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A worker-centered path to cut emissions, increase value added and strengthen global supply chains

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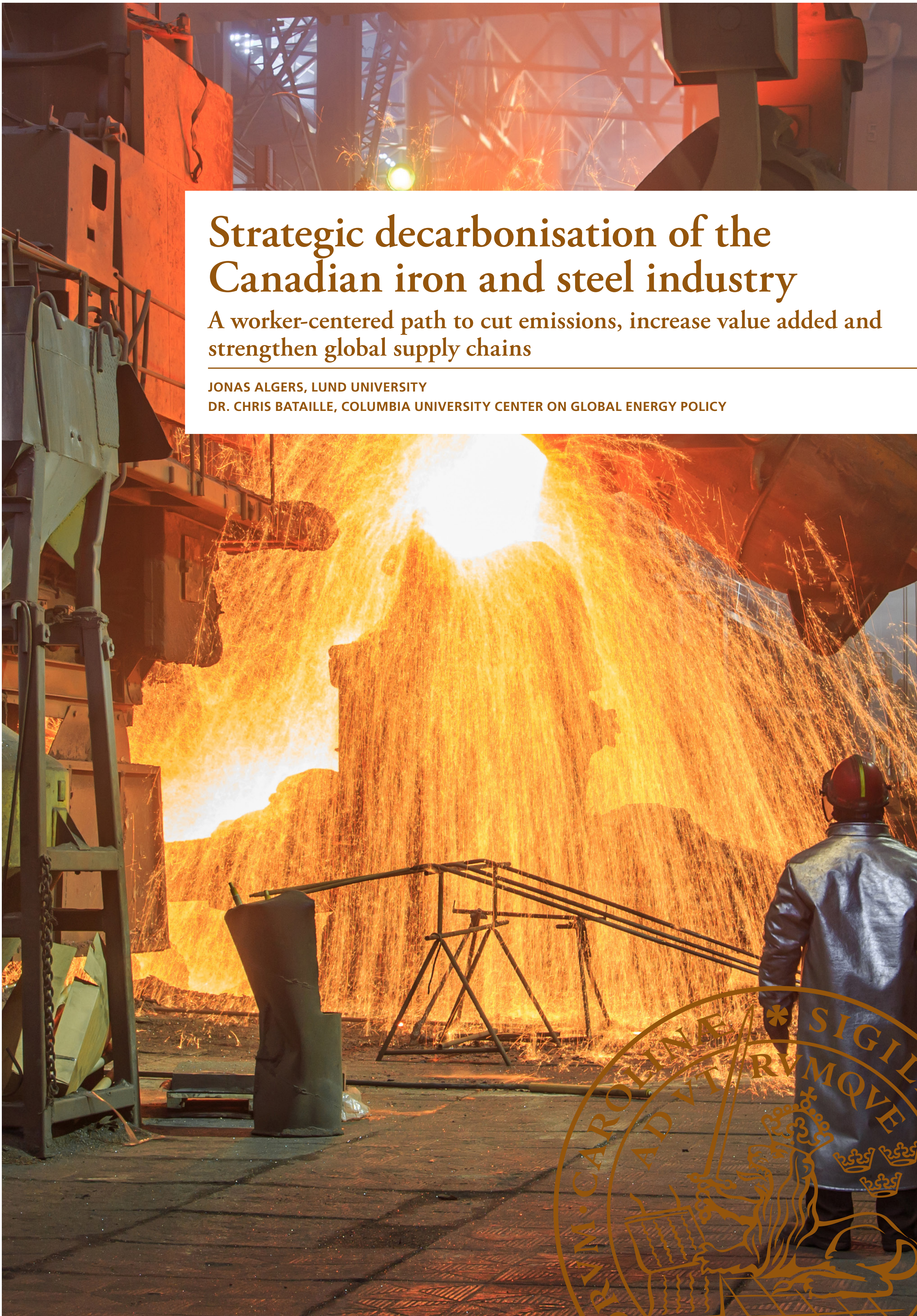

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1. Preamble

Climate action is a top priority for Canadians. In recent years, they have experienced wildfires and extreme weather, powerful indicators that global heating is spiralling out of control. Continuing to delay action will only increase the frequency and intensity of these events. It is unsurprising, then, that a large majority of Canadians – in particular Ontarians, Québecois and British Columbians – agree that if their government does not act on climate now, it will be failing its people (Simpson, 2023).

As a party to the Paris Agreement, Canada has set the bar high for climate action. In 2021, the Canadian Net-Zero Emission Accountability Act was enshrined into law, cementing the government's intention to reach net-zero emissions by 2050, setting five-year emission reduction targets and publishing plans on how to reach them (Canada.ca, 2024a). Transitioning to net-zero is a challenging task, one where key opportunities and high risks have to be carefully weighed up in order to achieve a transition that is effective, rapid, and politically sustainable.

This report was conceived of and produced because Canada's iron and steel industry could decarbonise in a way that ticks many crucial boxes – reduce emissions, create well-paid jobs, and strengthen global green supply chains. The iron and steel sector is one where Canada is already a significant global player, with natural resources providing comparative advantages. Moreover, it is a sector where Canada can contribute to large emission reductions both at home and abroad. Lastly, the sector is an important employer, providing family-sustaining wages for people with varying education levels.

The aim of this report is to analyse Canada's potential to transition to a low-emission iron and steel industry. It opens by explaining how steel is made and the recent technological advances that have made a transition to green steel possible. It maps out the evolving global context, one that posits both risks and opportunities for the transition. The report then analyses the potential for a transition in the upstream iron sector – with Canada being a major iron ore exporter, this sector has the potential to enable large emission reductions and new export revenue. To add context on feasibility, the report weighs up the potential for an iron and steel transition in Canada by making comparisons with Sweden - where green iron and steel decarbonisation processes are more advanced, and delving into the implications of such a transition for workers. The analysis also covers the metallurgical coal sector, which supplies coal for the global steel industry, and the risks associated with an expected global fall in demand. Lastly, the report considers decarbonisation as a transition to a new iron and steel value chain.

By capitalising on existing opportunities, Canada could speed up innovation and industrial development, while reducing emissions domestically and helping trading partners to reduce theirs. By leveraging its competitive advantages of large high-grade iron ore reserves, strong renewable energy resources and advanced infrastructure, Canada could demonstrate clean technology and commercial viability at scale, enabling other countries to follow in its footsteps. Such a transition plan could provide significant emission reductions, more value added captured in Canada, and stronger employment prospects for people working in the industry.

2. Executive summary

The context:

The global steel, iron and metallurgical coal industry is emission intensive. While the Canadian steel industry is cleaner relative to peers, it still contributes to 2 percent of national emissions. If counting total domestic and foreign emissions produced when making steel from Canadian iron ore, we reach 105 Mt CO2, which is equivalent to 16 percent of Canada's territorial emissions. The Canadian government has set the target to reach "net-zero" emissions by 2050, which will require a rapid reduction of domestic emissions. The rest of the world will also need to transition away from using fossil energy, presenting a critical opportunity for Canada, a major iron and metallurgical coal exporter, to reimagine its contribution to the global market.

Canada's steel industry is significant and can be decarbonised in tandem with its iron industry. It is, however, in Canada's upstream iron making and metallurgical coal mining activities that we identify the country's biggest potential contribution to abate the global steel industry's emissions. Canada produces about 13 million tonnes of steel per year, of which about half is emission-intensive, and primarily made using coal. However, Canada has much larger deposits of iron ore than it needs for its domestic industry, meaning that it exports most of its iron ore for use abroad. In 2023 Canada exported over 44 million tonnes of iron ore, making it one of the largest exporters of iron ore in the world. This could instead be exported as green iron in the form of "Hot Briquetted Iron" (HBI), supporting global decarbonisation. Canada also exports significant amounts of metallurgical coal – 28 million tonnes in 2022. These exports currently fuel emissions-heavy coal-based steel production globally.

The challenges:

At the time of writing, several emission-intensive steel mills did not have transition plans in place. These include Stelco and ArcelorMittal Contrecoeur, which have no announced plans to reduce emissions from their current levels, let alone to the "near-zero" emissions needed to comply with the Paris Agreement. While Contrecoeur has low emissions compared to other existing mills, it remains unclear how the two sites will reach net-zero emissions by 2050 – which is both a government and Canadian Steel Producers Association (CSPA) target.

Existing transition plans at the Algoma and ArcelorMittal Dofasco steel mills are experiencing significant delays and/or lack of clarity as to the path ahead. The ArcelorMittal Dofasco site is the largest steel mill in Canada and has been awarded a grant from the federal government to support its transition. Whatever technology route ends up being used at Dofasco, the decarbonisation of this site will be a key test for the Canadian steel industry and government, as this transition plan is more complex than the one at Algoma that is already underway.

It remains unclear whether these existing transition plans will hit the "near-zero" emissions needed to align with the Paris Agreement. The transition plan for the ArcelorMittal Dofasco site, for instance, aims to switch from coal to fossil gas. While this would indeed reduce emissions from current levels, the reduction will not be substantial enough to meet the International Energy Agency's (IEA's) classification of "near-zero", which is what is needed to reach the targets of the Paris Agreement.

Several transition plans imply job cuts across sites, placing much of the burden of adjusting to a Paris-compliant industry on the shoulders of workers. This risks undermining the political sustainability of the transition, unless there is wider retraining and creation of new employment opportunities. While any major industrial shift is likely to lead to large geographic changes in terms of employment, workers must be factored into and not left behind by the transition. It is important, then, that the transition of the steel industry is not a simple reduction of emissions, but includes a comprehensive plan to strengthen employment opportunities in new sectors.

Canada is a leading player in the declining metallurgical coal industry. Canada is an important global player in the metallurgical coal market, with several important mines in the west of the country, in British Columbia and Alberta. However, across all scenarios in the IEA's World Energy Outlook, export revenue, jobs and profits in this sector are set to decline – the only question is how quickly. This reality can be faced in two ways: passive acceptance, or actively transitioning away from the market before the market transitions away from Canada.

The opportunities:

Five factors stand out as key enablers of an ambitious Canadian steel transition. 1) Rich iron ore resources, 2) large potential for wind expansion near iron ore resources, 3) strong power and transport infrastructure, 4) a highly skilled workforce, and 5) broad political backing for net-zero emissions by 2050.

The shift away from fossil fuels is an opportunity for Canada to diversify its exports and strengthen supply chains amidst growing geopolitical challenges. With a comprehensive strategy to decarbonise its iron and steel industry, Canada could reduce emissions, increase value added, and generate essential jobs. This report estimates that Canada could competitively develop a domestic green hydrogen-based iron industry, increasing annual value added by up to 25 billion Canadian dollars, and creating more than 14 000 jobs in a maximum case, plus jobs in the renewable energy and power sector. Such a transition could lead to a net increase in jobs and value added while slashing emissions at home and abroad.

This transition is enabled by the technological switch towards direct iron reduction for steelmaking, a technology route that has lower emissions and enables a separation of key parts of the steelmaking supply chain. Rather than transporting iron ore and coal to a site where the inputs are transformed into iron and then steel, iron can be made closer to iron and renewable energy resources for shipping to steel mills elsewhere. Thanks to its strong iron and renewable energy assets, Canada could become a major green HBI producer and exporter, reducing emissions, creating jobs and strengthening global green supply chains.

Canada produces high-quality iron ore in large quantities. Several companies in Canada are already investing to enable further processing of iron ore from their mines to ensure it can be used in “direct reduction”’ – one of the routes used in low-emission steelmaking. Some mines are not making these investments yet but have a high grade of iron ore. Developing production of high quality iron ore will be necessary to shift iron production away from the conventional route based on the blast furnace, towards the direct reduction route.

The bulk of Canada’s iron ore assets are in the east of the country, where population density is low and wind speeds are good, making it well-placed for an expansion of wind power. There are also strong hydropower assets in the area that have strong integration benefits with intermittent renewable energy. In this way, Canada is similar to Sweden, where several large iron and steel companies have launched ambitious strategies to decarbonise their entire production with low-cost renewable energy.

The Québec grid is well-developed, having been built to transport hydropower from the north to population centres in the south. This could be an important asset if new, power-intensive iron reduction plants were located in the area. There are also already rail tracks, which are needed to transport iron ore to the coast, and ports that could be used for shipping green iron. These assets would be key to a rapid transition and quickly establishing Québec and Canada as a reliable supplier of green iron ore.

Most iron ore mines are located in Québec and Labrador. These areas have a strong industrial tradition and skilled workers. While workers have too often been on the losing side of industrial transitions, this one to export green iron would require a large number of skilled workers to build the necessary energy and industrial assets, as well as to operate the electrolysers and direct reduction furnaces. This will require careful consideration of how the labour market can develop to support new industrial development.

Looking ahead:

Although policy recommendations do not fall within the scope of this report, two overarching policy related challenges must be addressed. Firstly, steering the global market towards low-carbon steelmaking, and, secondly, managing the geographic impacts of Canada’s iron and steel industry:

Diplomatic efforts to ensure demand for green iron and steel products will likely be needed. Together with other large iron ore exporters with scope to export green iron (e.g. Australia, Sweden, South Africa), Canada has the potential to reduce trading partners’ emissions, strengthen global supply chains, and ease pressure to expand renewable energy. These countries could form a significant negotiating bloc within existing international initiatives to coordinate industrial decarbonisation, such as the Climate Club, Leadership Group for Industry Transition (LeadIT), Industrial Deep Decarbonisation Initiative (IDDI), and industry-specific forums such as the OECD steel committee. What could be even more effective, though, is a joint diplomatic effort to market these countries’ offerings to potential buyers.

The iron and steel transition will not affect all parts of Canada equally. It is likely that demand for labour will fall in Ontario as the province’s large steel mills transition away from integrated sites to simpler electric arc furnaces. At the same time, demand for metallurgical coal will fall in the west of the country, while the potential for green iron exports would primarily create opportunities in the east. With such a potentially uneven geographic distribution of risks and rewards, the politics of the transition could become quite complex – citizens in a "losing" part of the country may not want to support the development of the "winning" part of the country. This would increase pressure on the federal government to proactively consider how to support the transition to "net-zero" across the country.

Canada is better placed than many countries to quickly transition its iron and steel industry. Thanks to its plentiful and high-quality iron resources, strong renewable resources, good infrastructure and skilled workers, Canada is well-positioned to domestically reduce iron ore for use in steelmaking both at home and abroad. Emissions can be reduced incrementally through investments in the best available technology. In doing so, the iron and steel industry could show that decarbonisation is possible and enable other emission-intensive industries to find comparable ways to hit Canada's target of net-zero emissions by 2050.

1 Introduction: Steel, iron and metallurgical coal production in Canada

The global steel industry has a significant emission reduction potential. Today, the sector emits about 11 percent of the world's CO2 emissions across the supply chain (International Energy Agency (IEA), 2019), making it one of the largest industrial sectors by emissions. In Canada, the steel industry produces 2 percent of total domestic emissions (Khan et al., 2023) and contributes about 4.2 billion Canadian dollars to GDP (CSPA, 2024a). The industry is also an important employer, with 23 000 workers employed directly in the industry and more than 100 000 jobs indirectly supported by the industry (CSPA, 2024b).

There are eight significant steel mills in the country, with most located in the provinces of Ontario and Québec. In this report, we will focus on the largest and most emission-intensive mills – the ArcelorMittal Dofasco, Algoma and Stelco mills in Ontario, and the ArcelorMittal Contrecoeur mill in Québec. These top steel mills are shown in the table below.

