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Mining decarbonization

Enhancing Canada's low-carbon advantage in the global critical minerals race

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Inco Ltd. exploration camp sits at the base of Discovery Hill at Voisey's Bay, Nfld. The Labrador site contains one of the world's largest ore bodies of nickel, copper and cobalt. (CP PHOTO) I996 (stf/Andrew Vaughan) av

1. Introduction

Critical minerals stand at the intersection of global climate action, economic growth, and geopolitical tensions. The resources in question—in particular, cobalt, copper, lithium, nickel, graphite, and rare earth elements—are the building blocks of the future economy. Demand for these resources is surging as the deployment of clean technologies continues to grow.

Mining and processing these minerals generate significant emissions, pushing the sector's footprint upward while the rest of the economy strives to decarbonize. To balance this challenge, the mining industry must explore innovative ways to cut emissions while still meeting the growing demand.

These six critical minerals are the essential ingredients of the global low-carbon economy. Companies in Canada and around the globe will need a steady supply of all of them for a range of applications, such as batteries for electric vehicles and energy storage, solar panels, and transmission lines (Energy Transition Commission 2023, Bingoto et al. 2023).

Canada's abundant resources have long offered the country a competitive edge. Now the critical minerals discussion is extending the nation's advantage to the ground under our feet.

In an upcoming companion report to this paper, the Canadian Climate Institute will explore how Canada can unlock investment in the upstream portion of the value chain—the portion with the strongest potential. This nation's critical minerals endowment, paired up with clean energy sources such as hydroelectricity, positions the country as a reliable and responsible supplier to domestic and global markets.

This paper explores the specific challenges and opportunities of growing Canada's critical minerals sector while maintaining our competitive carbon advantage. This paper draws on research undertaken for the upcoming larger report to discuss three distinct barriers to the sector's decarbonization. This paper also outlines policy options available to governments to address these barriers, and in doing so solve one of the key challenges needed to fulfil Canada's potential as a reliable, responsible supplier of the low-carbon critical minerals the world needs.

Teck's Highland Valley Copper mine is pictured in British Columbia's interior, Sunday, March 26, 2017. THE CANADIAN PRESS/Jonathan Hayward

2. Background

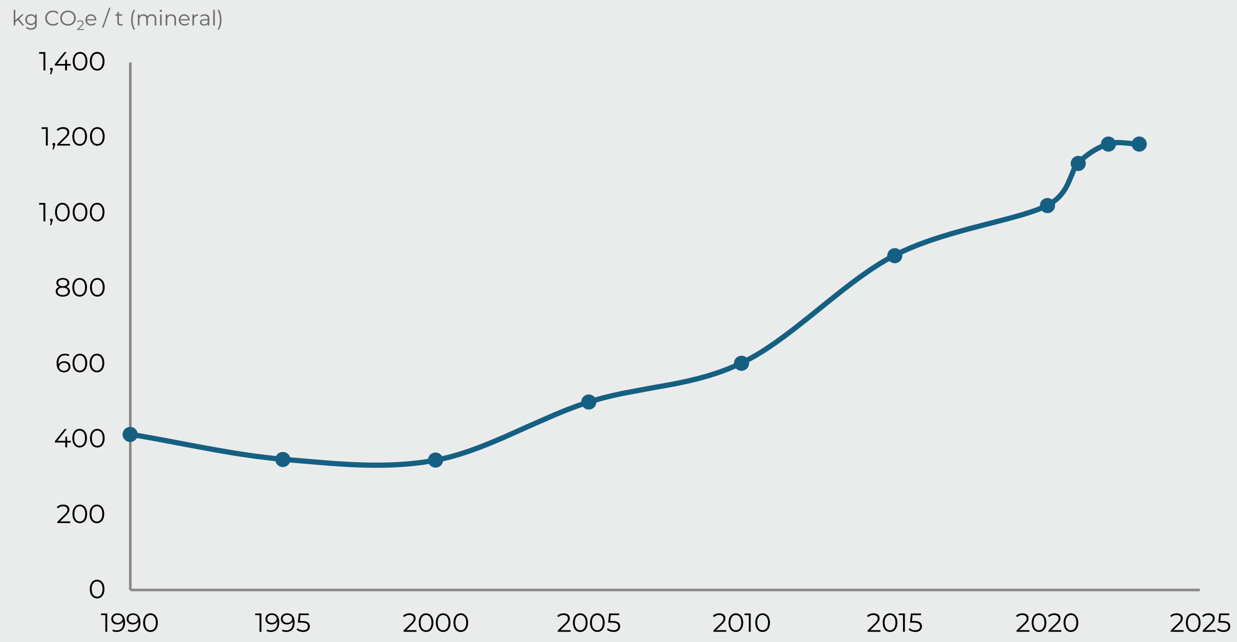
A business-as-usual approach to increasing critical-minerals mining will raise Canada's greenhouse gas emissions.

Mining is an emission-intensive sector. Depending on the resource in question, each tonne of produced minerals will emit between five and 100 tonnes of carbon dioxide equivalent (CO_2e) (SKARN n.d.). In Canada, emissions from all types of mining have increased from 8 megatonnes of carbon dioxide equivalent (Mt CO_2e) in 2015, to 11 Mt CO_2e in 2022—a 35 per cent jump. This increase is primarily attributed to the higher energy intensity the industry used to produce them. (Linden-Fraser 2024). While direct emissions from mining represented 1.5 per cent of Canada's overall annual emissions, the growing emissions make up a sizable portion of many mining jurisdictions that range from 4 per cent in Quebec to 30 per cent for the Northwest Territories. (Environment and Climate Change Canada 2024)

As shown in Figure 1, the minerals mining sector's emissions intensity has nearly doubled since 2005 levels. As companies expand and deepen their mines, they must transport the extracted ore further, which consumes more energy and produces more emissions.

Average per-project emissions intensity has been increasing because companies typically begin operations in areas with the highest ore grades. As companies expand mines to areas with lower-grade ores, they extract more materials for the same amount of produced minerals.

