

INDUSTRY

Aluminum



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] ¹
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.

¹ All noted references can be found in the full Playbook document.

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 billion² 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 billion³ 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]

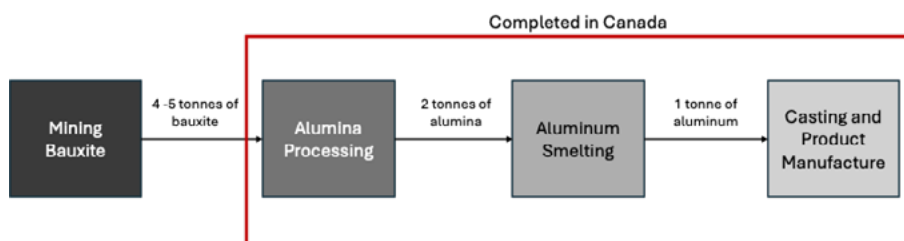


Figure 33. Flow diagram of aluminum production in Canada[436]

² In 2024 Canadian dollars

³ In chained (2017) Canadian dollars

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

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

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

10.4.3 Net-Zero Pathways

Novel smelting technologies

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

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

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

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

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

Recycling

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

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

Net-zero energy or electrification

Although casting and product manufacturing account for only a small portion of total emissions, these processes will need to transition away from fossil fuels. Achieving carbon neutrality will require fuel switching to biofuels or hydrogen, electrification of equipment (heat batteries or heat pumps), and/or implementation of heat recovery technologies.[441,450]

In the near term (before 2030), decarbonizing alumina production can be addressed through mechanical vapour recompression, which captures and reuses waste heat, and electric boilers powered by renewable electricity. Looking further ahead, post-2030 options include hydrogen calcination (replacing natural gas with hydrogen and pure oxygen) and electric calcination, where electricity fully supplies the thermal energy required for the process.[451]

Competitiveness Implications

Canada's aluminum sector already carries one of the lowest carbon intensities among global producers anchored in hydroelectric-powered smelting across Quebec and British Columbia. Inert-anode technology, being commercialized domestically through the Elysis joint venture with a 2027 deployment target, would go further: eliminating process emissions that account for 93% of the sector's remaining footprint and potentially reducing operating costs by 15%. That would position Canadian producers to offer among the lowest-carbon primary aluminum available anywhere at commercial scale. But that position only delivers competitive value if it is demonstrated in time. Canada exported \$17.4 billion in aluminum in 2024, 92% to the United States. The U.S. transportation sector is already the largest end-use market for North American aluminum, and it is where green-procurement standards and carbon-intensity thresholds are likeliest to reshape sourcing first. If those frameworks take effect before Canadian inert-anode production is commercially operating, Canada will have missed the window to establish itself as the benchmark low-carbon supplier, competing instead on terms set by the performance of others.



10.4.4 Priorities For Action

There are multiple steps to decarbonizing the aluminum sector. Policy, funding, fiscal incentives, and investments are needed to support the development and implementation of carbon-neutral smelting technologies, improvement of recycling systems, and full decarbonization of energy supply. To address challenges with technological development, scaleup, and mass deployment, Canada will need to direct more government support towards innovative smelting technologies. To improve recycling, extended producer responsibility programs must be implemented and monitored across the country so progress

is trackable. Investment is also needed to improve infrastructure at recycling plants. [442] Additionally, infrastructure investment is needed for further electrification as well as to support scaleup of alternative fuel production.

Procurement support such as standards could be put in place, especially in the auto industry, to ensure uptake of green aluminum. More long-term, Canada needs to secure global agreements for green aluminum uptake and/or associated carbon pricing to ensure that Canadian green aluminum is cost competitive in global markets.



