**Overcoming Remoteness: Innovations to Support Economic Development, Critical Minerals, and Security in the Arctic**

By Heather Exner-Pirot

June 2023

**Executive Summary**

Remoteness has a dramatic effect on human and economic development. In remote locales, such as the North American Arctic, costs are much higher for services, goods, and infrastructure than in the rest of North America, yet the needs are greater to cope with the distances and challenging environment.

However, current geopolitical and economic circumstances may prompt change. The Arctic has long been described as a bonanza of resources, especially oil, gas, and minerals. Yet currently in Canada's territories there is almost no oil and gas production. Despite the fact that mining production accounts for 99 percent of the territories' exports by value, it is still a relatively small portion of Canada's mining production and almost none of it is in critical minerals. Rather, the vast majority of production has been concentrated in the more easily transportable diamonds, gold, and silver, and, in one case due to proximity to tidewater, iron.

The demands for energy transition and the needs of the sectors supplying it require far greater mining activity as we move from a hydrocarbon-intensive energy system to a mineral-intensive one. At the same time, the world is seeking security as it aims to reduce its resource dependency on adversaries such as China and Russia. However, despite the growing importance of friendly and enhanced supplies of critical minerals, and the understanding that the North American Arctic holds significant quantities of these, the region remains an expensive and challenging place in which to mine.

Although many articles on the Arctic claim that it is becoming more accessible to develop resources there due to climate change, in reality this is not the case. Changes in the climate do not counterbalance the other, more prohibitive, challenges that resource development faces in remote areas, not least from climate change itself.

The challenges associated with resource development in the Arctic broadly mirror those that remote communities face more generally, and include lack of infrastructure; extreme weather conditions that make outdoor work difficult and expensive; sparsity of population, which makes it difficult to attract and retain qualified labour; and environmental concerns about disturbance to water, wildlife, and plant life. In fact, while there is a growing political recognition of the importance of critical minerals from the Arctic there is still limited support from the public for an expansion of mining activities. If anything, support has been diminishing.

Thus, new strategies are needed if development is to grow in the Arctic. Fortunately, a number of transformative technologies are on the horizon. They include small modular reactors (SMRs)

which could supply energy (both heat and power) to remote locations, airships (lighter-than-air, low-environmental-impact aircraft that operate under their own power) that could supply cargo transportation to and from remote regions, and fibre networks that could give remote locations good communications and through which mines could implement numerous technological upgrades including autonomous drilling, driverless haul trucks, drones for surveying and safety, wearable technologies, and predictive maintenance.

These transformative technologies would benefit not just residents of remote regions and mining operations in the area, but the military. The need to defend North America and deter Russia – and China – from attacking in the first place depends on a strong military presence in the Arctic. This is where SMRs, airships, and fibre optic lines can serve a dual purpose (civilian and military), and perhaps the military could be secured as an anchor customer.

The combination of the desired energy transition and the need to secure critical minerals from friendly sources may finally be the impetus needed to shake the region out of its current development paradigm. Fortunately, technologies are now emerging that have the potential to address the challenges that remoteness imposes on energy, transportation, and connectivity. These have the potential to not only improve the quality of life for the region's inhabitants, but allow more economically and environmentally responsible development of critical minerals.

**Introduction**

What distinguishes the Arctic from other regions? Common answers include latitude, vastness, sparsity of population, or extreme cold. But from a development perspective, the most important one is remoteness: distance from services, markets, and policy-making.

Remoteness has a dramatic effect on human and economic development. Costs are much higher for services, goods, and infrastructure, yet the needs are greater to cope with the distances and challenging environment. Northern societies have evolved to be independent and resilient. But there are persistent gaps in quality-of-life indicators such as life expectancy, educational attainment, and household income; and enormous disincentives to investing in the region, despite the presence of large deposits and reserves of natural resources.

This is a situation that has persisted for decades, without much in the way of innovation to alter the status quo. The strategy to address remoteness has generally been to secure more transfers from centralized governments to prop up standards of living, without meaningfully improving them.

However, geopolitical and economic circumstances may now provoke disruption. The demands for energy transition and the needs of the sectors supplying it demand far greater mining activity as we move from a hydrocarbon-intensive energy system to a mineral-intensive one. At the same time, there is a security need as the world seeks to reduce its resource dependence on adversaries such as China and Russia.

One of the few untapped and friendly regions in the world with significant quantities of critical minerals is the North American Arctic: Alaska, Greenland, and the Canadian territories. But to gain access to them, we must first find better ways to address remoteness. That is the task of this paper. It proceeds in three sections.

The first section explores the qualities of remoteness and how these affect economic development. It highlights the practical differences between rural and urban communities in the Barents region, encompassing the northernmost parts of Norway, Sweden, Finland and northwest Russia, which has year-round road access and grid connectivity, with remote areas of the North American Arctic accessible only by plane, ice road, or seasonal sealift. The quality of being remote has much more of an impact than being at a high latitude.

