and operational efficiencies can deliver incremental emission reductions, deeper structural changes are needed to address both energy-related and process emissions.[380] Recent sector analyses suggest that demand-side measures, such as material efficiency, increased reuse and recycling, and reduced over-specification (i.e., the practice of specifying concrete strength, cement content, or durability requirements beyond what the application requires, resulting in unnecessarily high cement use and associated emissions), could account for a significant share of cumulative emissions reductions through 2050. These measures would complement supply-side approaches such as fuel switching, additional binders, and CCUS.[381] Given the long operating lifetimes of cement kilns, decisions about major retrofits and reinvestment over the next one to two decades will be critical in determining whether the sector can align with net-zero trajectories. Key elements that can contribute to such a transformation include:

Net-zero energy: Replace fossil fuels burned in kilns to provide heat with renewable (or other net-zero) energy. Options include the use of biomass and waste-derived fuels, electrification, and hydrogen.[77] Waste and biomass are already used as partial substitutes for fossil fuels within the sector, but some waste streams have associated air pollution risks, and provincial policy barriers have limited their deployment in Canada relative to international best practice. To date, alternative fuels have included waste wood, paper, textiles, plastics, tires, and asphalt shingles. Moving to 100% alternative fuels in kilns presents additional technical and practical challenges, including maintaining a consistent fuel mix, the availability of fuel supply, managing life-cycle emissions, and addressing

air pollution. Electrification, with electrified kilns and pre-heating technologies, is technically plausible but has not been demonstrated at an industrial scale and would require substantial kiln redesign. Hydrogen is another potential alternative but would again require kiln redesign, as well as access to a reliable and affordable supply of low-carbon hydrogen.[77]

Low-carbon cements: Reducing the proportion of clinker in the final cement mix by adding supplementary cementitious materials (SCMs) can significantly reduce emissions. Blast furnace slag and coal fly ash are the most common SCMs used today, although supplies are being disrupted as decarbonization proceeds in other sectors; these could be replaced with recovered landfilled materials, recycled construction materials, unprocessed limestone, or calcined clay, amongst others. The Cement Association of Canada has a roadmap to increase SCMs and decrease clinker substantially in cement blends by 2050 (see Figure 31).[373] New SCMs are being actively researched, developed, and sourced, such as incorporating local calcined clays and limestone with clinker and gypsum, which can reduce process emissions by around 40%.[382]



Figure 31. Canada, Clinker-cement ratio targets for decarbonizing production proposed by the Cement Association of Canada (2020-2050)

Source: Cement Association of Canada, 2023. Canada's cement and concrete industry action plan to net zero.[373]

More fundamentally, novel clinker chemistries could replace traditional limestone-derived clinker—a number of such chemistries, with varying emission intensities, are currently being explored. One option is alkali/geo-polymer-based-cement, which could reduce emissions by 70% compared to conventional clinkers using widely available minerals.[77] Magnesium silicate or ultramafic cements could eliminate emissions entirely or even achieve carbon negative results, but these remain in the early development phase and material availability and cost may limit their potential contribution.[373]

Carbon capture, utilization and storage

(CCUS): Capture of CO₂ from process emissions, and perhaps also from fuel combustion, could play an important role in the solution mix.[382,383] Captured CO₂ can be permanently sequestered in geological formations or used in other industrial processes. Some approaches are already being deployed on a small scale, such as injecting CO₂ into wet concrete, where it can both strengthen the building material and store carbon within the finished structure. Internationally, multiple full-scale CCUS projects in the cement sector are now moving into funded demonstration and early commercial deployment. These include operational and advanced projects at European cement plants, such as Heidelberg Materials' Brevik facility in Norway, as well as proposed large-scale applications under development in Canada, including at Heidelberg's Edmonton plant.[384,385] In addition, it may also be possible to accelerate the natural carbonation of concrete as it ages, by exposing crushed concrete to air or concentrated CO₂ streams, for example, to

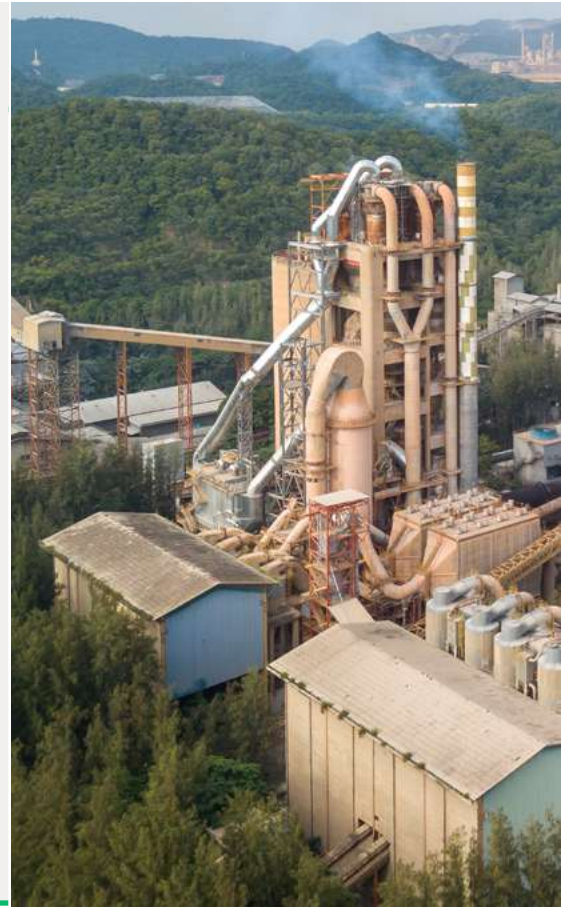
reduce the lifecycle GHG emissions of cement and concrete. However, the viability of CCUS at scale depends not only on capture technologies but also on the availability of shared CO₂ transport and long-term storage infrastructure.

Demand reduction: Cement use can be minimized by improving the design of structures to require less new cement and concrete, and to employ more recycled construction material. Concrete can also be replaced by other materials that have lower emissions profiles, such as timber, the use of which can yield significantly lower emissions than concrete in similar applications.[386] New forms of wood construction, including cross-laminated timber, could compete with concrete in low- to mid-rise construction, but have yet to be widely adopted. Research is ongoing into a variety of net-zero (or in some case net-negative) building technologies. Demand can also be reduced by extending the service life of existing structures through adaptive reuse and retrofit, delaying the need for new cement- and concrete-intensive construction.[381]

Cost remains a key challenge for deep decarbonization, particularly for a low-margin product such as cement. Cement is often cited as one of the most difficult and potentially expensive industrial sectors to decarbonize.[382] Some analyses suggest costs could double, which would translate to roughly a 30% increase in the cost of concrete. However, experience with past cost estimates for meeting other environmental objectives and the possibilities for significant technological advances suggest this may be an overstatement.

Competitiveness Implications

Canada's cement plants are not owned by domestic firms competing in a national market; they are facilities within multinational portfolios, and the question that determines their future is whether those multinationals direct their next generation of decarbonization capital here or elsewhere. That contest is already underway: these same firms are advancing fully funded CCUS-equipped cement facilities in Europe and evaluating large-scale investments in the United States. With kiln assets built to last decades, the reinvestment decisions made over the next 10 to 15 years will determine which facilities become low-carbon flagships and which do not. Canada has relevant advantages: geological CO₂ storage, emerging transport infrastructure, the potential to anchor demand through public procurement. But those advantages only matter if they are in place before capital decisions are locked in.



10.2.4 Priorities for Action

There is no single pathway to decarbonize the cement industry. Demand for low-carbon cement remains limited, and wider adoption of lower-carbon cements may require adjustments in construction techniques and building codes, as alternative cement compositions can differ in setting times or structural characteristics.[387]

Despite these challenges, decarbonizing cement is critical and can complement other sectoral transitions in buildings, heavy industry, and rollout of CCS technologies and the hydrogen economy.

Governments should encourage R&D and support large-scale demonstration and early commercial deployment of technologies that address both energy-related and process emissions. These include options such as

electric, hydrogen, and biofuel heating; CCS applications; and novel cement chemistry.

Policy levers such as carbon pricing, performance-focused building codes, and public procurement can help create demand for lower-carbon cement. In particular, ensuring that codes and standards can keep pace with innovation by moving from prescriptive, material-specific requirements toward performance-based standards can enable the deployment of new and alternative low-carbon materials while maintaining safety and durability. [381] Additional measures to improve building design to reduce material usage, discourage landfill of construction waste, and encourage recycling of building materials can further lower system-wide emissions. Given that the cement industry is dominated by a small number of large multinational firms, international coordination—particularly on R&D, demonstration, and financing—can accelerate change.[388]

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

10.2.5 Cement Pathways Table

Not promising Potentially meets criteria Meets criteria			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Heat											
Alternative Fuels (biomass and waste)	Bridge Pathway Limited by biomass and waste availability.	Deploy Support supply chain buildout and connection of kilns to waste or biomass sources.	 Reduces kiln heating and energy emissions. Reduction depends on fuel carbon intensities. Fuel substitution typically isn't 100%.	 Depends on the fuel sources and availability but can be less expensive than other solutions as it leverages existing assets.	 Can create niche economic clusters and rural jobs tied to biomass/waste supply chains. Production of low-carbon construction material.	 Commercial and used globally. Full-scale plants in Canada. Very high rates of substitution are difficult to achieve.	 Strong fit. Alternative fuels can often be integrated with existing burners and fuel handling. High substitution complicates operations.	 Conditionally suitable as reliable local supply chains are needed to ensure consistent supply of alternative fuels.	 Mixed acceptance. Depends on whether waste-derived fuels are perceived as incineration and on air and water emissions.	 High relevance for cement operators and provinces. One of the most deployable near-term levers for kiln heat. Appears in major cement facilities in Canada.	 Co-benefits include waste diversion. Concerns around air pollutants and lifecycle. Uncertainty if biomass/waste is not sustainably sourced.
Electrification	Potential Decarbonization Pathway Could fully eliminate kiln energy emissions if used with decarbonized electricity.	Incubate Fund R&D.	 Eliminates kiln heating and energy emissions with decarbonized electricity. Must be combined with efforts to manage process emissions.	 Economics are uncertain and depend on availability of affordable low-carbon electricity. Requires major retrofits.	 Production of low-carbon construction material.	 Large scale prototypes underway globally, research and development occurring mostly abroad.	 Requires substantial process redesign. Easier for greenfield sites.	 Requires very high-capacity electrical interconnections which may require grid infrastructure upgrades.	 Generally positive with visible reduction in fossil fuel combustion.	 Interest where low-carbon electricity is available and there are strong carbon commitments. Some pilot projects in Canada.	 Reduction in air pollution. Large electricity requirement, so there may be competition for low-carbon electricity.
Hydrogen	Potential Decarbonization Pathway Could fully eliminate kiln energy emissions if used with net-zero hydrogen.	Incubate Fund Canadian demonstrations and pilots. Support buildout of hydrogen supply chain and infrastructure or co-location of production with cement kilns.	 Can reduce combustion-related CO ₂ when hydrogen is low-carbon.	 Depends on availability of affordable low-carbon hydrogen.	 Strategic opportunity with regional hydrogen and cement production hubs. Production of low-carbon construction material.	 Global commercial-scale demonstrations have occurred. Still in research and development.	 Conditionally applicable for kiln heat with fuel system modifications. High substitutions not tested. Evidence indicates it is applicable without major retrofit.	 Requires establishment of low-carbon hydrogen supply chain and infrastructure.	 Generally acceptable, but there can be some concern around the safety of hydrogen.	 Interest where hydrogen sources may become available.	 Reduced air pollution. Higher system complexity.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Hybrid Energy Mix (combination of alternative fuels, electrification and/or hydrogen)	<i>Potential Decarbonization Pathway</i> Could either serve as a decarbonization, enabling, or niche pathway depending on market development. Must be combined with process emissions management.	Incubate Fund Canadian demonstrations and pilots. Develop guidance on optimizing fuel choice for regional advantages.	Can significantly reduce kiln heat emissions assuming input energy sources have low carbon intensities and fossil fuels are eventually eliminated from the energy mixture.	Allows for adjustment to lowest-cost and most available mix. Operational costs rise with multiple systems.	Depends on the fuel types chosen. Can contribute to broader industrial electrification or hydrogen strategies, but does not necessarily achieve economies of scale.	Global commercial-scale demonstrations have occurred with hydrogen and alternative fuels. Many mixes still in R&D.	Retrofitting can be incremental and work well in brownfield sites. Facility changes will depend on the energy types selected.	Infrastructure and supply chain is dependent on the energy sources chosen. Multiple supply chains provide flexibility but also increase complexity of coordination.	Issues will depend on energy blend chosen, but should be generally accepted.	Relevance is high as research, piloting, and demonstration have typically occurred with hybrid strategies (partial integration of one or more of the identified heating pathways).	Depends on hybrid mix, but may lower burden on infrastructure and maintenance schedules. Expedited progress if facilities can substitute new energy types in partial amounts.
Low Carbon Cement											
Alternative Chemistries	<i>Potential Niche Pathway</i> Can lower clinker production emissions and energy requirements but contingent on commercialization.	Incubate Fund R&D.	Can lower energy and process emissions associated with clinker production (lower firing temperatures, clinker blending requirements, or direct emissions). Reduction depends on chemistry used.	Vary with chemistry and availability of feedstocks. Estimated costs are currently higher than incumbents.	Develop new mineral and cement precursor supply chains with export potential. Some chemistries may have improved structural or chemical properties.	Alternative chemistries are at different levels of R&D. More research needed to determine which chemistries are suitable for which cement applications.	Some chemistries may fit well into existing production processes while others may require different firing temperatures and curing times. Development of standards and regulations is required.	Supply chains are immature for materials needed for new chemistries. Domestic sourcing may be available for some materials while others may need established international sourcing.	Affordability of materials, particularly as it applies to housing, will be a concern. Some skepticism may occur around use of new materials.	Interest is rising with Canadian stakeholders. Likely to be caution around adopting materials with fundamentally different chemistries in construction.	Benefits will depend on the alternative. Could be cement with improved properties.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Carbon Capture Utilization and Storage	<i>Potential Decarbonization Pathway</i> Can be used to manage either energy or process-related emissions.	Enable Support buildout of CO ₂ infrastructure in regions with geological storage and projects that incorporate utilization of capture carbon.	Without radical change to cement chemistries, essential to get to net zero.	Potentially viable pending policy, funding tools, etc.	Strong opportunity to be an anchor tenant for the CCUS industry.	Multiple projects leading to full scale are under construction in Canada. Globally advanced projects are also underway.	Feasible with high emissions capture for both energy and process emissions. Requires additional operational expertise, space, and energy. Can be added during retrofit schedules.	Needs CO ₂ pipelines and storage access. Hub models and permitting capacity are constraints. Some regions with natural storage are better positioned.	Some concerns regarding CO ₂ leakage from storage.	Investment from multiple Canadian companies, active research environment.	Links to broader applications including hydrogen production. Captured CO ₂ can be injected into concrete for strengthening. Extra burden on electrical infrastructure and capacity.
Supplementary Cementitious Materials (SCMs)	<i>Enabling Pathway</i> Recognized broadly as a strategy for reducing clinker use and associated emissions.	Deploy Support scaling for commercial SCMs and R&D for new SCMs. Build out supply chains that align SCM production with Canada's natural resource endowment. Accelerate regulatory changes.	Significantly reduces clinker use and associated emissions. Near-term lever while other technologies develop. Cannot reach net zero alone as clinker emissions are not eliminated with incumbent cement chemistries.	Economics depend on the material. New materials may and need support as supply chains scale.	Opportunity to build new supply chains for SCMs, repurpose local industrial waste. Align Canada's natural resource endowment clustering mining with cement.	Varies according to the SCM. Many have high maturity but as those are exhausted, more novel options will need R&D to mature.	Little change required. SCMs are incorporated at the mixing stage. Curing times may need adjustments and standards and regulations will need to be developed.	Scaling alternative SCMs may require new processing facilities, quarries, and logistics.	No particular issues. Proof of sustainability performance with environmental product declarations will improve optics.	Very high relevance, used today broadly across industry today. Seen as an essential near-term decarbonization lever by many stakeholders.	Benefits will depend on the SCM. Could improve cement properties. Industrial waste diverted from landfills.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Optimizing Material Use and Lifespan											
Optimizing Design	Enabling Pathway Near-term solution to reduce lifecycle emissions by lowering clinker demand.	Deploy Update standards to include new materials and design practices. Provide best practices for material choice. Support scaling of mass timber supply chains.	 Material efficiency and reduced over-specification save costs and emissions. Complements supply-side measures.	 Can reduce overall project costs by lowering material use, avoiding unnecessary margins beyond calculated factors of safety, extending asset lifetimes with longer-lasting materials, and using lower-cost materials.	 Grows sustainable building sector expertise and domestic advanced wood products. Adds high-value services and products to exports rather than just raw material.	 Material-efficient design and substitution are well-established practices. Mass timber and hybrid wood-concrete systems are commercial but broader adoption is uneven.	 Some training or reskilling is needed to broadly implement sustainable design practices and materials. Codes and standards may need to be updated.	 Established supply chains. Some expansion will be needed to scale mass timber products.	 Generally well accepted as framed as innovation and climate leadership. Some concerns with fire safety.	 High relevance to many stakeholders up and down the supply chain. Increasing demand for optimized design as a cost-saving measure. Greening government strategy.	 Reduces waste, lowers lifecycle costs. Support for building out the forestry sector and manufacturing.
Recycling	Enabling Pathway Recycled concrete as substitute for aggregates, replaces primary materials but does not target larger clinker emissions.	Deploy Scale recycling infrastructure. Support R&D focused on incorporating recycled concrete as SCMs.	 Compliments other pathways by replacing primary materials required as aggregates in concrete. Repurposes otherwise wasted materials.	 Often good economics, especially when landfill tipping fees are high. Provides local source of aggregates.	 Moderate local job creation at concrete recycling facilities.	 Widely practiced in Canada primarily for roads. More development is needed to reuse fines and aggregates.	 Requires crushing and sorting facilities. No changes to cement plants. Effective when planned into demolitions.	 Recycling infrastructure is uneven across regions. Transport distances can be cost prohibitive, especially in rural areas.	 Concrete recycling is well understood, practiced today, and socially accepted.	 Highly relevant to some stakeholders including waste management in municipalities, and green infrastructure.	 Reduces landfill burden. Lowers lifecycle emissions from quarrying. Benefits strongest when transport distances are low.

10.3 STEEL AND IRON

Function	Basic material of industrial civilization; key input to construction, automotive, energy, manufacturing, and other sectors.
GHG emissions	Total Emissions: 2.1% of Canadian emissions in 2023 (14.5 Mt).[389] Primary Steel: Represents ~54% of Canadian steel output, 91% of total sector emissions (13.2 Mt CO₂e in 2023).[389,390] Secondary Steel: Represents ~46% of Canadian steel output, 9% of total sector emissions (1.3 Mt CO₂e in 2023).[389,390]
Options for decarbonization	Primary Steel: - Decarbonization Pathways: Electric arc furnaces, direct reduced ironmaking with net-zero hydrogen. - Bridge Pathways: Carbon capture and storage for blast furnaces and basic oxygen furnaces. - Niche Pathways: Biomass based charcoal, selected fuel switching. - Enabling Pathways: Hot briquetted iron, co-located iron and net-zero hydrogen production. Secondary Steel: - Decarbonization Pathways: Scrap-based electric arc furnaces. - Niche Pathways: Selected fuel switching.
Stage of transition	Primary Steel – Emergence: Select integrated facilities have begun moves to electric arc furnace or direct reduced iron-electric arc furnace. Most output remains coal-based, and near-zero blast furnace-basic oxygen furnaces remain pre-commercial. Secondary Steel – Mature: Technically mature and already much lower-emission than blast furnace-basic oxygen furnace. Near-zero primary iron inputs are emerging. Clean electricity access for electric arc furnaces varies across regions.
Nature of the problem today	Asset-replacement cycles limit timing for long-lived assets; lack of commercially available low-carbon iron/steel technologies; thin margins and expected cost increases; low willingness to pay green-steel premiums; major needs for clean and cheap electricity, hydrogen, and CO ₂ infrastructure; limited availability and quality of scrap; limited supply of direct reduction grade iron ore.
Other systemic issues	Highly competitive and trade-exposed sector; global oversupply and subsidization push prices downward; Canadian producers face scale disadvantages and tariff pressures; carbon capture and storage risks locking in coal-based production; transitions to electric arc furnace impact local labour and shift skill requirements.
Strategic opportunities and concerns	Growing demand from industries with lifecycle emissions targets; Canada has globally low steel GHG intensities; access to low-carbon electricity and emerging hydrogen supply; risks include reliance on natural gas direct reduced iron, limited net-zero energy, local employment impacts, tariff exposure, and volatile export markets.

Priorities for action	Advance R&D and pilots for low-carbon iron and steel; improve scrap recovery and upgrading; secure clean electricity and hydrogen supply; establish offtake agreements and procurement mandates; develop product standards; define site-specific transition pathways.
Longer-term issues	Border-carbon leakage and competitiveness; securing long-term clean-energy, hydrogen, or biomass supply; aligning with emerging near-zero definitions; ensuring transitional natural gas direct reduced iron does not become a long-term end-state.
Indicators of progress	Sector-wide emissions and emissions intensity; share of output from net-zero pathways (hydrogen-direct reduced iron, carbon capture and storage-enabled operations, molten oxide electrolysis,); blast furnace-basic oxygen furnace retirements/conversions; low-carbon electricity penetration; scrap utilisation and quality; investment in hydrogen, electricity, CO ₂ , biomass, and scrap-processing infrastructure.

10.3.1 Current Status

Steel is a foundational material for Canada's industrial economy due to its high strength-to-weight ratio and versatility across applications.[391] Globally, demand is driven by buildings and infrastructure (52%), mechanical equipment (16%), and the automotive sector (12%), with additional use in metal products (10%), electrical equipment (3%), and other transport segments (5%).[392]

Canada has a well-established steel sector. In 2024, iron and steel mills contributed \$3.1 billion to GDP and steel product manufacturing added \$1.3 billion,¹⁸ supporting approximately 23,000 jobs.[393,394] Steel is an important source of export earnings as well. From 2015 to 2024, the average annual value of exports was \$10.0 billion, peaking at \$14.1 billion in 2022 due to post-COVID demand before decreasing to \$12.1 billion in 2024.[395,396] Canada's steel is typically exported almost entirely to the United States (91%), Mexico (4%), and the Netherlands (1.3%)[397]. Canada has maintained a steel trade deficit since 2005, and in 2024, imports originated mainly from the U.S. (45%), China (9%), and South Korea (6%).[398] Given the steel industry's heavy reliance on trade with the U.S., American tariffs, along with Canada's

retaliatory measures, have tightened profit margins and introduced volatility into the Canadian steel market.[399] As a result, increased focus has been placed on expanding interprovincial shipments of domestic steel products, which are usually constrained by high transportation costs.[400]

Steel production involves two main steps :

- **Ironmaking**, which is carried out either in blast furnaces (BFs), which use coke or biomass-based reductants such as biochar to remove oxygen from iron ore and produce molten iron, or through direct reduced iron (DRI), which uses syngas (a mixture of hydrogen and carbon monoxide produced from natural gas or coal) or pure hydrogen to remove oxygen without melting the ore.
- **Steelmaking**, where impurities are removed in basic oxygen furnaces (BOFs) or electric arc furnaces (EAFs). Traditional integrated plants combine BF ironmaking with BOF steelmaking, while mini mills use EAFs to produce secondary steel from recycled scrap and, in some cases, primary steel from DRI feeding EAFs. Additional downstream operations include continuous casting, reheating, and hot rolling.

¹⁸ Chained (2017) Canadian dollars

In 2023, Canada's steel sector produced 6 million tonnes of iron and more than 12 million tonnes of steel, representing about 0.6% of global production.[401–403] The sector includes two integrated BF-BOF mills in Ontario, one ilmenite-based integrated facility in Quebec, and nine stand-alone (EAF-based) mini-mill facilities across Alberta, Ontario, Quebec, Manitoba, and Saskatchewan. Only one mini-mill facility, ArcelorMittal in Quebec, also operates DRI-EAF in addition to scrap-EAF. There are 16 finishing facilities producing finished steel goods from semifinished products.[390] The Canadian Steel Producers Association includes 17 member companies across more than 30 facilities in these provinces.[404]

10.3.2 Nature of the Problem

Iron and steelmaking accounted for about 2.1% of national emissions in 2023 (14.5 Mt CO₂e)[389] with approximately 67% from process emissions and 33% from combustion. Emissions intensities vary significantly between production routes: integrated **BF-BOF facilities represented about 54% of production but roughly 91% of emissions**, while **EAF mini-mills accounted for 46% of production and about 9% of emissions**.[390] These figures are expected to change beginning in 2026, following the completion of Algoma Steel's transition from BF-BOF to scrap-based EAF production, which will significantly increase the share of EAF steelmaking and reduce sector emissions by up to 3 Mt CO₂e.

Scrap-based EAF production is lower-emission, but scrap quality and supply cannot meet long-term demand from current BF-BOF production. Continued production of primary

iron from ore is required and remains a primary focus for lowering emissions. **Figure 32** displays steel production emission intensities from the Transition Accelerator report *Hydrogen and the Decarbonization of Steel Production in Canada*[390], and global benchmarks.¹⁹

Integrated BF-BOF facilities produce primary steel from iron ore and supply many of the flat and high-specification products required in automotive, energy, and construction applications. Although these mills perform relatively well compared with global peers, they are responsible for the majority of sectoral greenhouse gas emissions[390] due to the coal-based chemistry of blast furnace ironmaking and the high process emissions embedded in coke and BOF operations.