FIGURE 1 - Greenhouse gas intensity of mineral mining has risen in Canada
Average annual intensity for copper,nickel, lead and zinc



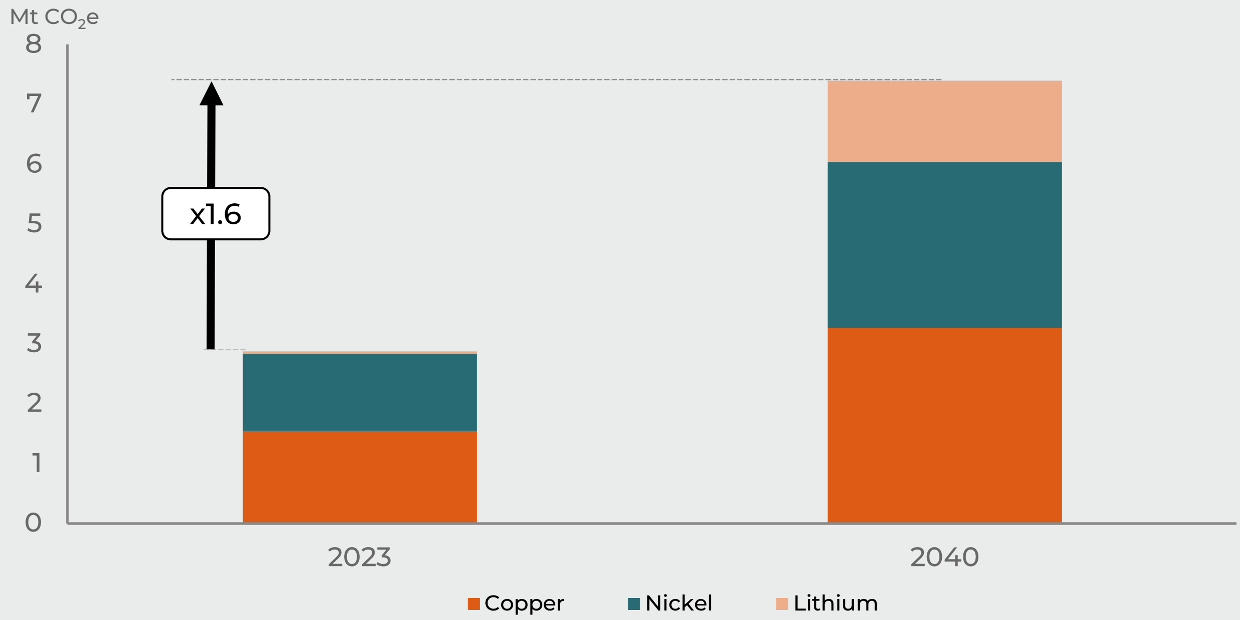
Source: Canadian Energy and Emissions Data Centre n.d.
Historical emissions intensity includes copper, nickel, lead, and zinc ore mining.

Previous work from the Canadian Climate Institute's 440 Megatonnes project has shown that if Canada were to fully realize the enormous economic potential of a robust critical minerals mining sector, the country would need to attract between $30 billion and $73 billion in investment in upstream mining projects by 2040 (Trottier-Chi 2024).

If Canada were to achieve the low end of this estimate, the sector's carbon pollution would grow significantly. Under that scenario, we estimate that emissions from the production of three minerals—copper, nickel, and lithium—would be 1.6 times higher in 2040 than in 2023 (see Figure 2).[1] This is consistent with other studies that find emissions associated with growth in the six critical minerals globally would grow by one-and-a-half times by 2035 if emission intensities remain the same. (Pinnell et al. 2024)

FIGURE 2 - The ramp-up of nickel, copper and lithium mining in Canada could more than double current emissions

Domestic greenhouse gas emissions from mining production in Canada



Production values used based on scenario by (Trottier-Chi 2024). Emissions intensity values for years 2023 to 2030 are adopted from SKARN Associates and are assumed to be the same until 2040.

1. The investment estimate includes three other minerals (cobalt, graphite, and neodymium), but the increase in emissions from these minerals is either too small or could not be calculated due to a lack of Canadian specific data.

Canada produces minerals with low carbon intensity—presenting both an opportunity and a challenge

A number of Canada's mining regions, including Quebec, Manitoba, and British Columbia, benefit from exceptionally low-carbon power grids. Companies that can access this clean electricity to power their mines offer lower emissions intensity minerals (SKARN 2024).

This low emissions intensity presents an early competitive advantage for Canadian minerals in global markets in the short and medium term, but Canadian producers will inevitably lose that edge as other jurisdictions catch up.

BOX 1 - Sources of mining-sector emissions

Various mining activities produce greenhouse gas (GHG) emissions. First, heavy equipment such as haul trucks burn diesel fuel as they move ore and waste materials around a site. Diesel generators also produce power on remote operations (Winkelman 2024). Both of these are Scope 1 emissions. Meanwhile, grid-connected projects must account for the emissions associated with electricity generation—the realm of Scope 2 emissions.[2]