The paper then outlines the implications of remoteness on gaining access to critical minerals in the Arctic. Despite the growing importance of friendly and enhanced supplies of critical minerals, and the understanding that the North American Arctic holds significant quantities of these, the region remains an expensive and challenging place in which to mine. This is manifested in weak mining investment and production levels. There is no reason to believe that Alaska, Greenland, and in particular the Canadian territories, will be meaningful sources of critical minerals anytime soon.

Finally, the paper seeks to address challenges to remoteness by describing three technologies that could address, respectively, energy, transportation, and connectivity. These include small modular reactors and microreactors, airships, and fibre networks. Each of these technologies has promising applications for communities, the mining industry, and the military, and may help move Arctic development out of its current stasis.

**The rural and remote Arctic**

The Arctic is often described homogenously: as a single region characterized by ice, cold, and darkness, and especially by latitude. The simplest and most conventional definition of the Arctic is the area above 66$^{o}$ latitude, i.e., the region that experiences both 24-hour daylight and 24-hour darkness for at least one day a year.

From an economic development perspective, there is tremendous variation in the region's features, challenges, and opportunities. Latitude correlates poorly with them. In particular, there is almost no comparison on the conditions for human settlement between the Barents region and the rest of the Arctic. That is because the Barents is warmer, which has allowed it to become far more populated and connected to transportation, communications, and energy networks.

The southern half of the Barents Sea, including the ports of Murmansk (Russia) and Vardø (Norway) is ice-free year round due to the warm North Atlantic Drift. The region is entirely served by electricity transmission lines and road connectivity. The area is inhabited by more than 5 million people with an average population density of 2.9 inhabitants per square kilometer. This compares to 0.03 people per square kilometer in northern Canada, 0.045 in the North Slope Borough of Alaska, and 0.14 in Greenland. The Euro-Arctic region is better described as "rural" than "remote."

Meaningful distinctions also exist in the non-European Arctic. The southern part of Alaska, which is bathed by the relatively warm Pacific waters of the Alaska Current, is in a similar circumstance to the southern half of the Barents Sea and its conditions more closely approximate rural than remote ones. For example, the Port of Alaska in Anchorage is consistently ice free, and icy conditions have never stopped operations there.

Even Greenland has more open waters than northern Canada. The capital, Nuuk, enjoys year-round ice-free water access, thanks to warm waters brought by the Gulf Stream. That means Nuuk's port supports a healthy fishing industry and receives cargo all year, rather than having to rely on annual summer sealift as is the case in Arctic Canada.

If one acknowledges the difference between rural and remote, and between seasonal and year-round access, then it makes no sense to compare development pathways in remote communities in the Canadian Arctic with rural and urban ones in the Barents region. Tromsø is not a model for Iqaluit, let alone Tuktoyaktuk.

Such distinctions have been described in the past as a measure of *nordicity*, or northernness, as the Canadian geographer Louis-Edmond Hamelin wrote in his renowned 1979 book with William Barr. Hamelin identified 10 natural and human measures of nordicity: latitude, summer heat, annual cold, types of ice, total precipitation, natural vegetation cover, accessibility by means other than air, air service, population, and degree of economic activity. Each component was graded on a scale of 0–100, where 100 represented extreme nordicity, to calculate a total out of 1000, which the North Pole represented. Anything over 200 could be considered "north," which was further delineated into near north, middle north, far north, and extreme north. The more north, the more remote.

On such a scale, there are wide distinctions between various Arctic and northern cities, with Reykjavik, Anchorage, Tromsø, Rovaniemi, and Arkhangelsk on the lower end of the scale, and Yellowknife, Fairbanks, and Nuuk in the middle. Villages and hamlets in the North American and Russian Arctic are the only ones that would be considered far and extreme north. As such, their economic development context is completely different from the others.

Current Canadian government definitions of "rural" and "remote" focus on two things: low population density and accessibility to key services such as education, health care, high-speed internet, and retail and professional services. These factors matter in everyday life as they imply barriers to acquiring basic public goods. Being more distant from service centres results in high transaction costs, in both time spent to access services and the resources needed to do so.

Common additional costs include:

- Transportation costs
- Freight costs
- Telecommunication costs
- High rent or lease costs
- Energy costs related to lack of infrastructure and extreme climate
- Costs for recruitment and retention of professionals
- Lack of an economy of scale (and thus higher per capita costs)
- Associated cost of living (housing, food)

By most definitions, a community with no road access is considered remote. Remoteness is also associated with lack of population density, or the number of people living within a square kilometer. The two generally correlate, though the City of Iqaluit is an anomaly. Although it has no road access, it has a population of 8000 and good access to services and public goods, though they come at a higher cost.