Table 1: Top emission-intensive steel mills in Canada

Steel mill	Location	Production capacity (Mtpa)	Emissions (Million tonnes)	Workforce
ArcelorMittal Dofasco	Hamilton, Ontario	4.05	4.7	5000+
Algoma	Sault Ste. Marie, Ontario	3.2	4	2700
Stelco	Nanticoke, Ontario	2.5	3.5	1370
ArcelorMittal Contrecoeur	Contrecoeur, Québec	2.4	1.1	1900

Usually, the size of a steel mill is given by its annual production capacity. The largest mill in Canada is ArcelorMittal Dofasco, located in Hamilton, Ontario. It has a current production capacity of 4.05 million tonnes of steel per annum (mtpa) (Global Energy Monitor, 2024). The mill emits over 4.7 million tonnes of carbon dioxide per year (Crawley, 2022) and has a plan to reduce emissions. The second largest mill is the Algoma mill, located in Sault Ste. Marie, Ontario. Algoma has a production capacity of 3.2 mtpa, but this is set to increase to 3.7 mtpa as part of their ongoing transition (Global Energy Monitor, 2024). This site emits over 4 million tonnes of CO2 per year (Crawley, 2022). The third largest mill is the Stelco site in Nanticoke, Ontario on Lake Erie, with a production capacity of 2.5 mtpa (Global Energy Monitor, 2024). This mill emits over 3.5 million tonnes of CO2 per year (Crawley, 2022). Finally, the fourth largest steel mill in Canada is the ArcelorMittal site in Contrecoeur, Québec. This site has a production capacity of 2.4 mtpa (Global Energy Monitor, 2024), and emitted about 1.1 million tonnes of greenhouse gases in 2022 (ArcelorMittal, 2023; Arsenault, 2022). Its significantly lower emissions relative to the Stelco site, which has similar production capacity, is due to its use of a different technology and fossil gas, which will be explained in depth later in this report. Together, the top four steel mills employ about 11 000 workers.

The contemporary steel industry depends on iron and coal inputs, making the steel industry just one part of a larger, highly interdependent supply chain that will be significantly affected by any steel transition. Crucially, Canada is also a major producer and exporter of iron and metallurgical coal, both of which are used in conventional steelmaking. These iron ore and coal exports fuel high emissions outside of Canada. With the rest of the world transitioning away from fossil-based steelmaking, demand for these resources will be significantly impacted.

Canada is a large iron ore mining country, with 69 million tonnes of iron ore mined in 2022 (Natural Resources Canada, 2024b), contributing about 5 billion Canadian dollars to GDP (Natural Resources Canada, 2024d). The mines are mainly located along the geological formation called the Labrador Trough, along the Québec and Labrador border in the east of the country. This is where 92 percent of Canadian iron ore is mined, with one iron ore mine further north on Baffin Island. The mines are important employers in remote parts of the country, providing jobs to over 9000 workers according to the companies themselves (ArcelorMittal, 2024a; Champion Iron, 2024b; Rio Tinto, 2024; Tacora Resources, 2024; Wat, 2024). The mines are outlined in the table below.

Table 2: Iron mines in Canada

Mine	Production capacity (mtpa)	Location	Owner
Fire lake	4	Québec	ArcelorMittal
Mont Wright	22	Québec	ArcelorMittal
Bloom Lake	15	Labrador	Champion Iron
Scully	4	Labrador	Tacora Resources
Carol lake	17	Labrador	Rio Tinto
Menihek region	4	Labrador and Québec	Tata Steel Minerals Canada
Mary River	6	Baffin Island	Baffinland Iron Mines Corporation

Metallurgical coal is an important mining industry supplying the iron and steel sector. Over 27 million tonnes of metallurgical coal was mined in Canada in 2022 (Natural Resources Canada, 2024a), and these mines are located in eastern British Columbia and western Alberta. Total coal mining contributes about 12.5 billion Canadian dollars to Canadian GDP, or 17 percent of the value of minerals mined (Natural Resources Canada, 2024c), though this includes thermal coal. Today there are about 5400 workers employed in metallurgical coal mining, in remote parts of the Rocky Mountains. The mines are compiled in the table below.

Table 3: Metallurgical coal mines in Canada

Mine	Location	Owner	Production capacity (Mtpa)
Willow Creek	British Columbia	Conuma Coal Resources Ltd.	5
Brule	British Columbia	Conuma Coal Resources Ltd.	
Wolverine	British Columbia	Conuma Coal Resources Ltd.	
Grande Cache	Alberta	CST Canada Coal Limited	1.3
Fording river	British Columbia	Glencore	26
Greenhills	British Columbia	Glencore	
Line Creek	British Columbia	Glencore	
Elkview	British Columbia	Glencore	

The global iron and steel transition will greatly impact the value of these assets, with demand for metallurgical coal declining as the steel industry shifts away from coal-based production. An exit strategy is therefore needed to ensure that the transition away from coal does not inflict social and economic damage to the communities in question. On the other hand, the iron sector has potential for significant growth. Canada's rich iron ore and renewable energy assets give the country a significant advantage as the global steel industry shifts from coal to low-carbon steelmaking. This will be explained further in the report. However, to understand this potential, we have to first lay out the technological options for low-carbon steelmaking and the global context in which the Canadian iron and steel transition is happening.

2 Technological and global context

2.1 From a “hard-to-abate” to “decarbonisable” sector

Recent advances have transformed the iron and steel sector from a “hard-to-abate” to “decarbonisable” sector. Previously considered to be difficult to transform, there are now new ways forward for the steel industry (IEA, 2019, 2023b; Kupzok & Nahm, 2024; Vogl et al., 2018).

The traditional, highly emission-intensive way of making steel is the blast furnace-basic oxygen furnace route (BF-BOF). First, iron ore and coal are mined and turned into pellets and coke respectively. These two resources are then used in a blast furnace to reduce the iron ore to iron, which is by far the most energy and emission-intensive step in the traditional steelmaking process. This iron is then turned into steel in a basic oxygen furnace by precisely setting the carbon level (at 0.01-2 percent). About 70 percent of the world’s steel is produced in this way (IEA, 2019) and, including indirect emissions, results in almost 3 tonnes of CO2 per tonne steel[1] (IEA, 2022).

Scrap-based steelmaking (also called “secondary steelmaking”) has been in the mix for a long time. In this instance, steelmaking is based on melting scrap that already has (close to) the right chemical properties. It is done in an electric arc furnace (EAF) that can be powered with clean energy, thereby producing steel with low emissions. However, because of the limited supply and unequal geographical distribution of scrap, and the (so far) more limited quality of the steel produced with scrap, primary steelmaking will still be needed in the future. Therefore, the main challenge facing the iron and steel industry is how to produce primary steel with low emissions.

Today, there are new low-carbon steelmaking technologies that make it possible to quickly decarbonise this industry. By using green hydrogen instead of coal, steel emissions can be reduced to a very low 53 kg per tonne steel (Vogl et al., 2018). Using hydrogen requires a switch to a direct reduction furnace – reducing the iron ore into direct reduced iron (DRI) fed into an EAF, where the DRI is made into steel with very low emissions. There are several green steel projects across the globe that are planning to use this technology in commercial-scale projects, which are set to come online around 2026 (Vogl et al., 2023), as it is the most likely technology to deliver large emission reductions in line with the Paris Agreement’s timelines.

[1] This figure includes emissions from fossil fuel use in iron ore agglomeration, producing reduction agents, fossil fuel use in ironmaking, fossil fuel use in steelmaking, lime fluxes, electrodes, off-gases, imported electricity, heat and hydrogen, fossil fuel supply, raw material supply. Emissions included in fossil fuel supply cover extraction, processing and transportation of coal, oil and fossil gas, including methane emissions and flaring.

2.2 Iron and steel decarbonisation in times of geopolitical rivalry

The iron and steel sector is an important upstream sector producing a material that is widely used across downstream sectors and is therefore often considered to have strategic value. Switching away from importing coal to using domestically sourced renewable energy has become increasingly attractive for steelmaking countries.

However, the transition of the iron and steel industry is happening at a time of growing geopolitical rivalry and economic competition. The growth of China in industrial production has become a key concern for policymakers in Ottawa, Washington D.C., and Brussels alike, and ensuring that industry can both decarbonise and remain competitive is a key priority. Today, China is by far the largest steelmaking country, producing around 54 percent of all steel on the planet, well ahead of the second country, India, at 7 percent, not to mention Canada at 0.6 percent (WorldSteel, 2023). China is also dominating both the supply of critical raw materials as well as production of key low-carbon technologies needed for the green transition (IEA, 2023a).

Meanwhile, the European Union has launched its Carbon Border Adjustment Mechanism (CBAM) which will tax the import of emission-intensive steel, cement, aluminium, hydrogen and electricity, and eventually all goods, which will significantly impact global steel supply chains. The US has introduced large legislative packages such as the Inflation Reduction Act investing in domestic low-carbon production. Together, Washington and Brussels tried to negotiate a Global Agreement on Sustainable Steel and Aluminium (GASSA) that would build a new trade-club of likeminded countries to support the development of cleaner industries and address the global overcapacity of emission-intensive production. Prior to the US election, the White House announced that they had established a new team to work on the joint issues of climate and trade (Podesta, 2024), and trade will receive substantial attention and likely increases in tariffs under the Trump Administration.

Overall, the decarbonisation of industry in general, and steel in particular (due to its high trade share) will be significantly shaped by the geopolitical tensions of today.

2.3 A worker-centered transition

Transitioning the iron and steel industry will directly affect the lives of tens of thousands of people. This sector is an important employer, providing well-paying jobs for workers with and without college degrees. It directly employs 23 000 workers and supports up to an additional 100 000 workers in Canada (CSPA, 2024). The iron and metallurgical coal mining sectors employ several thousands more across the country and are often key in supporting local communities in more remote parts of the country.

Recent history shows that, for a transition to be politically sustainable, it has to have workers and local communities at its heart. If people feel they have historically been on the losing side of deindustrialisation, and due to be hit once more by policies developed in far-away capitals for an abstract “greater good”, then it is unlikely that they’ll perceive decarbonisation as being in their interests (see e.g. Breetz et al., 2018; Meckling & Karplus, 2023; Meckling et al., 2015; Voeten, 2024) for an analysis of political dynamics of decarbonisation). Such a transition risks providing fertile ground for climate-scepticism.

At the same time, transitioning to a net-zero world is an enormous task, which of course can only come to fruition if there are workers able to build the necessary infrastructure, industry and technology to replace the existing fossil-based global energy system. It will be difficult to have any meaningful transition without workers. If the transition is a well-planned process towards a new, low-emission iron and steel industry, rather than a series of site closures and offshoring of work and emissions, then it could create significant opportunities for working people across Canada.

The iron and steel transition has the potential to be a net job creator in Canada, through an expansion of green iron production. By leveraging the competitive advantages of an already skilled and organised Canadian workforce, the expertise and know-how concentrated in existing industrial sites, and the well-developed infrastructure across the country, policymakers and companies can make decarbonising Canada's iron and steel industry an attractive proposition to the workers and communities affected. This is highly necessary to ensure the transition happens quickly and is politically sustainable.

2.4 Low-emission steelmaking technology routes

In 2022, the International Energy Agency (IEA) published the report Achieving Net Zero Heavy Industry Sectors in G7 Members to advise and guide G7 countries on their path to net-zero emissions. The report includes a key comparison of steelmaking production routes and their global average emission levels, as well as a comparison with the "near-zero" emission levels possible. The "near-zero" definition is used to show what emission levels are possible with known technologies, while acknowledging that zero-emission production is either technically difficult or economically unviable.

The IEA defines "near-zero" as producing 400 kgCO2e/tonne steel in the primary route, using 100 percent iron ore as a metallic input, with the threshold falling down to 50 kg CO2e/tonne steel as the share of scrap increases to 100 percent[2]. This can be compared to the global average BF-BOF emissions of 2 945 kg CO2e/tonne steel across the supply chain for the BF-BOF route. As its power supply is already at almost zero emissions, Canada has an advantage in reaching near-zero emission production compared to other countries with more emission-intensive power production.

[2] It is possible and economic to blend scrap in various primary steelmaking routes in order to reduce costs and to manage temperatures in liquid metals. The US company NUCOR in particular has focused on using as much scrap as possible, blending in new DRI based iron as necessary to meet batch requirements.

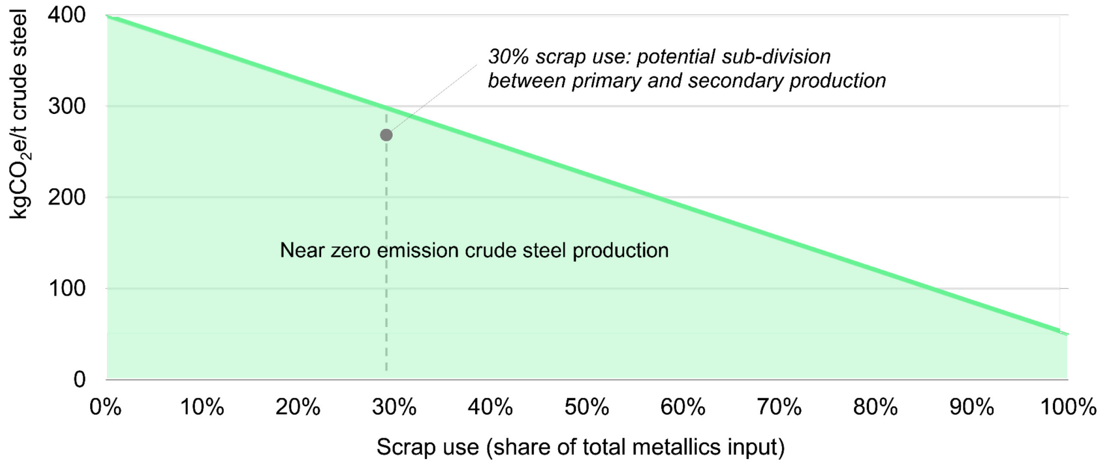

Figure 1: IEA linear emission threshold for the "near-zero emission" crude steel definition (IEA, 2022).

Several companies are planning to reduce emissions by retrofitting the traditional BF-BOF with carbon capture storage (CCS) technology. The advantage of this approach is that it does not require the replacement of the existing BF-BOF facilities and therefore is less capital intensive and allows for operations to continue without any major changes. In its report, the IEA shows that the BF-BOF-CCS route can reach below the threshold of 400 kg CO2e/tonne steel by 2050 (IEA, 2022). However, this estimate does not include retrofits – i.e. IEA estimates that, by 2050, we will be able to build new, advanced BF-BOF-CCS facilities that have high enough capture rates to reach below the near-zero emission threshold. Until then, CCS technology in new facilities will not be sufficient to reach net-zero. With retrofits on existing facilities, the capture rate is even lower. The latest Intergovernmental Panel on Climate Change (IPCC) report finds that it is "difficult to retrofit BF-BOFs beyond 50% capture, which is insufficient for long-term emission targets" (Bashmakov et al., 2022).