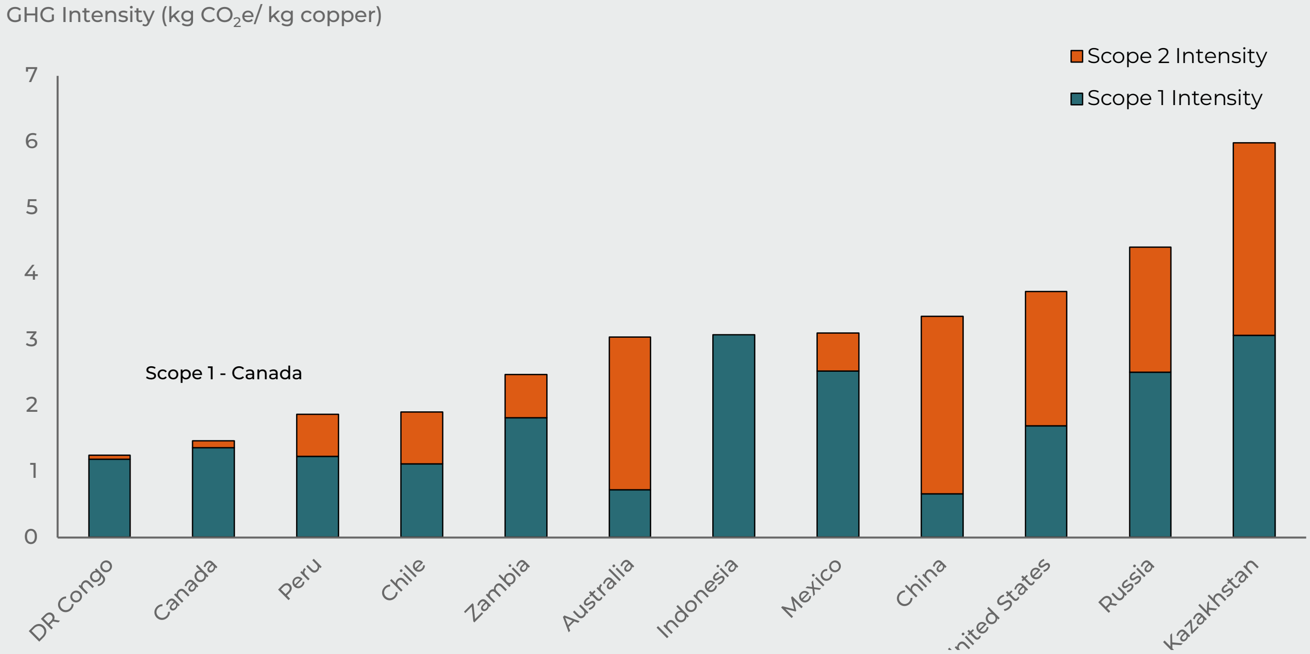
Even grid-connected mines rely heavily on diesel fuel for materials handling. For example, at Canada's 21 copper-producing mines, diesel emissions accounted for 96 per cent of Scope 1 emissions (SKARN 2024).[3]

Scope 2 emissions can be offset either directly by sourcing electricity from renewable sources or indirectly via power purchase agreements. Mines connected to low-carbon grids enjoy low Scope 2 emissions. This leaves the diesel fuel displacement as the core challenge of the sector's decarbonization.

2. Other sources, such as fugitive emissions in coal mining or emissions from the use of explosives in blasting, are either not relevant to critical minerals or represent a very small portion of the total emissions.
3. Analysis by Canadian Climate Institute based on proprietary data from SKARN Associates.

As shown in Figure 3, due to its low Scope 2 emissions, Canada ranks second among the top 12 copper-producing nations on emissions intensity. But other countries, such as Chile and Australia, boast lower Scope 1 intensity.[4] As other mining economies rapidly reduce their emissions intensity by transitioning their grids to low-emissions sources, Canada could lose its low-carbon competitive advantage if Scope 1 emission intensity remains at the same level.

FIGURE 3 - Canada's copper mines have some of the lowest carbon intensity



Source: SKARN Associates. Values are based on 2022 production.

4. The difference in Scope 1 can be attributed to various factors, including ore grade. While many mines in Canada and Australia have similar ore grades, on average, Australia has more producing mines with higher ore grades.

Low-carbon producers in Canada will have a long-term competitive advantage

Canadian mines are not only competing on cost, but also on carbon.

In our flagship *Sink Or Swim* report, we modelled the impact of the global energy transition upon various Canadian economic sectors. We found that the mining and minerals industry can be exposed to declining profitability from transition risks. (Samson et. al. 2021)

That said, companies that reduce the carbon intensity of their critical minerals will largely shield themselves from these energy-transition risks. In contrast, those producing higher-carbon materials and products will find themselves at a disadvantage as global economies decarbonize.

Canada's large-emitter trading systems (LETS) has effectively lowered mining-sector emissions while maintaining the industry's competitiveness. The system's built-in flexibility incentivizes companies to invest in low-carbon innovation without impacting production levels (Dion and Linden-Fraser 2024).

Early signs that low-carbon critical minerals have an advantage are already starting to emerge. Companies with ambitious internal climate targets are tapping into a new category of sustainable finance products that offer more attractive terms for lower-carbon projects. For example, in 2021 Newmont, a leading gold and copper producer, became the first mining company to issue sustainability-linked bonds with a USD$1 billion offering (Newmont 2021). The interest payable on the notes will increase if the company falls short of its 2030 climate targets. The following year, U.K.-based Anglo American issued a €745 million bond similarly linked to in-house carbon-reduction goals (Anglo American 2022).[5] Despite the recent ESG backlash, major mining companies have continued pursuing their emissions targets.

Canadian mining companies that invest in climate solutions today are positioning themselves for success as low-carbon producers of tomorrow. Manufacturers using critical minerals can achieve greater Scope 3 reductions by sourcing from the lowest carbon mineral producers.

Despite these promising opportunities, the process of decarbonizing critical mineral mines is fraught with challenges. We outline the lead barriers in the following section.