Canada has one of the lowest population densities in the world, at 3.9 persons/km$^2$. Statistics Canada considers a population density of less than 400 people/km$^2$ and a population centre of fewer than 1000 residents as a threshold for "rural" (Murphy 2019). The Statistics Canada class of "more remote" is attributed to an average population density of 0.4 people/km$^2$ and accounts for 3.7 percent of the Canadian population. Just 0.7 percent of Canadians, living in 604 census districts, live in the "most remote" category with an average population density of 0.1 residents/km$^2$ (Statistics Canada, 2022).

Figure 1: Remotest communities in Canada.

| Most remote communities in Canada | Jurisdiction | Remoteness score |
|---|---|---|
| Grise Fiord | Nunavut | 1.0 |
| Resolute | Nunavut | 0.984 |
| Kugaaruk | Nunavut | 0.980 |
| Peawanuck | Ontario | 0.978 |
| Taloyoak | Nunavut | 0.969 |
| Kugluktuk | Nunavut | 0.966 |
| Berens River | Manitoba | 0.962 |
| Webequie | Ontario | 0.941 |
| Kangiqsujuaq | Quebec | 0.937 |
| Wunnumin | Ontario | 0.931 |

Source: Statistics Canada (2023a), Index of Remoteness.

**Resource peripheries and critical minerals**

Remoteness is also expensive for mining activities. According to the Prospectors and Developers Association of Canada (PDAC 2015), transporting resources from remote mines costs far more than for their road-accessible counterparts with the gap growing the heavier the product: the discrepancy is about 15 to 20 percent higher for diamonds, double the cost for gold, and 2.5 times the cost for base metals (copper, iron, thallium, zinc, nickel, aluminum, and lead). Operating costs are also 30 to 60 percent higher. These conditions demand world-class deposits and high commodity prices to justify proceeding.

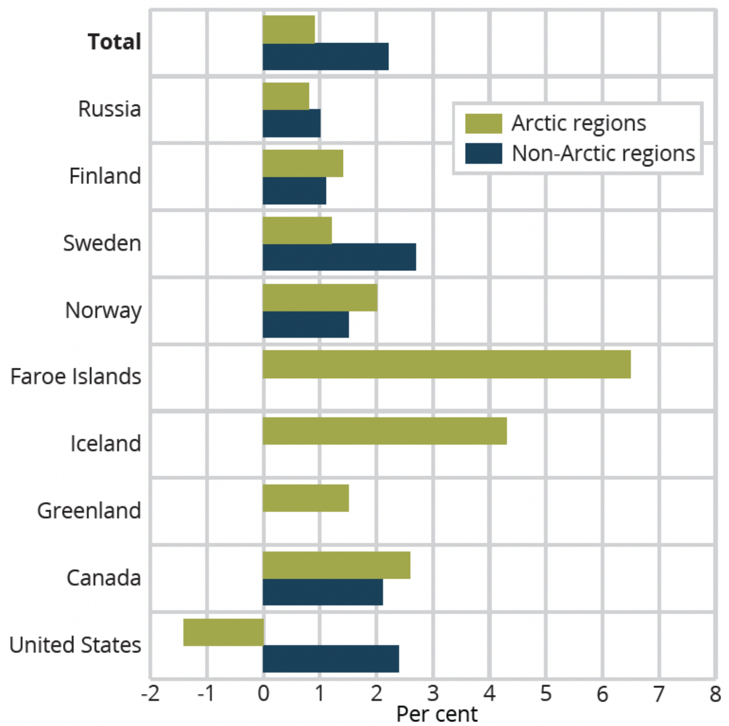
The Arctic has long been described as a bonanza of resources, especially oil, gas, and minerals. It is a classic resource periphery: a region distant from the economic core where the dominant sector is in primary industries such as fishing, logging, mining and fossil fuel production. Many – even most – mainstream news articles note that climate changes are making its bounty of untapped resources more accessible, and that this is a key driver of economic and strategic interest in the Arctic. Most government reports, strategies, and studies of the Arctic assert this as well. And yet there is no evidence that this is happening. That's because climate change does not drive resource development in the Arctic; commodity prices do. And commodity prices have not been sufficient to drive new development in the Arctic in a meaningful way in the past decade.

Much of the current discourse on an Arctic "race for resources" arose during the boom phase of the last commodities cycle. The infamous image of the Russian flag being planted on the seabed at the North Pole in 2007 and the Ilulissat meeting of the Arctic Five (Canada, Russia, USA, Denmark/Greenland, and Norway) in 2008 came when benchmark oil prices were hitting a peak of $147/barrel. Many other commodities hit peaks in or around 2008-2012. But then the down phase of the commodities cycle hit, and investor interest in Arctic resource development plummeted.

