

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]¹ 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.

¹ 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]² and the question of whether inert-anode technology and hydrogen-based ironmaking can mature in time to meet ongoing capital cycles.



² All noted references can be found in the full Playbook document.

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 billion³. [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)⁴. [361]

Many Canadian mining companies operate abroad. Of the sector's \$343.2 billion⁵ 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]

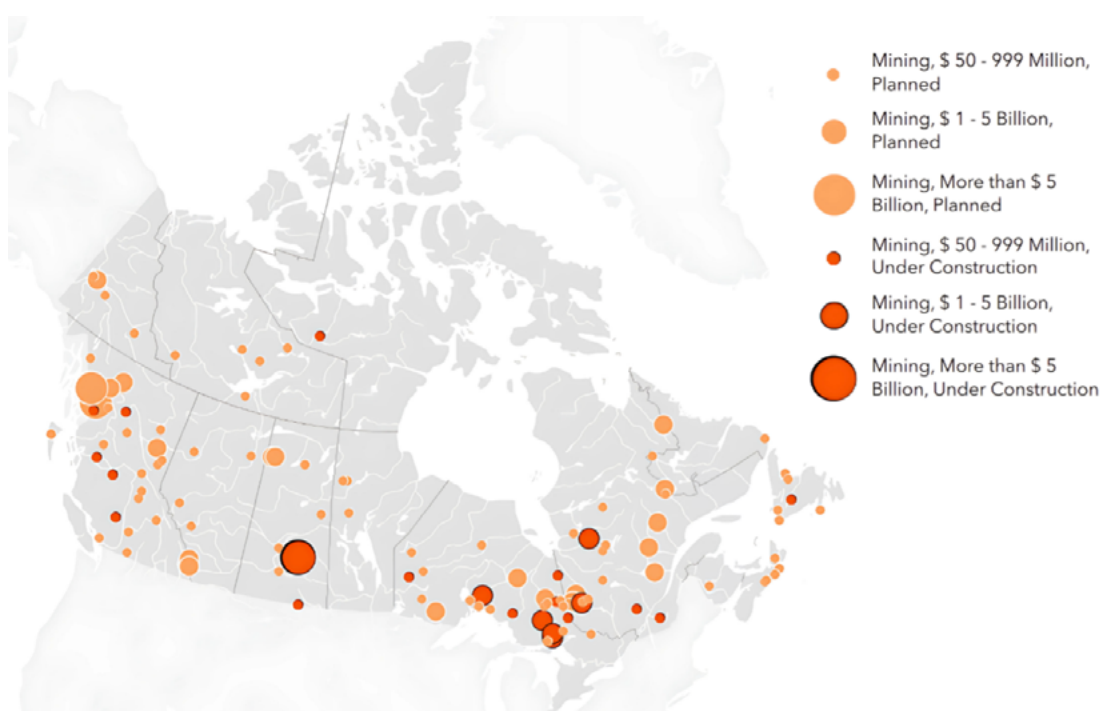


Figure 28. Canada, Major planned and under-construction mining projects

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

3 In chained (2017) Canadian dollars

4 In 2024 Canadian dollars

5 In 2023 Canadian dollars

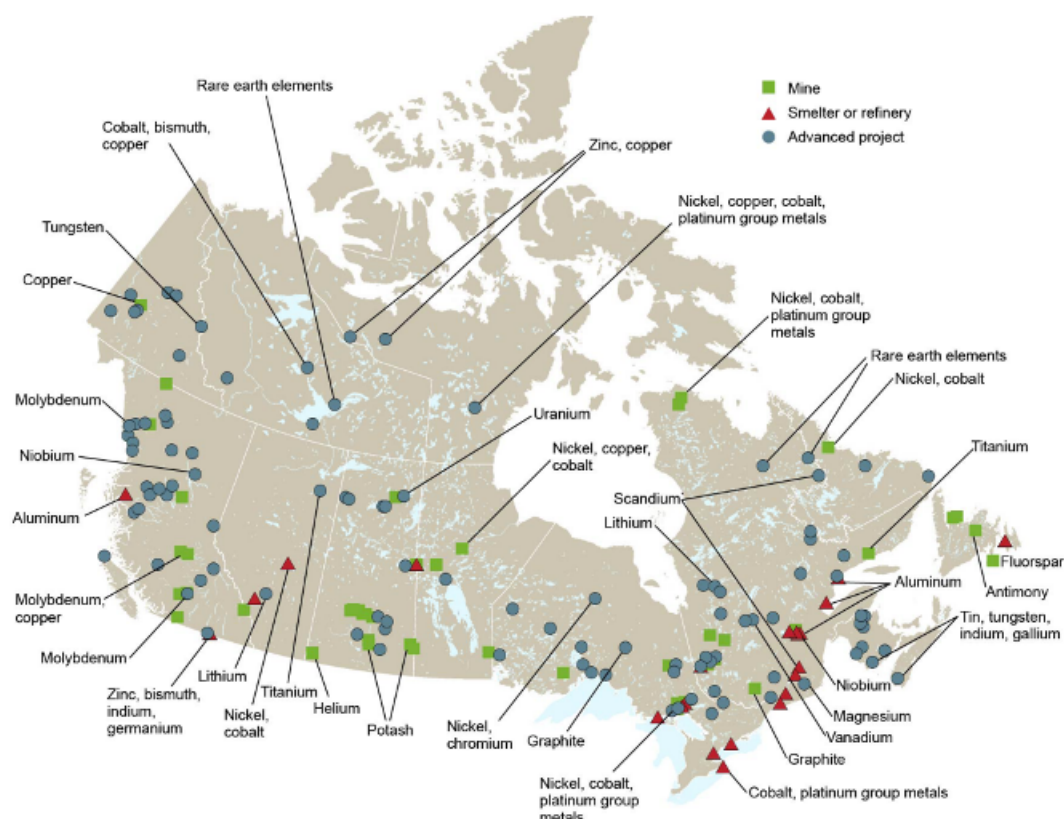


Figure 29. Canada, Critical mineral project locations (2022)