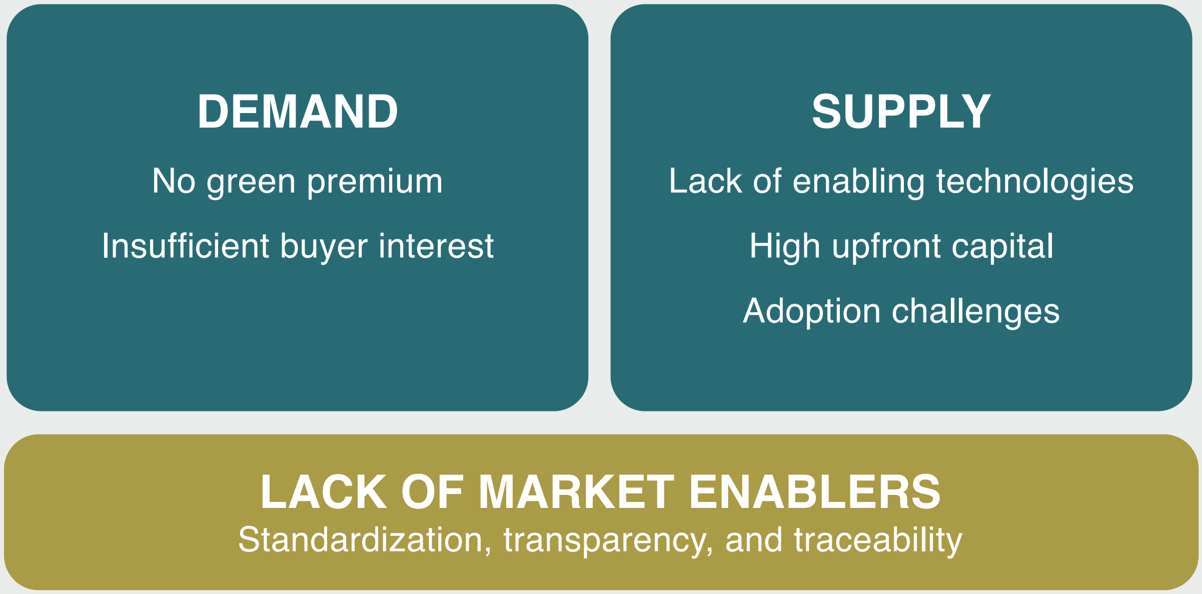
5. By 2030, Anglo American aims to reduce its Scope 1 and Scope 2 emissions 30 per cent below 2016 levels

3. The decarbonization challenge

A range of systemic barriers are constraining mining companies from investing in emissions reductions. Broadly speaking, we can slot these barriers into one of three categories:

- barriers to demand for low-carbon minerals
- barriers to supply and adoption of decarbonization technologies; and
- lack of market-enabling standards.

FIGURE 4 - A combination of demand, supply, and market-enabling factors hinder mining decarbonization investment



Demand-side barriers: The minerals market doesn't yet differentiate on carbon

Currently, there is very limited market demand for low-carbon critical minerals. Price rules, and buyers are unwilling to pay a green premium.

Environmental performance differentiators

A **green premium** refers to a product's perceived or actual higher value if it is produced with strong environmental standards, including low carbon emissions.

Conversely, a **carbon discount** refers to the lower value or discount for assets that environmentally underperform, or have high carbon emissions intensity.

Producers with strong environmental performance are competing with other producers with poor environmental standards and regulations. In March 2024, Australian producers, among others, urged the London Metal Exchange (LME) to consider creating a green nickel contract to differentiate lower-carbon nickel prices. A month later, after requesting feedback from market participants, the exchange advised members it would not be pursuing the idea. (London Metal Exchange 2024).

In issuing its decision, LME stated that a parallel contract would fragment liquidity in a relatively small market. It also flagged that industry will need time to adopt a specific methodology for assessing carbon emissions and to share audited product carbon footprint data at the point of purchase, which is not currently common practice.[6]

6. LME endorsed Metalshub's proposed definition of low-carbon nickel as that with a maximum of 20 tonnes of CO_2 equivalent per tonne of output (London Metals Exchange 2021).

Metalshub, a digital spot-trading platform and LME partner, first offered low-carbon nickel in 2023. The platform offers buyers a certificate of the commodity's carbon intensity at the point of purchase. But the market has yet to materialize. For most months of 2024, Metalshub reported no low-carbon nickel transactions whatsoever. Between January and December of that year, low-carbon nickel transactions comprised just shy of two per cent of the metal's overall trading volumes (Kreft 2024).

Market infrastructure barriers: A fragmented supply chain and limited incentives hold back traceability efforts

A standard 25-kilogram ingot of low-carbon copper looks identical to a conventionally produced copper bar beside it. Because of this, any industry- or government-led effort to develop a low-carbon critical minerals market must prioritize robust carbon tracking.

Nations will need accurate, tractable emissions intensity data to establish the regulatory frameworks needed to differentiate minerals and products based on environmental performance—including emissions intensity. Potential buyers of low-carbon minerals similarly need accurate data to effectively implement their Scope 3 emissions reduction strategies.

It won't be easy. The critical minerals value chain is complex and global, which presents a challenge for efforts to ensure transparency and traceability to the raw material producer. Minerals are estimated to have travelled an average of 50,000 miles from extraction to a final electric battery cell, which is then assembled into a battery pack and later into an electric vehicle (Carreon 2023). Raw materials undergo significant refining and processing in order to create precursor materials, which are then used in active components of a final product, such as a battery anode (Heimes et al. 2018).

Assessing the collective environmental performance of both raw materials and final products of them will require new standards, verification tools, and, most importantly, agreement between a large number of actors who may not envision direct benefits for their efforts.

Then there's the ongoing murkiness around what actually defines low-carbon for some minerals. Unlike commodities, such as aluminum, which have more or less standardized processes to extract and manufacture (The Aluminum Association 2024), some critical minerals are literally all over the map. Multiple types of deposits require various approaches to extraction and processing, each of which will influence the energy and emissions intensity of the final product (IEA 2021b).

Nickel offers a textbook example. Depending on the method a company uses to extract the metal, and its electricity source, its emissions intensity can range from five to 105 kg CO_2e for each produced kilogram (Tijsseling et al. 2023).

Further, the current patchwork of competing sustainability standards is increasing confusion for minerals producers and customers who already subject their products to multiple standards. (Day, Jodha et al. 2024). For example, a copper producer can adopt the Copper Mark, a Towards Sustainable Mining standard (TSM), and the principles of the International Council on Mining and Metals (ICMM). A recent effort to consolidate these standards started in 2023, with the goal of implementation starting in 2026 (Consolidated Mining Standard Initiative 2024).

Mining standards are necessary but not sufficient. To ensure the integrity of any new certification process through the value chain, the mining industry, investors, Indigenous Peoples, downstream consumers, and governments must collaborate on transparent and reliable traceability mechanisms. Fortunately, on this front there are some encouraging signs of progress.