A way to look at this in the contemporary context is gross regional product and growth. The authoritative source is from the ECONOR project, a series of reports entitled *The Economy of the North* (for 2005, 2008, 2015 and 2020) published by the Arctic Council and led by its Sustainable Development Working Group. Its latest report, for 2020, confirms what is intuitively obvious: that low commodities prices have had a dampening effect on the regional economy. Far from demonstrating "emerging economy" trends, the Arctic region actually grew slower than the non-Arctic parts of the respective Arctic states between 2012 and 2018, the years the latest report analyzes.

Figure 2: Average annual economic growth of Arctic and non-Arctic regions, by country, 2012-2018 (percent)

**Figure 3.11. Average annual economic growth of Arctic and non-Arctic regions, by country. 2012-2018. Per cent**




Source: Glomsrød, Duhaime, and Aslaksen (eds.) (2021).

That said, the region has grown significantly this century. Its economic activity totalled US$225 billion (based on purchasing power parity) in 2003, or 0.44 percent of the global economy (Duhaime and Carron 2003), and grew to US$615 billion in 2018 (based on purchasing power parity), or 0.7 percent of the world economy. But the majority of this activity has been in Russia, which represented 73 percent of the Arctic's economy in 2018 (Glomsrød and Wei 2020). A notable decline, by contrast, has occurred in Alaska, for one straightforward reason: oil production there arose following the 1970s oil crisis when the United States was desperate for domestic sources, but it peaked in 1989; in 2020 Alaskan oil production was at its lowest point in over 40 years (EIA 2021). The rise of cheap shale oil and gas production in the lower 48 states limited investor interest in more expensive plays, especially the Arctic offshore, which also suffered from limited social license, following environmental campaigns such as Greenpeace's "Save the Arctic". The recent approval of ConocoPhillips' Willow project in Alaska's North Slope together with higher oil prices might have the effect of reversing Alaska's economic decline.

The story that bears emphasising is this: the majority of Arctic economic growth in the past decade has taken place in Russia, and it has taken place in LNG (liquefied natural gas). This has little to do with climate change and a lot to do with the emergence of a global LNG trade alongside Russian state policies that favour fossil fuel development.

Russia is the world's second largest producer of natural gas and holds its largest gas reserves. The Arctic accounts for 80 percent of Russian gas production (IEA 2022). Production has historically been concentrated in western Siberia, but major projects in the past decade have shifted to Yamal, Eastern Siberia and the Far East, and the offshore Arctic (IEA 2022). Russia has plans to triple its LNG output from its Arctic regions by 2030 (Humpert 2023).

The Ukraine war, perversely, has helped increase Russian Arctic LNG exports. Unlike pipeline gas, Russian LNG is still not subjected to western sanctions. Its LNG exports to Europe actually rose in 2022 and early 2023 (Staalesen 2023). That said, in future, Russian LNG will likely be sent in increasing volumes eastwards, to Asian energy importers, given the current geopolitical circumstances. But this reorientation will pose logistical headaches. Shipping east from Yamal to Asia requires significantly more icebreaking assistance than going west to Europe, as the eastern portions of the Northern Sea Route are much icier. Year round shipping will be challenging even with nuclear ice breaking assistance.

By contrast, there is almost no oil and gas production in Canada's territories. And despite the fact that mining production accounts for 99 percent of the territories' exports by value (Statistics Canada 2018), it is still a relatively small portion of Canada's mining production and almost none of it is in critical minerals. Rather, the vast majority of production has been concentrated in diamonds, gold, silver, and iron. Diamonds and precious metals are produced in smaller quantities than base metals such as copper, nickel, and zinc and can be flown out of remote mines quite easily. The infrastructure does not allow for much else. The Mary River iron mine on Baffin Island is an easily explained exception: its ore comes from a world-class, high-grade series of deposits that happen to be only 100 km from tidewater. In its case, it was deemed economic to build a tote road to port. It also is on the far eastern side of the Northwest Passage and closer to Baffin Bay and the Labrador Sea, which is less ice choked than more westerly locations. But this circumstance is very nearly unique.

Canadian Arctic mining growth has come from a handful of projects, led by a boom in diamond mining in the Northwest Territories (NWT) at Burgundy's Ekati, Rio Tinto's Diavik, and De Beers' Gaucho Kué mines; and in gold and iron mining in Nunavut: Baffinland's Mary River iron mine, Agnico Eagle's Meliadine and Meadowbank mines, and B2Gold's Back River Gold Project (see Appendix 1 for a list of North America's Arctic mines). However, based on current and planned projects, mining production in Nunavut is expected to peak in 2024, and all three NWT diamond mines are expected to cease operations by the end of the decade having reached their natural end of life. The result will be anemic growth, if not decline, in territorial GDP.