The steelmaking route with the lowest emissions estimated in future production is the H2-DRI-EAF route, using hydrogen as a reductant, normally made from electrolysis of water with electricity. If the hydrogen used is produced with low-carbon electricity, this steelmaking route (known as H2-DRI) has emissions of about 53 kg CO2/ tonne steel (Vogl et al., 2018). Canada – in particular the iron ore mining province of Québec – has very low emissions from power production, and therefore is well placed to reach very low emissions in H2-DRI production early. This technology also has the benefit of enabling a separation between the ironmaking step (called "iron reduction") and the steelmaking step. While blast furnaces and basic oxygen furnaces have strong integration benefits, primarily in the energy saved by not reheating the material, iron made in the iron reduction step can be compressed into tradable iron products after reduction in a direct reduction furnace, into briquettes called "Hot Briquetted Iron" (HBI). Therefore, the energy-intensive ironmaking step can be located where there are strong low-carbon energy sources and shipped to steel industries elsewhere.

The DRI-EAF route using fossil gas and carbon capture can reach low emissions (albeit higher than hydrogen) but requires large investments in new fossil-based infrastructure and it is difficult to reach high carbon capture rates. The world's only commercial-scale steelmaking site is the Al Reyadh DRI-EAF site in the United Arab Emirates, where only about 25 percent of total emissions are captured (Nicholas & Basirat, 2024). Other technologies in the IEA compilation are either at a very early stage of development (iron oxide electrolysis) or have a lower long-term emission-reduction potential. In this report, we will therefore look more closely at the H2-DRI-EAF route, as this route has good potential to reduce emissions in the short term and because of Canada being rich in low-carbon energy and iron ore.

Critically, steelmaking facilities and related infrastructure are major investments with a payback time that lasts several years. Building or updating a steelmaking facility can often require a pause in operations, incurring major loss of revenue (Vogl et al., 2021). If a facility is to be replaced there are significant outlays required in demolition, environmental clean-up costs, and pensions for workers that have technology-specific skills that are no longer needed. These costs can be significant (Rimini et al., 2020) and pose significant barriers, making the steel industry expensive and, correspondingly slow to change (Algers & Åhman, 2024; Deily, 1988; Grubb et al., 1995). It is therefore important that the path all the way to net-zero emissions is considered when making technology choices and investing in new facilities in order to avoid costly investments in facilities that will have to be replaced again before reaching net-zero in 2050.

Reaching net-zero does not, however, require moving to a given technology at a single point in time. Rather, "net-zero ready" facilities and investments can be a way to move along a path to net-zero emissions while allowing for the upstream or downstream supply chain to adjust over time. This could be, for example, building a steel mill that can use hydrogen as the reductant when costs fall sufficiently, and thus is "hydrogen-ready" while waiting for the hydrogen to be supplied in sufficient quantities, and in the meantime using fossil gas.

However, the key limiting principle with this "net-zero ready" approach to decarbonisation is that investments in temporary feedstock or fuel should not be so large as to disincentivise a switch to low-carbon feedstock when it is ready – i.e. the payback time on the investment in temporary fuel must be short enough for the switch to low-carbon fuel to be economical as soon as possible.

2.5 Blue and green hydrogen

Hydrogen can be produced in various routes. The two we will discuss here are the "blue" and the "green" types. The first is produced from fossil gas – carbon dioxide is separated, captured and removed, leaving hydrogen as the remaining product for further use. The second is produced via electrolysis – water is split into hydrogen and oxygen in an electrolyser using clean power. Both routes are likely to be used on the path to net-zero, with geographic specialisation depending on the resources (clean power, fossil gas, water) and carbon dioxide storage sites available, factors which affect the costs of either option. The reduction in the cost of electrolysers will also affect the affordability of green hydrogen.

Both green and blue hydrogen have their limitations. Green hydrogen requires large amounts of clean power – 50 kWh of power/kg hydrogen (Vogl et al., 2018) – making the cost of clean power the central cost component of this route. Blue hydrogen, on the other hand, is more energy-intensive, risks leakage of carbon dioxide at the transport and storage stages, and is vulnerable to upstream fugitive methane leakage, all of which can lead to lower emission-reductions than calculated and large local pollution (Nicholas & Basirat, 2024).

Steelmaking using green or blue hydrogen requires some sort of storage. Large-scale storage has been tested and proven to reduce the cost of green hydrogen by up to 40 percent by leveraging power markets (Vattenfall, 2023). This means green hydrogen for steel has strong integration benefits with intermittent renewable energy. By limiting the production of hydrogen to the times that power prices are low, it can be produced at an overall lower cost.

2.6 Competitiveness of low-carbon steel

The commercial viability of low-carbon steelmaking will depend on its competitiveness against both carbon-intensive steel and other low-carbon sites, with different factors influencing each type of competitiveness.

To be competitive, the price premium for low-carbon steel must be as low as possible, which can be accounted for by emphasising the differences between “green” and “carbon-intensive” steel (known as “product differentiation”). In this way, differences in cost can be managed either through carbon pricing or passing the higher costs onto consumers. Carbon pricing increases the cost of production with high emissions. As this cost is then passed onto consumers, it raises the price of, and thus disincentivises the purchase of, emission-intensive products. Through carbon pricing, low-carbon steelmaking can become competitive, as the initially higher costs of producing steel are balanced against the now higher costs of the carbon emissions of the traditional route. Carbon pricing can therefore be an important measure for incentivising the use of low-carbon steel and shaping the market. However, as the Canadian steel industry is highly integrated with the wider North American industry (about half of Canada’s steel is exported, primarily to the US), the US would also need to price carbon (or impose alternative cost-increasing “sticks”, such as strict emission regulations) for this measure to be viable. This may be unlikely in the short term with new US administration, but more so in the medium-to-long term.

Another way to manage the higher costs of low-carbon steel production is by passing on the “green premium” to consumers, by selling a “green” product at a higher price. Few consumers buy crude steel – most of us buy products like cars, domestic appliances and computers, or use bridges, railways and houses that have embedded steel in them. As such, steel is merely a cost component of final goods, and price increases for steel translate to smaller price increases for the end product. Currently, price increase estimates are around 0.3-2.1 percent for a car, a house or a domestic appliance using low-carbon steel rather than emission-intensive steel (Delasalle et al., 2022). Automakers and other companies could therefore sell a product that uses low-carbon steel at a higher price and capture a consumer segment that is interested in paying more for such products, a comparable example being electric vehicles relative to traditional vehicles (Bataille, Stiebert, Algers, et al., 2024). Combining a carbon price and a green premium passed on to consumers is likely to be the most effective approach that policymakers and corporations can employ to boost the competitiveness of low-carbon steel against emission-intensive steel.

A still greater challenge lies in making early individual low-carbon steelmaking sites as competitive as possible. While this hurdle may seem minor compared to the broader transition from emission-intensive steelmaking, it is critical in shaping the scale and order of early premium-paying markets. Failure of overly expensive early investments in green steel making could cast a cloud over the industry as a whole.

The competitiveness of each individual low-carbon steelmaking site will depend on the local costs of key inputs such as energy, resources and labour, as well as policy support. For sites using hydrogen, the cost of key resources like fossil gas, carbon storage, clean energy and water will be key determinants of competitiveness. Decarbonisation of each individual site should be based on an estimate of the long-term costs of these key components.

3 Low-carbon iron exports - An unrealised potential

3.1 The current iron mining industry

Iron and steel are two intimately integrated sectors. Most steel is made using iron as the primary input, and iron is almost exclusively used to make steel. For Canada, however, the iron sector is significantly larger than the steel sector. In 2022, 55.1 Mt of iron ore was exported, leaving 13.9 Mt for domestic use and inventories, as seen in Figure 2. We will therefore start the sectoral analysis with iron ore production.

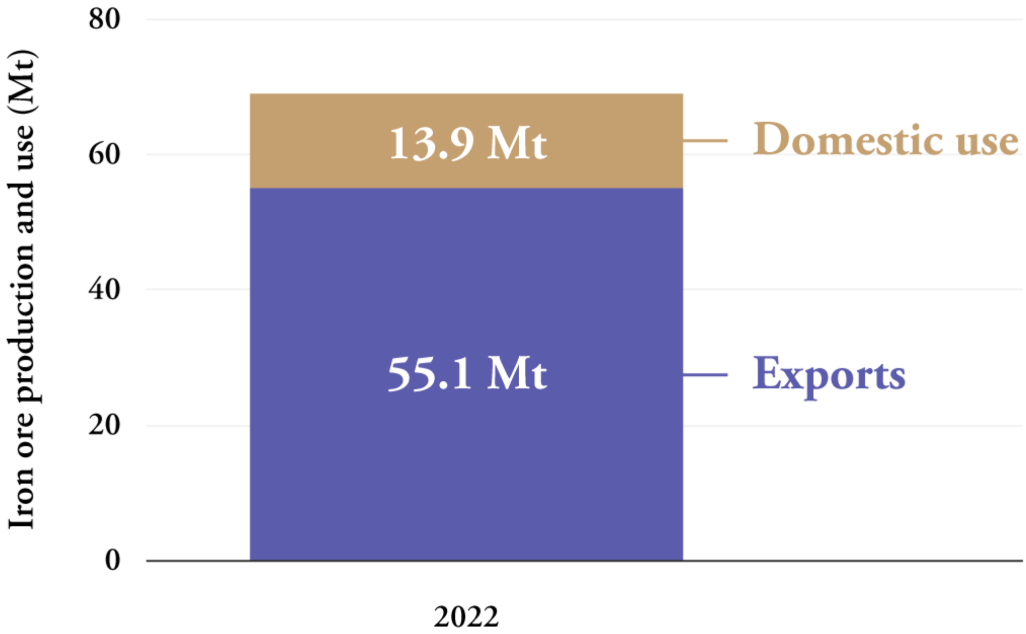

Figure 2: Canadian iron ore production and use in 2022 (Mt).
Share of iron production (69 mt) that was either exported (55.1 mt) or used domestically (13.9 mt) in 2022.

Iron is one of the most significant minerals mined in Canada. In 2022, 5 billion Canadian dollars' worth of iron was mined in the country, making it the fourth most valuable mineral mined in Canada after potash, gold and coal (Natural Resources Canada, 2024c). The iron mining sector employs over 9000 workers, making it a key employer in remote parts of the country, such as Baffin Island and the North Shore of Québec (ArcelorMittal, 2024a; Champion Iron, 2024b; Rio Tinto, 2024; Tacora Resources, 2024; Wat, 2024). See Appendix II for a summary of key stakeholders.

In Figure 3 you will find the Canadian "Minerals and Mining Map", showing only iron ore mines. The mines are located primarily in Québec and Labrador, with a mine also on Baffin Island, Nunavut. Québec and Labrador produce 92 percent of all iron ore in Canada, with Nunavut in the north producing 8 percent (Natural Resources Canada, 2024d). The Québec and Labrador mines are concentrated in the same geography due to the Labrador Trough, a geological formation with large iron ore deposits right on the border between Québec and Labrador.

Figure 3: Map of iron ore mines in Canada.
Source: Natural resources Canada.

As the Canadian iron ore mining industry is concentrated in the east of the country, the rest of this report will focus on the incumbent industry in this region and its potential for a transition. Potential mines in new areas have been excluded from the analysis, but we acknowledge that new projects may be important for the future Canadian mining industry.

The table below lists the active iron ore mines in Canada. The production capacity of the mines, as well as iron ore quality has been reviewed based on press releases and public announcements. There are crucial differences between types of iron ore. For direct reduction, a given quality of pellets called "DR-grade" is necessary and not always available. Investments are already being made to enable production of DR-grade pellets, while some mines have a high concentration of iron ore, but no ongoing DR-grade investments have been identified.

Table 4: Canadian iron ore mines and ore grade

Mine	Production capacity (Mtpa)	Owner	Iron ore content	Source
Fire lake	4	ArcelorMittal	DR-grade	(ArcelorMittal, 2021)
Mont Wright	22	ArcelorMittal	DR-grade	(ArcelorMittal, 2021, 2024b)
Bloom Lake	15	Champion Iron	DR-grade	(Champion Iron, 2024a)
Scully	4	Tacora Resources	65.9%	(Tacora Resources, 2024)
Carol lake	17	Rio Tinto	65%	(Mooney, 2021)
Menihek Region	4	Tata Steel Minerals Canada	64.5%	(Tata Steel Minerals Canada Limited, 2024)
Mary River mine	6	Baffinland Iron Mines Corporation	DR-grade	(Thyssenkrupp, 2023)

There are three active mines where no upgrading investments were identified: the Scully and Carol Lake mines owned by Tacora Resources and Rio Tinto respectively, and the Menihek region mines, operated by Tata Steel Minerals Canada. However, as the mines are located along the same geological formation, there is reason to believe that these mines also have the potential to upgrade their iron ore output to produce DR-grade iron ore pellets. Due to these high-grade iron ore deposits, Canada may be well-suited to play a key role in the transition of both the domestic and the global iron and steel industry.

3.2 Changing export markets

Canada is not only a major iron ore mining country, but also one of the largest iron ore exporters in the world. In 2023, Canada was the world's third largest exporter of iron ore, after Brazil (354 million tonnes) and Australia (891 million tonnes) (World Integrated Trade Solution, 2024). Canada exports iron ore to a variety of markets, compiled in Figure 4. Each block represents an exporting destination and is scaled based on the size of the export market.

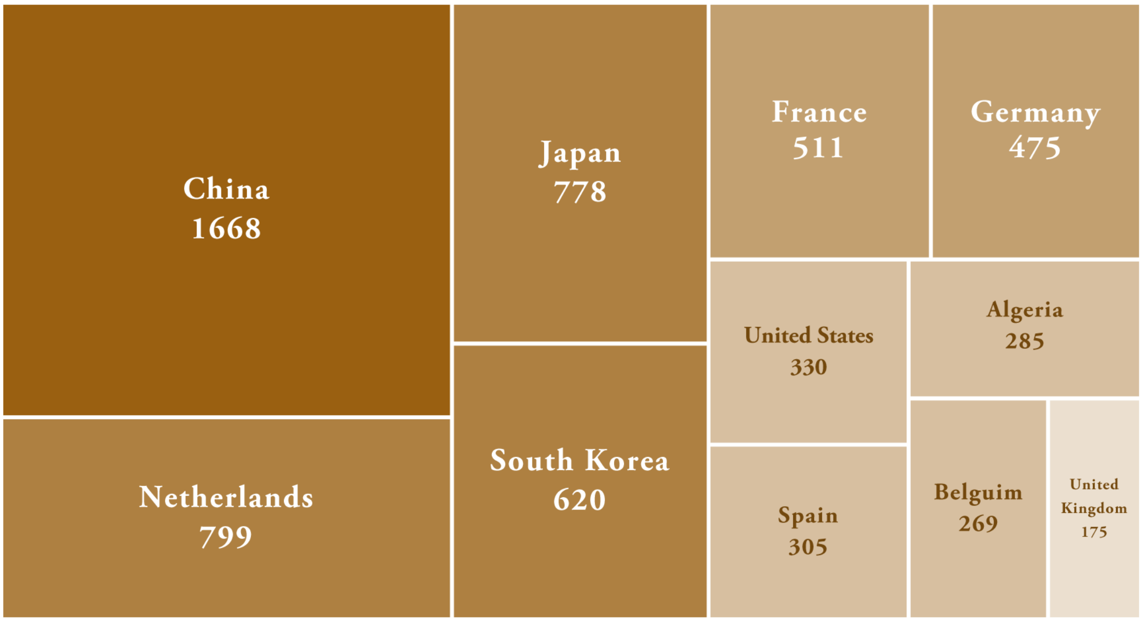

Figure 4: Top export destinations of iron ore from Canada in million US dollars.
Source: Observatory of Economic Complexity.