- As part of its recently launched Energy & Mines Digital Trust pilot project, the Province of British Columbia is working to develop digital credentials that industries, including the mining sector, could use to demonstrate sustainability (Province of British Columbia 2024). The province has also pledged to participate in the UN's nascent Critical Raw Material Traceability and Sustainability project.
- The Global Battery Alliance—a collaboration of more than 170 companies, non-governmental organizations (NGOs), and governments—recently completed a series of pilots that independently tracked and verified multiple environmental attributes of materials used by 10 battery manufacturers (Global Battery Alliance 2024). (For more, see Box 2.)
    - In late 2024 the International Standards Organization published ISO 59014, a standard outlining principles, requirements, and guidelines for environmental management, traceability, and the recovery of secondary materials (International Standards Organization 2024).
    - The International Energy Agency (IEA) published a practical eight-step roadmap to help ensure traceability systems are fit for purpose and aligned with the realities of global supply chain (IEA 2025)

While these pilots and voluntary standards are not yet widely adopted, they are critical building blocks for developing a robust infrastructure for low-carbon mineral markets.

BOX 2 - How a battery passport can give Canadian mineral producers a competitive advantage

The Global Battery Alliance, a collaboration of more than 170 companies, NGOs, and governments, is advancing the battery passport—a digital traceable record that tracks and provides detailed information about a battery's lifecycle, including its origin, production processes, materials used and their carbon footprint, safety, and recycling information. Similar to how VIN numbers are engraved in vehicles, a QR code can be physically visible in a battery pack used in an electric vehicle.

The passport solves a range of existing challenges, in that it:

- validates the environmental performance of a battery's raw materials, including how and where they were mined and sourced
- documents technical specifications, such as the various minerals used during manufacturing
- provides recyclers with critical data needed to ensure more cost-effective and targeted recycling processes; and
- tracks the import and export of batteries within a given region.

In July 2023, the EU approved a new battery regulation that will require all batteries sold in the EU market to have a battery passport regardless of the origin of the battery.[7] Enforcement will begin in February 2027, with certain requirements coming into effect in different phases between 2024 and 2028 (TÜV SÜD Group 2024). Some electric vehicle EU manufacturers, such as Volvo, have started to leverage the battery passport to better market their products (Foote 2025).

As the passport regulations are implemented, Canadian producers with strong environmental performance will be able to more easily and favourably differentiate their minerals. The environmental metrics of Canadian producers will be prominently featured in the passport, appealing to manufacturers seeking compliance with EU regulations (Rizos and Urban 2024).

7. For battery capacity higher than 2 kWh (The European Parliament and The Council of the European Union 2023).

Supply-side barriers: Technology adoption faces multiple hurdles

A combination of supply-side factors currently disincentivizes the mining sector from investing in low-carbon solutions. For this discussion, we group them into three overarching barriers: technology readiness, adoption readiness, and deployment costs (including access to low-carbon electricity).

To recap, diesel fuel and electricity contribute the lion's share of mining-sector GHG emissions. Companies active in jurisdictions with high Scope 2 emissions (see Figure 3) can pursue economic short-term carbon-reduction opportunities from electricity, including virtual power purchase agreements.[8] That means replacing diesel with low- or zero-emissions energy sources is a central part of the decarbonization challenge for many companies.

8. In such an arrangement, a mine operator will purchase renewable energy credits from a renewable power producer to offset the emissions from the power it purchases from the grid. This allows a company to claim emission reduction attributes even when the mine is not physically connected to the renewables project.

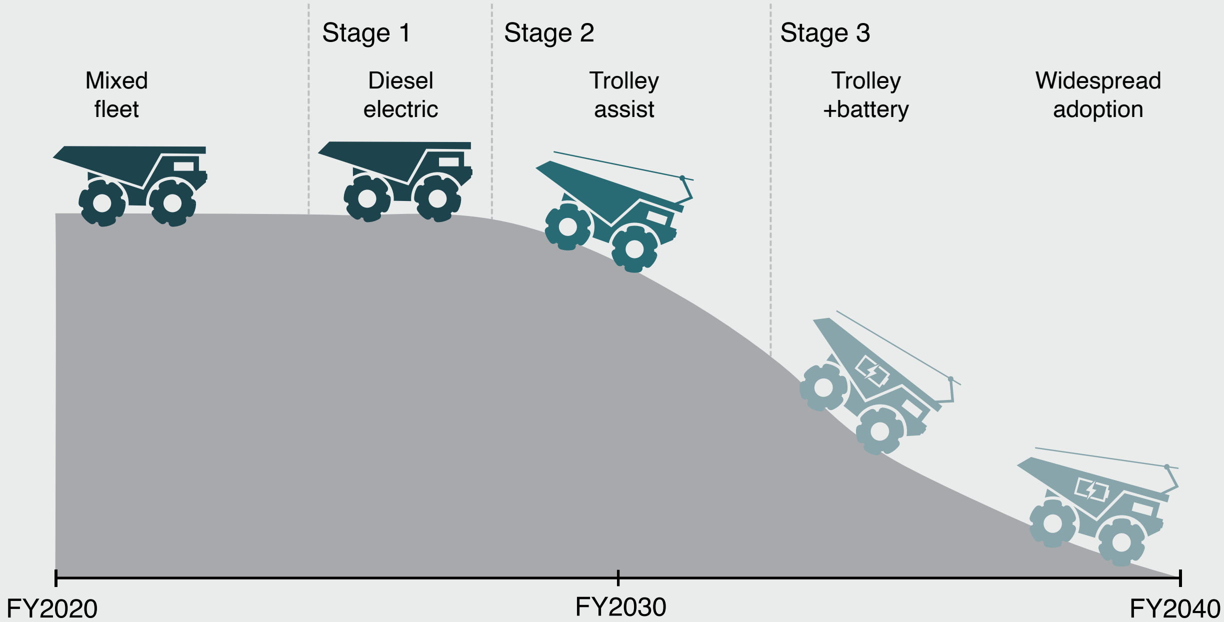
Hurdle 1: Needed technologies for open-pit mines are not yet ready for prime time

Most mining equipment relies on diesel, with zero-emission machines still at varying stages of development.