**A less inaccessible Arctic**

Although many articles on the Arctic claim that it is becoming more accessible to develop resources there due to climate change, in reality this is not the case. Regardless of the warming that is occurring, resource development in the Arctic will not prove viable for any foreseeable future because changes in the climate will not counterbalance the other, more prohibitive, challenges that resource development faces in remote areas, not least from climate change itself. These challenges broadly mirror those that remote communities face more generally, and can be distilled into the following:

- Lack of infrastructure, especially in transportation, energy, and communications, that make it either logistically impossible or prohibitively expensive to develop greenfield (new) projects.
- Extreme conditions, in particular cold, wind, and storms, that make outdoor work difficult and expensive, require high energy consumption, and compromise the effectiveness of parts and materials.
- Sparsity of population, leading to difficulty in attracting and retaining qualified labour and necessitating extra costs in the form of wage premiums and transportation and camp costs.
- Environmental concerns about disturbance to water, wildlife, and plant life, both by local or Indigenous populations who often rely on the land for some portion of their food security and have cultural and spiritual connections to the territory, as well as by southern, urban voters and shareholders who dislike the idea of resource extraction in the Arctic.

Furthermore, in many ways climate changes make resource extraction projects more difficult in the Arctic, not easier: the length of the seasons for winter roads that many remote mines and communities depend upon for re-supply have become shorter; the costs of maintaining railroads and roads on melting permafrost have become higher; and coastal erosion that can affect ports is increasing. Perhaps the only advantage to a warming climate is a slightly longer shipping season that is adding a few weeks to what is currently a three- to five-month window. But even shipping seasons are highly variable from year to year, and unpredictable sea ice patterns and small icebergs or “bergy bits” keep navigation challenging. Insurers charge up to 40 percent more than basic premiums for Arctic transits, and even then marine insurers in general have been paying out more for ship damage than they collect in premiums (Saul 2020). The Arctic market is risky and small, and many have no interest in shipping to or from it.

Because the Earth tilts at a 23$^{o}$ angle, the Arctic will always be dark and cold in the winter and the sea ice will always come back. The Arctic’s March sea ice maximum is not decreasing as dramatically as the September sea ice minimum, and was 95 percent of the 1980-2010 average in March 2023 (NSIDC 2023). Canada’s Northwest Passage is much icier than the Northern Sea Route, and is difficult to navigate due to its many narrow and shallow points and limited infrastructure. Even without ice it is a poor route – and it almost always has ice.

**The Critical Minerals Gap**

The designation criterion for calling minerals “critical” is political, not geological. “Critical” refers to metals and elements deemed scarce, concentrated, and/or otherwise essential to the economy, including those needed for the low-carbon energy transition. Different countries designate different minerals as critical. Canada, for example, has 31 elements on its list, while the United States has 50. The United States excludes copper, helium, potash, and uranium from its list, while Canada includes them. Rare earth elements (REEs) are a group of 17 heavy metals that are often deemed to be critical minerals, and can be counted as a group or individually.

The recent political focus on critical minerals – strategies, alliances, agreements, and, in the fall of 2023 a summit that will be hosted by the International Energy Association – is meant to highlight two things: (1) the West's dependence on China and other illiberal countries for much of its mineral needs; and (2) the need to greatly expand production of key elements such as copper, nickel, lithium, manganese, cobalt, and REEs to meet the requirements of the energy transition.

*Security aspects*

The Russian invasion of Ukraine threw into sharp relief the risks associated with depending on adversaries for resources. In that case, the dependency was Europe, which relied heavily on Russia gas. After the invasion the continent experienced an energy crisis which it has so far navigated thanks to a warm winter, huge growth in LNG exports from the United States and others (such as Russia), and a collective €800 billion in energy subsidies (Sgaravatti et al. 2023). However, there will continue to be economic consequences for relying on, and subsequently deciding to sanction, Russian pipeline gas.

What would happen if China invaded Taiwan? If some North American commentators have chided Europe for its Faustian bargain with Russia, they and others recognize that the West is even more dependent on China for many of the materials upon which our civilization depends than is Europe on Russia for its energy needs, and that we would be hard pressed to sanction China if, for example, it violated Taiwanese sovereignty. Taiwan is also critical to western economies as it supplies the semiconductors needed for digital phones, electric cars, military equipment, and much more. The West would have no good options should China invade Taiwan.

China is the world's largest miner, accounting for 25.4 percent of global production, and is the top producer of 29 different commodities (Austria, Federal Ministry of Finance 2023). Beyond mining, China is dominant in the refining and processing of many minerals, giving it influence on the trade and pricing of many more products (IEA 2021).

But the problem of critical mineral dependence goes far beyond China. Unlike oil, natural gas, and coal, which are found on every continent, minerals tend to be geographically concentrated, with only a handful of countries accounting for a majority of global production of certain minerals. The world is highly dependent on China for REEs, Indonesia for nickel, the Democratic Republic of Congo for cobalt, and Peru and Chile for copper, for example, and that dependency is already leading to export controls and nationalization strategies. The lesson of OPEC+ is that states will use their resource monopolies to their geopolitical advantage whenever they are able.