Mini-mills produce secondary steel primarily from recycled scrap using EAFs and, where higher-quality iron units are required, from DRI or hot briquetted iron (HBI). This route has substantially lower emissions than BF-BOF operations and contributes a significant share of Canada's steel output. [390] Continued expansion of secondary production, including entry into higher-grade flat products, depends on strengthening scrap collection, sorting, and quality upgrading, as well as securing low-carbon primary iron feedstocks and electricity to complement recycling.

Canada's steel transition can be framed through two production pathways:

- **Primary Steel Production (BF-BOF & DRI-EAF):** Converts iron ore into primary steel through BF-BOF (or emerging DRI-EAF processes) and accounts for a majority of sectoral emissions.

19 "Transition Accelerator Report" values are drawn from *Hydrogen and the Decarbonization of Steel Production in Canada*. "General" refers to global benchmarks not specific to Canadian steel production processes, and *How Clean is U.S. Steel* provides additional estimates for Canadian steel GHG emissions. Note that emissions accounting boundaries and electricity grid emission factors vary across these sources.

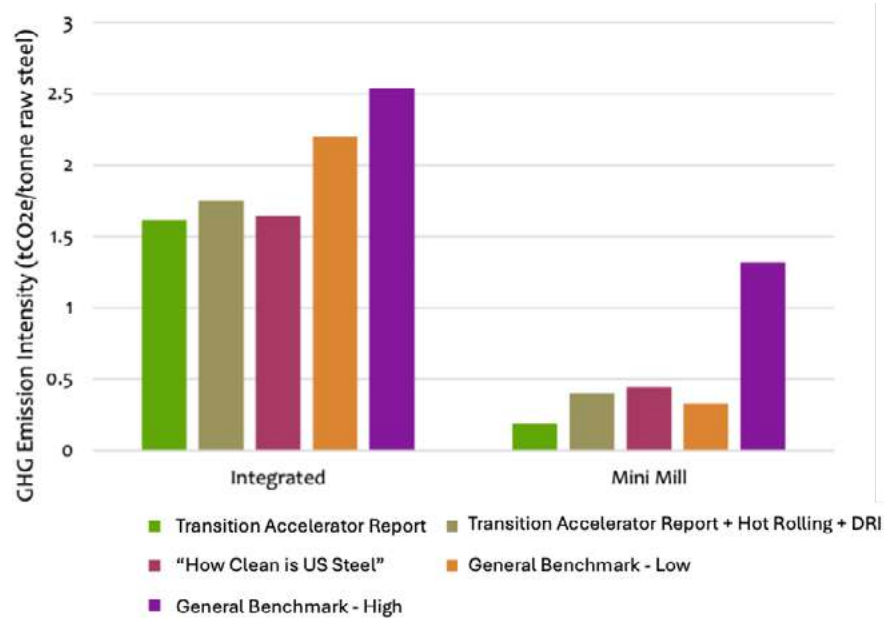


Figure 32 Comparison of the emissions intensity for Canadian steel by production route

Source: Transition Accelerator, "Hydrogen and the Decarbonization of Steel Production in Canada"[390]

- Secondary Steel Production and Material Efficiency:** Re-melts secondary recycled scrap in EAFs and plays an important role in lowering emissions through recycling, circularity, and material-efficiency strategies that reduce demand for virgin steel.

Primary Steel Production

Primary integrated steel mills are anchored by capital-intensive, long-lived assets. Blast furnaces operate for decades between relines, limiting opportunities for major process changes. Any recent upgrades at Canadian sites extend the life of existing BF-BOF equipment, narrowing the near-term window for transitioning to alternative technologies. The global steel market also faces persistent overcapacity and thin margins, constraining producers' ability to finance "first-of-a-kind" decarbonization or BF-BOF carbon capture and storage (CCS) projects.

System-level constraints compound these challenges. Large and reliable supplies of low-carbon electricity and hydrogen will be required to support primary steel DRI-EAF conversion or hydrogen-based ironmaking, yet these resources are not available at scale in most regions. Trade exposure and uncertainty around demand for low-emission steel further increases investment risks, making early conversion difficult without coordinated infrastructure planning and clear long-term market signals.

Low- to no-emission ironmaking technologies remain in early stages of deployment, and their maturity, scalability, and cost vary widely. Many pathways require large-scale clean electricity, hydrogen, sustainable biomass, or CCS, yet these inputs remain difficult to access because of infrastructure, cost, and geographic limitations.[405] Existing equipment lifespans also create challenges for recovering capital if assets are retired early.

Preliminary estimates find low-carbon steelmaking to cost 15–40% more than conventional processes[390,395,406], and near-term prices will be strongly influenced by hydrogen availability and pricing.[407]

Secondary Steel Production

Scrap-based EAF production provides significant emissions reductions relative to producing primary BF-BOF steel from iron ore. However, secondary scrap supply alone cannot meet projected demand: the total available scrap is insufficient and its quality varies, limiting its use in applications requiring high-grade or advanced flat steels.[408] Expanding secondary production therefore depends on improved scrap collection, sorting, and contaminant control, as well as the availability of low-carbon primary iron units such as DRI or HBI.

EAF operations also depend on provincial electricity costs and grid carbon intensity. These factors affect both operating margins and achievable emissions performance. Access to natural gas, clean electricity, hydrogen, and DR-grade iron ore will determine the feasibility of producing low-carbon DRI or HBI to complement scrap. Like integrated mills, mini mills face pressure from global oversupply, tariff uncertainty, and narrow margins. These factors influence the pace at which plants can justify investment in new DRI capacity, upgraded power systems, and enhanced scrap-handling infrastructure.

10.3.3 Net-Zero Pathways

The Canadian Steel Producers Association states that transformative projects already announced may deliver more than a 45% reduction in sectoral greenhouse gas emissions by 2030, with additional measures required to achieve the industry's longer-term ambition of net-zero emissions. [409,410] This figure was primarily dependent

on two projects: Algoma Steel's EAF transition (completed in January 2026) and ArcelorMittal Dofasco's Hamilton DRI-EAF project (materially restructured, with DRI production shifted to Contrecoeur and federal funding agreement extended to 2050).[411] Nonetheless, achieving the industry's longer-term net-zero ambition requires addressing both energy-related emissions and process emissions inherent to iron reduction.[412]

Primary Steel Production

The primary pathway for integrated BF-BOF sites to reduce emissions while maintaining the ability to produce steel grades that required a primary iron input is a structural transition to DRI-EAF configurations. Facilities would initially rely on natural gas-based DRI (NG-DRI), then transition to hydrogen-based DRI (H₂-DRI) as low-carbon hydrogen becomes available. H₂-DRI is the most promising pathway currently available for achieving near-zero ironmaking, while NG-DRI paired with top-gas CCS could deliver substantially lower emissions relative to BF-derived hot metal.

Emissions reduction measures can lower greenhouse gas emissions in existing BF-BOF operations but cannot fully eliminate them. CCS can address BOF-related emissions where carbon storage capacity exists, but a BF-BOF facility typically achieves no more than ~50% capture after retrofit while extending the lifespan of coal-based systems.[413] Combining CCS with hydrogen injection, biochar substitution, and efficiency improvements can reduce coal and coke use and achieve deeper emissions reduction but may still fall short of net-zero requirements.

Blast furnaces can also be retrofitted to capture both combustion and process-related emissions, but such configurations remain pre-commercial, increase system

complexity, and are subject to site-specific technical and economic constraints.[414] More broadly, CCS integration at integrated steel plants is capital intensive, energy intensive, and technically complex due to multiple emission sources and off-gas streams. As existing assets reach end of life, replacement with DRI-EAF configurations offers a pathway to deeper emissions reductions, especially when paired with low-carbon hydrogen and electricity.

Two steel plants in Ontario have progressed projects to electrify and decarbonize operations, supported by largely repayable funding agreements with both the federal and provincial governments[415,416]. One plant, Algoma Steel (Sault Ste. Marie, Ontario), ended integrated steelmaking and shut down its coke-making and BF-BOF facilities in mid-January 2026—a year earlier than previously planned. The facility now produces steel exclusively via Electric Arc Furnace (EAF), with one EAF in operation since summer 2025 and a second EAF to be commissioned later in 2026.[417,418] However, the plant will not be able run both EAFs at full capacity simultaneously until new local and regional transmission lines are installed to supply the total power demand of 300 MW.[419,420] Another plant, ArcelorMittal Dofasco (Hamilton, Ontario) has broken ground on a project to transition the site to DRI-EAF steelmaking, with a hydrogen-ready DRI plant that will initially operate on natural gas.[421]

Beyond emissions reduction, DRI-EAF configurations can also offer advantages over BF-BOF, including greater operational flexibility. As blast furnace ironmaking is a continuous process that is difficult to start and stop, integrated BF-BOF operations are generally less able to adjust output quickly in response to demand. In contrast, EAF steelmaking is a batch process and is

commonly described as more flexible, including the ability to reduce operating days or stop and restart more readily, which can help producers better align production with changing market demand and idle capacity during downturns.[390,422]

Hot Briquetted Iron (HBI), a denser and more stable form of DRI, offers several advantages. It can be used as a sole iron source or blended with scrap to meet quality requirements in EAF steelmaking.[423] Its higher density and lower reactivity simplify transport relative to DRI, enabling strategic geographic separation of ironmaking and steelmaking to reduce emissions, which is sometimes called “spatial decarbonization.”[41] Iron production can occur in hubs with access to DR-grade ore and low-cost clean hydrogen, while steelmaking can be located where scrap availability and clean electricity are abundant.[424]

Over the longer term, multiple electrolysis-based ironmaking technologies—including low-temperature electrowinning and high-temperature molten oxide electrolysis (MOE)—could enable near-zero primary iron production when supplied with sufficient low-carbon electricity.[425,426] Switching entirely to EAF steelmaking would eliminate most on-site emissions where electricity is zero-carbon, but this would also triple electricity demand per tonne of steel[390]. Scrap availability and quality will also limit the extent to which EAF steelmaking can meet future demand[424], emphasizing the need to decarbonize primary ironmaking even as EAF capacity expands.

Secondary Steel Production

Further decarbonizing the secondary mini-mill production route centres on three levers: maximizing the use of high-quality scrap, ensuring access to low-carbon electricity for EAF operations, and securing low-carbon primary iron sources to supplement recycling.

Canadian steel contains high levels of recycled content, with approximately 7 million tonnes of scrap utilized annually by steel producers, but more action can be taken to improve the availability and quality of scrap and thereby minimize the need for supplementary primary iron.[427] Designing products that allow for steel to be easily recovered and developing more infrastructure to collect and distribute reclaimed steel can increase the supply of scrap.[428] As steel can be recycled almost infinitely, contaminants that are difficult to remove can accumulate and affect the mechanical properties of the metal. Implementing standards for scrap steel classification and

processing, as well as employing technological innovations for more advanced sorting, testing, and treatment of scrap, can improve its quality.[429]

Where scrap supply and quality cannot meet the specifications for all flat and advanced grades, EAF steelmaking can be supplemented with lower carbon primary iron units (NG-DRI, H₂-DRI, HBI, MOE) instead of pig iron. Additional emissions reductions from both integrated steel mills and mini mills can come from electrifying downstream processes, including reheating and rolling, where suitable thermal storage or heat pump technologies can replace fossil fuels.

Competitiveness Implications

Canada produces roughly 0.6% of global steel and faces persistent scale disadvantages in finished products — conditions decarbonization alone will not reverse. But the worldwide shift from blast furnace to electric arc furnace steelmaking is reshaping which segment of the value chain matters most. As EAF capacity grows, steelmakers need merchant primary iron that scrap cannot supply. Hot briquetted iron is the form best suited to fill that gap: dense, shippable, and produced by decoupling ironmaking from steelmaking and siting it where DR-grade ore, clean electricity, and hydrogen converge. Canada holds that input combination. Co-locating hydrogen generation with ironmaking avoids the transport and storage costs that burden hydrogen supply chains elsewhere. Two Ontario BF-BOF conversions already underway provide near-term anchor demand, with the U.S. EAF market — destination for 91% of Canadian steel exports — as the scaled export pathway. The question is whether Canada will build low-carbon HBI supply capacity before competing jurisdictions lock in their own iron feedstock chains, and whether hydrogen infrastructure will advance at the rate the window requires.



10.3.4 Priorities for Action

Support for research, development, and demonstration is needed to bring innovative technologies and solutions to market.[405] As DRI with low-emission hydrogen is currently the only technologically available net-zero solution for ironmaking, it is important to develop regional and provincial strategies around hydrogen production, storage, and transport. In parallel, enabling conditions for low-emissions secondary steelmaking must be maintained, including access to clean electricity and high-quality scrap feedstocks.

Support and buildout of hubs with hydrogen production and ironmaking facilities (which include HBI) can help reduce the costs associated with low-carbon primary ironmaking. These hubs will be key to improving economic feasibility and ensuring efficient deployment of hydrogen-based DRI technologies. For secondary steel production, strengthening domestic scrap collection, sorting, and upgrading systems can increase the availability of suitable feedstock and support higher recycled content in steel production.

A domestic market for premium low-carbon steel should also be developed to drive investments in decarbonization technologies. Public procurement, large companies motivated by ESG targets, and smaller companies acting collectively, for example through buyers' clubs, represent likely first purchasers of low-emission steel. Key early demand sectors include automotive, construction, renewable energy, and white goods, as companies in these sectors are increasingly setting lifecycle emissions targets and may provide producers with revenue certainty through offtake agreements that

commit them to purchase goods before their production at a predictable cost.[430] Alternatively, procurement requirements can specify emissions standards for products or use policies, such as the application of a carbon price to products, when reviewing bids. Suppliers should work closely with buyers to ensure common emissions definitions, calculation methodologies, and targets. Terms such as low-carbon, green, or low-emissions steel can have different meanings among stakeholders and require greater alignment to support market transparency. Once early demand markets are secured, the uptake of low-carbon steel across other sectors can be addressed. Additional derisking measures include long-term clean-power contracts and government support for grid upgrades, scrap supply, and DRI or HBI feedstock availability ahead of project construction.[431]

Carbon leakage (defined as production shifting to jurisdictions with weaker climate policies) remains a competitiveness risk to Canadian steel producers and reinforces the need for policy alignment beyond domestic measures. Border carbon adjustments and related trade measures can support low-GHG steel; however, because Canada represents a small share of global steel output and China produces more than 50% of the world's steel[392], their effectiveness depends on adoption by major steel-producing and importing jurisdictions.[422] In the Canadian context, any BCA would need to be carefully sequenced with North American trade-policy developments to avoid compounding existing export-market pressures. As a result, Canadian decarbonization strategies must be paired with international coordination to avoid competitiveness impacts while enabling investment in low-emissions steel.[422]

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

10.3.5 Steel and Iron Pathways Table

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Ironmaking											
Direct Reduced Ironmaking (DRI) with Net-Zero Hydrogen	Decarbonization Pathway The only scalable net-zero option available today.	Enable Support commercial-scale DRI projects. Invest in hydrogen supply infrastructure and align policies and/or subsidies to close the cost gap.	 Can be net zero but depends on the carbon intensity of hydrogen.	 Net-zero hydrogen costs are high and require carbon pricing or some type of subsidies.	 Potential economic opportunities in producing low-carbon hydrogen and iron for domestic and international markets.	 A full-scale green hydrogen iron plant operates in Sweden.	 Requires process and regulation changes to switch operations from natural gas to hydrogen.	 Requires hydrogen supply chain and infrastructure which is not established, as well as stable supply of DR-grade iron ore pellets.	 Can be some concern around the safety of hydrogen.	 Seen by some producers and government as a feasible option, but significant investment risk still exists with uncertain carbon pricing and dependencies on hydrogen market.	 Better air quality with discontinuation of natural gas combustion.
Biomass based charcoal, or “biochar”	Niche Pathway Limited by biomass availability and competition, and carbon intensity of biochar.	Incubate Support Canadian pilot projects to establish performance data and feedstock logistics. Develop biomass supply chains while managing competition with other sectors.	 Can be net zero or even negative emissions, but only when coupled with high enough carbon capture rates.	 Biochar is more expensive than coal and coke but may have lower energy requirements for production.	 Canada is building the largest biochar plant in North America.	 A few pilots and demonstrations have occurred globally. Large-scale testing to begin in Canada.	 Biochar and coke have different properties, so complete substitution does not work for all furnaces.	 Supply chain for biochar is emerging. Biomass logistics and procurement can be difficult.	 Lacks public visibility but will have similar concerns to operating a regular BF.	 Some steel plants in Canada have already committed to trying biochar. The government is investing in biochar.	 Avoids methane from waste decomposition.
Molten Oxide Electrolysis	Potential Decarbonization Pathway Could produce net-zero iron without combustion.	Incubate Fund R&D partnerships and monitor international demonstration progress.	 Achieves net zero and can reduce lifecycle emissions associated with mining and waste.	 Higher capital and operational costs than other alternatives. High-temperature processes with large electrical demand.	 Technology is not developed or deployed in Canada. Abundant clean electricity offers an advantage.	 Full scale is expected soon. Demonstration plant in Brazil produces some iron.	 Easier maintenance because of multiple small vessels operating independently. Retraining and regulation changes required.	 Requires scale-up of net-zero electricity. Lower quality inputs can be used in production.	 No particular concerns. Environmental impacts are very low.	 Investments into the technology from companies that operate in Canada.	 Works with all iron grades. Byproduct is oxygen, no air quality concerns. No water or hazardous chemicals are needed.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electro-winning	<i>Potential Decarbonization Pathway</i> Could produce net-zero iron without combustion.	Incubate Track pilot results and support research collaborations. Prepare enabling conditions should the technology reach commercial readiness.	Achieves net zero and can reduce lifecycle emissions associated with mining and waste.	Modularization could reduce costs to the point of competitiveness with incumbent steel production.	Technology is not developed, tested, or deployed in Canada.	One project in pilot phase internationally and a few other research groups in Europe and Australia.	Easier maintenance because of multiple small vessels operating independently. Retraining and regulation changes required.	Requires scale-up of net-zero electricity. Lower quality inputs can be used in production.	No particular concerns at this time, but full environmental impacts unknown.	Backed by the biggest steelmaker in the U.S. and climate tech investors.	Can use lower-grade ores and tailings, less mining product is wasted. Environmental impacts are not yet well documented.
Hot Briquetted Iron (HBI)	<i>Enabling Pathway</i> Decouples steel and iron production so that iron can be manufactured where low-carbon energy (i.e. hydrogen) is available and shipped to steel facilities in other provinces.	Deploy Advance HBI production capacity. Position Canada as a low-carbon HBI exporter. Build out hydrogen supply where HBI is produced.	De-couples iron and steel production so each may be produced in a region with access to a relevant low-carbon energy source.	Slightly higher capital and operating costs due to additional processing step. Transportation costs may rise if steel production is completed far from iron production.	Creates a new export opportunity of low-carbon HBI from DRI. Canada has abundant hydrogen production potential compared to other countries.	Commercial technology with two HBI plants in the U.S.	Requires installation of briquetting equipment into existing DRI plants. Need the space to add this process downstream of hot DRI production.	Fits into the existing supply chain and transportation for global shipping. Improves supply chain by decoupling iron and steel.	No particular concerns.	Linkage to lowering emissions may not be well understood.	HBI can improve product quality out of EAFs and produce basic grade steels with lower-grade scrap, reclaiming scrap and reducing waste.
Co-located Iron and Net-Zero Hydrogen Production	<i>Enabling Pathway</i> Increases feasibility of critical ironmaking pathway.	Enable Invest in co-location planning and infrastructure at existing DRI sites. Support regulatory and permitting frameworks for integrated hydrogen-iron facilities.	Improves access to low-carbon-intensity hydrogen.	Better economics than separate production. Transportation and storage costs are significantly reduced.	Potential economic opportunities in producing low-carbon hydrogen and iron for domestic and international markets.	A couple of pilot hydrogen hubs operate in Canada with other sectors as end users.	Space can be limited near existing steel plants so can constrain hydrogen production. Zoning is already industrial for iron production.	Storage and transport infrastructure for hydrogen is avoided. Local H ₂ consumption reduces the need for robust supply chains. If steel production is present, electrical grid requirements may add complexity.	Can be some concern around the safety of hydrogen.	Aligns with iron producer interests as it lowers the risk of investing in hydrogen as a fuel by securing supply.	Land use changes near existing iron facilities. Positive air quality benefits. Potential for other industries to cluster near hydrogen hubs.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Iron and Steelmaking											
Carbon Capture and Storage (CCS) for Blast Furnaces (BF) and Basic Oxygen Furnaces (BOFs)	Bridge Pathway Provides emission reductions so long as BF-BOF remains in use.	Don't Prioritize Track existing projects but prioritize hydrogen DRI and EAF pathways. Support CCS technologies and CO ₂ transport and storage networks.	 Cannot get to net zero alone due to multiple off-gas sources and dilute flue gases.	 High costs even where government support is available.	 Potential economic opportunities in CCS supply chain.	 Demonstration; one steel facility operates with CCS outside of Canada.	 Allows for continued use of BFs and BOFs. Regulations and permitting can be difficult. Capture rate is currently low.	 Requires buildout of carbon offtake infrastructure and supply chain.	 Skepticism about the continued use of fossil fuels and carbon leaks. Need to engage community to gain support.	 Expected to become less relevant as many steelmakers planning for low-carbon steelmaking are opting for hydrogen DRI.	 Doesn't fully address local air pollution. Continued coal mining upstream emissions.
 Steelmaking											
Electric Arc Furnaces (EAFs)	Priority Decarbonization Pathway Used widely today to recycle scrap steel. Can be combined with decarbonized ironmaking to produce primary decarbonized steel.	Deploy Accelerate the transition to EAF steelmaking by supporting grid and scrap supply chain investment.	 Already widely implemented and replaces basic oxygen furnaces, eliminating combustion emissions. Requires decarbonized electricity.	 Current successful technology that runs economically today.	 Supports construction jobs but can reduce steel jobs with higher-efficiency operations. Potential to meet domestic and international demand for low-carbon steel.	 Commercial and widely used globally and in Canada.	 Significant operator training hours needed to switch from BF-BOF as the operating process is different.	 Electrical demand is tripled per tonne of steel. Scrap steel can't fully meet demand. Can be issues with obtaining enough high-quality scrap steel or decarbonized iron.	 No particular concern. Local air quality benefits.	 Switchover already being implemented by two Canadian steel companies.	 Uses more recycled steel. Significantly reduces air emissions.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Casting, Hot Rolling, and Reheating											
Heat Batteries	Potential Decarbonization Pathway Could support all casting, hot rolling, and reheating temperatures with net-zero heat, contingent on commercialization for higher temperatures.	Incubate Fund demonstrations for high-temperature applications in steelmaking. Support development of co-located clean power to improve economics.	 Net zero but depends on carbon intensity of electricity.	 Currently relies on carbon credits or restructuring of electrical rates for competitive pricing. Capital costs expected to fall.	 Some research is occurring on coupling thermal batteries with nuclear power. Useful to multiple Canadian industries.	 Commercially available up to middle operating temperatures. Technology for high temperatures is expected to be commercial within the decade.	 Would need to replace current furnaces, and align with equipment replacement timelines, but operates very similarly. Can use renewables to provide industrial heat, avoiding intermittency.	 Strongly tied to availability and pricing of electricity. Functions better with co-located clean power.	 Change is implemented within a facility. May be pushback with land changes with buildout of renewables.	 Fits long-term goals but low relevance because this affects a small portion of energy and emissions.	 Land required to co-locate renewables. Less air pollution from replacement of combustion furnaces.
Industrial Heat Pumps	Potential Niche Pathway Can be net zero with clean electricity, but applies to very specific low-temperature use cases.	Incubate Fund targeted demonstrations for low-temperature steelmaking applications. Monitor technology advances toward higher temperature capabilities.	 Net zero, but depends on carbon intensity of electricity.	 Could be cost competitive for low low-temperature use cases.	 Not developed in Canada. Could be useful to multiple Canadian industries.	 Early commercial deployments in U.S. and Europe. Hasn't been used within steel and iron sector.	 Only provides low temperature heat, so useful for limited types of reheating.	 Requires clean electricity. Industrial heat pump supply chain is emerging.	 Change is implemented within a facility and therefore probably not public facing.	 Fits long long-term goals but low relevance because this effects a small portion of energy and emissions.	 Less air pollution from replacement of combustion furnaces. HFC leakages are possible from refrigerants.
Fuel Switching (RNG or Hydrogen)	Niche Pathway Low-carbon fuel substitution. Availability will depend on location and adoption by other closely located sectors.	Enable Support biofuel and hydrogen production. Focus on facilities where fuel switching can be paired with broader decarbonization.	 Reduces combustion emissions in product manufacturing and casting, but dependent on feedstock carbon intensities.	 Hydrogen and biofuels carry cost premiums.	 Could boost Canada's bioenergy and hydrogen sectors.	 Some fuel-switching options are already commercially available.	 Low-disruption for biofuels that are drop-in. More significant retrofit required for hydrogen.	 Requires some infrastructure: biofuels need storage. Hydrogen needs more substantial upgrades.	 Supported for cutting GHGs and improving air quality, though biomass fuels raise some forestry concerns.	 Fits long long-term goals but low relevance because this effects a small portion of energy and emissions.	 Reduces air pollutants.