China is the largest export destination, with the Netherlands and Japan close second[3]. However, if considered a bloc, the EU is the largest export market at 2359 million US dollars. South Korea is also important at 620 million US dollars, as is the US at 330 million US dollars.

These export markets will evolve. At the time of writing, China is experiencing significant overcapacity and seeing sluggish demand for steel, causing a fall in production. The country is both cracking down on the expansion of steelmaking and planning a large expansion of scrap-based steelmaking to lower emissions (Zhang, 2024). This transformation towards scrap-based steelmaking is likely to grow as the pool of available scrap enters structural growth and demand stagnates. On top of this rising use of scrap, China is turning towards hydrogen direct reduction with the new 700 million US dollars H2-DRI project led by the state-owned enterprise (SOE) HBIS (LeadIT, 2024). Chinese SOEs have traditionally had a role in driving industry development in China (Li et al., 2022), and this recent move by HBIS could signal that China's industry will soon develop several new projects with a similar profile.

The EU is already pushing ahead on steel decarbonisation, with many different low-carbon direct reduction projects in the pipeline, as documented by the LeadIT Green Steel Tracker (Vogl et al., 2023). The move towards direct reduction and EAFs is likely to continue in the EU, and the European Commission has identified hydrogen-based steelmaking as the main decarbonisation strategy for the industry, and expects that this production route will constitute a rapidly growing share of primary steelmaking (Joint Research Centre, 2022). South Korea is also moving towards hydrogen-based steelmaking. Its dominant steelmaker, POSCO, is investing over 40 billion US dollars until 2040 in Australia to develop hydrogen

[3] Please note that this shows export destination – exports to, for example, the Netherlands, are likely to be shipped further to steelmakers in other countries in Europe.

direct reduction there (Min-hee, 2022), harnessing Australia's strong solar power and iron ore resources. The Australian mining company Fortescue has formulated its ambition to supply China with 100 mtpa of direct reduced iron (Burton, 2024). The UK has already made the decision to demolish its remaining BF-BOFs and switch fully over to EAFs fed by scrap and/or "Hot Briquetted Iron" (HBI).

The US already has a high share of EAFs, using scrap for around 70 percent of its steelmaking (Bureau of International Recycling, 2022), and is now also aiming to develop hydrogen direct reduction projects. The US Department of Energy is considering granting 500 million US dollars to a "hydrogen-ready" direct reduction project by Cleveland-Cliffs (Office of Clean Energy Demonstrations, 2024).

3.3 Shifting iron demand will require shifting iron supply

Crucially for Canada, these transformation plans across export markets will lead to shifting demand for iron ore products. Right now, Canada is primarily exporting iron ore for use in blast furnaces. However, to remain competitive in an evolving global steel sector, it will be important for it to make its iron products compatible with the DRI-EAF production route.

While blast furnaces can use a wide range of iron ore qualities, from ≥ 58 percent fines and better, the DRI-EAF route requires prepared iron ore pellets with more than 66 percent iron ore content (Agora Industry & Wuppertal Institute, 2023). Currently, such pellets only constitute about 3-4 percent of iron ore shipments, and lack of supply has been raised as a potential bottleneck in the global steel transition, with the IEA estimating that the share of iron production based on hydrogen direct reduction will grow to 15 percent by 2035 and to 44 percent by 2050 – the largest share of all low-carbon sources (IEA, 2023b). The lack of iron ore of the relevant quality, relative to the expected growth in demand, has led to the Canadian federal government designating DR-grade iron ore a critical mineral (Natural Resources Canada, 2024b)

Given this context, a key challenge for iron ore exporters like Canada will be supplying iron ore of the relevant quality. There are several routes by which this transition can be managed. Either mines have the right high-grade iron ore, and the production of pellets can be more easily changed, or new mines with the right iron content can be opened. The lack of iron ore of the relevant quality can also be managed through a process called "beneficiation", which entails refining the iron ore product until it has the right quality. For example, while most of the iron ore mined today is non-magnetic hematite, magnetite (which, as the name indicates, is magnetic) can be upgraded to 66+ percent by grinding it and sorting it with electromagnets. Finally, by adding another step with a smelter and lime slagging after direct reduction, the iron grade can be improved. Such plans are already under way in Australia (Australian Trade and Investment Commission, 2024).

3.4 Canada's iron ore potential

While the transition to direct reduction in the global steel industry poses significant challenges for Canada's iron ore producers, it also creates opportunities, as the country's mines enjoy a high share of iron ore content. Shifting to direct reduction will have major implications for the iron and steel supply chain globally. As mentioned, iron ore grades must adapt to new technologies, but also the switch from metallurgical coal to hydrogen as a reducing agent. This will lead to a fall in demand for coal and a large increase in demand for green hydrogen.

Several recent studies have analysed the implications of a transition to hydrogen in the steel industry, as well as the competitiveness of various geographical regions based on available iron ore and renewable energy resources (see for example (Bataille, Stiebert, Eng, et al., 2024; Devlin et al., 2023; Devlin & Yang, 2022; Gailani et al., 2024; Lopez et al., 2023; Samadi et al., 2023; Verpoort et al., 2023). A key conclusion of these studies is that low-cost renewable energy will be a key competitive advantage, drawing investments to energy-intensive industries in general, and to steel in particular. On top of the issue of economic competitiveness is also the issue of geopolitical rivalry. In today's increasingly fractious global context, energy security is increasingly prioritised. This is particularly noticeable in the EU, which suffered a shock in energy markets after the Russian invasion of Ukraine in 2022. Using domestically sourced renewable energy is an increasingly attractive option compared to relying on global fossil fuel markets, both in Europe and elsewhere (Draghi, 2024).

The transition to hydrogen-based steelmaking will lead to an adjustment of the iron and steel supply chain. Historically, ironmaking and steelmaking have been co-located in order to capitalise on the integration benefits for heat and infrastructure, particularly relevant for BF-BOFs. However, with the shift to direct reduction and EAFs, there are fewer integration benefits, meaning that the iron reduction and the steelmaking steps can be separated to integrate the energy intensive iron-reduction step with energy production. The transition to hydrogen-based steelmaking can therefore bring about a shift to trade of the intermediate product, HBI. This is a compressed reduced iron product that can be added in an EAF for steelmaking and potential blending with scrap. If the HBI is produced with green hydrogen, we can call this "Green Hot Briquetted Iron" (green HBI).

With a strategic restructuring of the iron and steel supply chain, iron ore producers like Canada can harness their energy assets to capture a larger share of the iron and steel value chain by transforming their own ore into iron for export to steelmakers abroad. This adjustment could yield benefits to iron ore producers and steelmakers alike. While iron ore producers can capture a larger part of value added domestically and export a higher-value product, steelmaking countries lacking strong renewable energy assets can avoid the costs and time needed to build up clean energy production and DR-furnaces at a large scale. Major steelmaking EU countries (Canada's main trading partners for iron ore) could import green HBI rather than reducing iron ore themselves, as the region needs to expand renewable energy production to decarbonise their power system – a limited problem in Canada. The EU will also soon introduce their Carbon Border Adjustment Mechanism (CBAM), which will impose a carbon levy on imported products and could favour green HBI.

The benefit of importing green HBI is even larger for countries with a large existing fleet of EAFs such as the US, which produces about 70 percent of all its steel using EAFs, and the UK, which will soon transition to 100 percent EAF-based steelmaking. An expansion of green HBI production in Canada would have particularly strong synergies with the US, where the iron and steel industry is already highly integrated with Canada's. The US has a large fleet of EAFs that can be fed with green HBI from Canada. At the same time, the US grid is more emission-intensive than its Canadian counterpart, and it will be challenging to develop enough renewable energy to both decarbonise the grid and produce hydrogen for iron reduction. If iron reduction can be done in Canada, the US will have a stable supply of iron from a reliable partner, and Canada will find a reliable market for a higher value added product.

The EU, US and UK constitute almost half of Canada's iron ore export destinations. In addition, South Korea and Japan, with their limited renewable energy resources, could benefit from a strategic restructuring of the iron and steel supply chain that separates the iron reduction and the steelmaking steps. So far, South Korea has invested heavily in Australia, and Japan has been slower in switching to hydrogen-based steelmaking. These export markets are strategic partners and allies for Canada, positioning it as a key stakeholder in supporting a cost-effective decarbonisation of the iron and steel industry in these countries. However, competitors are advancing rapidly – Sweden's iron ore mining company LKAB, which produces 80 percent of the EU's iron ore, has a strategy to convert their entire operations to green HBI exports. Similarly, Australia, the world's largest iron ore exporter, has launched a strategy to combine their iron and energy resources for the export of green HBI and steel (Australian Trade and Investment Commission, 2024).

3.5 Unlocking higher value iron with renewable energy

Canada has strong renewable energy resources, providing potentially key competitive and strategic advantages as the world shifts from fossil-based steelmaking. Hydropower constitutes 60 percent of the total power supply in Canada, reaching 94 percent in Québec and 97 percent in the province of Newfoundland and Labrador (Canada Energy regulator, 2024). In the previous geostrategic environment without a large transition of the global economy, Canadian energy utilities have focused on increasing revenue by selling clean power to consumers by expanding transmission lines to major demand clusters in the south of the country and the US. However, in the context of a large transition of the global economy – and the geopolitical rivalry that goes with it – the iron and steel transition could provide a new, more strategic use of Canadian metallurgical and energy resources, transmission infrastructure based on increasing value added in Canada, and help trading partners reduce their emissions quickly.

Canadian iron ore assets are primarily located along the Labrador Trough in Québec and Labrador. On either side of it are some of the world's largest hydropower stations: La Grande 2 and Churchill Falls at 5616 and 5428 MW of generation capacity each, and several other hydropower stations. Transmission lines from the stations have been built to transport power down to the south of the country and the US, from Labrador via the town of Sept-Iles on the shore with a large port for iron ore exports.

This infrastructure could be a strong asset if Canada were to develop direct reduction in the country for export of HBI. Hydropower is cheap and dispatchable, making it a low-cost balancing power that could complement intermittent renewable energy, such as onshore wind. Hydrogen-direct reduction (H2-DRI) is power intensive, so a large-scale expansion of direct reduction in Canada will require a substantial increase in power production. The region around the Labrador Trough has a potential for onshore wind expansion, as it has strong wind power potential and low population density. The map in Figure 5 is from the Global Wind Atlas, showing the capacity factor and annual energy yield of a wind turbine across geography.

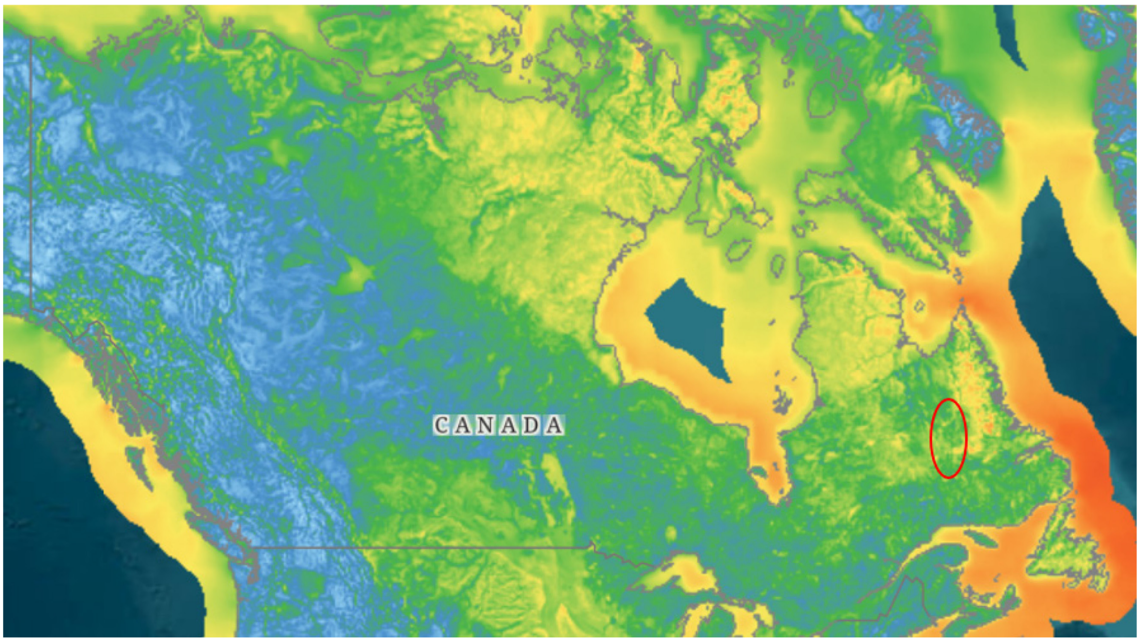

Figure 5: Map of wind energy yield across Canada.
Source: The Labrador Trough and main iron ore mines are marked with a red oval. The bluer the colour, the lower the estimated annual energy yield. The more yellow and then red, the higher the estimated annual energy yield of a turbine. Source: Global Wind Atlas.

In Figure 5, we can see that the area around the Labrador Trough has some of the strongest wind energy potential in Canada. In the far north of Québec and Nunavut are the strongest onshore wind energy sources, although these areas are highly remote. Labrador and central Québec in particular have strong wind energy potential, along with the plains of Saskatchewan and Alberta.

An expansion of onshore wind around the Labrador Trough could increase the supply of clean energy to power direct reduction of iron. By combining this with low-cost hydropower, the east of Québec and Labrador has the potential to be a clean power engine for the iron and steel transition at home and abroad. Newfoundland and Labrador also have an important offshore petroleum industry, with key sites to the south and east of Newfoundland. In the long term, the province could build on the lessons from the transitions from offshore petroleum to offshore wind that have already taken place in the UK, Norway and Denmark, as wind speeds are particularly good in the waters around Newfoundland and offshore wind projects produce larger volumes of electricity.

3.6 Respecting First Nations

Recognition and respect for First Nations and Indigenous communities across Canada is crucial for a politically sustainable transition of the iron and steel industry, as well as the Canadian government's pursuit of reconciliation with Indigenous communities. An onshore wind power expansion can be either extractive (with local costs and outsourced benefits) or based on reconciliation (with fairly distributed costs and benefits). There are cases where onshore wind expansions have been highly disruptive for Indigenous communities, for example in Norway (Norwegian Government, 2023) and Sweden (Cambou, 2020). The Indigenous Sami, traditionally a nomad people herding reindeer across the northern Scandinavian peninsula, have seen onshore wind expansions on sacred land and in grazing areas. The iron transition in Northern Sweden, where iron ore miner LKAB is planning large scale HBI production, will be associated with a large expansion of primarily onshore wind and this has been discussed as a potential infringement on the rights of the Sami people and in conflict with the traditional reindeer herding (de Leeuw & Vogl, 2024).