*Aspects of Energy Transition*

In practice, a low-carbon energy transition means moving from a hydrocarbon-intensive to a material-intensive energy system. Clean energy technologies, including turbines, solar panels, transmission and distribution networks, batteries, and more, require a wide range of minerals and metals.

According to the International Energy Agency (2021), the energy sector's overall demand for critical minerals could increase by as much as six times by 2040 to hit a net-zero by 2050 scenario. For particular minerals, the numbers are even greater: a demand that is 42 times greater for lithium, 25 times greater for graphite, 21 times greater for cobalt, 19 times greater for nickel, 7 times greater for REEs, and 2.7 times greater for copper, all versus 2020 levels.

The North American Arctic is vast, and mostly unexplored and undeveloped from a mining perspective. Geologically, it offers perhaps the best untapped potential for Canada, the United States, and their western allies to secure friendly, stable supplies of critical minerals. However, as noted earlier, there is a reason the region hasn't met its mining potential: the costs are too high.

Even under current conditions, with many jurisdictions concerned about the supply of critical minerals and enacting incentives and strategies to boost production, global mining production has stalled. Far from meeting energy transition requirements, the world is mining less than it did in 2019. The *World Mining Data 2023* report identifies that the sector has yet to match the peak production of 18 billion metric tons it achieved in 2019.

The recent drop in mining is attributable to a number of factors, including declining ore grades and quality of deposits, regulatory uncertainty, a lack of social license for extractive industries, and ESG pressures – the movement in investment circles to consider "Environment, Social and Governance" factors in investment decisions, which inherently disadvantages resource extraction.

The production decline is also a result of waxing and waning commodities cycles. The last super cycle took place from 2000 to 2014, driven largely by impressive economic growth from China as it reaped a demographic dividend from its one-child policy. But the boom inevitably became a bust, and overinvestment soon resulted in low prices and subsequently losses for resource companies.

Capital expenditures (capex) for the mining sector collapsed from a peak of US$164.1 billion in 2012 to just US$65.8 billion in 2016. It experienced a modest recovery up to 2022 of US$98.3 billion, but is expected to fall by US$11 billion in 2023 to US$87 billion, with no expectation of it picking up beyond that (Murphy 2022).

Matching this drop in spending is a drop in financing. Here the picture is even more dramatic. Global mining sector financing (debt plus equity) hit a peak in 2013 of US$119 billion. In 2022 – despite the short boom that followed Russia's invasion of Ukraine – it reached a decade low of just US$42 billion, down 35 percent from 2021 (PDAC 2023).

Miners are facing price volatility, high interest rates and capital costs, supply chain woes, and labour shortages. While political interest in critical minerals is rising, prices have not been high enough consistently enough to trigger more development. These are global problems, but they deter investment in the North American Arctic as much as anywhere.

Even if spending and investment in mining were to rebound today, it would be a decade or more before production trends reversed. That is because it takes on average 15.7 years globally for a mine to move from exploration, to discovery, to proposal, to approval, to financing, to construction, and finally to production (Manalo 2023). It is very difficult to see how the western world will reduce its mining dependence on China, or produce the raw materials needed to meet its climate goals and policies over the next decade.

**Social License for Mining in the North American Arctic**

While there is a growing political recognition of the importance of critical minerals from the Arctic – the 2022 United States National Strategy for the Arctic Region and the 2021 European Union Communication on the Arctic mention it explicitly – there is still limited social license for an expansion of mining activities (i.e., it has little support from the general public). If anything, support has been diminishing. Three examples illustrate this.

*Alaska*

The first is Pebble Mine in Alaska. The Pebble mineral deposit is located about 200 miles southwest of Anchorage. It is touted as the world's largest undeveloped deposit of copper, a key element for electricity-related technologies, and is estimated to contain 80.6 billion pounds of copper, 107.4 million ounces of gold, and 5.6 billion pounds of molybdenum. Its reserves at current prices are worth hundreds of billions of dollars (PebbleWatch Undated) However, it is also near the headwaters of Bristol Bay, which supports the world's largest sockeye salmon fishery. That fishery is of both economic and cultural value, and Indigenous groups that will be adversely affected by the mine are broadly against the project.

After attracting controversy and speculation for years, the US Environmental Protection Agency effectively vetoed the Pebble project in January 2023 by restricting the disposal of any construction or mine waste within the watershed. The Biden Administration supported the move, but Alaska Governor Mike Dunleavy opposed it (Bennett 2023).

A few weeks later the Biden Administration did approve the massive Willow project on Alaska's North Slope; it holds an estimated 600 million barrels of oil. The response was almost poetic: in energy, the equal and opposite reaction to shutting down copper is to produce more oil.