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
- Not promising
- Potentially meets criteria
- Meets criteria

10.1.5 Mining 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
 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 billion⁶. [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

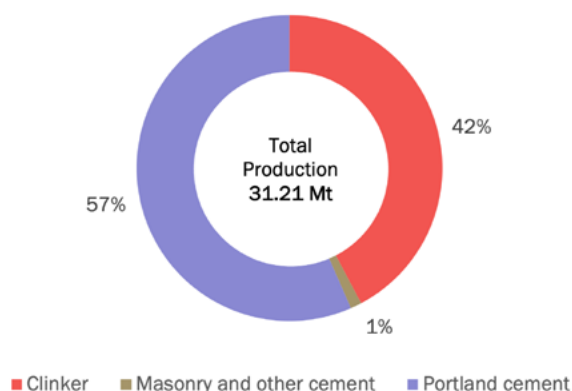


Figure 30. Cement and Clinker Production in Canada

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]

⁶ 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]

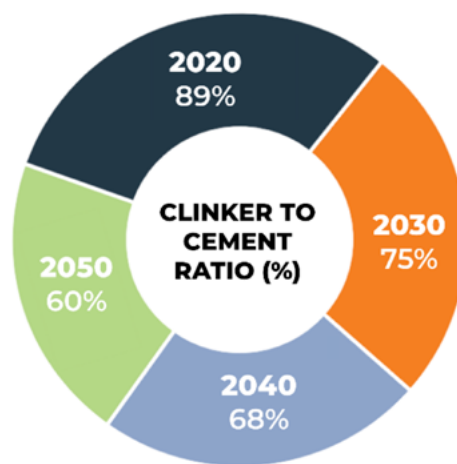


Figure 31. Canada, Clinker-cement ratio targets for decarbonizing production proposed by the Cement Association of Canada (2020-2050)

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,⁷ 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.

7 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.⁸

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.

⁸ "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.