Heavy-equipment manufacturers are testing fully-electric versions of the so-called ultra-class haul trucks used in open-pit mines, and they may not be commercially available before 2030 (BHP 2024).[9] For a mining company to shift to an all-electric ultra-class truck, the technology would need to be de-risked, fully tested, and commercially available.

Figure 5 from BHP's 2024 Climate Transition Action Plan illustrates the evolution of electrifying haul-truck fleets in open-pit mines. The company does not expect electric trucks to significantly displace diesel before the end of this decade.

FIGURE 5 - BHP expects it will gradually electrify its haul-truck fleet between 2030 and 2050



Diesel electric refers to trucks that use electric motors but are powered by a diesel generator inside the truck instead of an internal combustion engine. Image adapted from BHP 2024b

9. Ultra-class haul trucks offer payload capacities between 150 and 400 tonnes. For comparison, trucks used in underground operations can haul between 15 to 60 tonnes.

Original equipment manufacturers (OEMs) and multinational mining companies are actively field-testing electric ultra-class haul truck prototypes in a bid to accelerate their commercialization (BHP 2024a). The earliest indication of an all-electric mining haul truck deployment in open-pit mines is the partnership between the Australian mining company Fortescue and mining equipment manufacturer Liebrherr where 240-tonne battery electric trucks are planned to be validated in the field by 2026 (Fortescue 2024).

Until electric-powered trucks and support equipment are widely available for open-pit mines, companies have two options to reduce Scope 1 emissions:

1. They can fuel their existing fleet with biodiesel and renewable diesel. Such biofuels offer life-cycle emissions 40 to 84 per cent lower than those of petroleum diesel (Xu et al. 2022).[10]

2. They can implement a trolley-assist system where a truck with a diesel-powered electric engine is drawing electricity through a physical connection. These hybrid trucks reduce diesel use by switching to electrical power delivered via an overhead pantograph and catenary when hauling ore out of the pit. A number of trolley-assist pilot projects in British Columbia have demonstrated promising results.[11]

It's a different story with underground mines. Thanks to innovation and declining costs, several OEMs now offer electric versions of widely used underground-mining machines.

While diesel remains the energy source of choice in underground mines around the world, a small but growing contingency of companies are adopting fully-electric equipment, which offers benefits beyond emission reduction. By not burning diesel in underground mines, less ventilation is required to heat or cool the mine, and workers are not exposed to particulate matter from diesel exhaust (see Box 3). Underground mining electrification is not limited to battery electric vehicles. Five mines have successfully deployed electric light-rail ore conveyor systems, including the Copper Cliff in Sudbury, Ontario and Goldex mine in Quebec, where the company says its technology has significantly reduced emissions and operating costs (Railveyor 2024).[12]

10. Life-cycle emissions vary depending on multiple factors, such as the type of biofuel used and the emissions generated while producing the fuel.
11 Copper Mountain Mine in British Columbia has operated **a trolley-assist system** for some of its mine haul trucks since 2022. FPX Nickel expects its trolley-assist system could reduce diesel consumption 30 per cent over a given mine's life (FPX Nickel 2024).
12 Reductions in emissions and operating costs will vary depending on mine design, electricity emissions intensity, and energy prices.

BOX 3 - With support from investment tax credits and large emitter trading systems, Canadian underground mines are starting to deploy battery-electric equipment

Canada's system of investment tax credits and large-emitter trading systems (LETS) are directly supporting industry uptake of zero-emissions underground mining equipment.

With a boost from tax breaks and the government incentive programs funded by industrial carbon pricing,operators are putting battery-electric machines in underground mines across the country. Sample deployments include Foran Mining's McIlvenna Bay project in Saskatchewan, Glencore Canada's Onaping Depth project in Ontario, and Newcrest Mining's Brucejack mine in British Columbia (Yakub 2022; Gleeson 2024; International Mining 2024; Electric Autonomy Canada n.d.).

This creates a virtuous cycle: governments incentivize early adopters to pilot the new technologies, which in turn spurs OEMs to further innovate—reducing costs and improving performance. For example, equipment manufacturers are testing out underground battery-swapping stations that would dramatically reduce equipment downtime for charging (Gehm 2024).

Table 1 below outlines the benefits and costs for battery-electric underground vehicles.

TABLE 1 - Benefits and costs of battery-electric equipment in underground mining operations

	Benefits	Costs
Capital Costs	Reduces the need for ventilation and diesel fueling infrastructure Higher productivity potentially reduces overall fleet size	Equipment and needed electrical infrastructure upgrades
Operating Costs	Lowers fleet maintenance costs Electricity costs can be more predictable than diesel Reduces carbon compliance costs	Battery and charging infrastructure servicing costs
Other	Higher acceleration and speed Reduced maintenance due to fewer moving parts Improved air quality and reduced noise and temperatures for workers	Change management and training

Adapted from Blinn and Persson (2023)

Hurdle 2: Even when electrified equipment is available, many mines lack access to reliable low-carbon, low-cost power

Any mine-decarbonization plan cannot be executed without access to reliable and low-carbon electricity. In interviews for this paper, several mining experts highlighted that the absence of electricity infrastructure can be a technical and commercial challenge for a project.

For grid-connected mines, meeting a significant increase in electricity demand can translate into additional infrastructure to upgrade electricity supply and transmission capacity.

Off-grid mines using on-site diesel power generation will most likely not invest in transmission infrastructure and will likely remain dependent on diesel if it remains the lowest-cost option. On a global basis, approximately one in 10 copper mines are in this position (SKARN 2024).

Given the extensive timelines associated with mine development, governments must navigate the tension between building infrastructure to support new mines and the likelihood that not all proposed mines in a particular area will be developed.