10.4 ALUMINUM

Function of the Sector	A lightweight, conductive, and easily recyclable metal used predominately for transportation equipment, packaging, and construction.
GHG emissions	0.9% of national emissions in 2023, 6.1 Mt CO ₂ e (93% process, 6% combustion).[432]
Options for decarbonization	Decarbonization Pathways: Inert anodes, heat batteries, mechanical vapour compression, electric calcination. Niche Pathways: Fuel switching, industrial heat pumps, electric boilers. Enabling Pathways: Wetted cathodes, recycling.
Stage of transition	Emergence: Inert anodes, heat batteries, electric calcination, wetted cathodes. Diffusion: Mechanical vapour compression, fuel switching, industrial heat pumps, electric boilers, recycling.
Nature of the problem today	Lack of commercially available low-carbon smelting technologies, low or stagnant recycling rates, and lack of global agreements to favour green aluminum.
Other systemic issues	Adverse health and environmental impacts from aluminum mismanagement, air pollution beyond greenhouse gas emissions.
Strategic opportunities and concerns	Market for export of novel aluminum smelting technologies. Potential to reduce operational costs, improve air quality and worker health, and improve revenue streams with recycling. Need intergovernmental collaboration to improve recycling. Strategies are needed to ensure cost competitiveness of green aluminum.
Priorities for action	Invest in research, development, and support for deployment of emerging smelting technologies; incentivize uptake or impose standards for green aluminum use; improve regulations and funding for recycling and invest in infrastructure for net-zero energy supply.
Longer-term issues	Planning for smelters to have 100% renewable electricity, decarbonizing ancillary materials, designing aluminum products efficiently, and developing carbon capture and storage for any residual emissions.
Indicators of progress	Deployment of novel smelting technologies, percentage of green and/or recycled aluminum, proportion of power and heating supply that is net zero.

10.4.1 Current Status

Aluminum is made from bauxite ore, which is mainly mined in Australia and China. To make aluminum, 4-5 tonnes of bauxite are processed into 2 tonnes of an intermediary, alumina, which is then smelted using electrolysis into 1 tonne of aluminum (See Figure 33).[433] Aluminum is used in many applications because it is lightweight, corrosion-resistant, conductive, and indefinitely recyclable. [433,434] In North America, aluminum is used mainly in the transportation (38%), packaging (19%), and construction (14%) industries.

Canada produces both alumina and aluminum. Bauxite is not mined in Canada. There are three aluminum and alumina producers in Canada: Rio Tinto, Alcoa, and Alouette, who own and operate 10 smelters (nine in Quebec and one in B.C.), as well as 1 alumina refinery.[436]

Canada has the fourth-largest aluminum industry in the world, which in 2024 produced 1.5 million tonnes (Mt) of alumina and 3.3 Mt of aluminum, and exported \$17.4 billion²⁰ in aluminum products.[436] 92% of Canada's aluminum exports went to the U.S.[436] In 2024 the industry supported 11,250 jobs (more than half in Quebec) and contributed \$4.6 billion²¹ to the Canadian GDP.[359,437]

Canada's low-carbon aluminum is more than an economic asset; it's a strategic advantage in the race to decarbonize global supply chains. By 2050, global demand for aluminum is expected to increase by 50%.[438] As countries and industries seek to cut emissions, demand will increase for low-carbon materials. Since aluminum produced in Canada emits around six times less GHGs than elsewhere in the world,[432] this sector will play a vital not only in domestic manufacturing, but in the automotive, aerospace, and renewable energy sectors worldwide striving to meet net-zero goals.

10.4.2 Nature of the Problem

Aluminum production in Canada is energy intensive, requiring heat for alumina refining and electricity for aluminum smelting. Additionally, smelting produces significant direct CO₂ and perfluorochemicals (PFC) emissions as carbon anodes are consumed in this process.[439] Of the 6.16 Mt CO₂e emissions produced by the Canadian aluminum industry in 2022, 93% is from process GHG emissions, 6% is from fossil fuel use (heating and transportation), and less than 1% is from electricity consumption. [186,432] Currently, availability is low for novel technologies that avoid or abate smelting's direct carbon emissions.[440]

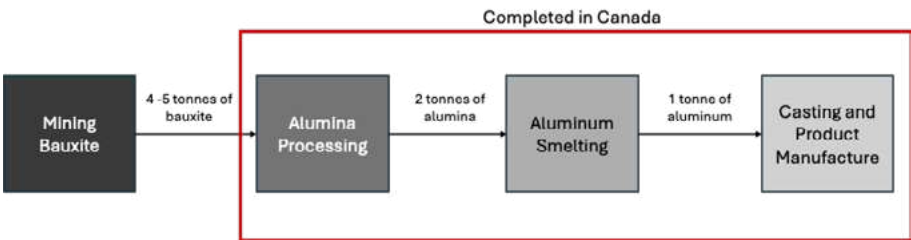


Figure 33. Flow diagram of aluminum production in Canada[436]

²⁰ In 2024 Canadian dollars

²¹ In chained (2017) Canadian dollars

Still, Canadian aluminum has one of the lowest global carbon intensities, at 2.0 tonnes CO₂e/tonne aluminum.[432] This is because it is produced in B.C. and Quebec, which generate electricity from hydropower, while thermal energy is provided by natural gas.[441]

On average globally, products manufactured with recycled aluminum require 95% less energy and generate 97% less GHG emissions than primary aluminum.[441] Although recycled aluminum has low emissions, it can be hard to improve recycling beyond current rates because of the many steps and stakeholders in the value chain.[442]

The uptake and cost competitiveness of low-carbon aluminum is challenged by the lack of standards requiring its use or global agreements on carbon pricing for aluminum. The cost competitiveness of green aluminum is at risk without such standards or agreements.[441]

10.4.3 Net-Zero Pathways

Novel smelting technologies

Eliminating smelting emissions requires the replacement of carbon anodes with non-emitting materials and/or the deployment of carbon capture and storage (CCS) technologies. Non-consumable or inert anodes eliminate direct GHG emissions associated with smelting as oxygen is produced instead of carbon dioxide.[441] There is additional potential for inert anodes to be coupled with wetted cathodes to reduce smelting energy requirements.

In the near term, high-amperage conventional smelting technologies such as Rio Tinto's AP60 represent a meaningful incremental step. AP60, when powered by hydroelectricity, produces approximately half the emissions per tonne of aluminum compared to the older smelting technology it is replacing in

Quebec. These gains are achieved through efficiency improvements to the smelting cell, and the technology is currently being deployed commercially at Rio Tinto's Arvida facility.[443]

In Canada, Rio Tinto, Alcoa, and the Quebec government have already launched Elysis, an inert-anode company, which is expected to commercially deploy in 2027.[444] If Elysis' technology was adopted in all aluminum smelters in Canada, it has the potential to reduce GHG emissions by more than 6 million tonnes per year (equivalent to the annual emissions from 1.8 million cars).[445] Elysis' technology would essentially eliminate process emissions, equating to a 93% reduction in aluminum production emissions. This technology also has the potential to offer aluminum facilities a 15% reduction in operational costs.[446]

Commercial viability of carbon-neutral smelting technologies is key to lowering emissions, so more research and development is needed to enhance reliability and cost-competitiveness.[441]

Recycling

Aluminum recycling limits the need for mining, alumina refining, and smelting and is already quite successful in Canada with 90% recycle rates in the automotive and construction industries.[436] Additionally, Rio Tinto has invested into expanding an aluminum recycling facility in Quebec and building a new facility in Brampton, Ontario.[447,448]

Factors such as lack of consumer compliance, collection infrastructure, municipal recycling facility funding, and older sorting infrastructure reduce consumer recycling rates.[442] Additionally, recycling programs are not regulated, with responsibilities divided amongst levels of government, making comparison, analysis, and improvement difficult.[449]

Net-zero energy or electrification

Although casting and product manufacturing account for only a small portion of total emissions, these processes will need to transition away from fossil fuels. Achieving carbon neutrality will require fuel switching to biofuels or hydrogen, electrification of equipment (heat batteries or heat pumps), and/or implementation of heat recovery technologies.[441,450]

In the near term (before 2030), decarbonizing alumina production can be addressed through mechanical vapour recompression, which captures and reuses waste heat, and electric boilers powered by renewable electricity. Looking further ahead, post-2030 options include hydrogen calcination (replacing natural gas with hydrogen and pure oxygen) and electric calcination, where electricity fully supplies the thermal energy required for the process.[451]

Competitiveness Implications

Canada's aluminum sector already carries one of the lowest carbon intensities among global producers anchored in hydroelectric-powered smelting across Quebec and British Columbia. Inert-anode technology, being commercialized domestically through the Elysis joint venture with a 2027 deployment target, would go further: eliminating process emissions that account for 93% of the sector's remaining footprint and potentially reducing operating costs by 15%. That would position Canadian producers to offer among the lowest-carbon primary aluminum available anywhere at commercial scale. But that position only delivers competitive value if it is demonstrated in time. Canada exported \$17.4 billion in aluminum in 2024, 92% to the United States. The U.S. transportation sector is already the largest end-use market for North American aluminum, and it is where green-procurement standards and carbon-intensity thresholds are likeliest to reshape sourcing first. If those frameworks take effect before Canadian inert-anode production is commercially operating, Canada will have missed the window to establish itself as the benchmark low-carbon supplier, competing instead on terms set by the performance of others.



10.4.4 Priorities For Action

There are multiple steps to decarbonizing the aluminum sector. Policy, funding, fiscal incentives, and investments are needed to support the development and implementation of carbon-neutral smelting technologies, improvement of recycling systems, and full decarbonization of energy supply. To address challenges with technological development, scaleup, and mass deployment, Canada will need to direct more government support towards innovative smelting technologies. To improve recycling, extended producer responsibility programs must be implemented and monitored across the country so progress

is trackable. Investment is also needed to improve infrastructure at recycling plants. [442] Additionally, infrastructure investment is needed for further electrification as well as to support scaleup of alternative fuel production.

Procurement support such as standards could be put in place, especially in the auto industry, to ensure uptake of green aluminum. More long-term, Canada needs to secure global agreements for green aluminum uptake and/or associated carbon pricing to ensure that Canadian green aluminum is cost competitive in global markets.



Criteria Status

-
- Fails to meet criteria
-
- Meets in some respect
-
- Potentially meets criteria
-
- Meets criteria

10.4.5 Aluminium Pathways Table

Not promising Potentially meets criteria Meets criteria			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Aluminum Smelting											
Inert Anodes	Priority Decarbonization Pathway Essential for net-zero smelting.	Enable Support full scale validation and subsequent mass deployment through policy, financing, and regulations.	 Sector-wide implementation could reduce aluminum production emissions substantially.	 Could cut facility operating costs, though costly to adopt initially.	 Positions Canada as a smelting tech leader, creating jobs and export opportunities in the long term.	 Late R&D, though full-scale validation is still pending.	 Require new cell designs and maintenance routines but build on existing smelting processes.	 No major external infrastructure is needed. Canada's hydro power complements inert anodes within modified smelters.	 No concern.	 Key to net-zero goals, with strong backing from producers and government.	 Eliminate carbon anode production, improve safety, air quality, and potentially reduce costs.
CCS	Potential Dead-End Pathway Serves as a last resort retrofit if primary solutions stall.	Don't Prioritize Unlikely to be relevant in this sector as other pathways are emerging. Monitor as an option for residual emissions.	 Cannot fully eliminate direct emissions. Requires significant electricity so grid carbon intensity matters.	 Costly.	 Adds cost without boosting productivity or value, waste gas management step.	 Still testing lab and pilot-scale technologies.	 Technically feasible but CCS could complicate smelter operations and maintenance.	 CCS faces major infrastructure gaps with lack of CO ₂ pipelines and storage sites.	 May win support if it preserves jobs and cuts emissions, but CO ₂ pipelines and storage could face local opposition.	 Producers see CCS as a last resort — being explored mainly to complement carbon-free smelting.	 Lack of CO ₂ storage where aluminum is produced. End-use cases for CO ₂ can also be enablers for more emissions.
High-Amperage Smelting Pots	Bridge Pathway Near-term efficiency and emissions improvements to conventional smelting. Part of net zero if modifiable to work with inert anodes.	Deploy Support with green procurement or other policy measures. Scale deployment on asset replacement cycles, but ensure investment in inert anode technology proceeds in parallel.	 Reduces emissions per tonne significantly through improved cell efficiency and lower anode effects, but does not eliminate process CO ₂ from carbon anode consumption.	 More efficient than incumbent technologies, with lower operating costs. Capital investment in new smelting cells is substantial and most cost-effective when timed to asset replacement cycles.	 The primary technology is proprietary, and the owner operates in Quebec. Deployment generates significant construction activity and regional economic benefits. Operational expertise is exportable, with active deployment studies underway.	 Mature with full-scale deployment, currently scaling with a major expansion.	 Requires replacement of existing smelting cells and associated infrastructure, but leverages existing site assets, grid connections, and workforce skills. Process fundamentals are identical to incumbent technology.	 Requires little change to external infrastructure. Performance is contingent on access to clean, reliable, and abundant electricity.	 Substantially reduces existing air quality emissions and associated community concerns.	 Supported by Canadian producers and governments. Directly relevant to regions with abundant clean electricity and to customers facing increasing carbon intensity requirements.	 Significant particulate matter reductions improve worker and community air quality. Does not eliminate carbon anodes. Reduces energy consumption per tonne, lowering demand on the electrical grid.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Wetted Cathodes	Enabling Pathway Specialized efficiency upgrade — valuable in enhancing an already green aluminum production system.	Incubate Support R&D and pilots.		 High upfront cost, but longer cell life and energy savings can offset it over time.	 Minimal impact.	 Still in R&D. Not yet commercially proven for long-term aluminum cell use. May require more research to combine with inert anodes.	 Requires modifications to the cell design and operating practices.	 Little to no external infrastructure is needed. Implemented within smelting pots.	 Unlikely to face public scrutiny.	 Not a focal point since it doesn't directly drive big emissions cuts on its own.	 Cuts electricity use and may boost output, lowering costs and indirect emissions per tonne.
Casting and/or Manufacturing											
Fuel Switching (i.e. hydrogen or biofuels)	Niche Pathway Low-carbon fuel availability will depend on location and adoption by other closely located sectors.	Enable Build out relevant infrastructure or supply chain to improve fuel procurement logistics. Support increased production of alternative fuels.	 Dependent on fuel carbon intensities. Reduces combustion emissions in product manufacturing and casting.	 Hydrogen or biofuels can carry premiums.	 Could boost Canada's bioenergy and hydrogen sectors.	 Some fuel-switching options are already commercially available.	 Low-disruption — biofuels are largely drop-in.	 Requires some infrastructure — biofuels need storage. Hydrogen needs more substantial upgrades.	 Widely supported for cutting GHGs and improving air quality, though biomass fuels raise some land-use concerns.	 Cuts emissions in ancillary operations, aligns with policy priorities, and expands markets for some energy suppliers.	 Reduces air pollution but not completely. Land-use changes for fuel production can be negative.
Heat Batteries	Potential Decarbonization Pathway Applicable for all temperatures required.	Incubate Support demonstrations and pilots in regions with low-cost electricity.	 Depends on carbon intensity of electricity.	 Very costly. Relies on carbon credits or restructuring of electrical rates for competitive pricing. Capital costs are expected to fall over time.	 Opportunities for Canadian manufacturers. Creates demand for on-site power generation technologies. Useful to multiple industries.	 A few commercial plants globally, designed for most required temperatures. Awaiting full-scale deployment in Canada.	 Would need to replace current furnaces but operates very similarly.	 Functions best when co-located with clean power. Strongly tied to availability and pricing of renewable electricity and natural gas.	 Change is implemented within a facility. May be pushback with land changes to build out renewables.	 Fits long term goals but low relevance because this affects a small portion of energy and emissions.	 Land required to co-locate renewables. Less air pollution from replacement of combustion furnaces.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Industrial Heat Pumps	Niche Pathway Can be net zero with renewable electricity but applies to specific low-temperature use cases.	Incubate Support demonstrations and pilots.	Depends on carbon intensity of electricity.	Only cost-competitive for low temperatures.	Not developed in Canada. Useful to multiple Canadian industries.	Early commercial deployments in U.S. and Europe. Have not been used within aluminum sector.	Only provides low to medium temperature heat. Applicable to a few types of manufacturing.	Requires clean electricity.	Change is implemented within a facility and therefore probably not public-facing.	Fits long term goals but low relevance because this affects a small portion of energy and emissions.	Less air pollution from replacement of combustion furnaces. HFC leakages are possible from refrigerants.
Alumina Refining											
Electric Calcination	Potential Decarbonization Pathway Eliminates fossil fuel use in calcination and enables steam recycling substantially reducing emissions and energy.	Incubate Support R&D and scale support as technology matures.	Eliminates emissions from calcination step. Depends on carbon intensity of electricity.	Electric calciners need major capital investment. Operating costs vary with provincial electricity prices.	Jobs generated through retrofit of existing facilities. Multinationals that operate in Canada are building expertise with the technology.	Piloted by companies that operate in Canada but R&D is occurring mainly in Australia.	Alters refinery equipment and process flow, but can be designed to fit existing sites.	Requires large, steady power. May need grid upgrades, on-site substation, or storage for continuous operation. May require buildout of co-located renewables.	Unlikely to face public scrutiny.	Adds major new grid load — key for utilities, planners, and policymakers aiming for deep decarbonization.	Enables waste-heat recovery from electric systems.
Mechanical Vapour Recompression (MVR)	Decarbonization Pathway Greatly reduces power and water demand.	Incubate Support pilots or demonstrations in the aluminum sector and then scale support for mass deployment.	Cuts refining emissions substantially by eliminating heating emissions associated with refining.	Cost parity with steam systems and offers lower operating costs, particularly with low-cost hydro.	Modernizes refineries, maintains jobs, and builds Canadian expertise in MVR which can be applicable in other industries.	Commercial in other industries but still in early trials for alumina refining. No Canadian uptake; pilots show near-term potential.	Can be added to Bayer-process refineries as a high-efficiency evaporation step without major changes.	Uses standard industrial equipment and is considered a low-risk, modular retrofit — not a full rebuild.	Unlikely to face public scrutiny.	Aligns with producer net-zero targets. Fits federal decarbonization priorities. Meets customer demand.	Reduction in water use by capturing and reusing steam that would be lost. May require buildout of co-located renewables.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electric Boilers	Niche Pathway Viable in specific regions or retrofit phases, but less resource optimal than MVR long term.	Don't Prioritize Watch economics; if there is improvement support adoption and trial of technology where electricity is low-cost. May complement MVR.	Depends on carbon intensity of electricity.	Viable in low-cost electricity regions like QC, but upfront costs exceed those of gas boilers.	Not a major economic driver, though it may benefit boiler industry.	Electric boiler technology is well-established.	Operationally straightforward. Operation unaffected — same function.	Have strong power access but need auxiliary infrastructure for peak loads.	Eliminates on-site emissions without use of fossil fuels. Electric equipment widely supported.	Assists in reaching emissions targets, boosts utility demand, and offers easy wins for policymakers.	High-efficiency boilers cut maintenance costs. Improved air quality and safety with no combustion.
Hydrogen Calcination	Potential Niche Pathway Key long-term lever and essential where electric calcination isn't feasible.	Don't Prioritize Watch maturity and economics. With improvement this may become relevant where hydrogen infrastructure is robust.	Reduces combustion emissions in product manufacturing and casting but dependent on hydrogen carbon intensities.	Low-carbon hydrogen calcination is costly and energy-intensive, with limited commercialization. Significant calciner retrofits likely required.	Could make alumina an anchor tenant for hydrogen. Regions with hydrogen potential do not have strong overlap with current alumina-production regions.	Hydrogen for alumina refining is in pilot stage, with research trials in Australia.	Same calcination as natural gas, but with water vapour instead of CO ₂ . Combustion needs adjustments.	Needs major new infrastructure — hydrogen production, storage, and air separation units.	Hydrogen supported as a clean fuel, though storage and safety raises some concerns.	Fits long-term decarbonization goals and government plans but isn't a top priority sector wide.	No harmful byproducts.
∞ Lifecycle Emissions											
Recycling	Enabling Pathway Cuts primary production emissions. Must be supplemented with a standard production pathway.	Deploy Improve recycling infrastructure and education to maximize lifespan of materials.	Significantly reduces processing emissions as smelting is eliminated.	Cost-effective and established — Canada has high recycling rates, though gains beyond that face higher costs.	New recycling facilities create jobs and boost the competitiveness of Canadian aluminum.	Practices and technology have been used for decades (i.e., automotive parts, building materials, etc.).	Recycling facilities may need to be scaled up. Significant challenges to increasing consumer facing recycling.	Basic infrastructure exists, but gaps in collection, sorting, and program consistency remain. Recycling rates are high for construction and automotive materials but lower or unknown for other products.	Widely accepted and initiatives can lead to new facilities.	Industry interest to reduce costs and emissions. Producers to meet consumer demand.	Reduction in energy use, bauxite mining, and landfill waste.

10.5 CHEMICALS AND PLASTICS

Function	Basic materials of industrial society. Used across all sectors. Chemicals: Especially for fabrics, solvents, fertilizers, pesticides, paints, cleaning compounds, and pharmaceuticals. Plastics: Especially for packaging, construction, and automotive manufacturing.
GHG emissions	Chemicals: 3.5% of national emissions, 23.8 Mt CO₂e in 2024[452]. Plastics: Less than 0.2% of national emissions, 1.1 Mt CO₂e in 2023[453,454].
Options for decarbonization	Fuel switching, electrification, carbon capture, utilization and storage, energy efficiency upgrades, alternative or recycled feedstocks, demand reduction measures, material efficiency, circularity, and improved recycling and waste management.
Stage of transition	Early Emergence
Nature of the problem today	Reliance on fossil carbon for feedstocks and energy, high and increasing demand for chemicals and plastics, low recycling rates and circularity, and mismanaged disposal.
Other systemic issues	Adverse health and environmental effects, persistent and bioaccumulating chemicals, plastic and microplastic pollution[455–457].
Strategic opportunities and concerns	Opportunities: Canada could be a first mover as many technologies are still in pilot and demonstration phase. Buildout of new value chains handling secondary plastics (i.e. recycled plastics) sustainably. Concerns: Increased dependence on alternative or bio-based feedstocks could have land-use and biodiversity impacts; chemical recycling processes energy-intensive or generate hazardous byproducts; risk that improved recycling and recovery could reinforce overconsumption of non-essential plastics rather than absolute demand reduction, increasing production of emissions-intensive primary plastics (i.e. virgin plastics).
Priorities for action	Invest in research, development, and deployment of carbon capture, utilization, and storage; alternative feedstocks; and electrified equipment. Improve regulations and funding for end-of-product-life management systems including demand reduction, reuse, and recycling.
Longer-term issues	Controlling leakage of chemicals (plastics, refrigerants, and fertilizers) into the environment and associated issues. End-of-product-life emissions (could be up to 50% of sector emissions)[458,459]. Availability of feedstocks and clean energy. Carbon supply in a decarbonized energy system.
Indicators of progress	Percentage of site energy as clean electricity or low-carbon fuels, percentage of captured emissions, decreasing carbon intensity of chemicals and plastics, percentage of alternative and recycled feedstock used, improved circular economy indicators, percentage of plastic diverted from landfill, number and success of extended producer responsibility programs.

10.5.1 Current Status

Chemicals are used across the economy, and it is estimated that 96% of manufactured products rely on chemicals to some extent[460]. It is possible to divide chemicals produced in Canada into four broad categories[454,461–463]:

- **Industrial chemicals:** Basic chemicals and synthetic resins, rubbers, and fibres used to make plastics, fabrics, and solvents. Greenhouse gas reporting program (GHGRP) facility emissions: 13.40 Mt in 2024.²²
- **Agricultural chemicals:** Fertilizers and pesticides. GHGRP facility emissions: 5.75 Mt in 2024.²³
- **Chemical products:** Paints, coatings, adhesives, soaps, cleaning compounds, toiletries, printing ink, and other miscellaneous chemical products. GHGRP facility emissions: 0.12 Mt in 2024.²⁴
- **Pharmaceuticals:** Medicines and associated compounds. GHGRP facility emissions: 0.07 Mt in 2024.²⁵

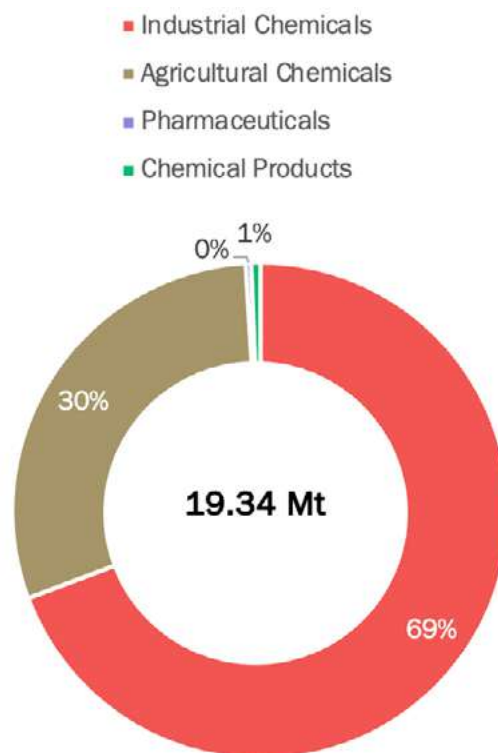


Figure 34. Chemical sector GHGRP facility emissions, Canada 2024[463]



²² NAICS codes 3251 and 3252

²³ NAICS code 3253

²⁴ NAICS codes 3255, 3256, and 3259

²⁵ NAICS code 3254

Plastics, produced from chemicals, are widely used due to their low cost, moldability, and versatility across applications such as packaging, automotive components, electronics, textiles, and construction materials.²⁶ Most plastics are discarded despite some being durable; in 2021, about 0.7 tonnes were thrown away for every tonne produced in Canada, creating major challenges for waste management and circularity[464].