*Canada*

On the northern end of Baffin Island, in Nunavut, lies one of the richest reserves of high-grade iron ore in the world. Mary River is the biggest mine by volume in the Canadian territories. Although Baffinland, the project proponent, only started production at its Mary River mine in 2016, it makes up 23 percent of Nunavut's GDP (Exner-Pirot 2022).

But its future is uncertain. The Mary River mine has posted operating losses in every year of its operation. To become more financially viable, Baffinland applied for a Phase 2 expansion, including a railroad and ore handling facility northwards at Milne Port that would have allowed it to double ore production to 12 million tons a year.

The expansion would also have seen more than $2 billion in royalties paid to Inuit organizations over the next 25 years, including over $1 billion to the Qikiqtani Inuit Association (QIA) and $1.4 billion to Nunavut Tunngavik Inc. It would also have meant $700 million in taxes to Nunavut and $1.4 billion to the federal government (Exner-Pirot 2022).

However, opposition from some local hunters and trappers concerned about the impact on narwhal and other species eventually led the Nunavut Impact Review Board, and subsequently the federal Minster for Northern Affairs, to reject the expansion in November 2022. The decision was contentious in Nunavut, often pitting hamlets, Inuit union workers, and the territory against Inuit organizations, hunters, and NGOs.

The decision was both surprising and unwelcome to the mining industry and is likely to make Nunavut specifically, and northern Canada more generally, less attractive for future investments based on political and social risk.

In some areas of northern Canada critical minerals mining is proceeding apace, notably uranium mining in northern Saskatchewan's Athabasca basin, copper and molybdenum mining in northwest British Columbia's Golden Triangle, and lithium mining in northern Quebec. But overall, critical mineral production in Canada has been declining, with copper, cobalt, nickel, zinc, uranium, and platinum group metals all down from 2019 (Statistics Canada 2023b). Voisey's Bay in Labrador, which opened in 2005 and holds large reserves of nickel, copper, and cobalt, is the last major greenfield base metal project in Canada. The oft-touted "Ring of Fire" in northern Ontario continues to face some local opposition and process snags, despite its potential in chromite, copper, zinc, nickel, and platinum group metals, and very likely won't produce until the 2030s. And the only rare earths mine in Canada, Nechalocho in NWT, suspended operations in the spring of 2023 due to high costs and low prices.

*Greenland*

Despite the hype around Greenland's resources, the nation produces almost no minerals. Instead, its economy is dominated by fishing and the public sector.

For several years after the closure of a gold mine in 2013, Greenland had no mining production. Two smaller projects have since opened up: the Aappaluttoq ruby mine in 2017 and the White

Mountain anorthosite mine in 2019. Forty-one companies hold exploration, prospecting, and exploitation licenses for Greenland, the majority of which are Canadian, Australian, or British (Menezes 2023). But the potential is far from being realized. According to a 2020 report from Statistics Greenland, only 95 people are employed in the extractive sector in Greenland (including 65 Greenlanders). The annual revenue from the sector was only DKK99,172 (CA$19,500), and the value added has been negative since 2015 (as quoted in Bjorst 2022).

Greenland has some excellent deposits of rare earth elements and due to China's production monopoly on those minerals there has been a strong geopolitical interest in developing them. However, because the nation's best deposit, Kvanefjeld, is co-located with uranium, developing it has become very contentious.

A ban on uranium mining had been repealed in 2013 to support the Kvanefjeld project. The proponent, Greenland Minerals, spent a reported €12 billion (McGwin 2022) on developing the mine. However, the 2021 elections in Greenland became something of a referendum on uranium mining. The Inuit Ataqatigiit party campaigned on a promise to issue a moratorium on uranium mining and stop the Kvanefjeld project, and it won the election. In July 2022 in a draft decision, the Greenland Ministry of Mineral Resources and Justice rejected Kvanefjeld's exploitation licence application, though as of writing the decision had not been finalized (S&P Capital IQ 2023).

While other mining projects are being explored and advanced in Greenland, and while the government has publicly stated it still supports non-uranium mining, the episode has affected Greenland's competitiveness.

*North American Arctic's Investment Attractiveness*

The frequent community opposition and political risk that northern mining projects face make them less attractive for the limited global mining financing and investment that is currently available. This is reflected in the annual survey of mining companies conducted by the Fraser Institute, a Canadian think thank. Its 2022 ranking of 62 jurisdictions is based on feedback from 180 mining and exploration company executives and shows that northern jurisdictions are attractive geologically but not politically:

- For overall investment attractiveness, Alaska ranks 11th, Yukon 20th, Nunavut 41st, and the Northwest Territories (NWT) 43rd out of 62. For the first time since 2010, there were not enough responses for Greenland in 2022 to include it in the rankings. However, its 2021 ranking was 61 out of 84.
- For the Best Practices Mineral Potential Index (an assessment of the jurisdiction's geology), northern jurisdictions are comparatively attractive. Yukon is 10th, Nunavut is 13th, Alaska is 15th, and NWT is 19th out of 47. In 2021, Greenland was ranked 57 out of 84.
- For the Policy Perception Index (an assessment of policies such as regulations, taxes, infrastructure, safety, and political stability and labour), northern jurisdictions,

especially Canadian ones, fare worse. Alaska ranks 13th, Yukon 31st, NWT 51st, and Nunavut 55th out of 62. In 2021, Greenland ranked 62 out of 84.