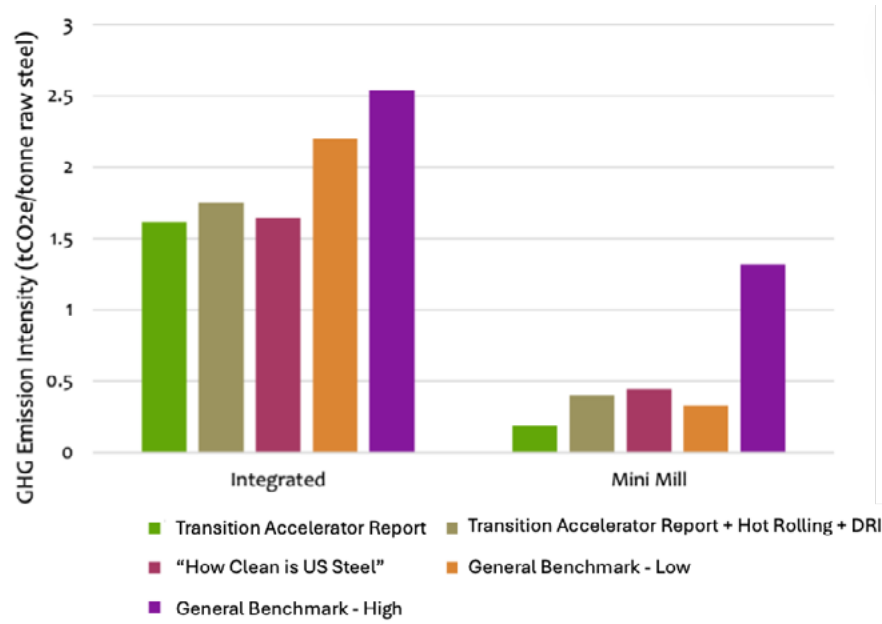


Figure 32 Comparison of the emissions intensity for Canadian steel by production route
Source: Transition Accelerator, “Hydrogen and the Decarbonization of Steel Production in Canada”[390]

- **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 billion⁹ 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 billion¹⁰ 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]

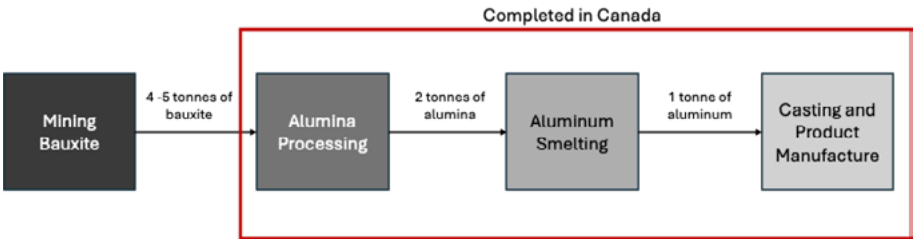


Figure 33. Flow diagram of aluminum production in Canada[436]

9 In 2024 Canadian dollars
10 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.



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	
	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.
r	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 CO₂ pipelines and storage sites.	May win support if it preserves jobs and cuts emissions, but CO₂ pipelines and storage could face local opposition.	Producers see CCS as a last resort — being explored mainly to complement carbon-free smelting.	Lack of CO₂ storage where aluminum is produced. End-use cases for CO₂ can also be enablers for more emissions.
	Reduces emissions per tonne significantly through improved cell efficiency and lower anode effects, but does not eliminate process CO₂ 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.		 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.		 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 2024.¹¹
- **Agricultural chemicals:** Fertilizers and pesticides. GHGRP facility emissions: 5.75 Mt in 2024.¹²
- **Chemical products:** Paints, coatings, adhesives, soaps, cleaning compounds, toiletries, printing ink, and other miscellaneous chemical products. GHGRP facility emissions: 0.12 Mt in 2024.¹³
- **Pharmaceuticals:** Medicines and associated compounds. GHGRP facility emissions: 0.07 Mt in 2024.¹⁴

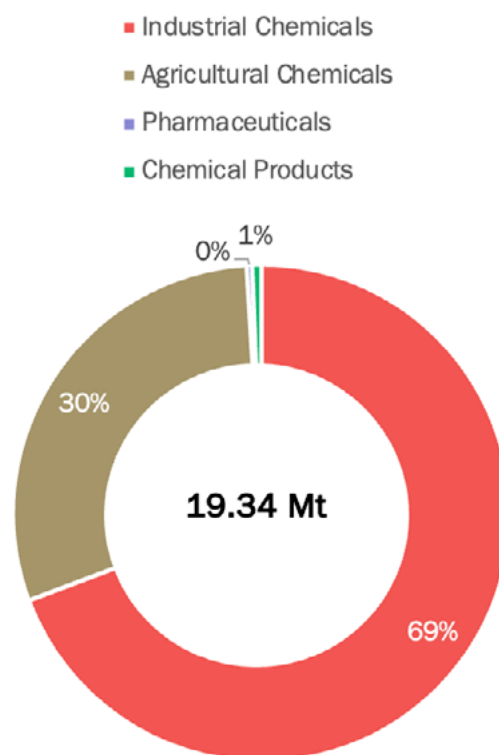


Figure 34. Chemical sector GHGRP facility emissions, Canada 2024[463]



¹¹ NAICS codes 3251 and 3252

¹² NAICS code 3253

¹³ NAICS codes 3255, 3256, and 3259

¹⁴ 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.¹⁵ 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 2024¹⁶[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 billion¹⁷ in products, with 77% going to the United States[462]. In the same year, the sector's GDP was \$32.2 billion¹⁸[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].