Historically, the iron ore mining industry has been associated with the resettlement and discrimination of Indigenous communities, with people being displaced from their traditional lands and discriminated against as they seek employment in the mining industry. In the past, energy development has been similarly devastating for First Nations in Canada. Hydropower development in both northern Québec and Labrador has violated Indigenous rights, including by displacing First Nations settlements (Martin & Hoffman, 2008), with lawsuits against Hydro-Quebec continuing to this day (Amador, 2023; Forrest, 2024). In some more isolated cases, Indigenous communities have been better represented in the process of renewable energy development, as seen in the case of the feed-in-tariff in the province of Ontario (Stokes, 2013). Reportedly, there has been progress on the relationship between mining and Indigenous communities, through various political and legal strategies guaranteeing returns for impacted communities, such as the Impact and Benefit Agreements (IBA), which allows communities to capture more land rent from mining activities (Rodon et al., 2022; Thériault et al., 2022). Nevertheless, there have been limitations to the Canadian approach, and more can and should be done to include Indigenous communities in building energy autonomy and reliability, and ensuring financial returns to communities that inhabit and rely on the land near wind turbines and infrastructure, for example via equity partnership (Hoicka et al., 2021; Stefanelli et al., 2019).

Any expansion of onshore wind in Québec must involve Indigenous communities and be based on prior and informed consent. According to the Canadian authorities, the Naskapi Nation of Kawawachikamach and Innus of Matimekosh are the Nations currently located close to the Labrador Trough, with potential areas for onshore wind development away from Indigenous settlements further to the south and west (Canada.ca, 2024e). However, a thorough plan for industrial and energy development that involves Indigenous communities with full respect for the UN Declaration on the Rights of Indigenous Peoples, including Free Prior and Informed Consent, will be pivotal for any expansion of renewable energy to be in line with the ambition for Indigenous reconciliation and a politically sustainable transition of the iron and steel industry.

3.7 Competitiveness and challenges for Canadian green Hot Briquetted Iron production

Canada's natural resources and infrastructure offer significant advantages for green HBI production, enabling greater domestic value capture while helping trading partners to decarbonise their iron and steel industries. This potential needs to be analysed in order to understand the extent to which a Canadian green HBI production could reduce global emissions, increase value added, and contribute to employment. In Figure 6, we have calculated the potential of green HBI exports, relative to iron ore and other green HBI export markets.

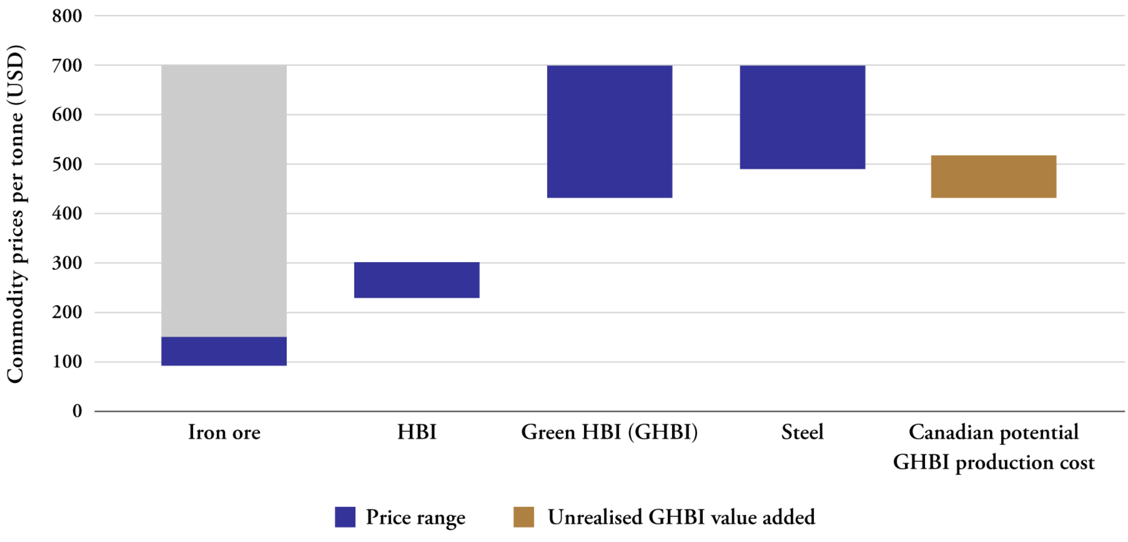

Figure 6: Commodity prices per tonne.
Comparison of commodities, author's calculation. Sources and assumptions provided in the appendix.

Figure 6 shows the price of iron ore and conventional HBI made with fossil gas on world markets over the past five years, compared with the following: IEA estimates of the cost of H2-DRI in China, India, the US and the EU by 2035 ("Green HBI"), a cost range for crude steel, including the costs of steel made in the traditional BF-BOF, and the fossil gas based DRI-EAF route ("Steel") (IEA, 2024), and, finally, the cost of potential GHBI production in Canada calculated for this report. The shaded area above the iron ore cost range is the value that is currently not captured in Canada by exporting iron ore, rather than DR-grade pellets. We make conservative assumptions on energy needs and use a discount rate of 12 percent, which is representative of standard firm rates of return for investment decision making. We make standard assumptions for CAPEX and operations and maintenance

(O&M) based on the academic literature, use data on wages from Statistics Canada, and power prices from Hydro-Québec for new onshore wind.

As a result of this analysis, we find that Canadian production of green HBI would be competitive on world markets – ranging between 430-520 US dollars, which is at the lower end of the IEA's estimated costs for green HBI production (430-700 US dollars). This cost advantage is also found in a recent report by the Rocky Mountain Institute, where Canada is estimated to be the second-cheapest site for green HBI production globally, after the US (Wilmoth et al., 2024).

Transitioning to domestic hydrogen direct reduction of iron ore could significantly boost value added within Canada. In the case of a global green HBI market where the price is set by the most expensive producer and the most expensive producer produces green HBI at the highest cost projected by the IEA, Canada could increase the domestic value added by more than 500 US dollars per tonne of iron product exported. It should be noted, though, that 1.5 tonnes of iron ore is needed for the production of one tonne of HBI (Bhaskar et al., 2022; Vogl et al., 2018). This is factored into this report's calculation, so exports in terms of tonnage would be reduced by the same factor. Should all the iron ore exported in 2023 (57 million tonnes) be domestically reduced and sold as green HBI (38 million tonnes), and assuming that the price of green HBI on world markets would be set by the most expensive production (marginal pricing), this transition would increase the annual value added within Canada by more than 18 billion US dollars, or more than 25 billion Canadian dollars, if all domestically produced iron ore were reduced before exporting. If the global market price were lower, say at 500 US dollars, the increase in value added would exceed 10 billion US dollars or 14 billion Canadian dollars. While it is more likely that a share of iron ore would be used for reduction and a remaining share used for other low-carbon steelmaking routes, this calculation shows that there is a significant potential to increase value added while cutting emissions through hydrogen direct reduction.

While most gains in emissions reductions in this scenario would not take place in Canada, but in iron reduction across BF-BOF sites abroad, this approach could significantly help Canada's trading partners reduce their emissions. Assuming that one tonne of steel requires 1.6 tonnes of iron ore, and that one tonne of steel made in the traditional route produces 2945 kgCO2e/tonne steel across the supply chain, Canadian iron ore is currently associated with emissions of about 105 megatons of CO2e, emitted both domestically and abroad. These emissions would be removed under the described scenario, implying a reduction of annual emissions by an equivalent of 16 percent of Canada's domestic emissions (Canada.ca, 2024d) primarily outside of the country's borders.

Under this scenario, power demand would increase significantly, requiring about 115 TWh for a full-scale transition to hydrogen-based production of 38 Mt of HBI, compared with the 210 TWh currently generated in Québec. This increase in demand would likely increase power prices, as new onshore wind is more expensive than the current low-cost hydropower-dominated grid. However, even with the cost of new onshore wind (7.8 Canadian cents (Hydro-Québec, 2024)) as the basis for the calculation, Canadian iron reduction remains competitive. A buildout of onshore wind and DRI facilities could be done stepwise over the coming decades so that the supply chain can make the required adjustments over time and to minimise the impact on other energy-intensive industries and the environment. However, the faster the buildout, the more rapid the emission reductions, and the better our chance of keeping temperature increases within safe limits.

Labour demand would also increase significantly to man the DRI furnaces and electrolysers, and to build out the required power supply and transport. The DRI furnaces and electrolysers alone are estimated to create up to 14 000 new jobs – approximately 60 percent of the current labour force in the steel sector – in a maximum case where all iron ore is reduced to green HBI domestically. That would more than account for the number of job losses as a result of the Canadian steel sector switching to EAFs, albeit likely in different locations. The geographical shift in the location of industrial production may provide a political challenge that has to be overcome with strategic planning and shifts in supply chains.

Achieving significant growth in green HBI production will require overcoming political challenges, for instance, how to finance the large development of clean power production in Québec and Newfoundland and Labrador. Increases in energy prices is likely to fuel political backlash (see (Voeten, 2024) for a discussion on how increased energy costs led to growing support for climate-sceptic parties and (Stokes & Warshaw, 2017) for how framing of energy politics affects political support for climate policy). Household demand for energy tends to be price-inelastic, meaning that even though prices increase people's basic energy needs, they will still consume that energy. As such, increasing the cost for ratepayers would be like an increase in taxes to fund the transition of private companies to lower emissions abroad.

There are alternative ways to fund the transition. With Hydro-Québec yielding healthy profits in the last few years (Coulton, 2023), a more strategic use of this publicly owned company could be to task it with building out renewable energy as a priority over dividends to the province. Another approach could be to support the transition at the federal government level. However, while recent experiences show that there are clear risks with some funding options, such policy decisions will depend on Canadian politics, the analysis of which is beyond the scope of this report.

4 The steel transition – Progress but at risk of falling short

4.1 The current steel industry

The Canadian steel industry is part of key supply chains and an important domestic employer, but also a large emitter of CO2. In 2019, Canada's steel sector accounted for 15 million tonnes of CO2, around 2 percent of the country's total emissions (Khan et al., 2023) and 20 percent of all emissions from its heavy industry. Reducing industry emissions would be a valuable and much-needed contribution to the Canadian government's target of hitting net-zero emissions by 2050. The Canadian Steel Producers Association (CSPA), which organises steelmakers in Canada, aspires to align with this government target. See Appendix II for a compilation of key stakeholders in the steelmaking industry.

The steel industry is also an important economic sector, contributing 4.2 billion Canadian dollars to the country's economy, directly employing 23 000 workers, and supporting up to an additional 100 000 jobs (CSPA, 2024). Canada's three largest steel mills – ArcelorMittal Dofasco, Algoma, and Stelco – have the largest emissions and workforce, and are all located in the province of Ontario. There are two steel mills with fossil-based production technologies in Québec – ArcelorMittal Contrecoeur and Rio Tinto Titane et Fer. Finally, there is one low-emission scrap-based site in Saskatchewan. Two of the steel mills with the highest emissions – Algoma and ArcelorMittal Dofasco – have transition plans[4]. However, while the Algoma site has progressed well and the low-emission EAFs are under construction, the Dofasco site appears to have stalled its transition.

Almost 60 percent of steel made in Canada is based on the emission intensive primary steelmaking route using a BF-BOF, while the rest is secondary steelmaking based on scrap melted in an EAF (Bureau of International Recycling, 2022). As secondary steelmaking is already low-emission, the rest of the report will focus on the primary steelmaking route.

[4] "Transition plans" here are defined as announced plans to switch a plant's production route by using new technology in order to reduce emissions.

The map and table in Figure 7 detail the major steel mills across Canada.

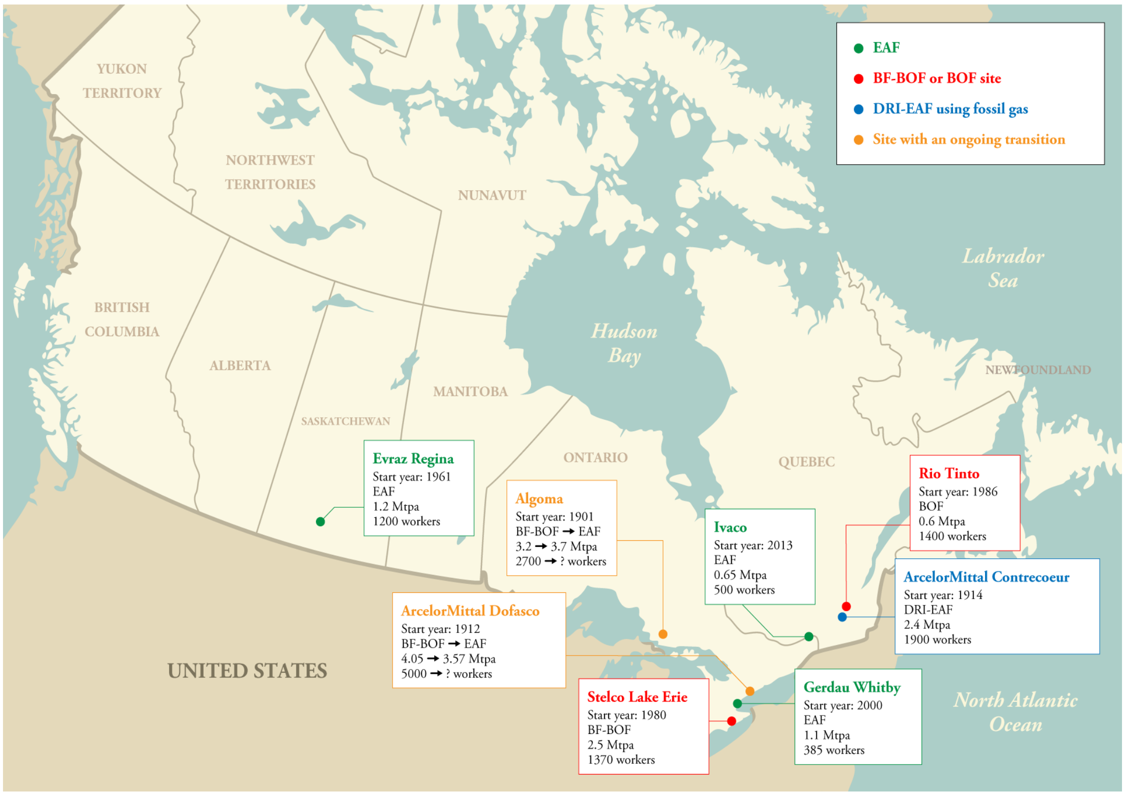

Figure 7: Map of Canada's steel mills.

While the Evraz Regina EAF is in Saskatchewan in the west, most of the Canadian steel industry is located in Ontario and Québec, close to downstream industries and iron ore supplies. On the map in Figure 7, we have colour-coded each site: green is an EAF, red is a BF-BOF or BOF site, blue is a DRI-EAF using fossil gas, and yellow is a site with an ongoing transition.

The largest steel mill is the ArcelorMittal Dofasco site in Hamilton with a current capacity of over 4 mtpa and a workforce of about 5000 workers. The second largest site is the Algoma mill in Sault Ste. Marie with a capacity of 3.2 mtpa and 2700 workers. While the ArcelorMittal Dofasco site plans a transition to DRI-EAF replacing metallurgical coal for fossil gas and a reduction in capacity, the Algoma site plans a transition to EAFs, instead feeding the EAF with scrap and iron inputs from other producers and to expand its total capacity. The remaining fossil-energy based sites without transition plans are the ArcelorMittal Contrecoeur and the RioTinto sites outside Montreal, as well as the Stelco mill on Lake Erie. The ArcelorMittal, Algoma and Stelco sites are by far the largest industrial emitters in Ontario at about 5 million, 4 million and 3.5 million tonnes of CO2 emitted respectively in 2019 (Crawley, 2022).