Given the extensive timelines associated with mine development, governments must navigate the tension between building infrastructure to support new mines and the likelihood that not all proposed mines in a particular area will be developed.

Governments will be hard pressed to invest in infrastructure that may outlast the mines that it would serve. Infrastructure investments should take into account the length and multitude of projects it can serve. In at least one case, governments have provided incentives for mining companies to invest in emissions-reducing projects that will outlive the mine's life. In 2024, the Government of the Northwest Territories announced it would provide $3.3 million from the Large Emitters GHG Reducing Investment Grant Program to establish a 3.5 megawatt solar farm at the Diavik Diamond Mine (Rio Tinto 2024). The panels will still be producing renewable electricity more than 20 years after the mine closes[13] (CBC 2024).

Further, mining is not the only industrial sector looking to electrify. Demand for power from a range of industrial sources is expected to significantly increase, escalating competition for clean and affordable electricity.

For example, in 2023 BC Hydro received 29 expressions of interest from companies seeking to tap into its proposed 500 kilovolt North Coast transmission project (BC Hydro 2023). Applicants represented ports, future hydrogen and liquified natural gas producers, and mining companies. The latter group generated the largest number of individual submissions.

13. Unlike roads or transmission lines, solar panels can be moved and installed in other locations.

Hurdle 3: Technology adoption will take time because not all mining companies will be early adopters

Canada's mining sector must overcome a range of financial, operational, and planning challenges to scale up decarbonization efforts.

In interviews, several mining and decarbonization experts observed that some companies are reluctant to pilot innovative technologies, citing the risk of near-term cost and performance penalties. The prospect of potential inefficiencies that come at the initial stages of technology adoption discourages companies from trying out new systems, which in turn slows broader adoption.

Upfront capital costs for low-carbon technologies are often higher than those of traditional equipment. Further, low-carbon solutions will challenge companies to revisit how they design, build, and operate their facilities. For example, as a mine operator electrifies its haul fleet, it will need to navigate a new set of operational constraints, such as optimizing charging and managing power demand.

Mines that elect to integrate variable renewable energy into their power supply will also have to recruit or cultivate new in-house expertise that operators historically didn't need.

Companies will find these implementation risks more manageable in the case of a new project, which will afford them an opportunity to plan and optimize all components, assets, and constraints from the get-go.

But existing mines are another matter. Companies must develop flexible plans that accommodate a mix of old and new solutions without impacting safety or operational performance. Those operating existing and mature mines typically fine-tune their operations over many years, and, as noted above, new technologies can introduce inefficiencies. Operators must be willing to ride out this period, and smooth over any potential bumps until they can fully capture the added value.

BOX 4 - Emerging processes could lower emissions intensity, but their impact will be limited

A series of nascent new technologies and processes could potentially help lower emissions intensities of critical minerals. These include direct lithium extraction (DLE), mine-waste resource recovery, and new recycling technologies.[14]

While these new methods hold the promise of lower emissions intensity, given their likely low volumes, their impact on the sector's overall GHGs will be limited. As the companies seeking to commercialize these solutions will need to compete with conventional production methods on cost, it will be critical that they prioritize carbon intensity in their development.

14. Direct lithium extraction is an emerging technology that seeks to extract lithium from brine sources such as underground aquifers or salt flats. Unlike conventional lithium extraction methods, which rely on large evaporation ponds that take months or years to concentrate the metal, DLE uses chemical or physical processes to extract lithium from brine in a matter of hours or days. Some evidence suggests that it can reduce the emissions associated with battery manufacturing by 34 to 91 per cent (Pinnell et al. 2024).

This factory is processing magnesium near Exshaw, Alberta Canada and is operating on a winter night.

4. A policy tool kit for decarbonizing mining

Despite the current lack of demand for clean minerals and the short-term cost challenges to decarbonize mining operations in Canada, governments have a critical role to play to maintain Canada's clean mineral advantage in the long term. Generally, the critical minerals value chain will need a combination of the following:

- **DEMAND PULL**: Buyers, importers, and manufacturers of end products that depend on critical minerals would need to prioritize carbon performance.
- **SUPPLY PUSH**: Mining companies, their investors, and governments would need to consciously support and/or prioritize low-carbon mining projects.
- **ENABLING SYSTEMS**: The mining sector, industry groups, and governments will need to match the complexity of the supply chain with transparent, traceable and comparable standards and systems that enable decision-making based on environmental performance including emissions.

For further context, Table 2 outlines the market failures that are holding back investment in Canadian mining sector decarbonization.

TABLE 2 - Links between decarbonization barriers and market failures that governments could address

Barrier	Underlying market failure	Impact on decarbonization investment	Relevant Policy Options
Lack of demand for low-carbon critical minerals	Externalities are not yet priced	Markets do not yet penalize minerals produced under poor environmental conditions, including those with high emissions intensity, and reward those produced responsibly	1, 3, 5
Lack of information infrastructure	Lack of traceability and transparency (information asymmetry)	Mineral buyers, investors, manufacturers, and customers lack information about the carbon intensity and origin of the source material	1, 3
Solutions for major mining emission sources are not yet commercially available	Underinvestment in research and development	Current incentives are insufficient for companies to fund typically high research and development costs—although solutions promise long-term benefits to both the industry and society at large	2, 5
Slow adoption of newly proven low-carbon technologies	Learning effects from early adoption of innovative technologies	Companies often struggle to fully capture the financial benefits of adopting new, uncertain technologies—leading to underinvestment in low-carbon solutions that would benefit Canadian society. Early adopters help drive down the costs of new technologies for everyone else	4, 2

Canadian governments can consider deploying a suite of policies that complement each other to address different challenges.

Here, we explore a range of policy tools at their disposal.

1. Incorporate emissions intensity in critical minerals-related policies

In our upcoming report, we explore investment support policies such as price stabilization through contracts for difference, among others.