Most chemical products are derived from oil and gas feedstocks and are therefore referred to as petrochemicals. Seven primary chemicals make up more than 60% of the chemical sector's energy consumption[465]. *Ammonia* and *methanol*, two primary chemicals, are made using natural gas[466]. Five other primary chemicals—*ethylene*, *propylene*, *benzene*, *toluene*, and *mixed xylenes*—are derived principally from natural gas liquids and light crude oil distillates. These seven primary chemicals can be consumed or processed further into thousands of other chemical and plastic products[459]. The olefins—ethylene and propylene—are produced predominantly by high-temperature “steam cracking” of ethane and propane. The aromatics—benzene, toluene, and mixed xylenes—are typically obtained from the catalytic reforming of naphtha.

In Canada, two-thirds of the chemicals produced, by mass, were ammonia (anhydrous 4.5 Mt and nitrate 1.1 Mt), polyethylene (3.6 Mt), and urea (3.5 Mt[458,467]. Plastic resin production (including polyethylene and polypropylene) represents a significant share of chemical manufacturing, with sales estimated at \$11.3 billion CAD in 2024²⁷[468].

Chemicals are produced by approximately 3,650 manufacturers in Canada. Chemical and plastic production is mainly located in Ontario (45%), Alberta (25%), and Quebec (16%), leveraging local fossil fuel resources and manufacturing capacity. In 2024, the sector employed 94,500 people, generated approximately \$77 billion in revenues, and exported \$55.6 billion²⁸ in products, with 77% going to the United States[462]. In the same year, the sector's GDP was \$32.2 billion²⁹[437].

Global chemical manufacturing is expected to triple by 2050 compared to 2010, with chemicals playing an important role in emission reduction technologies.

10.5.2 Nature of the Problem

The chemical and plastics sector relies on high-temperature production processes that use fossil-based fuels and feedstocks, making it emissions-intensive and fundamentally fossil-dependent, with decarbonization further constrained by long-life capital-intensive assets that drive lengthy intervals between major investments.

In 2024, the chemical industry emitted 23.8 Mt of CO₂e, representing 3.5% of Canada's annual emissions[452]. Most emissions originate from energy use within facilities (mainly fuel combustion and on-site electricity generation), while the rest come from industrial processes and the use of non-energy fuels and solvents (see Figure 35). An additional 14 Mt of CO₂e are linked to chemical feedstock production and end-of-life management, and 1.6 Mt of CO₂e is attributed to electricity purchase[458].

26 NAICS code 3261

27 2024 Canadian dollars

28 2024 Canadian dollars

29 Chained (2012) Canadian dollars

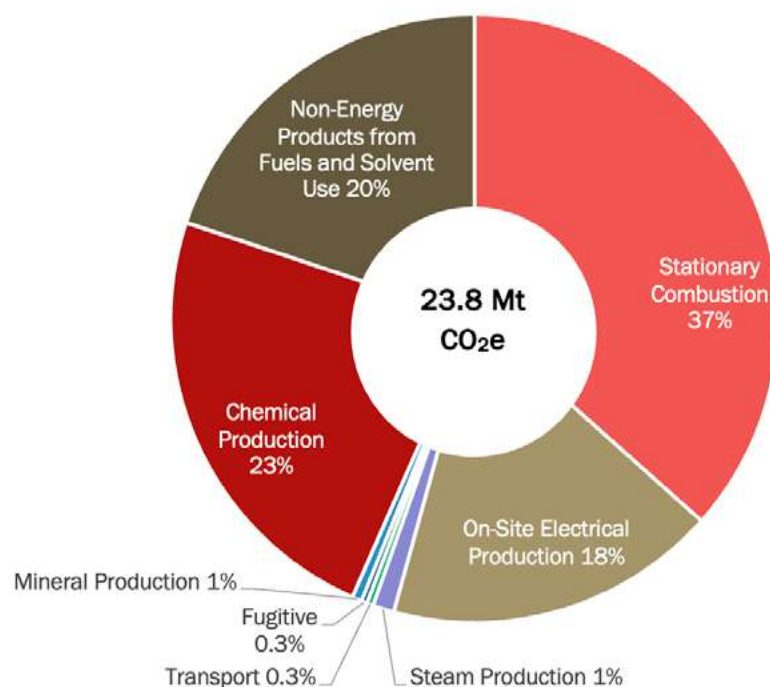


Figure 35. Chemical and fertilizer sector emissions by source, Canada 2024[452]

Plastics and rubber product manufacturing contributed 1.1 Mt CO₂e (less than 0.2% of national emissions) in 2023, because these facilities only transform plastic resins and rubber materials into final or intermediate goods[452,454,469]. Plastic production is carbon-intensive primarily due to upstream oil and gas extraction and high-temperature cracking processes to produce building-block chemicals such as ethylene and propylene[470,471]. End-of-life treatments including landfilling, recycling, and incineration also generate additional GHG emissions.

Decarbonizing the chemical and plastics sector is particularly challenging because it depends on fossil fuels not only for energy but also for material feedstocks, making it inseparable from the broader energy system. The sector must address emissions from energy use, processing, and waste management of embodied carbon while continuing the supply of essential chemicals and accommodating significant expected growth by 2050[459,460].

A major barrier to decarbonization is that chemical facilities are already highly optimized, leaving little room for further reductions without adopting new low-carbon production technologies, which remain immature and costly. The heterogeneity of products makes the standardization and widespread application of new solutions to existing facilities difficult. Geography also constrains solutions through limitations on accessible low-carbon electricity, carbon storage sites, and alternative feedstocks.

Chemical production involves substantial investments in equipment and infrastructure, and major changes (for example, switching processing technologies or feedstocks) are best timed with cycles of facility renewal every few decades[472]. Funding can often miss these major reinvestment cycles[458]. Additionally, the lack of carbon price certainty and/or low carbon prices disincentivizes investments in cleaner infrastructure[458].

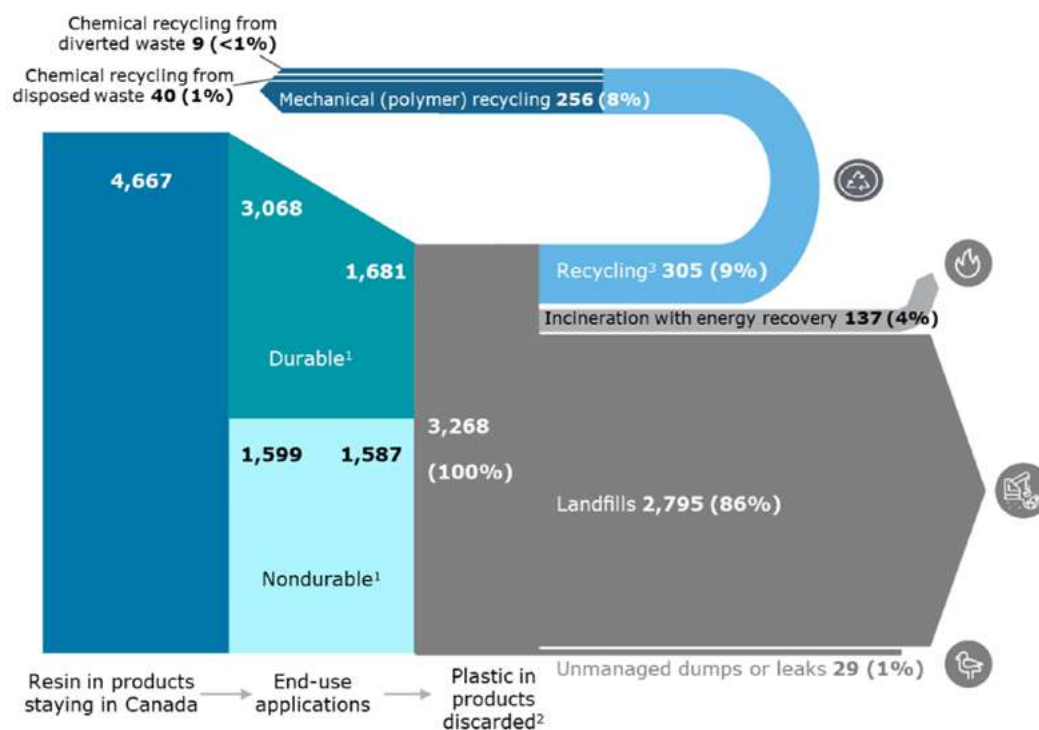


Figure 36. Recycling and disposal of plastics and resins in Canada, 2016 (thousand tonnes per year)[474]

Demand-side policies typically only focus on the effects of chemical or plastic pollution, targeting recycling or waste management. There is a lack of a broader strategy to address designing products for durability and reuse, or with less plastic and chemical usage altogether (e.g., downgauging, lightweighting), in order to reduce demand for emissions-intensive virgin materials[472].

Plastic recycling in Canada generally lacks standardization and efficacy[458]. In 2021, it was estimated that only 7% of discarded plastic was recycled, and 2% was incinerated with energy recovery[473]. In 2016, landfilling the remaining plastic resulted in an estimated \$7.8 billion³⁰ opportunity loss for Canada[474]. Additionally, the economics of plastic recycling are dependent on oil and gas pricing: when oil and gas are inexpensive, primary plastic outcompetes recycled plastic on price[474].

The intertwined nature of oil and gas production and the chemical sector adds a layer of complexity. As demand for transport fuels and fossil-based electricity generation declines while demand for plastics and other synthetic materials continues to rise, analyses indicate that petrochemical feedstocks could shift from being a secondary product of oil and gas refining to a primary output. This evolution could further tighten the integration between the two sectors, creating carbon lock-ins that slow the transition away from fossil-fuel-based energy systems, while also risking stranded oil and gas assets if future policies place significant downward pressure on fossil-based chemical production[472,475–477]. Decarbonization pathways for chemicals and plastics must therefore be considered alongside broader oil and gas transition pathways to support a coordinated shift across both sectors.

³⁰ 2016 Canadian dollars

Economic factors add further challenges. Chemicals are traded globally as commodities, and Canadian producers compete with jurisdictions with lower costs and less stringent environmental controls. With most Canadian chemical products exported to the United States, trade and environmental uncertainties pose additional risks to the sector's decarbonization efforts.

10.5.3 Net-Zero Pathways

Today, oil and natural gas provide both the energy (heat) and the building blocks (hydrogen and carbon) required for chemical and plastic production, making the sector doubly reliant on fossil inputs. In a net-zero chemical and plastics industry:

- **Heat** could be generated from net-zero electricity, oil and gas with CCS, sustainable biomass, or low-carbon hydrogen.
- Low-carbon **hydrogen** could be sourced from natural gas reforming with CCS, methane pyrolysis, or from water electrolysis with net-zero electricity.
- **Carbon** could come from oil and gas with CCS, recycled materials, sustainable biomass, or captured carbon dioxide.

These measures could be combined in different ways depending on lifecycle assessments, desired outputs, available resources, and the cost and maturity of various technologies. Initially, CCS will be important as fossil fuels will continue to provide the bulk of feedstocks even if energy is decarbonized. Later, alternative feedstocks, such as biomass and captured carbon, will become more prominent. If fossil carbon is incorporated into products (carbon is an element in all the base chemicals except ammonia), end-of-product-life emissions will require offset technologies such as direct air

capture (DAC). Plentiful, reliable, and affordable clean electricity is critical for the chemical industry to advance towards net zero. Circular economy strategies (e.g. recycling and reuse), though primarily aimed at reducing pollution and improving resource use, also reduce demand for energy and primary feedstocks, lowering lifecycle emissions and the burden of sourcing clean energy and sustainable biomass[478].

The four basic elements for decarbonization are therefore:

- 1. Carbon Capture and Storage (CCS)/ Carbon Capture and Utilization (CCU):** CCS can be applied to manage the feedstock, energy, and process emissions directly involved in chemical and plastic production[476]. Direct air capture (DAC), which requires more research and low-cost renewable electricity to become economical, or other carbon removal strategies could help offset remaining emissions[460]. Ultimately, captured carbon could be reused to make new chemical products[479]. CCS cannot be the only solution due to large electrical requirements, decentralized chemical facility emissions, limited geological carbon storage capacity, and associated high costs. Complementary solutions are also required[458].
- 2. Electrification and Fuel Switching:** Many chemical processes occur between 400 and 1,000°C, so heat and steam production from natural gas is today a large emission source. Electrified steam crackers, which address onsite energy emissions and can greatly improve efficiency, are progressing toward commercial-scale deployment, with the world's first demonstration plant now operating in Europe. However, capital costs for commercial-scale electric crackers may be prohibitively high in the

near-term and operating costs may also be uneconomic, especially where electricity is expensive[480]. For lower temperature heat (under 500°C), electric boilers, induction furnaces, electric arc furnaces, heat batteries, electric heat pumps, and mechanical vapour recompression can all replace fossil fuel-based heating equipment[458]. For larger equipment like crackers where the costs to electrify can be prohibitive, switching to lower-carbon fuels in the interim is a solution. For instance, equipment that currently runs on natural gas could be transitioned to renewable natural gas or hydrogen[461].

3. **Low-Carbon Feedstocks:** Chemical production could be converted to non-fossil feedstocks. Low-carbon hydrogen (produced by water electrolysis with non-emitting electricity, methane pyrolysis, or from natural gas reforming with CCS) can be used to make ammonia or combined with captured CO₂ to produce methanol—but cost and/or clean electricity availability are significant challenges[461]. Renewable biomass can also serve as a feedstock for both chemicals and plastics, but there are limitations with availability, sustainability, and technical complexity. Emerging biomass-based processes for chemicals and bioplastics often involve costly, multi-step transformations and require further research to become viable[470,479].

Recycled plastics and other secondary materials are another important feedstock option to reduce lifecycle and feedstock emissions and capture otherwise wasted economic value[481]. Mechanical recycling, which occurs today in Canada, can displace demand for primary resins but often produces lower-quality outputs due to impurities.

Chemical recycling, while subject to energy, cost, and maturity limitations, can produce “like-new” resins, using depolymerization or dissolution, or feedstocks of syngas or synthetic oil, using thermal conversion technologies such as pyrolysis or gasification. Another benefit of chemical recycling is its ability to process a wider range of plastic waste streams than mechanical recycling, particularly those that are mixed, contaminated, or otherwise difficult to recycle mechanically. These technologies represent potential pathways for scaling recycled inputs in high-value applications[474,476,482–484]. Recycling has two roles in this framework: reducing waste at end-of-life and supplying lower-carbon feedstocks back into the system.

4. **Demand Reduction and End-of-Life Management:** Measures such as better fertilizer application practices, changed cropping systems, reduction of food waste, and improved plastic end-of-life management can reduce demand or increase circular use of chemicals and plastics and correspondingly reduce sector lifecycle emissions[460,470,485]. These measures are intended to reduce avoidable and inefficient use while continuing to meet demand for essential chemical and plastic products. Designing plastic products to be more durable, reusable, or recyclable reduces demand for primary chemical inputs by keeping products in the economy longer[486]. Any material substitutions should be guided by lifecycle assessments that consider land-use changes and transport emissions[487]. Policies like extended producer responsibility (EPR) and better labelling can support more consistent sorting and collection, which are foundational to effective recycling and reuse.

When plastics cannot be recycled mechanically or chemically, end-of-life options include composting, incineration with energy recovery, and landfilling. However, compostable and biodegradable plastics often face barriers due to inconsistent facility capabilities and a lack of standardized certification. Incineration, while a potential route for unrecyclable plastics, raises concerns around GHG emissions, air pollution, and public acceptance.

A small portion of essential plastics and chemicals that cannot be recycled due to contamination concerns (e.g. medical waste such as syringes, gloves, and masks) will continue to end up in landfills, requiring mitigation through carbon offsetting or capture strategies[474].

10.5.4 Priorities for Action

1. Electrification and Clean Energy Supply (Short-Term)

Canada currently has no projects to electrify chemical facilities, so funding should prioritize demonstration projects for heat batteries, industrial heat pumps, and electric crackers. Financing should be put in place to help with electrifying other large equipment like boilers and furnaces. A regional deployment strategy may be considered, with trial electrification projects prioritized at chemical facilities in provinces that already have reliable low-carbon grid electricity, such as Quebec. Investments in on-site clean energy production and electrical storage should be supported for companies in provinces like Alberta, where grid electricity is heavily reliant on fossil fuels. Securing clean energy is especially important as carbon capture technologies are currently energy-intensive and necessary to decarbonize the chemical sector.

2. Carbon Capture and Pricing Certainty (Short- to Medium-Term)

CCS projects are best initiated in provinces that have proven geological storage, existing pipeline infrastructure, and established regulatory frameworks, providing early proof points and commercial success stories before expanding into more challenging regions. Investment in the research, development, and implementation of carbon capture technologies and strategies will also help bring costs down over time[461]. In the meantime, carbon contracts for difference could help to establish carbon price certainty and help investors with decisions on carbon capture implementation. Carbon border adjustments and support mechanisms will also help net-zero chemicals gain a foothold in the market.

3. Circularity (Short-Term with Ongoing Benefits)

The circularity of chemical products must be improved to reduce demand for virgin materials and minimize waste management emissions. Systems to manage end-use products can be improved by implementing programs such as mandatory extended producer responsibility (EPR) across the country so progress is trackable. Companies should be encouraged to design chemical products for recycling or reuse and reduce the use of all chemical products where possible. For industries such as agriculture, best management practices for chemical application can reduce demand.

4. Waste and Recycling Systems (Medium-Term)

Canada should invest in infrastructure for the collection, sorting, and reprocessing of chemical and plastic products, supported by clear national labelling standards and public awareness campaigns. These systems should be optimized for energy efficiency, and research into innovative recycling methods should be advanced to reduce the energy and GHG footprint of mechanical and chemical recycling[474]. A national plastics registry that collects high-quality standardized data on material flows from manufacture to end-of-life would improve transparency and guide evidence-based policy[488]. Single-use plastics bans, informed by local context and lifecycle GHG assessments for reusable or substitute alternatives, can reduce plastic pollution and lower end-of-life emissions[487,489]. Where single-use plastics cannot be avoided, recycled, or chemically converted, strategies such as landfilling paired with gas capture and carbon offsets may need support to manage residual emissions. Improving circularity and recycling systems requires coordinated, consistent approaches from municipal, provincial, and federal governments. This enables reduced investment risks and stable national markets for secondary materials.

5. Alternative Feedstocks (Long-Term)

Over the longer term, Canada will need to scale chemical production pathways that rely on non-fossil feedstocks. Whether using recycled materials, captured carbon, or biomass feedstocks, these feedstocks should not compete with food production and must be evaluated for availability, sustainability, and technological readiness.

6. Funding and Support (Cross-Cutting Enabler)

Funding programs should be designed with rolling intake to accommodate the operation and maintenance schedules of existing facilities. Additionally, technologies supported in funding programs should be evaluated without bias and guided by lifecycle assessments and techno-socio-economic benefits, as the industry is very diverse and the best solution for decarbonization will differ from project to project.



Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

10.5.5 Chemicals and Plastics Pathways Table

Fails to meet criteria Meets in some respect Potentially meets criteria Meets criteria			Economic		Technical			Social			
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Process Energy											
Low-Carbon Hydrogen (heat)	Decarbonization Pathway Applicable for heat applications where electric options are not viable and clean hydrogen is available.	Enable Support demonstration where economics are positive. Build out hydrogen generation and supply infrastructure.	 Reduces carbon intensity, but only net-zero with CCS or certified low-carbon supply.	 Hydrogen costs falling near hubs. Retrofits cheaper than full electrification when capital-constrained.	 Supports gas utility transition strategies. Strengthens hydrogen supply chain.	 Burner and control modifications are feasible at scale for hydrogen. Full-scale hydrogen plant under development.	 Minimal layout changes and short outages. Useful for peaking or reliability where electric power is constrained.	 Requires verified H ₂ supply and sometimes new storage. Trucking or pipelines depend on regional ecosystems. On-site fuel generation or hubs reduce infrastructure burden.	 Mixed views: sustainability of feedstocks and hydrogen safety are concerns and acceptance improves with transparency.	 Relevant to utilities and operators for near-term decarbonization planning. Canadian deployment occurring today.	 Concerns with methane leakage from blue hydrogen production.
Electrified Steam Crackers	Potential Decarbonization Pathway Applicable to high-temperature furnace heat as grids expand and decarbonize.	Incubate Support research and demonstration in Canada. Build out grid infrastructure.	 Electrified heaters eliminate combustion emissions from core furnace combustion. Depends on grid carbon intensity.	 Business case hinges on abundant, reliable, low-cost clean power. Early projects require co-funding.	 First-mover advantage in low-CO ₂ resins, advanced controls, high-skill electrical/automation jobs at resin hubs.	 Demo/early commercial globally.	 Major furnace revamps during multi-year turnarounds. Extensive control upgrade and operator training. Modification of tail gas used in process.	 Requires major grid infrastructure upgrades and reliable electricity.	 Generally acceptable. Local concerns focus on grid buildouts. Air and noise benefits help.	 Strategic for polyethylene/polypropylene producers in ON/AB/QC resin corridors.	 Eliminates furnace NO _x . Finer temperature control improves yields. Scaling electrical grid may have land-use concerns.
Electric Arc Furnaces (EAFs)	Niche Pathway Relevant for electro-thermal sub-processes meeting some high-temperature heat needs.	Enable Support demonstrations with positive economics. Build out grid infrastructure.	 Delivers zero-emission process heat when powered by clean electricity. Depends on grid carbon intensity.	 Economics depend on duty cycle, electricity price, and retrofit scope. Usually secondary to e-boilers/ e-crackers in chemical plants.	 Limited domestic opportunity beyond specialized OEMs/contractors. Part of broader industrial electrification.	 Mature in metals. Limited chemical deployments.	 Works where electro-thermal heating can be substituted without product impacts. Best aligned with batch or discrete operations.	 Requires high-capacity electrical feeds and transformers. Supply chain available via metals sector vendors.	 Positive with fewer combustion emissions onsite.	 Relevant to select intermediates or allied operations at multi-industry complexes. Not a sector-wide lever.	 Eliminates onsite flue gas, reducing NO _x and particulates. Precise temperature control can improve yields.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electric Boilers, Industrial Heat Pumps, Heat Batteries, Mechanical Vapour Recompression (MVR)	Niche Pathway Relevant to preheating, steam & hot-water loops at ammonia, resins, and solvents plants, excludes cracker furnaces that burn byproduct fuel.	Enable Support demonstration with dedicated funding, then deploy where cost effective along with grid buildout.	Delivers zero-emission steam, hot water, and low-temperature heat with decarbonized electricity. Abatement is smaller where site steam comes from cogeneration with CCS.	Capex moderate. Operational costs tied to electricity. Attractive where power purchase agreements, load management, or on-site generation exist.	Drives demand for Canadian equipment/services and grid buildout.	Technologies are commercial globally. Canada lacks deployments.	Needs spare waste heat and a nearby higher-temperature use for it. Adds little where site heat is already well integrated. Install during turnarounds; requires high-voltage training.	Needs interconnection capacity and stable, clean electricity. On-site renewables and storage can hedge availability and price risk for continuous chemical loads.	Generally positive. Seen as clean industry investment.	Top action for utilities, operators, and provinces seeking rapid Scope-1 reductions and electrification of heat and steam services.	Lower NOx/PM, improved operator safety, better temperature control, and efficiency. Frees gas for higher-value chemical synthesis.
Renewable Natural Gas (RNG)	Niche Pathway Works as an option where sustainable feedstocks exist and can meet supply. Feedstock scarcity limits scale.	Enable Support demonstration where RNG supply is secure	Only net zero if RNG fully displaces fossil natural gas. Requires low-carbon feedstocks. Methane leakage remains a concern.	RNG scarce and premium-priced. Retrofits cheaper than full electrification when capital-constrained.	Supports gas utility transition strategies. Strengthens RNG supply chain.	RNG is mature with limited deployment.	Drop-in fuel. Useful for peaking or reliability where electric power is constrained.	May be difficult for suppliers to connect to existing infrastructure, limiting supply. Competition for biomass.	Broadly accepted and seen as waste valorization.	Relevant to utilities and operators for near-term decarbonization planning. Canadian deployment occurring today.	Concerns with methane leakage from RNG transport and combustion.
On-site Clean Electrical Generation	Priority Enabling Pathway Required to meet the electrification demands of the chemicals and plastic sector.	Deploy Build out on-site clean electricity generation as existing assets reach end-of-life.	Reduces burden on the electrical grid and ensures electricity used is generated from non-emitting sources.	Many methods of on-site generation are at cost parity or can provide operational savings depending on scale.	Generates more jobs on-site at chemical and plastic facilities.	Many technologies for clean on-site generation are commercial today and have been implemented in other Canadian sectors.	Training of staff to maintain and operate the new processes. Depending on the technology, layout or available space may be a concern.	Reduces burden on electrical infrastructure. Most technologies have established supply chains.	Positive as grid power demand is lowered and more local jobs may be generated.	Power demand is expected to be very high, so on-site power generation will be essential. Current focus may be more on direct emission sources.	Reduced burden on electrical grid.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Primary Feedstock Substitution											
Low-Carbon Hydrogen (feedstock)	Decarbonization Pathway Has relevance to ammonia and methanol production.	Enable Support demonstration where economics are positive. Build out hydrogen generation and supply infrastructure.	 Directly decarbonizes Canada's large ammonia/ methanol production by replacing emissions- intensive hydrogen. Only net-zero with certified low-carbon supply.	 Hydrogen cost tied to electricity and/or capture performance and CO ₂ storage availability. Early offtake contracts help.	 Opens manufacturing, logistics, and export opportunities anchored in industrial hubs. Net-zero fertilizer production.	 Technologies commercial. Regional scaling and integration with CO ₂ handling still developing.	 Strongest fit where hydrogen can be produced on-site. Minimal product reformulation required.	 Requires low-carbon hydrogen infrastructure. Benefits from colocation with chemical production and proximity to CCS hubs for blue pathways.	 Mixed views: sustainability of feedstocks and hydrogen safety are concerns, and acceptance improves with transparency.	 Aligns with provincial strategies and export ambitions for low-carbon ammonia and methanol.	 Concerns with methane leakage from blue hydrogen production.
Biomass	Potential Decarbonization Pathway Applicable to some chemical production processes where sustainable feedstocks are available and production pathways are mature.	Incubate Support research and development of production pathways.	 Renewable carbon source for chemicals/ plastics. Life-cycle benefits depend on sourcing, land use, and competition with other sectors.	 Costs high due to preprocessing, conversion complexity, and logistics. Potentially viable where residues/ biogenic CO ₂ are accessible.	 Can create niche economic clusters and rural jobs.	 Emerging. Several routes remain pre-scale in Canada requiring further R&D/demos.	 Best where stable biomass supply exists. Requires new processes and technologies but can integrate with up- or downstream technologies.	 Requires certified supply chains, preprocessing facilities, and consistent specs. Obtaining sufficient volumes close to demand is challenging.	 Public support higher when feedstocks are non-food, local, and transparently certified. Caution around land-use impacts.	 Relevant to specialty chemicals, bioplastics, and regions with forestry/ agricultural residues.	 Repurposes waste biomass. Possible land use concerns.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Carbon Capture											
Carbon Capture and Storage (CCS)	Niche Pathway Essential for large, steady point sources. Cannot stand alone due to energy needs, dispersion, and cost.	Enable Support pilots and demonstrations. Build out CO ₂ transport and storage network.	 Captures process and combustion CO ₂ at chemical clusters. Decentralized emissions have lower capture efficacy. Net zero requires negative emissions.	 High capital and operational costs. Viability improves with price certainty (e.g., contracts for difference) and shared hubs lowering transport/ storage costs.	 Growth in engineering, construction, and storage services. Fosters CO ₂ network buildout leveraged by other sectors.	 Components mature. Site-level integration and optimization continue.	 Best on concentrated, steady streams. Requires additional electrical and space for capture units and compression. Substantial increase in operational complexity	 Needs CO ₂ pipelines and storage. Hub models and permitting capacity are decisive constraints. Some regions, like Alberta, are further ahead.	 Support improves with monitoring, reporting, verification standards, and Indigenous partnerships.	 Prioritized in AB/ON/QC clusters to maintain production and jobs while cutting emissions.	 Reduction in air pollution emissions from gas combustion. Some concerns about CO ₂ leakage.
Demand Reduction in Use of Chemicals and Plastics	Priority Enabling Pathway Avoids tonnes of primary feedstock production by addressing systemic inefficiencies across other sectors.	Deploy Incentivize demand reduction of carbon-intensive products and sustainable product substitution.	 Directly reduces upstream production, transport, and disposal emissions.	 Variable by sector and product but can provide cost savings through improved practices or products. Some costs associated with program design and monitoring.	 Opportunities for producers of alternative products.	 Many practices are well established or demonstrated systems within Canada.	 May require some logistical changes for reuse of goods.	 New sustainable product offerings need to be developed for some sectors.	 Reducing waste resonates with public. Behaviour change barriers exist for durable product models and food habits. Acceptability varies by product.	 Some practices are accepted today. Varies by sector.	 Varies by sector.
Product Design	Priority Enabling Pathway Avoids tonnes of primary material and improves recyclability, durability, and reusability.	Enable Build policy to incentivize or mandate design of products for reuse, recycling, and repair. Support product R&D.	 Design for circularity reduces lifecycle emissions, enables closed-loop material use, and lowers primary production.	 Often positive over product lifetime (reduced material/ production costs, extended use). Upfront R&D and redesign costs can be high.	 Stimulates innovation, eco-design industries, and repair, remanufacturing, and recycling markets. Creates skilled design and service jobs.	 Eco-design principles established. Application uneven across sectors (packaging and electronics ahead, others lagging).	 Requires changes to design workflows, new material specifications, and skilled labour for redesign and repair.	 Requires buildout of recycling, reuse, and repair supply chains and infrastructure. Improve product labelling and standards. Practical in sectors with established EPR and circular economy standards.	 Public support for durability, reparability, and reuse. May be resistance with redesign costs and adapting reusable formats.	 Some interest among manufacturers, brand owners, retailers, policymakers, and recyclers. Directly linked to extended producer responsibility frameworks.	 Can reduce waste, lower resource extraction, improve product longevity, and foster repair/reuse cultures.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Recycling and Systems											
Mechanical Recycling	<i>Priority</i> Enabling Pathway Cuts primary resin demand and creates lower-carbon feedstock. Cannot meet demand alone and only works with high-quality plastics.	Deploy Continue to build out collecting and sorting infrastructure. Mandate or incentivize producer buyback.	 Avoids up- and downstream emissions by substituting primary feedstock. Some emissions could be associated with energy use in recycling.	 Current cost-competitiveness is heavily tied to oil and gas pricing, demand, and collection.	 Generates local jobs in waste-handling facilities. Can encourage smart and sustainable product design.	 Mature technology.	 Functions similarly to traditional waste collection. May require additional logistics planning or training. Only works with high-quality plastics.	 Collecting and sorting high-quality plastics can be complicated. Market impacted by primary product prices if not mandated or incentivized. Not all locations have recycling infrastructure.	 Generally well accepted and implemented in many Canadian regions. Positive association with reduced landfilling.	 Secondary plastics can have impurities, making them less desirable. Relevant where mandates, EPR systems, company sustainability targets, or zero plastic waste strategies exist.	 Reduced burden on landfills and primary resource extraction and associated land use and water- and air-quality impacts.
Chemical Recycling: Thermal Plastic Conversion (Pyrolysis and Gasification)	Enabling Pathway Cuts primary feedstock demand by creating synthetic oil and gas but cannot meet demand alone.	Incubate Support pilots and demonstration. Improve existing collecting and sorting infrastructure.	 Reduces unmanaged disposal emissions and avoids upstream emissions but can add direct or energy-related emissions. Net-zero alignment may require carbon capture.	 Capital-intensive. Economics depend on tipping fees, heat, power, or product revenues, and stringent pollution controls.	 Generates local jobs where facilities are built. Development beyond a waste management solution depends on the buy-in for products (syngas, synthetic-oil, or carbon black).	 Pyrolysis and gasification have been demonstrated or are used in Canada today with coal or wood feedstocks.	 Typically requires buildout of a new facility with extensive permitting. Fits with current waste collection and management operations.	 Requires buildout of new supply chains for products.	 Health and air-quality concerns are moderate for gasification and pyrolysis as the process is contained.	 Relevant mainly to municipalities managing non-recyclable fractions. As supply chain expands, interest in products (synthetic gas, synthetic oil, and carbon black) may grow in relevance.	 Sanitation and land use improved from reduced landfilling and high recovery of hard-to-recycle plastics. Some air quality concerns.
Chemical Recycling: Depoly- merization and Dissolution	<i>Potential</i> Enabling Pathway Cuts primary resin demand by creating lower-carbon feedstocks, but functions only with certain plastics. Cannot meet demand alone.	Incubate Support research and development. Improve existing collecting and sorting infrastructure.	 Avoids up- and downstream emissions by substituting primary feedstock. Can be energy intensive and requires decarbonized electricity.	 High energy-related costs for depolymerization. High capital costs. Economics dependent on oil and gas pricing. Requires green premiums.	 Improves the quality of products offered in the secondary market. Minimal product degradation. Generates local jobs.	 Pre-commercialization.	 Some methods are selective for the type of plastic or are incompatible with impurities. Requires new facilities or additions to existing facilities.	 Collecting and sorting high-quality plastics can be complicated. Market impacted by primary product prices if not mandated or incentivized. Not all locations have recycling infrastructure.	 Public recycling practices already well accepted. Skepticism about the efficacy of chemical recycling.	 Relevant where mandates, EPR systems, company sustainability targets, or zero plastic waste strategies exist.	 Avoids downgrading of plastics, keeping them in the economy longer and reducing landfill burden. Waste products may be harmful.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Recycling Standards, Product Labelling, and Improved Extended Producer Responsibility (EPR)	<i>Priority Enabling Pathway</i> Critical for secondary plastic and chemicals market and primary feedstock demand reduction.	Deploy Implement improved plastic tracking and product labelling. Deploy standardized EPR systems.	Raises diversion and recycled content, decreasing primary resin production and associated upstream emissions.	Can provide cost savings through material recovery. Costs are shared between producers and governments.	Recovers economic value that might otherwise be landfilled. Encourages designing for recycling.	Approaches tested, mature, and proven.	Fits with existing recycling logistics and facilities.	Requires establishing consistent and clear product labels as well as tracking plastics as they move through supply chains.	Strong public support. Visible benefits reinforce participation.	Central to industry/ government roadmaps. Complements production decarbonization.	Litter/leakage reduction. Supports procurement of low-carbon materials.
Residual Emissions and Waste											
Incineration with Energy Recovery	<i>Niche Pathway</i> Last-resort option for managing waste. Limited role in a circular, low-carbon system.	Monitor Support where no other options exist.	Reduces unmanaged disposal emissions but can add direct or energy-related emissions. Applies to most or all plastics. Alignment typically requires capture or offsets.	Capital-intensive. Economics depend on tipping fees, heat, power, or product revenues, and stringent pollution controls.	Generates local jobs where facilities are built.	Mature technology used in Canada today.	Typically requires buildout of a new facility with extensive permitting. Fits with current waste collection and management operations.	Requires district energy or power interconnections. Strict emissions monitoring. Ash handling and disposal logistics.	Incineration is contested locally due to concern over health risks.	Relevant mainly to municipalities managing non-recyclable fractions.	Reduced landfilling and provision of district heat/power. Air- and water-quality concerns.
Plastic Composting	<i>Potential Niche Pathway</i> Option for specialized plastics. Limited role in a circular, low-carbon system.	Enable Develop labelling regulations and consumer guidance. Support R&D of low-temperature compostable plastics.	Applicable for very specifically manufactured plastics. Some GHGs associated with composting.	Composting facility capital and operating costs can be higher due to heat requirements. Requires more expensive compostable plastic inputs.	Generates local jobs where facilities are built. No development beyond a waste management solution.	Some bioplastics are produced and composted in Canada today, but many are mismanaged.	Some composting facilities do not get hot enough to degrade bioplastics, requiring new facilities or retrofit.	Upstream supply chain issues with manufacturing compostable plastics and then downstream with sorting these for compost.	Same level of acceptability to traditional composting. Requires education programs on labelling and composting correctly.	Requires specialized products with sufficient labeling. Typically only relevant with single-use consumer-facing products (utensils, plastic bags, etc.). Variable government interest.	Nutrients and carbon are recycled as fertilizer for agriculture. Air- and water-quality impacts are low.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
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Direct Air Capture (DAC)	Potential Niche Pathway Negative emissions backstop for unavoidable process/end-of-life emissions.	Incubate Support R&D and pilots.	 Offsets the remaining embodied carbon emissions in products. Requires decarbonized electricity.	 Currently high cost/kWh. Niche this decade pending technological improvements and clean-power availability.	 Engineering, construction, and storage services growth. Fosters CO ₂ network buildout leveraged by other sectors.	 Emerging deployments. Integration experience growing via pilots tied to CCS hubs.	 Adds energy load and siting complexity. Procurement via long-term contracts.	 Needs CO ₂ offtake/storage and low-cost clean electricity.	 Neutral-to-cautious due to perceived costs. Support improves when framed as small residual share.	 Limited near-term role. Strategic hedge for firms/governments targeting full net-zero balance sheets.	 Potential issues with land use and carbon leakage.

AGRICULTURE AND AGRIFOOD



The agri-food sector is a significant source of GHG emissions in Canada and presents distinct challenges for decarbonization



11. Agriculture and Agrifood

Function of the Sector	Provides food, fiber, and fuel. Foundational for health and prosperity.
GHG emissions	70 Mt CO ₂ e or 10.2% of Canada's total emissions from agriculture in 2024.[61] 6.4 Mt CO ₂ e or 1% of Canada's total emissions from food and beverage manufacturing in 2022. [490]
Options for decarbonization	Animal agriculture: Reduce emissions intensity (feeds, genetics, methane inhibitors, manure management); longer-term shifts toward lower-emission proteins. Cultivation & soils: Improved nitrogen management, diversified cropping, soil carbon-building practices (region-specific). Energy: Electrification, biofuels, hydrogen, and efficiency improvements on farms and in food processing.
Stage of transition	Early emergence.
Nature of the problem today	Emissions are biologically driven, geographically dispersed, and highly heterogenous. Production systems are optimized for yield using high input models, while markets and policies weakly incentivize emissions reduction and sustainable agriculture.
Other systemic issues	Soil degradation, biodiversity loss, water pollution, food waste, health impacts of processed diets, supply-chain concentration, labour constraints.
Strategic opportunities and concerns	Opportunities to strengthen rural resilience and position Canada in sustainable food markets. Climate change increases production risk (extreme weather, drought/flooding, vulnerability to pests and disease) but can make the growing season longer and warmer.

Priorities for action	Reform support programs to reward emissions reduction and resilience; reduce fertilizer- and livestock-related emissions; scale proven practices through research, trials, and extension; align processors, retailers, and finance with low-emission value chains; encourage alternative proteins.
Longer-term issues	Managing climate impacts on yields; clarifying the role and limits of soil and land-use carbon sequestration; transitioning toward agroecological production systems at scale.
Indicators of progress	Methane and nitrous oxide emissions intensity; fertilizer use efficiency and nutrient losses; soil organic carbon (context-specific); fossil fuel share of energy use; lifecycle emissions per unit of protein; food loss and waste.

11.1.1 Current Status

Canada is a major agri-food producer and exporter, with the sector accounting for about 7% of the country's GDP.[491] Crop production is dominated by field crops, including wheat, canola, corn, barley, soybeans, oats, and lentils, while beef, dairy, pork, and chicken are the major livestock products.[492,493] Approximately 2.3 million people are employed in the agri-food sector, equivalent to 1 in 9 Canadian jobs.[491]

About half of agri-food production by value is exported, with more than 60% of exports going to the United States while the remainder is consumed domestically.[494,495] Due to its export orientation, the sector is highly exposed to disruption in international trade patterns from disputes or geopolitical tension.

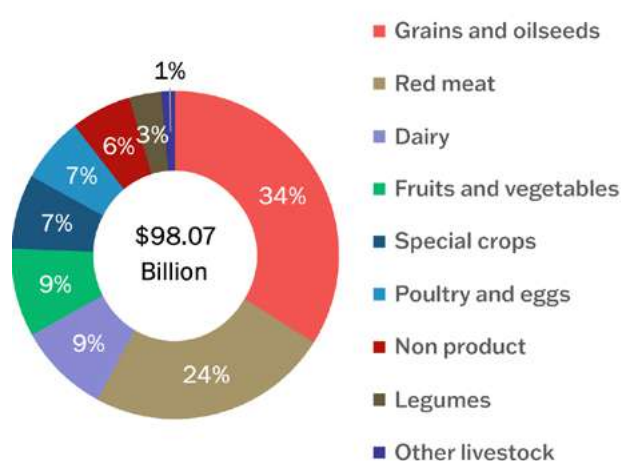


Figure 37. 2024 Farm cash receipts

Despite its economic significance, primary agriculture accounts for only about 10% of total sector employment. Most jobs are found downstream and upstream in the supply chain, including inputs and services (3%), food and beverage processing (14%), retail and wholesale (28%), and the food service industry (43%). In 2021, Canada had just under 190,000 farms.[491] In that year, total farm operating revenues were \$87.0 billion, with the top 10% of farms (with revenues exceeding \$1 million) generating approximately 69% of national farm revenues, while the 52% of farms with revenues below \$100,000 accounted for only 3%.[496,497]

These trends are reflected in the long-term decline in farm numbers and the increase in average farm size (Figure 38), as well as the highly uneven distribution of farm operating revenues (Figure 39). Beyond farms, corporate concentration is significant throughout the agri-food supply chain. This is particularly true for input supply (seeds, fertilizer, herbicides, pesticides, and equipment), food processing (meat packing, manufacturing) and retail (supermarkets).[498] In 2021, five food retailers had nearly 80% of the Canadian grocery market.[499]

In contrast to other social provisioning systems such as transport or buildings, agriculture relies directly on natural cycles and ecological systems, depending on local soil conditions, rainfall, and climate. Climate

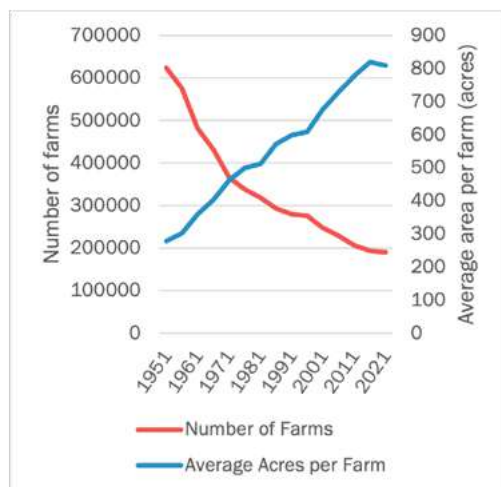


Figure 38. Number of farms and average area per farm (1951–2021)[254]

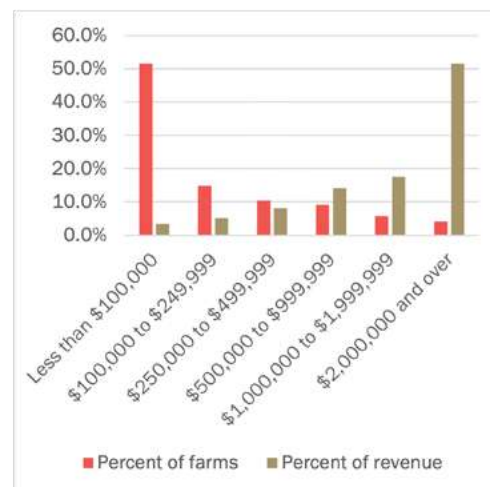


Figure 39. Distribution of farms by operating revenues, 2021

change is already impacting the sector, resulting in reduced revenue per hectare and sharply rising crop insurance payouts (\$1.9 billion in 2018 to \$5.7 billion in 2023). Larger impacts are expected in the future.[500]

At the same time, farming has a substantial environmental footprint, contributing to biodiversity loss and climate change, with pressures arising primarily from input-intensive land-use practices such as monocropping.[501] In Canada, about 6% of the total land area is currently in agricultural production, but this is often in the most settled areas, which historically supported high levels of biodiversity, such as the mixed wood plains ecozone and Carolinian forest.[491,502,503]

Despite these environmental and economic risks, agricultural support programs in Canada are comparatively less generous than in other OECD countries, contributing approximately 8% of gross farm receipts, compared with an OECD average of 13%.[504] Sector risk prevention, including crop insurance payouts, represents the largest component of federal agricultural spending at \$2.03 billion out of \$3.94 billion planned for 2025-2026.[505]

Two major technological revolutions are impacting the sector. Digital technologies like computer vision, edge computing for internet of things, remote and smart sensing, robotics (including drones), machine learning, and artificial intelligence are changing the ways crops and livestock are managed. Advances in biotechnology, including genome editing, nanotechnology, and marker-assisted selection are permitting new crop development, novel pest and nutrient control strategies, and the emergence of precision fermentation and synthetic proteins.[506,507]

11.1.2. Nature of the Problem

The agri-food sector is a significant source of GHG emissions in Canada and presents distinct challenges for decarbonization. Most emissions are from primary agriculture (within farm boundaries). In 2024, the agricultural sector accounted for 70 Mt or about 10.2% of Canada's total emissions, with food and beverages accounting for an additional 5.5 Mt in 2022.[61,490] Within agriculture, emissions arise primarily from animal production (53%), crop production (27%), and on-farm fuel use (20%).[508]

These figures, however, understate the full climate footprint of food production, as lifecycle emissions from the broader agri-food system also include upstream and downstream sources such as fertilizer and packaging production, retail, waste management, and transport, which are accounted for elsewhere in national GHG inventories.

Structural Emission Drivers in Modern Agriculture

Modern agricultural systems are emissions-intensive, reflecting decades of optimization for yield, scale, and cost reduction. High-yield cropping depends on mechanization and the extensive application of nitrogen fertilizers and other chemical inputs, while large-scale livestock production, particularly in high-income countries, is required to meet demand for animal protein.

Although most on-farm energy comes from diesel and other fossil fuels, fuel use only accounts for about a fifth of agricultural emissions; the majority stem from nitrogen fertilizer use and livestock production, including manure management and enteric emissions.[509] As a result, agriculture

accounts for almost 30% of national methane emissions and 75% of nitrous oxide emissions.[186] This underscores the limits of decarbonization strategies focused only on electrification or fuel substitution.

Nitrogen Fertilizers

The widespread adoption of nitrogen fertilizers in the second half of the 20th century enabled major gains in agricultural productivity and, together with fossil fuel combustion, roughly doubled the amount of reactive nitrogen circulating in the environment.[510,511] Nitrogen fertilizer use generates significant direct emissions in the form of nitrous oxide, a highly potent GHG, as well as indirect emissions from ammonia volatilization and nitrogen leaching from agricultural soils.[512]

In Canada, under a business-as-usual trajectory, fertilizer-related emissions could nearly double again by 2050.[509] Beyond climate impacts, fertilizer runoff contributes to air pollution and eutrophication of surface waters, driving toxic algal blooms that degrade water quality and harm aquatic ecosystems.[512]



Livestock Production

Livestock production, especially beef and dairy cattle, represents a central challenge within the agri-food system. Enteric fermentation and manure management account for a substantial share of agricultural emissions (37% and 12%, respectively), with cattle alone responsible for slightly more than a third of agricultural emissions.[186,490] When emissions associated with growing feed grain and farm fuel use are included, cattle-related emissions contribute an estimated 40% of Canada's agricultural emissions.[509]

Beef production is also characterized by low conversion efficiency: one analysis suggested that for the U.S. agricultural system, caloric conversion rates are about 3% for beef, 9% for pork, 17% for dairy, and 13% for poultry.[514]

Structural Emission Drivers in the Broader Agri-Food Supply Chain

Food loss and waste occur across the entire agri-food system, from farms and processing facilities to distribution, retail, food service, and households.[515–517] The scale is staggering, analysis suggesting that in Canada, 46% of food is wasted annually. This waste significantly amplifies the environmental footprint of the agri-food system. The total GHG impact of Canada's avoidable food waste in 2024 was estimated to be 25.7 Mt of CO₂e.[515]

Until recently, much of the problem was framed as a household issue, driven by overbuying, poor meal planning, spoilage, and the disposal of edible food. Research now highlights substantial losses in production, processing, and manufacturing, where inefficiencies, quality standards, and logistical constraints play a major role.[518] Thus, meaningful progress will require coordinated interventions across the supply chain to better integrate the environmental costs of

waste into food system design, production, distribution, and marketing.

Soils and Environmental Trade-offs

Conventional industrial farming systems have prioritized simplification and control of ecological interactions through monocropping and chemical inputs. While this approach delivers high yields, it has often done so at the expense of biodiversity, water quality, groundwater availability, and soil health, increasing pollution as well as reliance on synthetic pesticides, herbicides, and fertilizers.[519]

Soils play a pivotal but variable role in agricultural emissions. Depending on management practices, weather, and broader ecological conditions, soils can act as either net GHG sources or sinks.[520] The development of more farmland and poor maintenance of existing soil can disrupt soil carbon storage.[521] Maintaining or increasing soil organic carbon supports emissions reduction, improves soil structure, reduces erosion, enhances nutrient and water retention and delivery, and supports crop productivity.[522]

Why Agriculture Is Complicated to Decarbonize

The agri-food system will be among the most challenging sectors to transition to net zero. Emissions are highly dispersed across millions of acres and thousands of farms, making them difficult to measure, manage, and regulate. The sector is also extremely heterogeneous, with GHG footprints varying widely for the same product due to differences in feed composition, manure management, soils, yields, and climates.[523] These technical challenges are compounded by fragmented and underfunded public agricultural extension services, limiting the dissemination of practical mitigation options, constraining both awareness and adoption of decarbonization practices.[524–527]

Long-standing corporate, institutional, and political factors further limit intervention. Canada lacks a clearly articulated 2030 and 2050 decarbonization pathway for agri-food, contributing to uncertainty and delayed investment in emissions reductions.[488]

Addressing these challenges requires a rethink of established production paradigms and raises fundamental questions about both what is produced and how.[519] Most existing agricultural support programs focus on stabilizing prices, risk management, and encouraging exports, and in some cases may inadvertently reinforce environmentally damaging practices, such as reduced crop diversification.[500] Increasingly, however, there is recognition that sustainability and credible documentation of low-carbon supply chains can be a competitive advantage both in domestic and international markets.[529] While transition pathways remain contested, there is growing consensus that emissions reductions must be pursued alongside farm viability, healthy diets, biodiversity protection, water quality, and trade competitiveness.[519]

11.1.3 Net-Zero Pathways

Three emissions mitigation areas must be in place to move agri-food systems towards net zero:

- Addressing emissions from animal agriculture
- Reforming cultivation practices and managing soils
- Displacing fossil fuels across farms and food systems

No single intervention can deliver net zero. Instead, pathways will involve different combinations of these elements depending on region, production system, available infrastructure, and commodity.