The Canadian steel industry is highly integrated in the wider North American industry, with links to both upstream iron ore suppliers and downstream industries such as the automotive industry. The Canadian steel industry has a capacity of about 13 million tonnes of steel per annum (mtpa) (Cheminfo Services Inc., 2019), of which almost 7 million tonnes is exported

(International Trade Administration, 2024). Of these exports, about 85 percent goes to the US (Observatory of Economic Complexity, 2024). Over 50 percent of steel products imported to Canada come from the US. Meanwhile, almost all iron ore imported to Canada comes from the US (Observatory of Economic Complexity, 2024).

4.2 Progress on decarbonisation and remaining challenges

As mentioned, both the Canadian government and the Canadian steel industry have ambitious climate targets. The government has partnered with industry to support the transition of several sites. Through the Strategic Innovation Fund, the government has provided 400 million Canadian dollars for the transition of the ArcelorMittal Dofasco site from coal-based BF-BOF to fossil gas-based DRI-EAF, breaking ground in 2022 (Innovation Science and Economic Development Canada, 2022). The Strategic Innovation Fund has also supported the Algoma transition from BF-BOF to EAFs with 200 million Canadian dollars (Canada.ca, 2024b). Both sites aim to reduce emissions by about 3 million tonnes of CO2 per year from a current level of 4.7 and 4 million tonnes respectively (Crawley, 2022). The government is also supporting the decarbonisation of the Rio Tinto site outside of Montreal, though this decarbonisation plan is for the whole site, including other minerals, and it is not clear how large the emission reductions from steel production are expected to be (Canada.ca, 2024c). The three remaining sites, currently with no transition plan or where the transition has stalled, are Stelco, ArcelorMittal Contrecoeur, and ArcelorMittal Dofasco.

Table 5: Canada's steel mills.

Site name	Company	Location	Current technology	Last relining or installation	Planned technology change	Capacity (Mtpa)
Algoma	Algoma	Sault Ste. Marie, Ontario	EAF (due Q1 2025)	2025	EAF (transitioning from BF-BOF)	3.2 → 3.7
ArcelorMittal Contrecoeur	ArcelorMittal	Contrecoeur, Québec	DRI-EAF	1914	-	2.4
ArcelorMittal Dofasco	ArcelorMittal	Hamilton, Ontario	BF-BOF	2010	DRI-EAF (delayed)	4.05 → 3. 75
Evraz Regina	Evraz North America PLC	Regina, Saskatchewan	EAF	1981	-	1.2
Gerdau Whitby	Gerdau Long Steel North America	Whitby, Ontario	EAF	1965	-	1.1
Ivaco	Ivaco Rolling Mills	L'Orignal, Ontario	EAF	2013	-	0.65
Rio Tinto	Rio Tinto	Sorel-Tracy, Québec	BOF	1980	-	0.6
Stelco	Cleveland-Cliffs	Port Dover, Ontario	BF-BOF	2020	-	2.5

Source: Global Energy Monitor's Steel Plant Tracker.

4.2.1 Stelco

At the time of writing, the Stelco site on Lake Erie, along with the ArcelorMittal Contrecoeur site outside Montreal, is one of the sites without a transition plan. Instead, Stelco has been purchased by the US steelmaker Cleveland-Cliffs, which is the largest integrated steelmaker in North America and owns six out of ten blast furnaces in the US. The CEO of Cleveland-Cliffs, Lourenco Goncalves, was motivated to acquire Stelco due to the profitability of its existing operations and synergies with Cleveland-Cliffs' other production sites using the same BF-BOF steelmaking route (Friedman, 2024). Goncalves' strategic philosophy is based on aggressive expansion of the Cleveland-Cliffs market segment for stronger pricing power, and strengthening synergies across plants using the same technologies, suggesting that he is firmly committed to the blast furnace production route (Binnie & Flowers, 2023). Stelco relined and upgraded its blast furnace in 2020 (Stelco, 2020), a significant investment in the existing emission-intensive facilities at the site. Blast furnaces can typically run for up to two decades after their relining (Vogl et al., 2021). Therefore, it is more likely that any decarbonisation of the Stelco site in the short term will be attempted through carbon capture. However, this technology is underdeveloped for use in the BF-BOF steelmaking route. If such a plan is effected, it is essential that the capture rate be high enough and leakage sufficiently minimised for abatement to be considered compatible with the Paris Agreement (Bataille et al., 2023). If this does not happen, the emission reductions from retrofitting the facility with carbon capture is a considerable investment in extending coal-based steelmaking, which may not be compatible with Canada's goal of net-zero emissions by 2050.

4.2.2 ArcelorMittal Dofasco and Contrecoeur

The transition plan at the Dofasco site includes switching to fossil gas, while the Contrecoeur site, currently using fossil gas, has no commitment to switch to lower-emission technologies. The plan to use fossil gas at Dofasco will reduce emissions by about 60 percent, or 3 million tonnes of CO2 per year. This will require the construction of about 14 kilometres of pipeline to transport the gas, a significant investment in the temporary measure (Fehir, 2023). The cost of the pipeline is not known at the time of writing, nor is the degree to which the pipeline can be used for hydrogen in the future. ArcelorMittal states that the transition plan includes the ambition to switch to hydrogen over the longer term, and therefore the investment will make the site "hydrogen-ready" (ArcelorMittal, 2023). However, its significant investment in fossil-gas infrastructure, and lack of investment in the relevant equipment for hydrogen such as electrolysers and a low-emission heater to drive the 100 percent hydrogen reduction, suggest that the transition to hydrogen is disincentivised with this investment.

It is also unclear how hydrogen will be supplied to the company's Dofasco site in the future and whether the pipeline being built for the site itself will be hydrogen-ready. Recent research points to significant risks and challenges with using fossil gas-infrastructure for hydrogen (Martin et al., 2024). If ArcelorMittal plans to use blue hydrogen in the future and separate carbon from hydrogen at the site, then it will need to identify carbon storage sites that are economical to use. Due to the high transport costs of carbon dioxide, it is likely that ArcelorMittal will have to find a large and affordable carbon storage site near Dofasco (e.g. Ontario, the US), rather than transporting it to a storage site further away.

There have been recent media reports that the project at the Dofasco site is delayed, and construction has not yet started – two years after the groundbreaking ceremony with Prime Minister Justin Trudeau (Beattie, 2024). Such delays suggest that it will be difficult for ArcelorMittal to reach its own targets to build the planned facilities to reduce emissions by 2028, let alone transition to net-zero compliant technology at the site. If this is the case, ArcelorMittal has the option to make a simpler transition to EAFs and, instead, transport scrap and HBI from elsewhere (as is currently underway at the Algoma steel mill.) This would reduce the investments required at the site itself and speed up the transition process. In order for such a plan to successfully reduce emissions, the HBI imported to Dofasco should also have very low emissions and a plan to reach all the way to near-zero emissions. The risk with such a strategy is that it could lead to significant job losses (as was the case at Algoma), undermining the political sustainability of the transition. It is also important to bear in mind that Dofasco is the only integrated steel mill in Canada that is not unionised, leaving the workers without organised representation if there are negotiations over how the transition and employment should be handled (e.g. with alternative industrial development or pensions.)

The final site without a transition plan is the ArcelorMittal DRI-EAF site in Contrecoeur outside Montreal, which is using fossil gas as a reductant. ArcelorMittal has successfully tested the use of hydrogen at the site (ArcelorMittal, 2022), but has not announced any plan to switch to hydrogen and transition the rest of its power use to clean electricity. Its technological setup (DRI-EAF using fossil gas) and thus emission intensity is what the Dofasco mill is transitioning towards. The current emission intensity at the site is 640 kgCO2e/tonne steel direct emissions (Normand, 2024) which is significantly lower than the global average for DRI-EAF, likely due to the seemingly high scrap share of metallic inputs (ca 44 percent, assuming that the site produces 1.8 mtpa of steel (Global Energy Monitor, 2024a) with a maximum of 1 mtpa of DRI inputs (Midrex, 2022)). This is also the planned technology choice at ArcelorMittal Dofasco. However, this emission level is still far from the 400 kg CO2e/tonne steel threshold that the IEA designates "near-zero emission" assuming 0 percent scrap inputs, let alone the ca 250 kg CO2e/tonne steel required to be "near-zero emission" with 44 percent scrap use (IEA, 2022).

4.3 How to reach all the way to net-zero

Two key challenges remain for Canada's steel industry to be net-zero compliant and contribute to Canada's commitments under the Paris Agreement: 1) abating emissions sufficiently for steel mills to be "near-zero", as defined by the IEA and 2) ensuring strong employment prospects for steel workers so that the transition remains politically sustainable. The first challenge relates to understanding where the finish line is in the race to net-zero, and the second to making sure there is the political support to get there.

Firstly, unabated fossil gas is not a net-zero compliant reductant, and reaching net-zero will require a strategy that takes Canadian steel all the way – not halfway – to net-zero. The definition of "abated fossil fuels" is hotly contested: There is a big difference between reducing emissions from current levels to a lower level, and reducing emissions enough to align with the Paris Agreement. In a recent article, several leading authors of the latest Intergovernmental Panel on Climate Change (IPCC) report argue that, for emission reductions at existing industrial sites to be sufficient for the Paris Agreement, they must reduce over 90 percent of total emissions from current levels (Bataille et al., 2023). These levels are difficult to reach, as over 50 percent emissions reductions through CCS retrofits on steel plants are likely to be uneconomical (Bashmakov et al., 2022). There is therefore a risk that the current steel transition plans are too focused on how to reduce emissions at minimal cost, while overlooking the reality that these technology choices could lead to dead-ends in the longer term goal of reaching near-zero emissions. Decarbonisation plans for remaining steel mills should clearly outline how to reach near-zero.

Secondly, without an ambitious and comprehensive transition plan for the Canadian iron and steel industry, and employing instead on a reactive, ad hoc approach to reduce emissions, the transition may have a detrimental impact on local jobs and the purchasing power of local communities (Blackwell, 2021). This is particularly risky at Sault Ste. Marie in northern Ontario, where Algoma steel will transition away from the coal-based BF-BOF route to EAFs. As EAFs are easier to operate, and the site will no longer reduce iron or need a coking oven, there will be fewer tasks and jobs associated with steelmaking at the site. Sault Ste. Marie is in Northeastern Ontario, where the primary metals manufacturing industry constitutes the highest share of local employment (1.4 percent, ahead of the Hamilton-Niagara Peninsula at 1.2, in turn ahead of London and Windsor-Sarnia at 0.4 percent each) (Job Bank, 2024). The industry is also an important career path with family-sustaining wages for people with a high-school graduate degree, constituting 42 percent of employees in the primary metals manufacturing in Ontario, compared to postsecondary certificate at 38.8 percent and university degree at 13.3 percent. If there is not a comprehensive strategy to develop other segments of the low-carbon steel supply chain – such as the upstream low-carbon ironmaking discussed in this report, or downstream segments like clean technology manufacturing – that can compensate for job losses, or even increase the employment opportunities for ordinary Canadians, the transition may become politically unsustainable.

5 Metallurgical coal – Leadership in a "sunset industry"

Alongside iron ore, Canada is a major producer of another key resource for emission-intensive steelmaking: coking – or metallurgical – coal. This is a type of coal that has the right physical and chemical properties to make it suitable for use in a blast furnace.

Coal is the most carbon-intensive source of energy in the world, not only due to its role in power production, but within the steel industry, where the coal-based BF-BOF route is typically the most carbon-intensive way to make steel. Using a conversion factor of 2.668 tonnes of CO2 per tonne of coking coal (Global Energy Monitor, 2024b), we can estimate that about 72 megatons of global CO2-emissions originated from the 27 million tonnes of metallurgical coal that Canada produced in 2022, equivalent to about 10 percent of the country's territorial emissions.

Moving away from coal mining and finding other, low-carbon activities for communities, such as critical minerals mining, clean technology manufacturing or renewable energy development, could help reduce global emission significantly. Of all the metallurgical coal produced globally in 2022, Canada contributed about 2.4 percent. This makes Canada the seventh largest metallurgical coal producer in the world and third in the OECD, after Australia and the US (Natural Resources Canada, 2024a).

Figure 8: Map of active and former coal mines in Canada.
Source: Natural Resources Canada.

Most Canadian coal mining is located in the west of the country, in the mountains around the British Columbia-Alberta border. While there are two mines in the south of Saskatchewan and two mothballed mines in the province of Nova Scotia, all mines producing metallurgical coal are in the west.

Coal is responsible for much of the value of minerals mined in Canada. While it is difficult to find data for metallurgical coal specifically, coal mining in total accounts for about 12.5 billion Canadian dollars, or 17 percent of the value of minerals mined (Natural Resources Canada, 2024c). Today, there are about 5400 workers employed in metallurgical coal mining in remote parts of the Rocky Mountains. The global transition away from coal-based steelmaking is likely to significantly impact coal mining communities. Therefore, a proactive plan to facilitate this shift is needed. There are existing policies to support the transition from coal, such as the Canada Coal Transition Initiative – Infrastructure Fund, launched in 2020. This fund of 150 million Canadian dollars aims to help communities diversify their economies and transition away from coal by investing in infrastructure (Atlantic Canada Opportunities Agency, 2024).

5.1 Export markets and demand outlook

Because its metallurgical coal mines are in the west and integrated steel mills in the east, Canada exports most of its metallurgical coal. For this reason, Canadian metallurgical coal production will be significantly impacted by the iron and steel transition happening beyond its borders. See Figure 9 for the size of Canada's top metallurgical coal export markets by percentage.

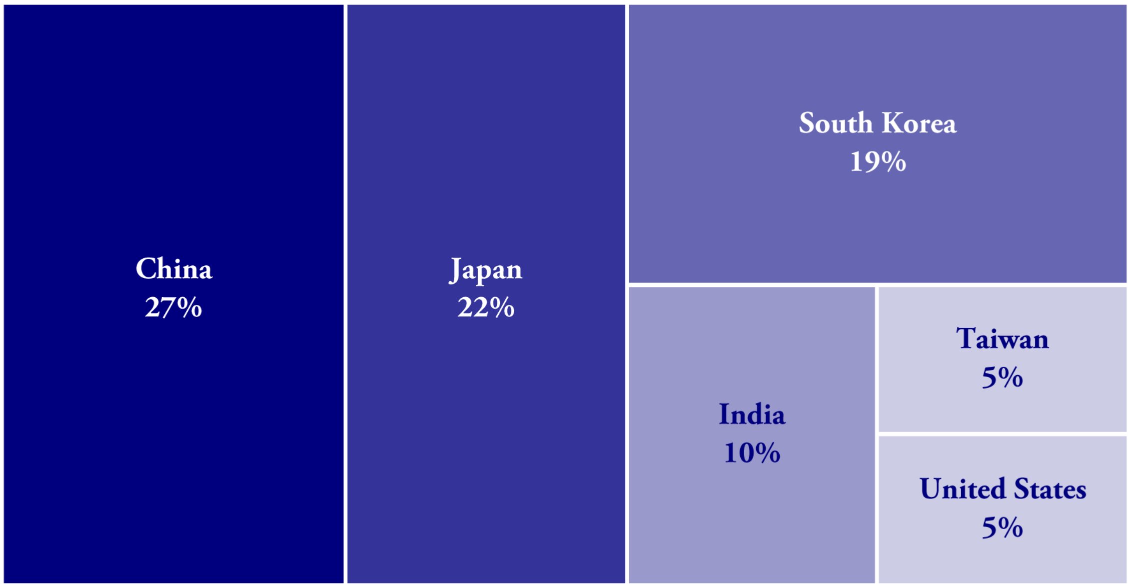

Figure 9: Canadian metallurgical coal export markets by percentage.
Source: Natural Resources Canada.