Governments could add emissions intensity as an additional criterion for companies seeking access to future and existing critical mineral support programs, such as the Strategic Innovation Fund (SIF). This may encourage proponents to shift their projects onto lower-emissions pathways. The Government of Canada could also integrate its climate policies with those addressing industry and trade, and leverage its presidency of the June 2025 G7 meeting to build support amongst its partners for such an integrated framework.

2. Support research and development of production methods with potential to reduce emissions and costs

A set of emerging technologies may help lower the carbon intensity of Canadian critical minerals production. These include:

- Piloting and testing of zero-emissions mining equipment and supporting infrastructure
- Direct lithium extraction
- Mine-waste resource recovery
- Recycling of mineral-rich products

While these solutions currently carry higher costs relative to conventional production methods, they could potentially reduce critical minerals' emissions intensity while rapidly responding to a ramp-up in demand.

The federal government can help de-risk these technologies by expanding the Critical Minerals Research Development and Demonstration program to include low-carbon mineral production and processing methods (Government of Canada 2024).[15]

15. The Critical Minerals Research, Development and Demonstration program allocates $192 million, with improved environmental performance as one of the expected project outcomes.

3. Directly support junior mining companies on carbon assessments and certifications

Junior mining companies often operate on limited budgets, and sustainability assessments understandably take a back seat to exploration and operational activities. Until carbon accounting and other practices become fundamental to business planning across the industry, governments can offer dedicated funding to support them.

At least one Canadian government has already recognized this benefit. In 2022, the Province of Quebec began offering mineral exploration companies and their service providers funding to pursue a pair of industry-specific standards under the ECOLOGO UL certification (Province de Québec n.d.). The standards provide third-party auditing of a mining company's sustainability practices (UL Solutions in Canada n.d.).

If companies begin pursuing third-party verification of their environmental performance, buyers and investors will be better equipped to differentiate clean minerals in the marketplace.

4. Require companies that receive funding for decarbonization projects to share outcomes

For obvious and understandable reasons, companies that invest in new technologies do not generally disclose their outcomes and findings. But when public funding supports technologies that improve environmental performance, it's reasonable to expect a level of transparency, so that society can benefit from the insights gained.

The federal government could require the companies it supports for new decarbonization technologies to disclose their best practices, lessons learned, and implementation findings. This could potentially help close knowledge gaps, accelerate learning rates, and reduce costs.

The Carbon Capture, Utilization, and Storage Investment Tax Credit already includes such a provision. But, as of yet, there is no corresponding disclosure requirement for companies pursuing the Clean Technology Investment Tax Credit, which mining companies can access for zero-emission mine vehicles and related equipment.

As a caveat, we recognize that any such knowledge-sharing requirement should balance the need to socialize a company's findings while minimizing administrative burden.

5. Maintain and enhance existing policies such as large-emitter trading systems and Clean Technology Investment Tax Credit

Existing policies such as Canada's large-emitter trading systems (LETS) and Clean Technology Investment Tax Credit (CT ITC) have proven instrumental in driving decarbonization investment in mining. LETS are the most significant policy driver of emissions reduction in Canada (Beugin et al. 2024) and the mining industry supports climate policy that addresses competitiveness and carbon leakage (The Mining Association of Canada 2022, MABC 2024).

Companies have an incentive to invest in decarbonization. For example, the CT ITC allows companies to recover up to 30 per cent of capital costs on certain investments such as non-road zero-emission vehicles and related charging or refuelling infrastructure.

To continue this investment momentum, mining companies require certainty about future LETS credit prices. Companies will invest in decarbonization if adjustments to LETS provide stronger certainty about robust credit markets (Sawyer and Linden-Fraser 2025; Sawyer, Linden-Fraser, and Beugin 2024). Policy stability in Canada can stand in contrast to policy uncertainty in the U.S. where shifts in the political landscape have started to cause uncertainty around decarbonization investment.

As investment in new critical minerals ramps up, existing regulations will have to be responsive to market and technological shifts, including what and how minerals are produced. For example, output-based standards will have to incorporate benchmarks for new commodities such as lithium, which can be produced as concentrate in Quebec to be further refined or through direct lithium extraction from brine that is expected to produce battery-grade lithium that doesn't require additional refining in Alberta. (E3 Lithium 2025).

Nemaska Lithium is seen under construction in Becancour, Que., on Wednesday, March 5, 2025. THE CANADIAN PRESS/Christinne Muschi

5. Conclusion

As nations jostle to secure the raw ingredients of tomorrow's technologies, Canada's abundant reserves and clean-energy resources position the country as the reliable clean minerals supplier of choice.

Producers, buyers, investors, and governments will need to surmount multiple hurdles to achieve and maintain that competitive edge. Canada must scale up its mining operations to meet the anticipated demand surge. But it must do so while reducing emissions and maintaining its low-carbon advantage.

The market isn't yet demanding low-carbon minerals. And even if that were to change tomorrow, a lack of transparency and traceability measures make them virtually indistinguishable from conventionally produced resources.

In a carbon-constrained global economy in the future, buyers seeking to reduce their supply-chain emissions will need to source cleaner minerals for their products. Investors will have to hold mining companies accountable to their decarbonization strategies, and mining companies will have to start aligning their capital and growth plans with their climate goals.

Governments could play an important role in this transition by integrating carbon reduction goals in all critical mineral-related policies and programs. Current policies are working. Strengthening existing policies, such as the large-emitter trading systems (LETS) can help the critical mineral industry reduce its emissions intensity while remaining competitive. Other policy tools—such as incentivizing low-carbon practices, facilitating knowledge sharing, and strategically funding early-stage technologies—can accelerate investment in decarbonizing mining operations.

Despite the currently lower investor focus on climate commitments, virtually all major mining companies are actively working to reduce their emissions. They understand that climate risk remains an investment risk (Arnold 2025).

Critical mineral mining is a major opportunity for Canada in the face of global efforts to decarbonize. Canada can realize this opportunity without exacerbating domestic emissions challenges. If Canadian governments maintain and implement smart policies, companies can ramp up their critical minerals production and also meet their long-term emission reduction targets. All actors can and should work together to deliver on new low-carbon economic opportunities.

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