Criteria Status

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

10.4.5 Aluminium Pathways Table

Not promising Potentially meets criteria Meets criteria			ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS		ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
 Aluminum Smelting											
Inert Anodes	Priority Decarbonization Pathway Essential for net-zero smelting.	Enable Support full scale validation and subsequent mass deployment through policy, financing, and regulations.	 Sector-wide implementation could reduce aluminum production emissions substantially.	 Could cut facility operating costs, though costly to adopt initially.	 Positions Canada as a smelting tech leader, creating jobs and export opportunities in the long term.	 Late R&D, though full-scale validation is still pending.	 Require new cell designs and maintenance routines but build on existing smelting processes.	 No major external infrastructure is needed. Canada's hydro power complements inert anodes within modified smelters.	 No concern.	 Key to net-zero goals, with strong backing from producers and government.	 Eliminate carbon anode production, improve safety, air quality, and potentially reduce costs.
CCS	Potential Dead-End Pathway Serves as a last resort retrofit if primary solutions stall.	Don't Prioritize Unlikely to be relevant in this sector as other pathways are emerging. Monitor as an option for residual emissions.	 Cannot fully eliminate direct emissions. Requires significant electricity so grid carbon intensity matters.	 Costly.	 Adds cost without boosting productivity or value, waste gas management step.	 Still testing lab and pilot-scale technologies.	 Technically feasible but CCS could complicate smelter operations and maintenance.	 CCS faces major infrastructure gaps with lack of CO ₂ pipelines and storage sites.	 May win support if it preserves jobs and cuts emissions, but CO ₂ pipelines and storage could face local opposition.	 Producers see CCS as a last resort — being explored mainly to complement carbon-free smelting.	 Lack of CO ₂ storage where aluminum is produced. End-use cases for CO ₂ can also be enablers for more emissions.
High-Amperage Smelting Pots	Bridge Pathway Near-term efficiency and emissions improvements to conventional smelting. Part of net zero if modifiable to work with inert anodes.	Deploy Support with green procurement or other policy measures. Scale deployment on asset replacement cycles, but ensure investment in inert anode technology proceeds in parallel.	 Reduces emissions per tonne significantly through improved cell efficiency and lower anode effects, but does not eliminate process CO ₂ from carbon anode consumption.	 More efficient than incumbent technologies, with lower operating costs. Capital investment in new smelting cells is substantial and most cost-effective when timed to asset replacement cycles.	 The primary technology is proprietary, and the owner operates in Quebec. Deployment generates significant construction activity and regional economic benefits. Operational expertise is exportable, with active deployment studies underway.	 Mature with full-scale deployment, currently scaling with a major expansion.	 Requires replacement of existing smelting cells and associated infrastructure, but leverages existing site assets, grid connections, and workforce skills. Process fundamentals are identical to incumbent technology.	 Requires little change to external infrastructure. Performance is contingent on access to clean, reliable, and abundant electricity.	 Substantially reduces existing air quality emissions and associated community concerns.	 Supported by Canadian producers and governments. Directly relevant to regions with abundant clean electricity and to customers facing increasing carbon intensity requirements.	 Significant particulate matter reductions improve worker and community air quality. Does not eliminate carbon anodes. Reduces energy consumption per tonne, lowering demand on the electrical grid.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Wetted Cathodes	Enabling Pathway Specialized efficiency upgrade — valuable in enhancing an already green aluminum production system.	Incubate Support R&D and pilots.		 High upfront cost, but longer cell life and energy savings can offset it over time.	 Minimal impact.	 Still in R&D. Not yet commercially proven for long-term aluminum cell use. May require more research to combine with inert anodes.	 Requires modifications to the cell design and operating practices.	 Little to no external infrastructure is needed. Implemented within smelting pots.	 Unlikely to face public scrutiny.	 Not a focal point since it doesn't directly drive big emissions cuts on its own.	 Cuts electricity use and may boost output, lowering costs and indirect emissions per tonne.
Casting and/or Manufacturing											
Fuel Switching (i.e. hydrogen or biofuels)	Niche Pathway Low-carbon fuel availability will depend on location and adoption by other closely located sectors.	Enable Build out relevant infrastructure or supply chain to improve fuel procurement logistics. Support increased production of alternative fuels.	 Dependent on fuel carbon intensities. Reduces combustion emissions in product manufacturing and casting.	 Hydrogen or biofuels can carry premiums.	 Could boost Canada's bioenergy and hydrogen sectors.	 Some fuel-switching options are already commercially available.	 Low-disruption — biofuels are largely drop-in.	 Requires some infrastructure — biofuels need storage. Hydrogen needs more substantial upgrades.	 Widely supported for cutting GHGs and improving air quality, though biomass fuels raise some land-use concerns.	 Cuts emissions in ancillary operations, aligns with policy priorities, and expands markets for some energy suppliers.	 Reduces air pollution but not completely. Land-use changes for fuel production can be negative.
Heat Batteries	Potential Decarbonization Pathway Applicable for all temperatures required.	Incubate Support demonstrations and pilots in regions with low-cost electricity.	 Depends on carbon intensity of electricity.	 Very costly. Relies on carbon credits or restructuring of electrical rates for competitive pricing. Capital costs are expected to fall over time.	 Opportunities for Canadian manufacturers. Creates demand for on-site power generation technologies. Useful to multiple industries.	 A few commercial plants globally, designed for most required temperatures. Awaiting full-scale deployment in Canada.	 Would need to replace current furnaces but operates very similarly.	 Functions best when co-located with clean power. Strongly tied to availability and pricing of renewable electricity and natural gas.	 Change is implemented within a facility. May be pushback with land changes to build out renewables.	 Fits long term goals but low relevance because this affects a small portion of energy and emissions.	 Land required to co-locate renewables. Less air pollution from replacement of combustion furnaces.

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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.

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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.