1. Addressing Emissions from Animal Agriculture

Animal agriculture, particularly ruminant livestock, is the largest single source of emissions in the agri-food supply chain. Two broad and complementary strategies are available: reducing emissions intensity within existing livestock systems and shifting production and consumption toward lower-emission protein sources.

e. Improving Livestock Production Practices

The GHG performance of the Canadian beef industry has improved significantly over the past decades.[530,531] Mitigation measures include improved animal genetics, higher-quality and more digestible feed, feed additives to reduce enteric methane, more advanced manure management systems, modified grazing practices, and enhanced soil and pasture management.[532]

Recent modelling suggests that combining these measures, rather than adopting them in isolation, may allow beef and dairy production to approach very low or net-zero emissions, particularly where soil carbon sequestration is increased. High-impact options like planting trees on pastureland and anti-methanogenic feed supplements deliver substantial emission reductions with relatively low costs compared to other measures.[533] How widely such outcomes can be replicated across Canadian producers remains uncertain and will depend on cost, scalability, verification, and producer adoption.

f. Shifting Protein Production and Consumption

A second pathway involves changes in both supply and demand. Over the past 40 years, Canadian meat consumption overall has decreased almost 10% (per capita beef consumption declined more than 40%, while chicken consumption has grown by almost 110%).[534–536] Decreasing meat

consumption broadly and moving to meats with higher calorie conversion efficiencies, particularly poultry or some farmed fish, could yield further emission reductions. There is increasing scientific evidence that diets high in fresh vegetables, legumes, nuts, and fish, with only a moderate quantity of animal protein, are conducive to health.[537,538] Although the proportion of the population committed to vegan principles remains small, there is a broad tendency to reduce consumption of red meat and dairy-based beverages.[539]

More transformative change would involve expanding the role of alternative protein sources:

- **Plant-based proteins:** Meat substitutes like vegetable-based burgers and non-dairy beverages like oat or almond milk have achieved commercial success over the past decade.[540] The trend has been driven by consumer concerns over health, animal welfare, and the environment, but also by advances in manufacturing that have improved flavours and textures in meat substitutes.[541]
- **Fermentation-based and cultured proteins:** Biotechnology advances have dramatically reduced the cost of creating animal proteins through enhanced fermentation, though commercial cost parity is uneven across production methods and scales.[542,503] Milk proteins such as casein are already being used in U.S. food products, with research on cellular meats advancing rapidly.[544] By producing proteins without raising a whole animal, these approaches could dramatically reduce emissions from enteric methane, manure, and feed production, while freeing agricultural land for other uses.[545,546]

Adoption of alternative proteins in Canada has been gradual and is likely to remain so, given its dependence on consumer acceptance and

preference. More rapid market disruption could occur if alternative products simultaneously meet consumer expectations and achieve price advantages over conventional livestock products. Changes are unlikely to result in a complete replacement of meat across all contexts.

The shift is made more complex by the export intensity of Canadian agriculture, since domestic production and domestic consumption are loosely coupled, especially in the beef and grain sectors. As a result, a shift by Canadians toward more plant-based diets would not necessarily reduce agricultural GHG emissions if meat production continues to be driven by export demand.

Despite their mitigation potential, uncertainties remain around consumer acceptance, regulatory frameworks, and the long-term health and environmental impacts of these technologies. Initial adoption is likely to be cost-led, particularly where fermentation-derived proteins undercut conventional animal protein prices. While shifts toward alternative proteins involve consumers more directly, demand is not independent; the agri-food industry has a significant role in shaping preferences through pricing, marketing, and product design.

2. Reforming Cultivation Practices and Managing Soils

Crop production and soil management are the second major source of agricultural emissions, largely due to nitrous oxide emissions from nitrogen fertilizers and soil processes. Addressing these emissions without compromising yields requires fundamental changes in cultivation practices and input management that are tailored to regional conditions and crop types. Key strategies include improving nitrogen management, enhancing soil organic carbon, and diversifying cropping systems.

a. Nitrogen Management

Synthetic nitrogen fertilizers are the dominant source of agricultural N₂O emissions.[186] To mitigate these emissions, multiple approaches are required to reduce inorganic nitrogen inputs (without yield loss). These include improving nitrogen use efficiency through the 4R principles (right source, right rate, right time, and right place) and adopting enhanced-efficiency fertilizers such as controlled-release products and nitrification inhibitors.[547,548] Precision agriculture tools, such as variable-rate application and real-time monitoring (guided by sensors or satellite data), can further reduce nitrogen losses by better matching inputs to crop demand.[549]

b. Soil Management and Organic Carbon

Managing soils to increase organic carbon is central to reducing emissions while improving soil fertility and water-holding capacity, and preventing erosion and nutrient loss. Practices that reduce soil disturbance and enhance organic carbon, such as residue retention with reduced or no-till cultivation, greater use of cover crops, and adding organic amendments (manure, green manure, biochar, and compost), can reduce emissions and improve the fertility of soils, especially in degraded soils or where land is restored from intensive agricultural use to grasslands, forests, or wetlands.[550,551]

In Canada, no-till practices are common, particularly in Western Canada.[512] The amount by which soil quality improves, nitrous oxide emissions reduce, and yields are impacted by no-till depends largely on climate and soil type.[553] As a result, reduced tillage is most effective as part of an integrated soil and nutrient management strategy rather than as a stand-alone mitigation measure.

Cover crops can reduce nitrate leaching and improve soil resilience by retaining residual soil nitrogen between growing seasons, and

one Canadian study identified increased cover cropping as the third most impactful natural climate solution, after avoiding disturbance of grasslands, peatlands, and wetlands.[548] However, emissions outcomes remain context-dependent, influenced by species selection, biomass production, termination timing, and local soil and climate conditions.[554]

More broadly, improved soil management is recognized as an important component of broader natural climate solutions, but there is significant uncertainty around the long-term magnitude, durability, and climate sensitivity of soil carbon storage. Sequestration rates are region-specific, vary by soil type, climate, and management, and often decline as soils approach saturation.[555–557] As such, increases in soil carbon should be viewed as complementary to, rather than a substitute for, direct emissions reductions from fertilizer management and energy use.[548]

c. Diversify Cropping Systems

Diversifying cropping systems through intensified rotations (less summerfallowing), greater inclusion of legumes, vertical farming, and in some cases multicropping can reduce emissions while improving nutrient cycling, pest control, and soil structure. Legume crops reduce reliance on synthetic nitrogen fertilizers by fixing atmospheric nitrogen, while vertical farming can reduce chemical use and facilitate electrification of machinery. [550,558–560]

Multicropping practices were displaced by the expansion of high-input monocropping, but when combined with modern crop varieties and technologies, more diverse cropping systems can maintain, or even improve, productivity while reducing emissions. [561,562] Evidence from organic farming systems demonstrates that cropping systems that avoid synthetic nitrogen can be productive under certain conditions, with

potential long-term benefits for soil fertility. However, outcomes are variable, and productivity may decline depending on crop type, soil conditions, and management practices.[563,564]

There are longstanding debates over the climate and biodiversity performance of conventional and alternative farming systems, including concerns that lower-yield approaches may increase land requirements. [565] While large-scale conversion to organic agriculture is unlikely in the near term (organic production currently represents about 3.3% of Canadian farmland), achieving emissions reductions will nonetheless require a clear shift away from business-as-usual cropping systems and wider adoption of diversified, lower-input practices where they are agronomically and economically viable.[566]

While the impact of organic farming requires context-specific fine-tuning, a significant domestic opportunity remains largely untapped. In 2020, Canadian organic imports outpaced exports—\$789 million versus \$461 million—revealing a substantial gap that domestic production could expand to fill.[567]

3. Displacing Fossil Fuels

Displacing fossil fuel end-use on the farm and throughout the food manufacturing industry, is conceptually straightforward: replace fossil-powered equipment with low-carbon alternatives. While this transition mirrors decarbonization efforts across the broader economy, it faces additional challenges in rural and remote settings. Today, fossil energy is used primarily for vehicles, machinery (e.g. tractors, harvesters, pumps), and heating (e.g. buildings, drying, food processing). On the farm, diesel engines dominate because of their high-power density and existing fuel infrastructure.

The main decarbonization pathways are electrification, hydrogen (or related net-zero

energy carriers), and biofuels, each with distinct benefits, constraints, and levels of readiness for on-farm deployment. Alongside these options, improving energy efficiency, such as better insulation in barns and buildings or reducing vehicle and machinery idling, can lower emissions while delivering immediate operational cost savings.

a. Electrification

Where clean grid electricity is available, light- and medium-duty vehicles and equipment can transition to battery electric options.[528] Some electric tractors have begun to enter the Canadian market.[529] Farm and food manufacturing heating can also shift to high-efficiency electric heat pumps, which often deliver operating cost savings alongside emissions reductions.[570]

In more remote or off-grid locations, on-site renewable energy including solar, wind, or bioenergy can supply electricity. These systems reduce reliance on diesel or propane generation, lower emissions and operating costs, and can provide revenue diversification where excess electricity is sold back to the grid.[571]

b. Hydrogen

Heavy machinery and long operating hours present challenges for electrification due to current battery energy density and charging limitations in rural settings. Hydrogen fuel cells offer a promising high-energy alternative for heavy-duty equipment and off-grid power, especially where long runtimes and quick refuelling are needed. However, widespread use depends on the availability of low-carbon hydrogen and rural infrastructure build-out, which is still nascent.[572]

c. Biofuels

Biofuels such as renewable diesel or biogas can also displace fossil fuels, particularly where electrification or hydrogen are less

feasible. Renewable diesel is a drop-in fuel compatible with existing diesel equipment, while biogas can be upgraded to renewable natural gas and used as a direct substitute for fossil natural gas in heating applications on farms and in food manufacturing. These fuels are made from biomass and can reduce greenhouse gas emissions compared to their fossil fuel counterparts, though their scalability and sustainability depend on feedstock and production methods.

Agricultural and agri-food operations have a unique advantage in biofuel production, as on-site wastes and residues can be repurposed into usable fuels in closed-loop systems or sold downstream. The appropriate biofuel pathway depends on operation scale and waste type, with options including fermentation, anaerobic digestion, pyrolysis, and gasification.[533] Many of these processes also retain nutrients in by-products such as digestate or biochar, which can be returned to fields as fertilizers, supporting nutrient cycling alongside energy production.[574]

Pathways Selection

There is no simple “one size fits all” solution for moving the agri-food system onto a net-zero trajectory.[525,535] Progress will require combining multiple strategies, reducing emissions from animal agriculture, reforming cultivation and soil management practices, and displacing fossil fuels, implemented in different proportions depending on region, production system, infrastructure, and commodity. No individual technology or farming model can deliver net zero on its own. Considerable practical experimentation and research, including participatory on-farm research, will be required to develop approaches suited to different conditions, regions, and sub-sectors.[576]

Competitiveness Implications

Canada is among the world's largest pulse producers (lentils, peas, and beans that rank among the lowest-emission protein feedstocks available), and plant-based proteins represent the sector's top-rated economic development opportunity. But the economic return depends on where the processing occurs. The margin in protein markets sits downstream: in ingredient isolation, formulation, product manufacturing, and the IP that surrounds them. Canada's pulse sector leads at the farm gate, yet R&D and capital investment in the country's food-processing industry have been declining, exactly the wrong trajectory for capturing this segment. Domestic processing capacity is also what converts a commodity export position into an export platform for finished, low-emission protein products. The structural advantage is real, but until processing capacity follows the feedstock, Canada will continue exporting low-margin pulse crops while importing the higher-value protein products made from them.

11.1.4 Priorities for Action

In the near term, priorities should focus on accelerating emissions reductions using measures that are already available while strengthening the institutions needed for deeper change. This includes intensifying research, trials, and scaleup of more sustainable cropping and livestock practices, reducing reliance on synthetic nitrogen fertilizers, and expanding the use of low-carbon energy across farms and food processing.[577–579] This can be integrated with efforts to address other challenges, including farm debt, high land costs, the difficulty of attracting young farmers, and corporate concentration.[577]

Reform of agricultural support mechanisms is already under active discussion, and emphasis on mitigation of GHGs and resilience in the face of climate risks could be built into program design. Existing programs could place greater emphasis on emissions reduction, soil health, and climate resilience, rather than only on income stabilization and production risk. Priority measures include support for cover crops, diversified rotations, tree planting, wetland restoration, improved pasture management, and verified reductions in fertilizer- and livestock-related emissions.

Public research and extension capacity must also be strengthened. Canada has a strong history of publicly supported agricultural research, but extension services that once provided farmers with practical, independent advice have been substantially reduced. Addressing climate risks and emissions at scale will require renewed investment in public research, education, and on-farm advisory services, including targeted support for young farmers, Indigenous producers, women, and new entrants.

Agri-food supply chains have a critical role in enabling change. Although agri-food emissions occur mainly on farms, they are shaped by decisions made by processors, distributors, and retailers. Better coordination across supply chains can reduce risk for producers, accelerate adoption of low-emission practices, and support credible documentation of emissions performance. Food processors and distributors can play a major role in building innovative and collaborative supply chains that mobilize knowledge, capital, and organizational capacity to work with primary producers to accelerate change. Recent efforts to market Canada as a sustainable agri-food producer could help expand markets while reinforcing incentives for lower-emission production.

Reducing emissions from nitrogen fertilizer and livestock production should be a priority. This includes wider use of enhanced-efficiency fertilizers, precision application, alternative cropping systems that build soil fertility, and regulatory or market mechanisms that encourage the adoption of lower-emission fertilizer products.[540] In animal agriculture, greater emphasis is needed on proven approaches to reduce enteric methane and improve manure management.

Promoting the uptake of battery electric or hydrogen fuel cell machinery and vehicles, on-farm renewable electricity generation, use of locally produced biofuels, and energy efficiency measures can lessen dependence on fossil fuels. Current fuel tax exemptions reduce incentives to shift away from fossil fuels, and alternative policy mechanisms will be needed to encourage low-carbon energy use.

Encouraging greater investment by the food industry in plant-based processed foods and early exploration of fermentation-based and cultured proteins (including careful assessment of their health, environmental,

and social implications) should begin now. On the consumer side, public education on healthy diets, food safety, and the environmental footprint of food (Figure 40) can support informed choices. Measures that strengthen connections between producers and consumers, such as local and regional markets, can further raise awareness while supporting farm incomes.

Over the longer term, it will be important to support research and trials of alternative agricultural paradigms, including approaches that operate at the landscape scale across multiple farms and land uses. This includes integrating GHG management into all aspects of the agri-food sector and establishing clear parameters for achieving negative emissions through soil management practices and land-use changes.

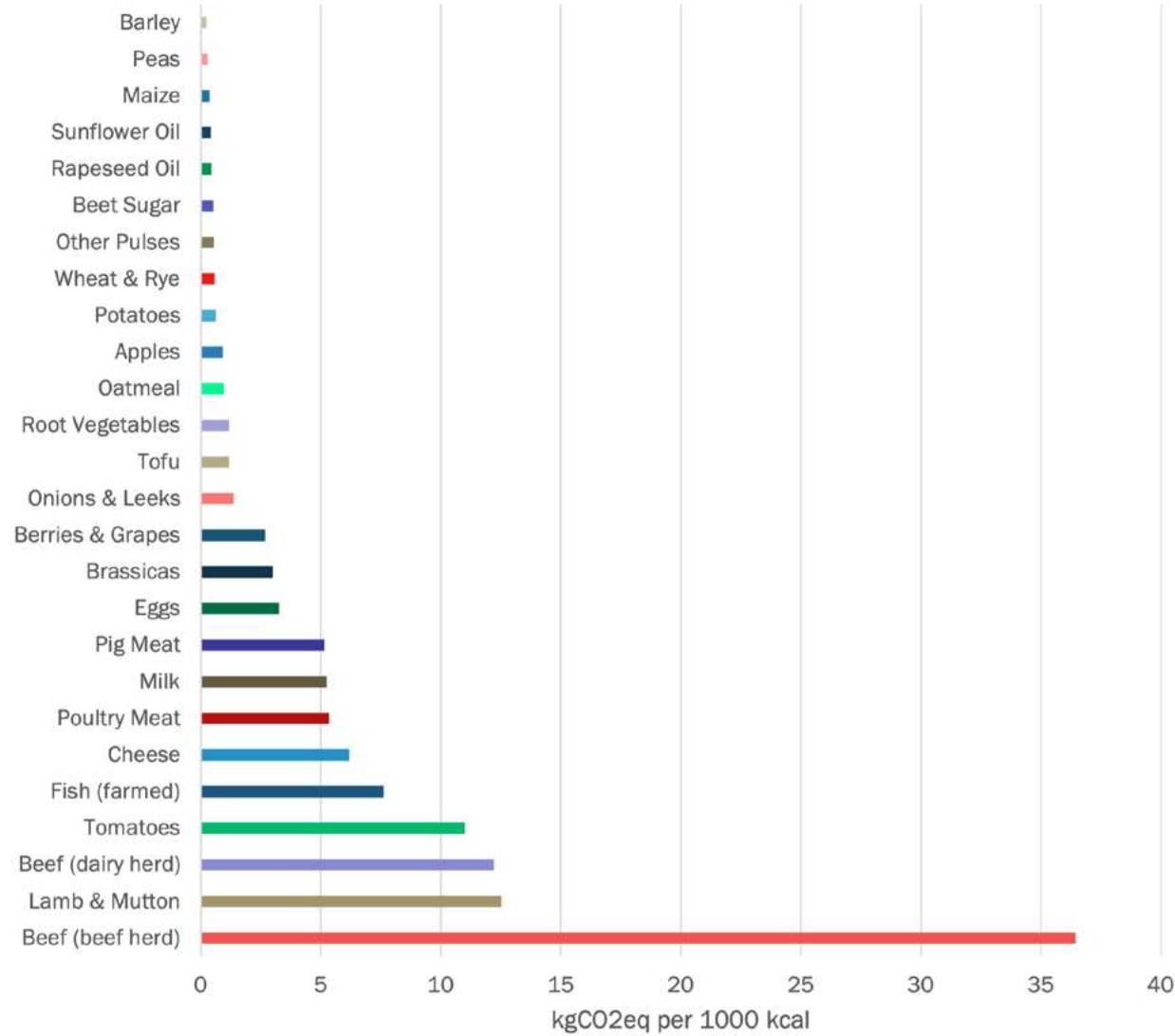


Figure 40. Comparing the carbon footprints of foods 1000 per kilocalorie[581]

ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
	ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Anaerobic digestion, acidification, or separation substantially reduce manure methane. Residual emissions remain.	Some methods low cost while more advanced systems are capital intensive. Project economics depend on scale, off farm substrates, and credit/incentive access.	Development of manure management technologies and expertise. Co-development of biogas generation. Buildout of nutrient recovery. Reduced dependence on imported fertilizers.	Most techniques are mature with commercial adoption occurring in Canada. Capital-intensive technologies are more limited.	Some strategies (i.e. more frequent manure removal) require few changes. Other strategies require installation of technologies, retrofit of existing buildings, and worker training.	Infrastructure for equipment supply largely established. Biogas offtake is difficult; consuming on-site reduces challenges.	Acceptance is generally high as long as odour and traffic remain limited.	Many farms already employ manure management techniques with uptake in technology adoption.	Improved nutrient recycling and displacement of synthetic fertilizers reduces lifecycle emissions and water pollution. Biogas reduces reliance on fossil fuels.
Potential for large reductions if powered by clean energy and scaled.	Cost competitiveness at scale is expected soon. Costs currently remain higher than most conventional products.	Canada has a large primary agricultural industry which can support growth in bioprocessing. Opportunities for IP and R&D from established research organizations.	Some products are commercial. Many others are in various phases of research, development, and scaling.	New food manufacturing facilities will need to be built out with novel processes. Regulatory environment needs development.	Commercial manufacturing and ingredient supply chains are nascent, with limited retail availability.	Acceptance is mixed as products can be perceived as highly processed. Safety and health are concerns.	Ongoing research in Canada. Some companies present in Canada.	Can reduce land use and air and water pollution. Creates food supply resilience. Further studies of health and environmental implications required.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Plant-Based Proteins	Priority Enabling Pathway Gradual shifts in demand toward less livestock and emissions-intensive products. Enables deep structural emissions reductions where applicable.	Deploy Support expanding manufacturing of higher value chain plant-based protein products with financing mechanisms. Provide education to consumers on the benefits of plant-based proteins.	 Can achieve net zero with zero-emissions crop practices.	 Plant based proteins are typically lower cost to produce and purchase than animal-based proteins.	 Canada has a major pulse market. Development and production of plant-based proteins (higher-value products) in the same supply chain would create significant IP, export, and job opportunities.	 Plant-based protein products produced and consumed regularly in Canada. Some development underway to improve nutritional equivalence, scalability, and digestibility.	 Some scaling of food processing facilities or buildout of new manufacturing processes will be required.	 Canada has an established and well-positioned plant-based protein supply chain which can readily be expanded. Infrastructure to transport crops and food products is established.	 Plant-based proteins are widely accepted. Most consumers choose both animal and plant-based proteins and choices in diet vary by region. Concern over high salt, fat, sugar, and additives in many products.	 Increasing demand for plant-based proteins from consumers drives market interest. Pulse producers looking for value add.	 Reduced water and land use when replacing animal-based protein, potential health benefits when a part of balanced diets. Many products are not nutritionally equivalent to livestock-based products.
Enhanced Animal Genetics	Enabling Pathway Reduces livestock emissions intensity. Cannot eliminate biogenic methane and must be combined with other livestock measures.	Incubate testing and demonstration. Provide extension services to farmers on how to select for and the benefits of selecting low methanogenic genetics.	 Selective breeding reduces enteric methane intensity but does not eliminate emissions. Must pair with other measures.	 Low incremental cost. Leverages existing breeding programs and AI. Benefits accrue herd wide over time. Operational savings from improved feed conversion.	 Some opportunity for Canadian IP and R&D. Expands Canada's leadership in dairy genomics and exportable genetics services.	 Genetic selection used widely today for a variety of purposes. Canadian research groups testing large-scale low-cost ways to select for low methanogenic genetics.	 Integrates seamlessly into existing breeding programs.	 Uses established milk recording, mid infrared spectroscopy, and genomic platforms.	 Non intrusive and animal welfare neutral. Generally, well accepted.	 Many stakeholders are involved in data sharing for ongoing research. Herd-level emissions reductions without changing facilities.	 Tracking genetics accurately improves diversity, animal health and longevity.
Improved Feed Digestibility and Quality	Enabling Pathway Reduces enteric methane per unit output. Doesn't eliminate emissions. More effective when combined with other measures.	Deploy Provide regionally specific information on growing and selecting high quality feed. Support development of additives.	 Higher forage quality and specific additives cut methane per unit output but not to zero.	 High quality feed may have cost increases, but these can be balanced by the improvements in performance.	 Builds demand for Canadian feed innovations and forage quality services.	 Practices are commercial today. Efficacy varies by diet. More advanced approaches, including additives are in R&D.	 High compatibility. Some changes to harvest timing and storage but fits with existing systems. Implemented through routine ration adjustments.	 Uses existing feed supply chains, labs, and advisory networks.	 Seen as positive as it aligns with better animal nutrition.	 Recognized by all stakeholders as a path forward. Seen positively due to alignment with efficiency and emissions intensity.	 Improved productivity and feed efficiency. Some approaches also reduce upstream emissions associated with crop production.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Modified Grazing Practices	Enabling Pathway Improves soil carbon and pasture efficiency in suitable regions, but impacts are context-specific and insufficient alone to achieve net zero.	Deploy Provide regionally specific extension services to farmers including case studies. Support local demonstrations.	 Can build soil carbon and reduce emissions if optimized. Outcomes are climate/soil dependent.	 Lower-cost measure requiring better planning, fencing and water distribution.	 Growth in advisory services and R&D.	 Grazing best management practices (rotational, adaptive, rest periods) are widely practiced. Better provision of information required to improve grazing practices.	 Fits with existing practices; may require small modifications such as the addition of more fencing and improved planning.	 Infrastructure and supply chain are in place.	 Acceptance high with improved pasture productivity.	 Producers can benefit from improved animal performance and forage utilization. Research is still ongoing.	 Improved soil carbon stocks, water retention, drought resilience, soil structure, and biodiversity. Pasture productivity is maintained or improved.
Enhanced Soil and Pasture Management	Enabling Pathway Builds soil carbon and reduces input needs, but sequestration limits and variability mean it must complement direct methane reductions.	Deploy Provide regionally specific extension services to farmers including case studies. Support local demonstrations.	 Practices increase soil organic carbon and reduce inputs but are complementary to enteric/manure abatement.	 Measures such as adding trees to pastures or nutrient planning have low to moderate costs and can improve forage yields.	 Growth in advisory services and R&D.	 Pasture reseeded and soil nutrient management are mature. Other techniques are not well documented or standard in Canada.	 Compatible with existing livestock systems. Mainly requires changes to planning.	 Infrastructure and supply chain are in place.	 Acceptance high with improved yields and low costs.	 Valuable to farms with grazing animals. Some practices are commonplace others are less understood and in R&D phases.	 Improved soil carbon stocks, nutrient and water retention, soil stability and biodiversity in pastureland. Reduced nitrogen runoff. Shade and shelter where trees are planted.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Crop Agriculture											
Efficient Fertilizer Application and Use	Decarbonization Pathway Reduces nitrous oxide emissions through improved nitrogen management but cannot fully eliminate soil emissions.	Deploy Continue to provide high-quality extension services on fertilizer application best management practices and their benefits.	 Lowers N ₂ O emissions materially. Not a full abatement to zero. Requires other measures to offset remainder.	 Potential return on investment from reducing fertilizer inputs through optimizing rate, source, timing and placement.	 Growth in advisory and training services.	 Nutrient stewardship is well established in Canada.	 Small modifications to planning and application practices may be required.	 Infrastructure and supply chains are largely in place.	 High acceptance for water quality benefits.	 Policy and government support is high. Lower operational costs are relevant to farmers.	 Demand reduction of primary fertilizers, improvements in water quality from reduced nitrogen loss.
Vertical Farming	<i>Potential Niche Pathway</i> Can significantly reduce land and input pressures for select crops if powered by clean electricity, but scale and crop applicability remain limited.	Incubate Support R&D. Assist with financing in favourable economic conditions.	 Can reduce land and pesticide use. Dependent on electricity carbon intensity.	 Economics remain challenging due to high capital and power costs. Profitable niches exist near urban markets and for premium produce.	 Opportunity for more variety in plants grown in Canada. Development of IP. Generates agricultural jobs in urban, remote, and northern communities.	 Commercial for some crops. Largely still in demonstration and pilot phases as economic outcomes are mixed.	 Requires buildout of new facilities, specialized skills and training, and tightly controlled climates.	 Depends on access to low-cost, reliable, clean power.	 Generally positive for local year-round food supply.	 Viewed as complementary to traditional farming. Relevance in limited markets. Costs and power constraints limit widespread interest.	 Significantly reduces water, pesticide, and fertilizer use. Shortens transport distance to consumers. Can integrate waste heat and renewables.
No or Low Till	Enabling Pathway Supports soil carbon retention and reduces fuel use, but sequestration is variable and insufficient on its own for net zero.	Deploy Provide regionally specific extension services. Support monitoring soil organic carbon to ensure effectivity in local conditions.	 Supports soil organic carbon retention and fuel savings. Effects vary by region/soil.	 Can improve yields under the right conditions. Reduces operational fuel costs. Stronger economics in the Prairies.	 Growth in advisory and training services and supply of specialized agriculture tools.	 Practices are widely adopted in Canada. Long-established in Prairies.	 Fits with existing farming practices.	 Used widely today across Canada with established equipment supply chains.	 High acceptance low public impact.	 Used widely by farmers for lower fuel costs, soil health, and potential yield benefits.	 Can improve or conserve soil water and nutrient retention. In the right conditions higher yield can occur.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Greater Use of Cover Crops	Enabling Pathway Enhances soil resilience and nitrogen retention.	Deploy Provide regionally specific extension services. Support research and monitoring focused on optimizing crop selection in local conditions.		 Relatively low-cost measure. Potential to increase yield in some cases when optimal cover crops are chosen. Optimal combination of amendments can improve yields.	 Advisory and training services.	 Use of cover crops is common. Resources exist provincially and federally advising on species selection.	 Typically fit with growing seasons. Main modifications are to planning.	 Seed supply chains are well established in Canada.	 High acceptance low public impact.	 Relevance is high to producers due to potential yield increases. Many government organizations offer advisory materials, but financial support is low.	 Reduces or prevents soil erosion. Can assist with pest or weed control. Improves overall soil health.
Adding Organic Amendments	Enabling Pathway Improves soil health and nutrient cycling, but net emissions depend on amendment sourcing and management practices.	Deploy Support further buildout of organic fertilizer market with financing mechanisms, regulatory changes, and extension services on best management practices.		 Many organic amendments are low cost as they are sourced from waste (i.e. compost, manure, sludge). Optimal combination of amendments can improve yields.	 Market generated around use of otherwise wasted materials.	 Organic amendments are used widely today. Research occurring to optimize combinations to simultaneously maintain productivity and reduce GHGs.	 Fits within existing cropping systems and equipment. Some concern over metals and other contaminants in sludges.	 Compost, sludge, and manure used widely today. Established supply chains.	 Mostly accepted. Some amendments require management of pathogens and odour.	 Interest from producers in low-cost fertilizer supplements or replacements. Attractive for soil health and waste diversion goals.	 Increased microbial diversity and soil health. Waste management solutions. Improved nutrient cycling and reduced reliance on primary fertilizers. Odour issues.
Biochar Addition	Enabling Pathway Can increase soil organic carbon and may mitigate N ₂ O emissions from soil.	Enable Support R&D and demonstration projects. Develop carbon credit protocols and quality standards.		 Production costs are high. Requires policy support.	 Supports domestic biochar production. Market generated around use of otherwise wasted materials.	 Demonstration and trials occurring in Canada. Further research on long-term impacts on soil health, productivity and carbon retention required.	 Can be applied using equipment, but density makes handling and application more difficult.	 Supply chain is emerging. Production in Canada is being built out.	 Accepted when produced from forestry residues.	 Some interest in terms of carbon credit generation.	 Can increase microbial activity, reduce nutrient leaching and improve water retention. May reduce biomass available for other sectors' decarbonization.

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Greater Inclusion of Pulses in Rotations	Enabling Pathway Reduces reliance on synthetic nitrogen through biological fixation, but broader system emissions persist.	Deploy Provide regionally specific extension services. Monitor soil nitrogen levels to ensure effectivity in local conditions.	 Legumes (pulses) can fix nitrogen from atmosphere, reducing required synthetic nitrogen fertilizer needs. Type of pulse and environmental conditions dictate effectivity.	 Can increase yields, diversify revenues, and decrease risk over time. Reduces operational costs associated with nitrogen fertilizer input.	 Can encourage value added processing and export growth for Canada's pulse sector, strengthening domestic supply chains.	 Mature agronomic practice widely used in Canada. Improvements continue with research selecting for higher nitrogen fixing genetics.	 Fits within existing cropping systems and equipment. Main changes are to planning.	 Seed supply chains well established in Canada.	 High acceptance; low public impact.	 Supported by producers, processors, and governments as a practical lever to reduce fertilizer related emissions and improve resilience.	 Improves soil structure and rotation diversity. Can reduce nitrate leaching and upstream fertilizer manufacturing emissions. Can break pest/disease cycles.
Multicropping (Including Intercropping, and Increased Frequency and Diversity of Rotations)	Enabling Pathway Improves nutrient cycling and reduces input intensity, but emissions reductions vary by crop, region, and management.	Deploy Provide regionally specific extension services to farmers, including case studies. Support local R&D and pilots on optimizing rotations to reduce GHGs.	 Reduces emissions by increasing soil organic carbon, reducing nitrogen fertilizer application, and withdrawing CO ₂ from the atmosphere. Impacts are rotation specific.	 Economics depend largely on selecting crops and rotations optimized for the soils and climate. Improves long-term profitability and diversifies revenues.	 Growth in seed sales and advisory and training services. Can support local processing facilities.	 Multicropping is mature, but optimizing crop rotations to reduce GHGs is still in R&D.	 Modifications to planning are required. May require investment in equipment or training. Adds complexity to operations	 Generally compatible with existing systems. May require regional market development for new crops .	 High acceptance; low public impact.	 Involvement from government and academia with ongoing R&D. Used by farmers but uncertainty around which systems are best.	 Diversifies revenue streams. Improves resilience to pests and environmental impacts (i.e. drought or late frosts). Improves nutrient cycling and soil structure.
Precision Agriculture	Enabling Pathway Improves input efficiency and reduces waste, but emissions reductions depend on adoption levels and integration with broader crop reforms.	Deploy Provide extension services on precision agriculture and financing mechanisms for small or remote farms to enable equitable access to tools.	 Reduces input related emissions through better timing, rate, and placement.	 Capital costs may require larger-scale operations. Can reduce operating costs including chemical and fuel inputs improving profitability.	 Growth in advisory and training services and supply of digital or precision agriculture tools.	 Used on some farms in Canada, especially in the Prairies. Some technologies in R&D.	 Some training on new digital or precision agriculture tools.	 Access to newer digital or precision agriculture tools may be difficult in remote areas and for small operations.	 High acceptance with reduced water pollution.	 Relevant to producers as operational costs and yields can be improved.	 Lower inputs (chemicals and fuels). Improved soil health and crop resilience. Reduced nutrient and pesticide runoff. Better data for decision making.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 All Agriculture											
Improved Regional-Specific Data Collection and Monitoring	<i>Priority</i> Enabling Pathway Foundational for accurate measurement, verification, and targeted mitigation. Essential for scaling credible, region-specific net-zero strategies.	Deploy Support mass deployment with financing mechanisms and extension services. Continue support of R&D to optimize systems.	 Enables accurate measurement of emissions and carbon retention, improves policy design, carbon credit integrity, and mitigation strategies.	 Upfront costs can be high for software, sensors, and data systems. Improved measurements reduce uncertainty, optimize inputs, and can improve yields.	 Growth in ag-tech firms in Canada and analytics and advisory services.	 Many technologies are emerging with increasing adoption. Optimization of these systems is occurring with further research and development.	 Integrate with existing operations.	 Implementation depends on broadband access, cloud computing infrastructure, and standardized data frameworks.	 Broadly accepted, with concerns around data privacy and ownership.	 Relevant to all stakeholders. Many ongoing projects collecting and aggregating data relevant to GHG reductions.	 Can improve yields, soil health, waste management, biodiversity, and climate resilience.
Organic Farming	<i>Enabling Pathway</i> Reduces synthetic input reliance and can lower emissions intensity in some systems but yield trade-offs and livestock emissions may limit net-zero potential.	Enable Support demonstration and extension services focused on minimizing yield losses. Improve supply chain regulations for organic certifications.	 Can reduce reliance on synthetic fertilizers, fuel, and pesticides lowering emissions. Can improve soil carbon retention, but may lower yields. GHG outcomes depend on circumstances.	 Viability depends on price premiums and certification costs. Some producers benefit from lower input costs, but yield penalties can reduce margins. Production does not yet satisfy consumer demand in Canada.	 Moderate opportunities in certification, advisory services, and value added markets/export niches.	 Mature and widely practiced, with established standards and supply chains, though adoption remains limited in Canada.	 Requires land management changes including a transition period. May require new equipment or more labour.	 Supply chain traceability and certifications add complexity.	 High acceptance aligning with environmental and animal welfare concerns.	 Government and producers for food security. Food retailers and brands to meet demand for organic food.	 Reduces pesticide and chemical fertilizer use and can improve biodiversity and soil health. May reduce nutrient losses, though land use trade offs can arise if yields are lower.

			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 On-Farm Energy use											
Battery Electric Vehicles and Equipment	<i>Potential Decarbonization Pathway</i> Electrifies on-farm energy use	Enable Support electrical grid expansion and upgrade in rural areas. Provide financing mechanisms to assist with piloting and demonstrating new technologies on farms.	 Net zero with clean electricity.	 Lower energy and maintenance costs than incumbent. High upfront costs and uncertain resale value. Expected to improve over time.	 Creates opportunities for Canadian clean tech manufacturing and service jobs and rural electrification services.	 Entering the market for small/medium equipment and specialty tractors. Heavy duty applications are still in demonstration.	 Good fit for light to medium duty tasks with predictable schedules. Requires charging access and may face downtime constraints during peak seasons. Currently prohibitive for heavy-duty vehicles.	 Grids may require expansion or capacity upgrades in many rural areas.	 Accepted as noise and air pollution are reduced.	 Lack of access to high-capacity power limits interest from producers. Some equipment models emerging in Canada.	 Reduces air and noise pollution. Enables greater ability to automate.
Heat Pumps	<i>Potential Decarbonization Pathway</i> Can significantly reduce emissions from fossil fuel heating applications.	Enable Support electrical grid expansion and upgrade in rural areas. Provide financing mechanisms to assist with piloting and demonstrating new technologies on farms and food and beverage manufacturing facilities.	 Can eliminate emissions from space and water heating in farm buildings, grain drying, greenhouses, and some food manufacturing. Emission reductions depend on availability of net-zero electricity.	 Often cost effective where electricity is low carbon and competitively priced. Economics improve with efficiency upgrades and incentives, though retrofit costs can be a barrier.	 Moderate opportunities for Canadian HVAC manufacturing/ins tallation and rural electrification services.	 Technologies are commercial globally. Agricultural applications are emerging with pilots and applied research underway. Limited models for very cold weather or high- temperature operations.	 Potential fit in many applications but may require some modifications or retrofits to existing heating systems.	 Requires grid access, high capacity, and clean grids. Grids may require expansion or capacity upgrades in many rural areas.	 No particular concerns.	 Some interest from Canadian research groups. Proven efficiency increases for greenhouse operations. Government support is limited.	 Eliminates air emissions and reduces fuel price exposure.
Hydrogen Powered Heavy Machinery	<i>Potential Niche Pathway</i> Offers a potential zero-emission option for heavy equipment.	Incubate Fund R&D of heavy-duty hydrogen farming equipment.	 Hydrogen could decarbonize heavy equipment where electrification is impractical. Net emissions reductions depend on low-carbon hydrogen supply.	 Currently high cost due to hydrogen production, storage, and limited refuelling infrastructure. Not competitive yet in most use cases.	 Longer term opportunity for Canadian hydrogen and heavy equipment innovation—partic ularly in regions investing in clean hydrogen hubs.	 Largely in research and pilot phases.	 Could offer fast refuelling and long runtimes, but handling/storage and safety protocols add operational complexity for farms. Would need new equipment.	 Requires refuelling infrastructure. Hydrogen transport/storage logistics and standards are still developing.	 Some safety perceptions and unfamiliarity may slow uptake.	 Interest from governments is growing, but farmers are unlikely to adopt hydrogen until costs and fuelling access improve.	 Reduces noise/air pollution. Potential to pair with renewable H ₂ production.

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Renewable Diesel (RD)	Bridge Pathway Provides near-term emissions reductions using existing equipment, but may require removals for net zero.	Enable Develop policies that assist with increased fuel costs and limited rural access to RD. Support until maturity increases for electric or hydrogen equipment.	 Lowers lifecycle GHGs compared to fossil diesel but not a net-zero end-state. Emission reductions depend largely on feedstock sustainability and carbon intensity.	 Not currently cost competitive in rural areas without policy supports.	 Opportunities in Canadian biofuel production but limited by feedstock supply.	 RD is mature. Procurement can be difficult especially in rural areas.	 RD is drop-in.	 Large volumes required to make economic case for fuel distribution.	 Concerns of competition with food crops.	 Appeals to farmers as it reduces emissions in the near term without changing equipment.	 Reduces waste and associated management as fuels are typically produced from waste. Land-use change concerns. Air pollution persists.
On-Farm Renewable Power Generation (Wind and Solar)	Enabling Pathway Can use land simultaneously for power generation and farming. Can also supplement grid-supplied electricity for farming operations.	Deploy Develop supportive policies where appropriate. Provide resources that assist implementation.	 On-farm wind and solar can displace fossil energy use on farms and/or farmland can generate renewable electricity without compromising farming operations.	 Economics have improved. Upfront capital and interconnection can be barriers.	 Supports local economic development through installation/maintenance jobs and domestic clean energy supply chains. Potential revenue diversification for farms.	 Technology is mature and applications are commercial on many farms in Canada.	 Generally practical where land/roof space and grid interconnection exist. Can support remote/off grid operations but add complexity.	 Interconnection regulations and distribution capacity can constrain projects.	 Some rural opposition to large utility scale developments.	 Strong interest from farms, rural communities, and utilities. Adoption is rising as reflected in Canadian farm surveys.	 Can reduce fuel use and air pollution. Can improve energy resilience, and enables pairing with electric vehicles/heat pumps.
On-Site Biogas Production (Biomethane /Renewable Natural Gas Production)	Enabling Pathway Can create closed-loop energy systems using agricultural residues, but scalability and lifecycle performance vary.	Enable Provide resources and develop policy to lower barriers to interconnection and fuel offtake. Support R&D and demonstration.	 On-site biofuel can cut emissions and displace fossil fuels for heat and power. Emissions reductions depend on feedstock sustainability and processing methods.	 Mostly economic where scale is large. Capital costs high, especially for digesters; operational complexity can increase costs. Interconnection and offtake can be cost prohibitive.	 Creates rural jobs and generates economic product from wastes.	 Biogas production is mature. Deployment can be difficult and limited to regions with policy support and larger-scale farms.	 Training for operators and feedstock logistics and planning are required. Requires consistent feedstock, which can be difficult to obtain from a single farm's operations.	 Interconnections can be cost prohibitive or unavailable in remote locations. Permitting and standards can be complex.	 Generally accepted as process produces energy from waste. Odour and truck traffic can introduce public concerns.	 Mainly relevant to large livestock farms for energy cost reductions and diversified revenue. Governments interested in biogenic methane reductions.	 Provides methane mitigation, renewable energy, and digestate. Recycles nutrients and may reduce reliance on synthetic fertilizer.

The background features a large, semi-transparent green rectangle on the left side. Overlaid on this and the rest of the page are faint, light-gray geometric patterns, including a network of interconnected lines and dots, and a large, pixelated shape that resembles a hand or a cloud. The text 'Part III' is written in white, bold, sans-serif font inside the green rectangle.

Part III

Putting It Into Practice



The point is not that every sector matters equally or that everything is connected. Rather, the pace at which any one sector can move is bounded by the pace of buildout elsewhere.

12. Implementation and Sectoral Interaction

The previous chapters analyzed Canada's pathways to net zero one sector at a time. That structure makes the transition tractable. However, it can obscure a defining feature of what is actually happening on the ground. Canada's electricity grid, transportation network, building stock, and industrial base are not running on parallel tracks. They are part of a shared landscape, with the choices made by each sector are increasingly determining the actions available to the others.

This chapter is about what that fact means for Canada when the sectoral analyses are read together. The argument runs in three steps:

First, **the sectoral pathways do not stand alone**. They are mutually reinforcing, and each one's progress depends on infrastructure, supply chains, and decisions originating in other sectors.

Second, **the global race to capture the value of this rewiring is well underway**, with Canada's main trading partners deploying industrial policies of unprecedented ambition to lock in their share.

Third, **Canada has the foundations to compete, but converting those foundations into a defensible economic position requires a more strategic approach** to decarbonization across sectors that has so far been absent. The decade ahead will decide whether Canada ties these advantages together or watches the connections form elsewhere.

More Than the Sum of Their Parts

The sectoral chapters in this report can be read individually, and most readers will focus on the sectors most relevant to them. But each describes the same underlying transition from a different vantage point. Decarbonizing electricity, electrifying personal vehicles, deploying heat pumps in buildings, electrifying mining and aluminum smelting, replacing blast

furnaces with electric arc steelmaking, producing low-carbon hydrogen, manufacturing batteries—these are not independent projects. They are facets of one connected buildout, and the engineering and economics of each is shaped by what is happening in the others.

Electricity is the most obvious example. Almost every other sector in this report has a pathway that runs through the grid. The sectoral chapters discuss what cleaner electricity will mean for transport, buildings, and heavy industry; the electricity chapter discusses what those new loads will mean for generation, transmission, and storage. These two perspectives describe a single problem. Canada cannot electrify millions of light-duty vehicles, deploy heat pumps at scale, switch aluminum smelters and steel mills to electric processes, and produce low-carbon hydrogen without expanding generation, building out interties, modernizing distribution networks, and managing peak demand far more actively than the current system was designed to handle. Conversely, the case for that grid investment depends on the demand materializing.

The connections do not run only through the grid. Critical minerals link mining, manufacturing, and end-use sectors in ways that scramble traditional sector boundaries. Canada's lithium, nickel, cobalt, copper, and graphite endowments are the upstream of the EV value chain that downstream auto plants in Ontario and battery cell facilities in Quebec will depend on. Those mines, in turn, are themselves candidates for electrification, with electric haul trucks and on-site renewable power offering both emissions reductions and lower long-run operating costs. North America's first commercial-scale electrochemical lithium refinery, commissioned in British Columbia in 2026 with federal backing, was assembled out of three things: Canadian mineral resources,

hydroelectric process power, and a supportive industrial policy[582]— a project that no individual sector chapter would have captured on its own.

Similar interdependencies pattern the rest of the system. Steel and cement are required to build the wind turbines, transmission towers, and concrete foundations that carry decarbonization forward. In the medium term, the low-carbon steel and cement that those installations require can be made viable only if buyers are willing to procure them at premium prices for long enough that the cost curves can bend. Hydrogen is being scaled to abate emissions in industrial heat, heavy-duty trucking, ammonia production, and certain marine applications, but the cost of producing low-carbon hydrogen is itself a function of the price of the electricity feeding the electrolyzer.

Even the construction sector, ostensibly an end-use category, sits at the centre of the system. A recent industry-led analysis of more than 600 Canadian construction projects found that 65% of jobsite emissions come from diesel, with grid connection and equipment electrification the dominant decarbonization levers, meaning that if lowering emissions is a priority, the speed at which Canada builds the projects it has committed to depends partly on how quickly the grid expands to reach those sites.[583]

The point is not that every sector matters equally or that everything is connected. Rather, the pace at which any one sector can move is bounded by the pace of buildout elsewhere. Treated as parallel sector portfolios, these connections are easy to lose. Seen together, decision-makers can more easily assess where to allocate finite capital and time for sectors that can leverage large-scale decarbonization across the system. The evidence suggests that decision-makers in peer countries have started to act in this way.

The World is Wiring Up

This is not a peculiarly Canadian observation. It is the dominant theme of the analytical work that has reshaped global energy policy in the past three years. The rapid scale-up of solar, wind, batteries, and electrified end uses is increasingly seen as a coherent technological wave whose economics are beginning to resemble those of the IT revolution.[74] The IEA's 2025 World Energy Outlook frames electricity as the heart of the modern economy: although it accounts for only 21% of total final energy consumption today, it is already the main source of energy for sectors representing more than 40% of global GDP, and is set to take a much larger share over the coming decade.[584] Many other organizations now treat electrification not as an environmental policy question but as the central determinant of which countries will host the most productive industries of the next 20 years.

China has acted on this view at a scale and speed that no other economy has so far matched. It accounts for more than half of global solar capacity additions, two-thirds of global growth in electricity demand since 2019, and 60% of global electric vehicle sales in 2025.[585] The combination of abundant clean generation paired with aggressive electrification of mobility and industry has converted a domestic buildout into a foreign-policy instrument: Chinese cleantech exports are now reshaping the energy systems of emerging markets and pulling allied investment toward Chinese manufacturers. This is no longer only an environmental story. It is the most consequential reorganization of global supply chains since the postwar period.[586]

Canada's peer countries have responded with the most ambitious set of industrial policies in a generation. The European Union tabled the Green Deal Industrial Plan and its centrepiece Net-Zero Industry Act,

which entered into force in 2024 and sets a binding target of producing 40% of the EU's annual deployment needs for strategic net-zero technologies domestically by 2030. [587] Japan's Green Transformation (GX) program has pledged approximately ¥150 trillion in mobilized public and private investment over 10 years.[588] Korea, India, and Australia have launched smaller but similarly directed packages. The common feature is the abandonment of any pretense that the energy transition will be coordinated through carbon pricing alone. In every major economy, governments are now explicitly choosing which segments of the future industrial system they intend to host.

For Canada, this is not principally a climate policy question. It is a question of where the country's economic base will be located in the coming decades. Analysis from the Transition Accelerator estimates that with a focused industrial strategy, Canada could capture an annual export opportunity of approximately \$600 billion in clean energy supply chains by 2035, building on the fact that Canadian clean energy supply chain exports already grew 21% faster than total exports over the past five years.[1] That growth is happening unevenly, and disproportionately with partners outside the United States. The countries that are wiring up are reshaping global value chains in real time, and where Canada chooses not to compete, the connections are made without us.

The Path Forward for Canada

The two arguments developed in this chapter bear directly on how Canada should sequence its response. The first is that the sectors analyzed in this report do not move at the same pace, and that some carry disproportionate leverage in the system. The second argument is that some of Canada's peer countries have already internalized this logic. Many are racing to build dominance over clean energy and low-carbon technology to ensure their industries are positioned to

reap the benefits of this early investment in the supply chains that will define the global economy in coming years.

The figure that follows attempts to map that logic onto a timeline. It consolidates the sectoral analyses of the previous chapter into a single map of when critical interventions are required across each pathway. It is meant as a planning tool, not a forecast.