Canada's main export market for metallurgical coal is China, followed by Japan, and South Korea is a close third. The China Iron and Steel Association has proposed a target of 30 percent scrap-based steelmaking by 2035 which – assuming total steel production remains the same – would lead to a reduction of metallurgical coal demand in China alone of about 160 million tonnes[5]. South Korea is already investing in the production of HBI in Australia to transition away from coal-based steelmaking. However, India is likely to grow its coal-based steelmaking in the coming decades, which may compensate for some of the reductions in coal-based steelmaking in other parts of the world.

The global transition of the steel industry, together with the rise in scrap-based steelmaking in China, is likely to have a major impact on the global market for metallurgical coal. In recent years the price of metallurgical coal on world markets increased due to supply shortages following the Russian invasion of Ukraine. However, because of the overcapacity of coal-based steelmaking in China, coupled with a drop in construction activity and rise in the use of scrap, we are likely to see metallurgical coal prices cool off permanently. The IEA estimates that the market for metallurgical coal is set to shrink, across all their 2024 World Energy Outlook scenarios, as shown in Figure 10.

[5] China's total steel production in 2022 was 1018 mt, 90.5 percent of which was produced via the BF-BOF route. Assuming this falls to 70 percent (from 921.3 to 712.6 mt), and that 770 kg metallurgical coal is needed per tonne steel, this leads to a coal demand reduction of 160 mtpa.

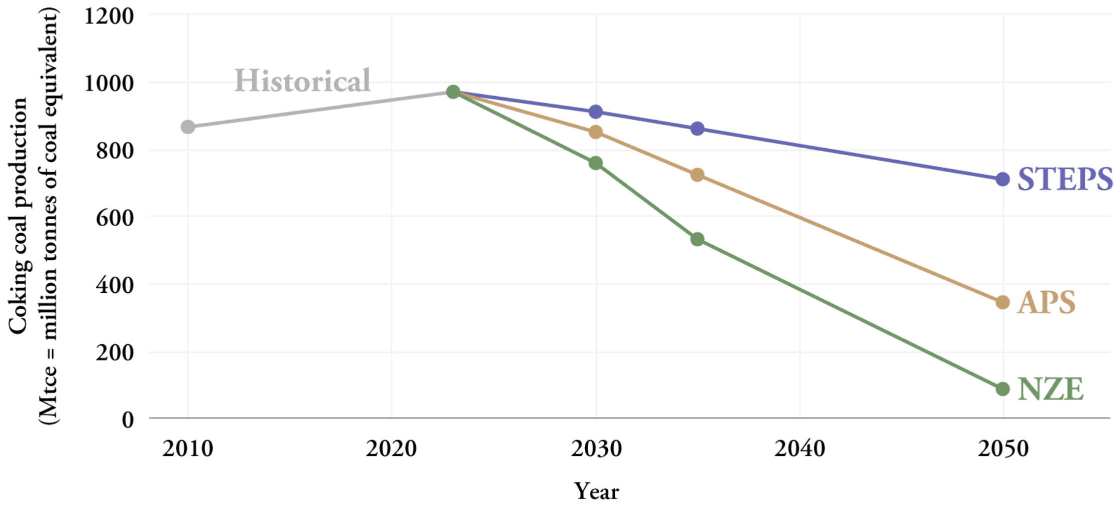

Figure 10: Metallurgical/coking coal production by IEA transition scenario.
STEPS: stated policies scenario showing the expected development with the current policy landscape. APS: announced pledges scenario showing the expected development based on announced pledges on decarbonisation. NZE: the change that is necessary for the world to keep the world temperature increase at 1.5 degrees. Source: IEA World Energy Outlook 2024.

Figure 10 predicts that the global metallurgical coal market will fall across all scenarios. The current policy landscape will see the market shrinking almost back to its level in 2010, while the announced pledges and ambitions for 1.5 degrees will require a drop below the levels in 2010.

The shrinking market for metallurgical coal will drag down prices, which in turn will lead to the most expensive production sites becoming unprofitable first. Canada may be at risk, as its metallurgical coal production is at the higher end of the cost spectrum according to several institutes, including Wood Mackenzie (Griffin, 2019) and the IEA (Baruya, 2018). It is possible, then, that Canada will see a more rapid drop in demand than shown in Figure 10.

For this reason, Canada's position in the metallurgical coal market can be summarised as a leader in a declining, or "sunset", industry. Across all IEA scenarios, export revenue, jobs and profits in this sector are set to decrease – the only question is how fast this will happen. This reality can be faced in two ways: passive acceptance of this decline, or actively transitioning from the market before the market transitions from Canada.

6 Decarbonisation as a transition to a new iron and steel value chain

Keeping the iron and steel industry fossil-based poses significant risks. While shifting to low-carbon iron and steelmaking is of course not risk free, creating a new value chain by separating iron reduction and steelmaking could strengthen the Canadian iron and steel industry. By harnessing Canada's comparative advantages – such as its strong renewable energy assets, high-quality iron ore, good infrastructure and a skilled labour force – the country could strengthen industrial development through the domestic production of green HBI, leading to growing export revenues and reduced emissions both in Canada and abroad.

Such a transition requires many changes, requiring new skills be built up and jobs created, while simultaneously reducing labour demand within traditional steelmaking. Sweden, a country with a similar profile to Canada, is already road-testing some of these changes, albeit at a smaller scale. In this chapter, we will first analyse Canada's potential for a transition in a comparative manner with the ongoing iron and steel transition in Sweden. We will then discuss how changes in labour demand could affect mining, iron and steel workers.

6.1 Comparing the transition in Sweden and Canada

Figure 11 provides an overview of key Swedish and Canadian iron and steel companies, their production capacity and their pledges to reduce emissions.

LKAB

- **Iron ore mining company**
- **26 Mtpa production capacity**
- **5200 employees**
- **Near-zero by 2045**
- **Plans to reduce emissions by 40-50 mn tonnes per annum**

SSAB

- **Steelmaking company**
- **3.8 Mtpa production capacity (in Sweden)**
- **5400 employees**
- **Near-zero by 2030**
- **Will reduce emissions by 8 mn tonnes per annum**

Stegra

- **Steelmaking company**
- **2.5-5 Mtpa production capacity**
- **Will hire 1500 employees**
- **Near-zero start-up**
- **Reducing emissions by 95% compared to standard route**

Figure 11: Swedish and Canadian iron and steelmaking companies. Note that Stegra was formerly called H2 Green Steel.

From Figure 11, it is clear that the Swedish companies are more ambitious on climate than their Canadian counterparts. The total emission reductions put forward by the three Swedish companies amount to over 50 million tonnes of CO2, while the Canadian companies have planned emission reductions totalling 6.2 million tonnes. In addition, the Swedish start-up Stegra (formerly H2 Green Steel) will start operations and double Swedish steelmaking capacity with very low emissions, crowding out emission-intensive steel elsewhere (Bataille et al., 2024).

Conditions for a transition of the iron and steel industry are no worse in Canada than in Sweden. In fact, Canada's natural endowments and infrastructural resources suggest that such a shift could be as ambitious as in Sweden. Drawing on learning from Sweden, four conditions signal strong potential for such a transition in Canada: Strong iron ore resources, large potential for onshore wind expansion, strong supportive infrastructure, and broad political backing for net-zero emissions by 2050.

As already broached in the iron ore section of this report, Canada's iron ore resources are of a high grade and investments are already being made in several mines to upgrade production of iron ore pellets to DR-grade level. This suggests that Canada could be an important driver in the global iron and steel transition if these resources are made available for low-carbon, rather than conventional emission-intensive, production.

In addition to iron ore, large quantities of clean power are needed for low-carbon ironmaking. This reduction step will be needed somewhere along the value chain, whether it be co-located with the final steelmaking step, at an intermediate point before further shipping, or co-located with iron ore mining. For Canada to increase the amount of value realised domestically, it could move up the value chain and co-locate iron ore reduction with the initial steps of the value chain, and instead ship green HBI for use in steelmaking abroad. This would harness the country's natural endowments to lower emissions both domestically and abroad. This strategy is being pursued by Swedish mining company LKAB and utility Vattenfall, two of the three companies in the joint venture HYBRIT. Like Sweden, Canada would have to significantly expand its clean power production. While Canada is well-placed for such an expansion, this potential has not yet been realised.

Table 6 provides a simple comparison of Sweden, and Québec and Labrador to illustrate the potential for a buildout of onshore wind in these key Canadian provinces.

Table 6: Comparing Sweden to Québec and Labrador.

Comparison: Québec and Labrador and Sweden	Sweden	Québec and Labrador
Population (million)	10.5	8.5
Geographic size	447,430 km²	2,070,000 km²
Distance Stockholm-Kiruna	956 km	
Distance Québec City-Labrador City		748 km
GW onshore wind (2023)	16,25	4,1
Iron ore production (2023)	36 mtpa	59 mtpa

Despite its smaller size and larger population, Sweden has about four times as much onshore wind capacity and Québec and Labrador combined.

While both Sweden, and Québec and Labrador are geographically large territories and sparsely populated, Sweden has four times the amount of onshore wind power as the Canadian provinces. The rationale for this build-out of onshore wind was not to reduce the consumption of fossil fuels in the power sector, as Sweden already had clean power (large hydro and nuclear assets). Rather, this expansion has been important for the supply of low-cost power. The integration benefits with flexible hydropower – also located in Northern Sweden – are significant, as hydropower can be saved to be dispatched when the wind is not blowing. Low-cost power is a key strategic advantage for Sweden's industry, attracting power-intensive projects such as data centres, steelmaking, mining and mineral refining, battery production and e-fuels. Such investments have positive knock-on effects on economic development that simple resource exports in the form of cross-border power transmission do not.

Iron ore mines in Canada are located at a similar distance from urban hubs as their Swedish counterparts. The distance between Québec City and Labrador city, a key mining hub, is shorter than the distance between Sweden's capital, Stockholm, and Kiruna, where LKAB has its headquarters and its largest mine. Figure 12 shows Sweden superimposed on Québec, with Stockholm and Québec City overlapping for comparison. Canadian mines are marked in blue and Swedish mines are marked in red.

Figure 12: Superimposition of Sweden on Québec.
To illustrate the distances between mining sites and urban centres across the two geographies.

LKAB is planning its first H2-DRI plant in Gällivare, in the southernmost of the three mines, for further shipment along existing rail tracks to the ports of Luleå and Narvik in Norway to the west of Sweden, where HBI can be shipped to the rest of the world. Canadian iron ore miners could locate their H2-DRI plants by the mines in order to reduce transport costs: 1.504 tonnes of iron are needed to produce one tonne of HBI, so reducing iron ore close to the mines could lower the total transport weight. Another option could be to reduce the iron ore by the coast before final transportation, for example in Sept-Iles where most Canadian iron is shipped from. However, the site's power-intensive production is likely to depend on access to sufficient transmission lines, as LKAB and Stegra have located their sites close to major transmission lines to have access to the power needed. The well-developed transmission system across Québec, currently used to transport power from hydro resources in the north to demand centres in the south, are a strong asset for hydrogen direct reduction in Canada, compared to other renewable-rich sites across the world without an existing transmission system.

In the Swedish decarbonisation plan, the H2-DRI site at Gällivare will mean that LKAB overtakes the ironmaking step from steelmaker SSAB – which is planning to build EAFs to replace its BF-BOF sites in Swedish Luleå and Oxelösund. This will also lead to fewer tasks and, therefore, jobs, as is the case in Algoma, Ontario.

However, when the final investment decision was made to close the Luleå blast furnace, the local union president Tomas Karlsson described it as "fantastic", saying that it was "great, because we are leading all steel mills in the world on the path to decarbonisation" (Rocksén, 2024b). The reason behind this optimism is that SSAB will keep all existing jobs at the Luleå plant, moving the downstream rolling segment of steelmaking from the city of Borlänge – where it is currently located – to Luleå. This change will also reduce the energy use, because there will be no need to reheat the steel slabs after transport. Even the union president in Borlänge, Sven-Erik-Rosén, said he was "optimistic", as new investments are being made in downstream production at the site – such as an SSAB subsidiary making steel panels for the construction sector (Rocksén, 2024a). Through this reshuffling of the steel supply chain, jobs in communities dependent on steelmaking are protected, and new jobs can be created where the value chain will grow. Rosén is also a deputy worker representative to the SSAB board, and this worker representation at SSAB may strengthen the company's commitment to employees' interests.

6.2 Labour outcomes in the iron and steel transition

Like Sweden, Canada's strong tradition of organised labour is a key asset in the transition of the iron and steel industry, as a skilled workforce is central for large construction projects – such as new renewable energy, transmission and industries – to successfully finish on time. As mentioned, the expansion of iron reduction in Canada could lead to 14 000 new jobs in a new green iron industry, in addition to new jobs in the renewable energy, grid and infrastructure industries. However, without a strategic approach to the role of workers in the transition, there are risks that this shift could have a negative impact on the labour market of Canada in general, and Ontario and Québec in particular, as this is where most of the country's iron and steel industry is located. If a transition has negative consequences for people working in the affected industries, there is a risk that the political sustainability of the transition will be undermined (Breetz et al., 2018; Stokes & Warshaw, 2017).

Today, the iron and steel industry is an important career path with family-sustaining wages for people without college degrees. Figure 13 shows the average wages over the past five years across all sectors, the manufacturing sector, the iron and steel sectors and electric power engineering construction which is the construction of wind turbines and solar panels.

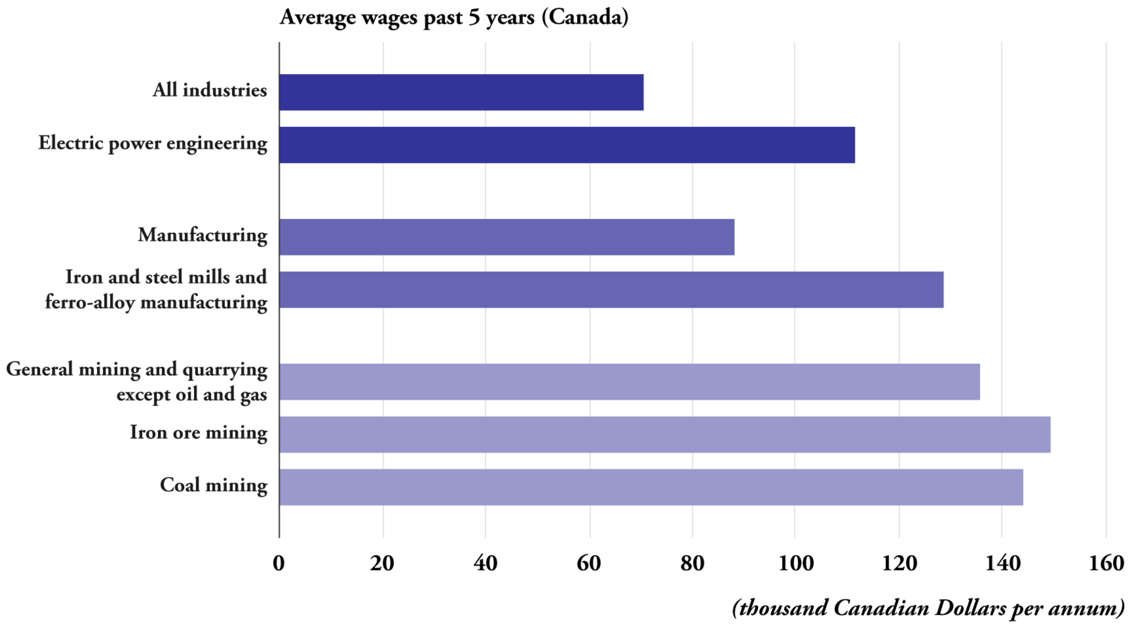

Figure 13: Average wages over the past five years in selected industries.
Source: Statistics Canada.