¹⁵ NAICS code 3261

¹⁶ 2024 Canadian dollars

¹⁷ 2024 Canadian dollars

¹⁸ Chained (2012) Canadian dollars

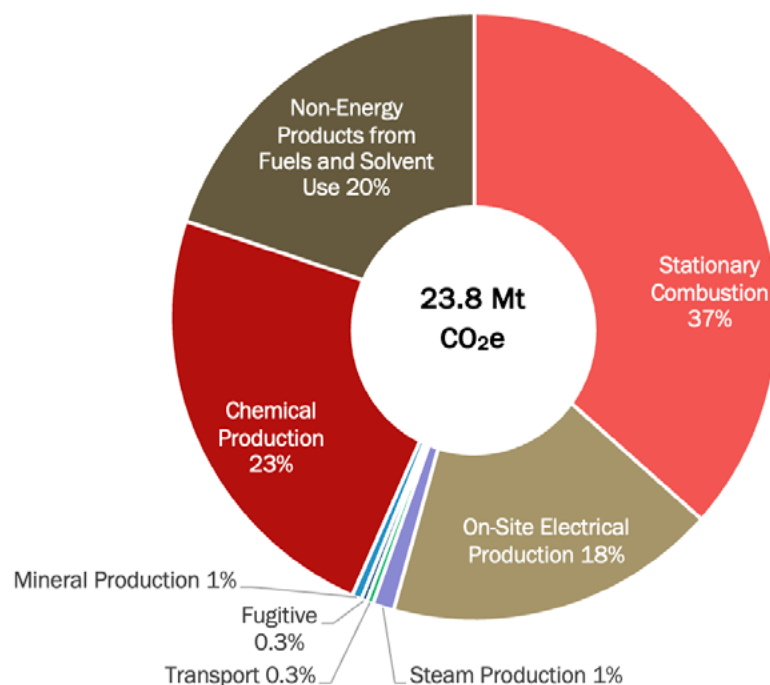


Figure 35. Chemical and fertilizer sector emissions by source, Canada 2024[452]

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].

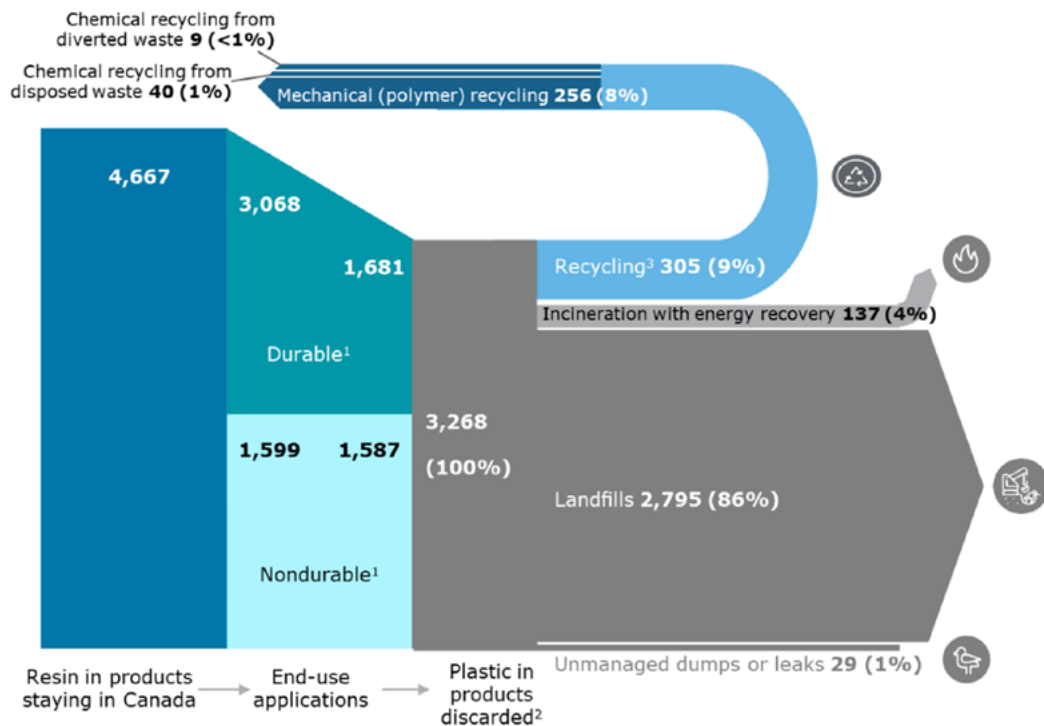


Figure 36. Recycling and disposal of plastics and resins in Canada, 2016 (thousand tonnes per year)[474]

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 billion¹⁹ 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.

¹⁹ 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			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	
 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.	

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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.

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 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.

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 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, repairability, 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.

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 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: Depolymerization 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.

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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.

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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.