Three features merit emphasis. First, the work in the immediate priority sectors (electricity, personal mobility, and buildings) must begin now and continue throughout the period; these are not “first-decade” sectors but “every-decade” sectors. Second, the medium-term opportunities (medium- and heavy-duty

vehicles, aluminum, hydrogen, steel, cement, mining, alternative fuels) depend on commitments made well before their commercial inflection points. Pilot projects, infrastructure investments, and procurement signals deployed in 2026 to 2030 help determine which of these sectors Canada is positioned to compete in by the late 2030s. Third, the long-term plays (agri-food and oil and gas) are not sectors which can be entirely neglected today. Both have meaningful actions available now, particularly methane abatement in oil and gas, and attention to nitrogen fertilizer use and soil health in agriculture, but neither anchors the whole system transformation the way electricity, mobility, or industrial decarbonization do.



Canada's Strategic Decarbonization Path

Legend

- Critical for progress on strategic decarbonization
- Important for progress on strategic decarbonization
- Supportive of progress towards strategic decarbonization

		2026	2030	2040	2050
Immediate Priorities	Electricity Low-carbon generation, grid, and storage 	Accelerate grid buildout and increase low-carbon supply Low-carbon supply scaling rapidly; storage being deployed; interprovincial interties advancing.		Continue building out the grid and increasing generation from low-carbon sources Long-duration storage emerges; distribution upgrades underway; interties operational; electricity generation decarbonizing. Generation is near fully decarbonized; electricity is being deployed to its full potential in industrial sectors.	
	Personal Mobility Electric vehicles and mass transit 	Charging infrastructure increasing; mass transit electrifying and expanding; PHEVs playing a bridge role for LDVs.		Majority of EV sales are electric; electrification of commuter bus and train fleets accelerating; private business case strengthens for charging infrastructure.	Nearly all new cars sold are EVs, Canadians have access to reliable electrified public transit.
	Buildings Heat pumps, retrofits, energy efficiency 	Deploy massively heat pumps, retrofit existing building stock, and ensure new builds are net zero over time. Retrofits in oil/propane buildings, heat pumps scale for residential and emerge for C&I as well as new builds.			
Medium-Term Opportunities	MHDVs Battery-electric and hydrogen trucks 	Battery-electric MDV depot rollout HDV demonstrations underway; renewable diesel deployed as drop-in bridge for existing fleets; depot charging being built out.		MDV scale-up, HDV commercial deployment Corridor charging infrastructure operational; deployment of H ₂ -FCEV trucks in long-haul niches.	Full fleet transition Long-haul transition completed; renewable diesel residual only in edge cases.
	Aluminum Inert Anodes and electrification 	Inert anode demonstration and MVR pilots Electric calcination pilots; recycling capacity expansion.		Commercial Scaling of inert anode deployment MVR rollout in alumina refining, electric calcination demonstration.	Sector-wide deployment Electric calcination deployment, electrified casting and rolling; closed-loop recycling.
	Alternative Fuels SAF and renewable diesel 	Scale renewable diesel and SAF projects from pilots to commercial-scale Aviation and marine offtake agreements signed; LCA protocols standardized; biofuel feedstock supply chains expanding. Regulatory frameworks in place; bio-synthetic fuels and e-fuels in demonstration; aviation transition gathering pace.			
	Hydrogen Electrolysis and ATR with CCS 	Strategic use demand build-up Demonstration projects to build demand in strategic applications, byproduct hydrogen captured, and low-carbon generation matures.		Scaling-up and integration into sectors Scaling of low-carbon hydrogen generation, and industrial heat applications including steel and chemicals.	Integration of SAF in aviation & RD in niche end-uses Marine fuel transition well underway; SAF well integrated in aviation; domestic production scaling to displace imports.
	Steel & Iron EAFs and hydrogen DRI 	Electric arc furnace deployment and scaling up of hydrogen-DRI to commercial scale Procurement signals from public buyers; first commitments to phase out blast furnaces.			
	Cement SCMs and CCUS 	SCMs scale-up; material efficiency in design Material efficiency standard in design; mass timber substituting for cement where viable; low-clinker formulations becoming default.		CCUS at major plants Procurement-driven low-carbon cement in infrastructure; hydrogen, electrified or low-carbon hybrid kilns emerging.	Sector-wide deployment Long-haul transition completed; renewable diesel residual only in edge cases.
	Mining Electric equipment and microgrids 	Electric haul fleet pilots On-site renewables and storage at remote sites; process electrification underway; recycling frameworks being developed.		Commercial Scaling of inert anode deployment MVR rollout in alumina refining, electric calcination demonstration.	Sector-wide deployment Electric calcination deployment, electrified casting and rolling; closed-loop recycling.
	Long-Term Plays	Chemicals & Plastics Electrified heat & low-carbon feedstocks 	Scale CCS, low-carbon heat, and circular feedstocks from pilots to commercial scale Electric and hydrogen heat demonstrations; CCS investment decisions for concentrated streams.		
Agriculture & Agri-Food Manure, fertilizer and on-farm energy 		Manure methane reduction; precision fertilizer use Improved regional data collection and connected practices; manure methane management and precision agriculture scaling.		MDV scale-up, HDV commercial deployment Corridor charging infrastructure operational; deployment of H ₂ -FCEV trucks in long-haul niches.	Full fleet transition Long-haul transition completed; renewable diesel residual only in edge cases.
Oil & Gas Methane abatement and electrification 		Methane abatement, electrification where feasible Beginning of upstream electrification; methane abatement being scaled across industry; CCS emerging at major facilities.		Upstream electrification & CCS scaling CCS operational at major facilities; methane controls fully deployed.	Full deployment in critical end-uses Domestic hard-to-abate sectors are running on clean hydrogen.

What This Means for Policy and Investment

With these details in mind, what is next for decision-makers? How should these signals be interpreted to make better decisions about Canada's path towards strategic decarbonization? Three considerations stand out.

The first is that policy and investment decisions should be evaluated for their cross-sectoral effects, not only their sectoral ones. Building out interties between Quebec, Ontario, and the Maritimes does not only secure electricity reliability; it makes a credible heat pump strategy possible in regions still on heating oil, lowers the per-unit cost of charging infrastructure for fleets and personal vehicles, and creates a path for low-carbon hydrogen production at scale.

Procurement requirements for low-carbon cement and steel in federal infrastructure projects do not only incentivize cutting emissions from those sectors; they create the demand signal that makes domestic decarbonization investment in those sectors financeable.

Investment in critical mineral processing in Ontario and Quebec does not only secure the upstream of the battery supply chain; it underwrites the case for the auto manufacturing base downstream. The accounting framework under which “electricity policy”, “industrial policy”, “trade policy”, and “climate policy” are separately authored and evaluated is the first thing the rewiring obsolesces.

The second implication is that timing matters more than it has in the past. Industrial supply chains form once, and where they form is heavily path dependent. The window for Canada to capture lead positions in battery materials, low-carbon aluminum, electric mining equipment, and EV manufacturing is open now and closing over the next few years. At the same time, it wouldn't be reasonable to expect Canada to be competitive in every single value chain linked to the low-carbon economy. Thus, an approach that emphasizes where Canada has a unique advantage or potential is critical. Once a value chain consolidates, the inputs, talent, and capital can be anchored here. Countries that move first in their areas of comparative advantage and sustain that commitment for 10 to 15 years tend to capture defensible positions; countries that move incrementally, then revisit decisions every electoral cycle, tend not to.[589]

The third implication is that the integration of sectoral pathways requires institutional capacity that must be deliberately built. Cross-sectoral coordination between the federal government, the provinces, Indigenous nations, regulated utilities, financial institutions, and major industrial actors is not a default state. It is a competence that countries develop through patient institution-building.



The countries that are most successfully moving down this path are not waiting for certainty before committing. They are committing in order to build certainty. Canada's choice is whether to do the same.

13. Conclusion: The Choice Ahead

The energy transition is moving from a question of whether the world will electrify to a question of who will manufacture, install, finance, and export the system that does. Canada starts this period with most of the assets the answer requires. Whether those assets compound into a position of durable competitiveness, or atrophy into a portfolio of disconnected projects, depends on whether Canada's federal and provincial governments, regulated utilities, industrial actors, financial institutions, and Indigenous partners can connect them together at the speed the global buildout requires.

What is clear from the analysis in this report is that uncertainty is not the principal obstacle. If policy and investment are oriented toward building the energy system of the future instead of chasing the cheapest emissions reductions available, choices are clear enough to propel short-term action with a long-term view. Moreover, while decarbonization, economic competitiveness, and affordability are sometimes presented as competing objectives, this report showcases how they can be mutually reinforcing. Solutions that achieve emissions reductions while strengthening Canada's industrial base or potentially delivering cost reductions to households and industries exist and must be deployed.

In acting on these opportunities, Canada must take three critical dimensions into account:

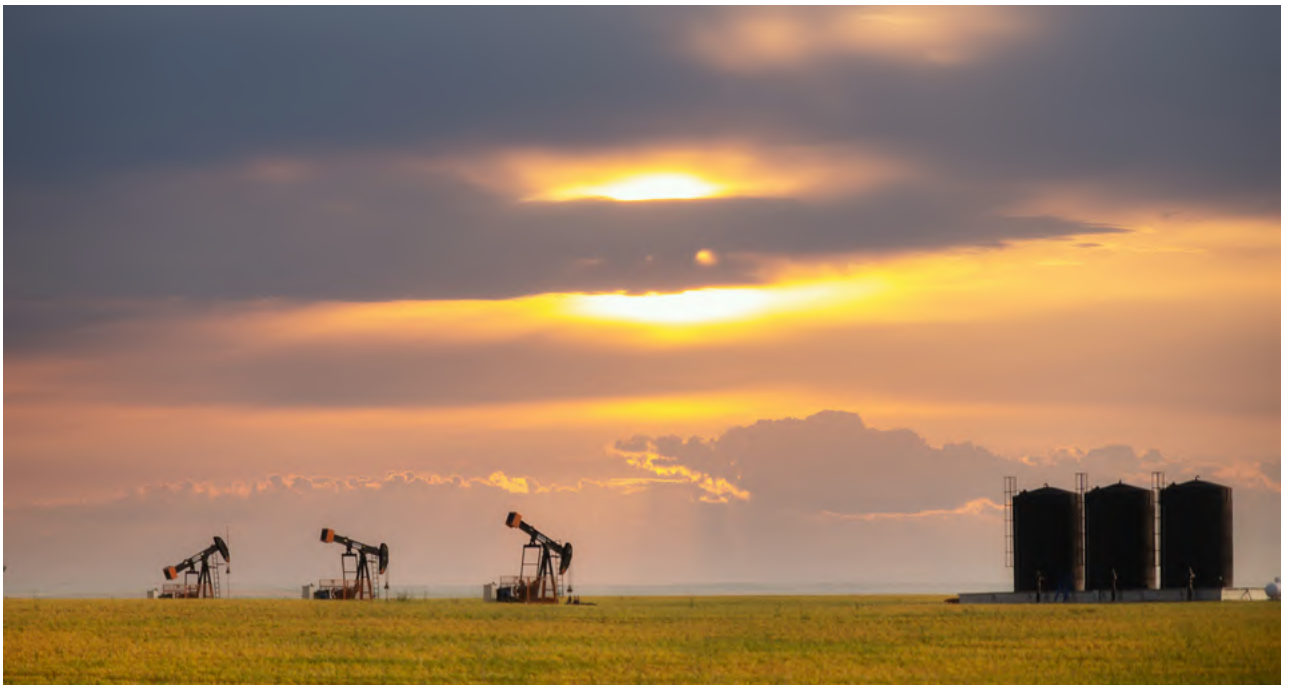
First, as the previous chapter described, there are complex interactions between systems and sectors that will influence the path to decarbonization. Most importantly, the electricity system will be expected to grow significantly to enable the decarbonization of sectors that rely on it. Decision makers should consider how to ensure the sectors that underpin the transition to a low-carbon economy are prioritized.

Second, the international context will have significant implications for the way the transition unfolds. Canada's energy transition is not developing in a domestic vacuum. It is being shaped by, and is reshaping, global supply chains, trade flows, and the geopolitics of raw materials and finished goods. Important trading partners including the European Union, Japan and South Korea are deploying industrial policies that combine production subsidies, procurement preferences, and embedded-carbon trade rules. Meanwhile international conflicts, increased geopolitical tensions, and rapid shifts in US policy have disrupted established energy markets, strategic alliances and trade patterns, lending increased attention to supply-chain provenance.

Demand for Canadian fossil fuel exports will be shaped by how quickly importing economies decarbonize their own systems. Demand for Canadian critical minerals, low-carbon aluminum, low-carbon steel, sustainable aviation fuel, and clean hydrogen will be shaped by how rapidly Canada establishes itself as a credible

supplier at the moment those markets consolidate. The window in which a country can establish a defensible position in a new value chain tends to be brief, and once that window closes, the capital, talent, and political momentum that would have anchored a domestic cluster flow elsewhere.

Third, the domestic context is no less important. Canada is a federation in which the provinces hold most of the relevant levers (electricity policy, resource development, building codes, and much of industrial regulation) and in which provincial economies, resource endowments, and political contexts differ substantially. Quebec's pathway will not look like Alberta's. Newfoundland and Labrador's offshore opportunities will be different from British Columbia's mining and hydrogen positioning. The Prairies will play a different role in agri-food than Ontario will in advanced manufacturing. This transition simply cannot succeed without continuous involvement of Indigenous communities across the country. These are not optional features of the implementation challenge. They are the implementation challenge.



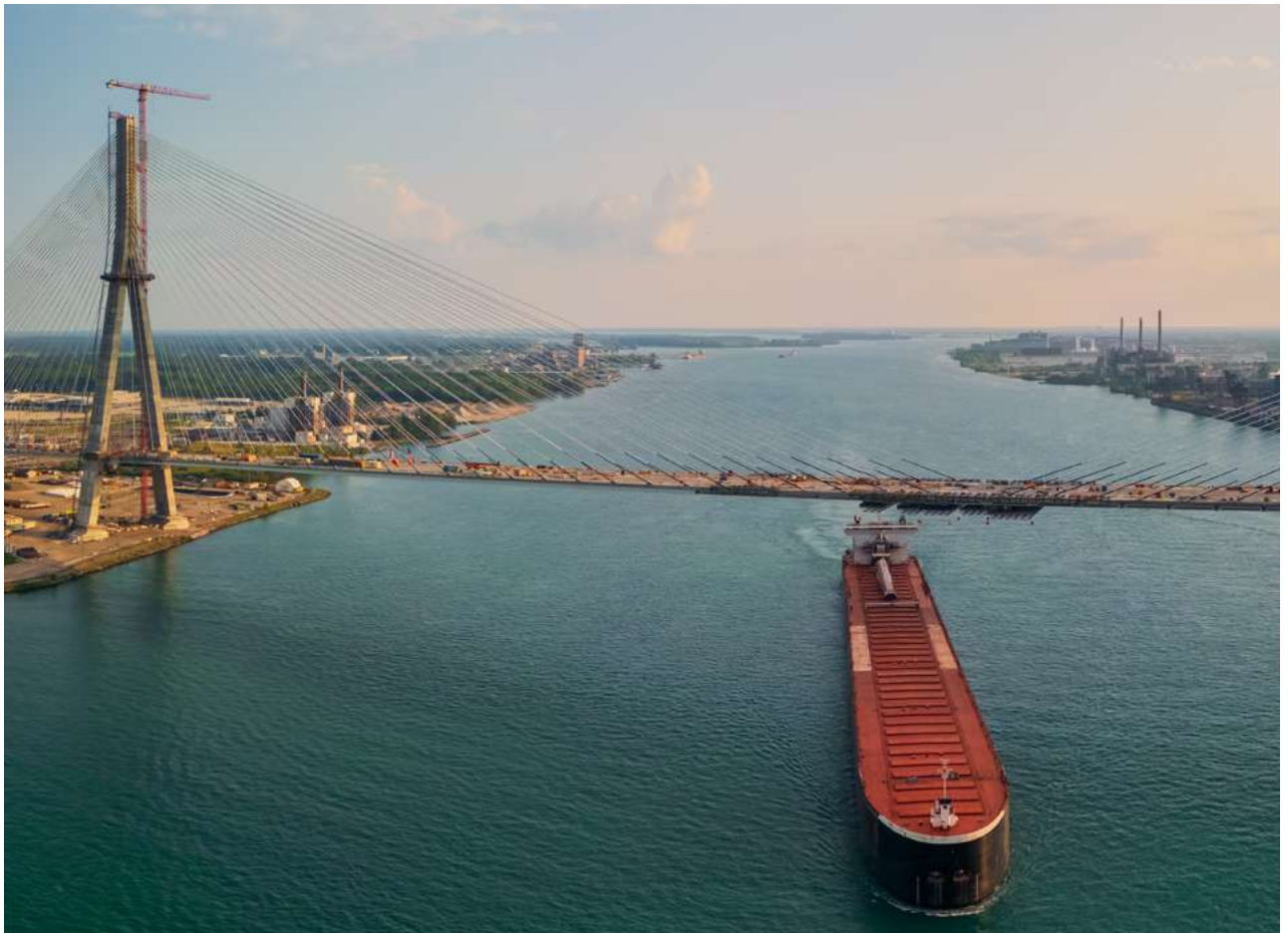
This is the test that the next decade poses. The sectoral chapters of this report have argued that the technologies and pathways are sufficiently understood to plan around.

The previous chapter has argued that the pathways are sufficiently interconnected that planning around them sector by sector will not be enough. What Canada needs now is not better sectoral analysis. It is the integrating layer above the sectors: a national strategy that treats the grid, the supply chains, the workforce, and the trade relationships as a single industrial system to be built, and that has the institutional capacity to keep building it for the 15 to 20 years it will take.

Canada's commitment to reach net zero by 2050 is, at its foundation, a mission to transform how this country produces and uses energy, and to build an economy that is no longer structurally dependent on burning fossil fuels. This commitment is itself rooted in the

global response to climate change, which remains the defining collective challenge of this century. What has shifted in the past decade is the prospect of meeting it by transforming the system, and of positioning the country at the leading edge of the industries that will define the coming years. The efficient, electrified economies of the future, organized around clean generation and the supply chains that connect to it, will be cleaner, but they will also be more productive, more resilient to global energy shocks, and better aligned with the trade and investment flows already in motion. For Canada, the climate imperative and the economic opportunity have converged.

The countries that are most successfully moving down this path are not waiting for certainty before committing. They are committing in order to build certainty. Canada's choice is whether to do the same.



Appendix A

Pathway Assessment Detailed Methodology

Detailed Assessment Criteria

All pathway elements were assessed on nine criteria, each scored on a scale of 1-5:

1. Alignment with Carbon Neutrality

This criterion evaluates the degree to which a pathway reduces greenhouse gas emissions and is compatible with the net-zero transition. A score of 5 indicates the pathway enables complete decarbonization of targeted emissions, while a score of 1 reflects negligible reduction potential or risk of long-term emissions lock-in.

2. Economic Viability

This criterion assesses the cost-competitiveness of a pathway relative to alternatives, including capital and operating costs, subsidy dependence, scalability outlook, and general applicability. A score of 5 indicates costs are competitive with or better than incumbents, with strong investment appeal, no subsidy requirement, and viability across most regions and market conditions, while a score of 1 reflects uncompetitive costs, dependence on unrealistic policy support, and extremely limited applicability where better alternatives exist.

3. Economic Development Opportunity

This criterion evaluates a pathway's potential to generate domestic economic growth across three dimensions: market opportunity (job creation, GDP, and export growth), innovation (Canadian R&D leadership, intellectual property, and clean technology commercialization), and competitiveness (integration with domestic

supply chains and Canada's positioning in high-value manufacturing or other economic activities). A score of 5 reflects strong performance across all three dimensions, while a score of 1 indicates a limited market with no meaningful domestic innovation or competitive advantage.

4. Maturity

This criterion examines the current stage of technological and commercial development across three dimensions: deployment status (technology readiness level), availability (access to the technology within Canada), and track record (operational experience and performance outcomes). A score of 5 reflects a fully commercialized technology with wide Canadian availability and extensive positive operational experience, while a score of 1 indicates an early-stage concept with no field trials or practical applications to date.

5. Operational Fit

This criterion evaluates the practical compatibility of a pathway with existing assets, workflows, regulatory systems, workforce skillsets, Canadian conditions including climate and geography, and on-site deployment practicality such as space, permitting, labour, and installation timelines. A score of 5 indicates seamless integration with existing infrastructure and practices with straightforward deployment across all Canadian regions, while a score of 1 reflects fundamental incompatibility with current assets and operational systems, making on-site deployment impractical within foreseeable timeframes.

6. Infrastructure and Supply Chain Suitability

This criterion evaluates the compatibility of a pathway with existing infrastructure and the readiness of domestic and global supply chains to support its deployment. A score of 5 indicates direct compatibility with existing infrastructure across most jurisdictions with no upgrades required and mature, reliable supply chains readily available, while a score of 1 reflects fundamental misalignment with current infrastructure and the absence of supply chains, with severe constraints in material availability or logistics.

7. Social Acceptability

This criterion evaluates the likelihood of public and community opposition or support across three dimensions: public perception (broader societal sentiment), community support (including Indigenous Peoples and affected communities), and equity alignment (impacts on affordability, access, and inclusion). A score of 5 reflects strong support across demographics with active community co-development opportunities and reductions in inequality, while a score of 1 indicates strong organized opposition, reputational stigma, and perceived injustice with a high likelihood of legal or political blockage.

8. Relevance to Stakeholders

This criterion assesses how well a pathway aligns with the mandates and priorities of key actors today — including industry, utilities, governments, and Indigenous organizations — and the extent of their active engagement. A score of 5 reflects strong alignment across multiple stakeholder groups with high levels of investment, advocacy, and direct ownership of delivery, while a score of 1 indicates misalignment with key stakeholder priorities and no meaningful engagement, investment, or inclusion in strategic planning.

9. Related Benefits and Costs

This criterion accounts for broader economic, social, and environmental impacts beyond direct emissions reductions, including co-benefits, externalities, and system-level effects. A score of 5 reflects multiple significant co-benefits across economic, environmental, and social domains with minimal negative externalities, while a score of 1 indicates minimal co-benefits and/or high indirect costs or risks of undermining other policy objectives.

Summary Criteria

Two criteria were used to summarize the implications of the nine criteria: Role in Net-Zero System and Signal to Decision Makers:

1. Role in Net-Zero System

This column identifies each pathway element’s fundamental compatibility with net zero based on its assessed contribution to system-wide decarbonization:

Table A 1. Role in net-zero system labels

Label	Definition
Decarbonization Pathway	A solution that can achieve net zero, is scalable, and can be deployed within a timeframe consistent with the decarbonization of its intended system. It should be prioritized for investment and policy support as a primary driver of decarbonization. <i>Passes all three diagnostic tests: depth, breadth, and timeliness.</i>
Niche pathway	A solution that can achieve net zero within a specific regional, sectoral, or application context, but fails on breadth when scoped to the full system. It can represent a viable net-zero solution within a specific system and warrants investment proportional to that more limited role. <i>Typically passes on depth and timeliness but fails on breadth at full system scale.</i>
Bridge Pathway	A solution that does not achieve net zero itself but delivers meaningful emissions reductions during the period in which net-zero-compatible alternatives are still maturing or scaling. It represents the best available option under current market conditions and is intended to be temporary, with its role diminishing as superior alternatives become commercially viable. Investments in a bridge pathway must not create lock-in that inhibits the eventual adoption of net-zero solutions. <i>Does not pass on depth but contributes meaningfully during the transition period.</i>
Dead-End	A solution that is incompatible with achieving net zero. It fails on one or more of depth, breadth, or timeliness, with superior alternatives available. Continued investment risks locking in emissions-intensive assets, diverting resources from viable pathways, and delaying meaningful progress toward climate commitments. <i>Fails on depth, breadth, or timeliness — superior alternatives exist.</i>
Enabling pathway	A solution that does not directly eliminate emissions itself but contributes to the successful deployment and performance of decarbonization pathways. This includes infrastructure, system integration technologies, energy efficiency measures, and other supporting capabilities without which net-zero-compatible solutions would be more costly, unable to function, or unable to scale. Its value is assessed in relation to the pathways it supports rather than as a standalone decarbonization solution.

Descriptors can be added to the role in the net-zero label these include:

Table A 2. Pathways tables role in net-zero descriptors

Label Descriptor	Definition
Priority	Appended to any pathway category to indicate the solution is a clear win across economic, technical, and social criteria and warrants immediate deployment and continued support.
Potential	Appended to any pathway category to indicate the solution does not currently meet all criteria for its assigned role but has the potential to do so as constraints related to technological maturity, economics, or other factors are addressed.

2. Signal to Decision Makers

This criterion identifies the most appropriate near-term action for decision-makers to progress a pathway from its current technoeconomic and social state toward net zero:

- **Deploy:** Mature, cost-effective, ready now — maximize deployment in relevant contexts with strong policy and investment.
- **Enable:** Promising but needs targeted support to unlock — invest in facilitating conditions, not just the technology.
- **Incubate:** Early-stage or niche — fund R&D, pilots, and enabling conditions. Protect and develop.
- **Don't Prioritize:** Uncertain, limited applicability, or superseded — watch but don't lead with investment.
- **Dismiss:** Does not contribute meaningfully to net-zero transition at a relevant scale — redirect investment and policy attention elsewhere.

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