In Figure 13, we can see that iron ore mining is the highest-wage sector in the sample, at about double the average of all industries. Coal mining is not far behind iron ore mining, and both offer higher wages than the general mining sector. Iron and steel mills are, in turn, high-wage sectors, ahead of general manufacturing. Finally, wages in electric power engineering construction are also fairly high, albeit below the level for all the sectors in the iron and steel sector.

This poses a challenge for the political sustainability of a transition of the iron and steel industry in Canada. First of all, if a transition of steel mills is equated with the loss of high-wage job opportunities, then the general welfare of steel workers and the purchasing power of steel communities risks falling. These impacts risk reducing the political support for a transition, and associating emission reductions with job losses, thereby undermining future transition plans. Secondly, if the alternative job sectors where growth is expected as a consequence of a transition (such as the electric power engineering construction sector) is lower wage than emission-intensive sectors, then the transition – even though emission-intensive jobs are replaced with low-emission jobs – risks leading to wage cuts for workers. Even if the value added is increased in Canada, wage cuts are likely to make working people – an important constituency – opposed to industrial transitions.

For these reasons, policymakers must develop a comprehensive iron and steel decarbonisation strategy that proactively seeks to address emission-intensity of these sectors, all the while ensuring strong employment and wage prospects. With this holistic approach, private companies, workers and their communities can share in the benefits of more value added in Canada. Alongside this, policymakers and unions should consider how wages in clean sectors can become competitive with those found in emission-intensive industries. If shifting from mining coal to building wind turbines will provide benefits to the workers who are now locked in fossil fuel production, the political support for the transition will be stronger and the transition quicker. While the viability of the transition depends on Canadian green iron and steel production remaining competitive, strong labour outcomes should be possible, as labour costs constitute a small part of total costs in these capital intensive industries (Mayfield et al., 2023).

7 Concluding remarks

The global shift away from fossil fuels poses significant risks of fossil fuel lock-in for Canadian industries. Without timely adaptation, Canada's iron and steel industries may struggle to stay competitive. While the strategies to decarbonise discussed in this report require major and challenging adjustments across Canada, they also present significant opportunities. Thanks to Canada's rich iron ore and renewable energy resources, as well as its strong infrastructure and workforce, it could increase the value added in-country by up to 25 billion Canadian dollars, creating over 14 000 jobs in the process, while cutting emissions at home and abroad to an equivalent of around 16 percent of Canada's total emissions. In doing so, it would also strengthen global green supply chains, promote trade with key global trading partners and allies, potentially compensating for the loss of fossil fuel export revenue – such as metallurgical coal – that will inevitably decline.

Rapid action is needed to capitalise on this opportunity. Current headwinds in the EU for hydrogen-based steelmaking is a window of opportunity for Canada to become a key exporter of green HBI. Australia is already moving quickly in this direction, and Brazil will soon have the opportunity to strengthen its role in global green supply chains by hosting the next United Nations climate meeting (COP30). Together with these and other major iron ore exporters, Canada could be part of diplomatic efforts to showcase the role of iron exporters in decarbonising the global iron and steel industry and strengthen global cooperation. In today's increasingly fractious geopolitical context, this kind of joint diplomatic and trade initiative is greatly needed – nations have a responsibility to work together to collectively deliver on the Paris Agreement and keep global temperature increases within safe limits. The Canadian iron and steel industry has the potential to play a key role in this endeavour.

1. Appendix I

Key stakeholders in Canada's iron mining industry

Assumptions	Value	Unit	Source
CAPEX electrolyser	0.585	€/kW installed capacity	(Devlin et al., 2023)
CAPEX DRI shaft furnace	230	€/t capacity	(Devlin et al. 2023)
O&M	3	% of CAPEX	(Vogl et al. 2018)
Discount rate	12	%	
Lifetime DRI shaft and EAF	20	years	(Devlin et al. 2023)
Lifetime electrolyser	10	years	(Devlin et al. 2023)
Electrolyser	2	[h/kW installed electrolyser]	(Devlin et al. 2023)
Shaft furnace	0.18	[h/tDRI]	(Global Energy Monitor 2023)
Labour costs	14906 CAD	Annual wage	Statistics Canada
Hours per year	1920	h/year	(Devlin et al. 2023)
Power costs	7.8 c/KWh	CAD	(Hydro-Québec, 2024)
KWh/kgH2	55		(European Parliament, 2020)
kgH2/tonne steel	58		(Bhaskar et al. 2022)
Iron ore costs	90-148	USD	St Louis Fed

2. Appendix II

Key stakeholders in Canada's iron mining industry

Champion Iron

Champion Iron is a listed mining company, owning and operating the Bloom Lake mining complex. The company has a capacity of 15 mtpa. Its main shareholders are Investissement Québec (8 percent) (a publicly owned investment company founded by the Quebecois National Assembly in 1998), the American private equity firm Wynnchurch Capital (8 percent), and CEO Michael O'Keeffe (8 percent). Champion Iron employs 1160 workers (Champion Iron, 2024b).

Tata Steel Minerals Canada

Tata Steel Minerals Canada was founded in 2010 and is a joint venture between Tata Steel (78 percent), the Québec government (18 percent) and New Millennium Iron Corp. (4 percent). It produces an average of 4 mtpa iron ore products and ships out from the port city of Sept-Iles. Tata Steel is a listed company, where the Indian private investment company Tata Sons owns a third of the company.

ArcelorMittal Mining

ArcelorMittal is a major steelmaking company, also owning significant mines in Canada, shipping iron from Port-Cartier, just west of port town Sept-Iles. Along with the infrastructure subsidiary, ArcelorMittal Mining employs 2500 people on the North Shore of Québec. The company holds assets all over the world, primarily in Europe and India. ArcelorMittal is a public company headquartered in Luxembourg, but the company's primary owners are the Indian Mittal family (about 35 percent) and the investment bank BlackRock (5 percent) (ArcelorMittal, 2024).

Rio Tinto – Iron Ore Company of Canada

The Iron Ore Company of Canada is a joint venture between Rio Tinto (58.7 percent), Mitsubishi (26.2 percent) and the listed investment company Labrador Iron Ore Royalty Income Corporation (15.1 percent). The company has an iron ore capacity of 23 mtpa and employs 2900 employees. It ships its iron ore from the port of Sept-Iles.

Tacora Resources

Tacora Resources is a privately owned company that owns and operates the Scully mine in Labrador, with a capacity of 6 mtpa, and employs 410 people. It ships its iron ore from the port town of Sept-Iles. Tacora Resources is owned by mining investors such as Proterra Investment Partners, Cargill and Aequor Holdings.

The Mining Association of Canada

The Mining Association of Canada is the main industry body for Canadian mining companies, covering companies mining a wide variety of resources, including iron ore. The association is an influential organisation, active in areas including environmental regulations and permitting, Indigenous affairs, and taxes.

United Steelworkers

The United Steelworkers is a trade union organising workers across North America, headquartered in Pittsburgh, Pennsylvania and led by President David McCall. Marty Warren is the national director for the United Steelworkers in Canada, and the Canadian union is affiliated with the Canadian Labour Congress (CLC). The union is the primary trade union for workers in the Canadian iron ore mining industry. The United Steelworkers is a founding organisation of the social-democratic political party the New Democratic Party.

Provincial government of Québec

Most of Canada's iron ore mining industry is located in the province of Québec. The provincial government is also the second largest owner of the Tata Steel Minerals Corporation, with an ownership stake of 18 percent (Tata Steel Minerals Canada Limited, 2024). The province is governed by François Legault and his party, Coalition Avenir Québec (a conservative and nationalist/autonomist party.) The main opposition party is the Liberal Party, and the next election will be held in 2026.

Provincial government of Newfoundland and Labrador

As several iron ore mines and related infrastructure are located in Labrador, the government of the province of Newfoundland and Labrador is important for the development of the iron industry. The province has been governed by the Liberal Party since 2015, with Andrew Furey as its premier since 2020. The next election is due in 2025. Furey has positioned the province as a potential hydrogen exporter, with prime minister Justin Trudeau and German chancellor Olaf Scholz signing an agreement in the province to establish trade in hydrogen (Depner, 2023).

Key stakeholders in Canada's steel industry

There are a variet3y of key stakeholders in the Canadian steel industry that are key to influencing the direction of change within the sector. In this section, we discuss them each in turn.

Canadian steelmakers

There are four key steelmaking companies that own and operate traditional integrated steel mills in Canada:

ArcelorMittal

ArcelorMittal owns two sites, the Dofasco BF-BOF site and the Montreal DRI-EAF site. With its 6.45 mtpa of steelmaking capacity, ArcelorMittal is the largest steelmaker in Canada, as well as being one of the world's largest steelmakers, the largest outside of China, producing over 68 million tonnes of steel in 2023. This puts it ahead of Nippon Steel at 44 million tonnes and POSCO at 39 million tonnes respectively. The company holds assets all over the world, primarily in Europe and India. ArcelorMittal is a public company headquartered in Luxembourg, but the company's primary owners are the Indian Mittal family (about 35 percent) and the investment bank BlackRock (5 percent) (ArcelorMittal, 2024).

Algoma

Algoma owns one site in Sault Ste. Marie and is the second largest steelmaker in Canada, with a steelmaking capacity of 3.2 mtpa. Algoma was founded in Canada in 1902 and was publicly listed in 2021. Its main shareholders are various investment banks and funds in the US and Canada.

Stelco

Stelco is the third largest integrated steelmaker in Canada, with an annual production capacity of 2.5 mtpa. In 2024, US steelmaking company Cleveland-Cliffs announced the acquisition of Stelco, which was approved by Stelco shareholders a few months later. The company was founded in 1910 and went bankrupt in 2007, when it was bought by the US steelmaker US Steel. The company was listed on the Toronto stock market in 2017.

Rio Tinto

Rio Tinto owns and operates a BOF site in Canada with a steelmaking capacity of 0.6 mtpa, making it the smallest traditional steelmaker in Canada. However, the company's primary product is titanium, with pig iron as a secondary product, as the ore is a blend of titanium dioxide and iron oxide. Rio Tinto is a listed British-Australian company with BlackRock as the main shareholder (about 6 percent) and the rest with an ownership stake at 3 percent or less.

Canadian Steel Producers Association

The Canadian Steel Producers Association (CSPA) is the main organisation of steelmaking companies in Canada, organising both traditional integrated steelmakers and scrap-based steelmakers, headquartered in Ottawa. The CSPA is an influential stakeholder, engaged in issues ranging from trade agreements and tariffs, to energy and industrial policy, and also represents Canadian steelmakers at the bi-annual OECD steel committee meetings, where member states discuss policy and market developments.

United Steelworkers

The United Steelworkers is a trade union organising workers across North America, headquartered in Pittsburgh, Pennsylvania, and led by President David McCall. Marty Warren is the national director for the United Steelworkers in Canada, and the Canadian union is affiliated with the Canadian Labour Congress (CLC). It is the primary trade union for workers in the Canadian steel industry, and therefore the main representative for labour across the steel industry, with the exception of Dofasco, which is not unionised. The United Steelworkers is a founding organisation of the social-democratic political party the New Democratic Party.

Provincial government of Ontario

As most of the Canadian steel industry is located in the province of Ontario, the policies and politics of the provincial government affects a large part of the Canadian steel industry. Since 2018, the province is governed by the Progressive Conservative Party and premier Doug

Ford. The premier has been supportive of the plans to reduce emissions from steel mills across the province. The next election will be in 2029.

Provincial government of Québec

The second most important province for the Canadian steel industry is the province of Québec. The province is governed by François Legault and his party Coalition Avenir Québec, a conservative and nationalist/autonomist party. Legault has been supportive of the steel transition plans in the province. The main opposition party with the most seats in the National Assembly is the Liberal Party. The next election will be held in 2026.

Key stakeholders in Canada's metallurgical coal mining industry

Glencore (Elk Valley Resources)

In 2024, Glencore took over four metallurgical coal mines in eastern British Columbia, from Teck Resources, headquartered in Vancouver. In 2022, the company produced 21.5 mt of metallurgical coal (ACCR, 2023). The company employs about 4000 workers across the four mines (Pawson, 2023). Glencore is a listed company, with South African Ivan Glasenberg as the main shareholder at 10 percent and Qatar Investment Authority at 8.5 percent.

Conuma Coal Resources Limited

Conuma Coal Resources Limited (CCRL) is a company owning several metallurgical coal mines in eastern British Columbia. The company has a capacity of 5 mtpa and employs 1100 workers. CCRL is a subsidiary to a company controlled by a fund called the Virginia Conservation Legacy Fund (Penner, 2016) and its owner, Tom Clarke, who is a self-declared environmentalist (Mider, 2022).

CST Canada Coal Limited

CST Canada Coal Limited (CSTCCL), owns the metallurgical coal mine Grande Cache in western Alberta. It is a subsidiary of the CST Group which is a listed company based in Hong Kong, China. The mine has a production capacity of 1.3 mtpa, and a workforce estimated at about 300 employees (Global Energy Monitor, 2024c).

The Mining Association of Canada

The Mining Association of Canada is the main industry body for Canadian mining companies, covering companies mining a wide variety of resources, including metallurgical coal. The association is an influential organisation, active in areas including environmental regulations and permitting, Indigenous affairs, and taxes.

United Steelworkers

The United Steelworkers is a trade union organising workers across North America, headquartered in Pittsburgh, Pennsylvania and led by President David McCall. Marty Warren is the national director for the United Steelworkers in Canada, and the Canadian union is affiliated with the Canadian Labour Congress (CLC). The union is the primary trade union for workers in the Canadian coal mining industry. The United Steelworkers is a founding organisation of the social-democratic political party the New Democratic Party.

Provincial government of British Columbia

As most Canadian metallurgical coal mines are located in British Columbia, the provincial government is an important policymaking entity for the country's metallurgical coal sector. The province has been governed by the New Democratic Party since 2020, with premier David Eby re-elected in 2024, and the Conservative Party of British Columbia the main opposition party. Premier David Eby has argued that metallurgical coal exports are less environmentally damaging than exports of thermal coal (MacLeod, 2023). The next election is scheduled for 2028.

Provincial government of Alberta

There is one metallurgical coal mine in Alberta, making politics in the province important for the coal mining sector. Alberta has been governed by the United Conservative Party since 2019, with premier Danielle Smith at the helm since 2022. The New Democratic Party is the main opposition party. Premier Smith supports the development of new metallurgical coal mines in the province (Nikiforuk, 2024).

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