In order for the Arctic to become a realistic source of the critical minerals the West needs to support the energy transition and reduce its dependence on illiberal and unstable sources, the investment landscape will need to shift significantly. It will be important for NWT, Nunavut, and Greenland in particular to achieve and demonstrate stronger public support, as well as governance capacity, if they intend to play a role in meeting critical mineral demand.

**Solutions for Remoteness in Energy, Transportation, and Communications**

The above sections have posited that the condition of remoteness has consequential impacts on economic development, and this is affecting not only the well-being and prosperity of northerners in the North American Arctic, but also the ability of the region to produce the critical minerals needed for the energy transition.

Fundamentally, from an economic development perspective, remoteness is about limits in energy, transportation, and communications options. If people were well connected on each of these fronts, they wouldn't be remote.

Our current approach to northern infrastructure has reached its limit; it will not be able to support future economic development in the region well (see Exner-Pirot 2019). New strategies are thus needed if development is to grow. Fortunately, a number of transformative technologies are on the horizon. This section outlines the potential of small modular reactors (SMRs) to supply energy to remote locations; the potential of airships to supply transportation to and from remote regions; and the potential of fibre networks to give remote locations good communications options.

*Small Modular Reactors*

Small modular reactors (SMRs) are advanced nuclear reactors that have a power capacity of up to 300 million watts of electric capacity (MWe) per unit. SMRs are: small – physically a fraction of the size of a conventional nuclear power reactor; modular – making it possible for systems and components to be factory-assembled and transported as a unit to a location for installation; and reactors – harnessing nuclear fission to generate heat to produce energy (IAEA 2021).

SMRs are seen as a solution to some of the main challenges to nuclear energy, including cost, scale, and safety. Small units are seen as a much more manageable investment than big ones whose cost often rivals the capitalization of the utilities that would build them. Achieving "economies of series production" for a specific SMR design will reduce costs further (IAEA 2021). In addition, the newest, or "Generation IV" models of nuclear reactors are designed to make them inherently safer than previous ones. They are equipped with passive safety systems that rely on the natural laws of physics, rather than people or equipment, to render them incapable of having a severe accident such as melting down.

SMRs have three main anticipated applications in Canada:

- *On-grid power* (150 $MW_e$ to 300 $MW_e$): Grid-scale power generation, including to replace coal-fired plants.
- *Extractive and heavy industries* (10 $MW_e$ to 80 $MW_e$): Off-grid SMRs for mining, oil sands, and other heavy industries, where emissions are hard to abate due to the need for high heat.
- *Remote communities* (<1 MWe to 10 MWe): To supply power to remote communities that currently rely primarily on off-grid diesel generators.

The former two are the most promising for the Arctic. Often referred to as "microreactors," there are a few Gen IV reactor models being designed specifically with remote applications in mind to provide a combination of heat and power. These include Westinghouse's eVinci (5 MWe up to 13 megawatts of thermal power (MWth)); Ultrasafe Nuclear Corporation's Micro Modular Reactor (5-10 MWe and 15-30MWth); and a design from X-Energy that is expected to be announced soon.

The obvious use for these microreactors is to replace diesel generation in the Arctic for the 280 communities in Canada that are not connected to the electrical grid or natural gas distribution pipeline systems. Diesel is transportable, storable, reliable, and can fulfill almost all remote community energy needs, including heat, power, and transportation. However, diesel is a high emitting source of energy, not only of greenhouse gas emissions but of black carbon particulates. These not only exacerbate climate impacts by making ice and snow darker and thus more absorbent of sunlight, but are also harmful to human health. Diesel generators can also create noise pollution.

Many diesel generators in northern Canada are aging and reaching the end of their service life. Wind and solar cannot replace diesel because they are intermittent, are limited in their availability to supply heat, and don't function well in extreme cold temperatures. Solar is a particularly poor source of energy in the dark Arctic winters. But microreactors could soon be an attractive alternative.

SMR developers are addressing common concerns about nuclear and remote energy in their designs. On safety, passive safety systems make accidents physically impossible, especially in microreactors where the amount of fuel is very small. To address weather-related concerns, microreactors can be built underground so that neither snow nor wind nor cold will affect performance. The below-ground siting also limits the opportunity for terrorists to steal the radioactive fuel for nuclear terrorism, but enhances their detection, delay, and response capabilities. Microreactor models do not require water for cooling like traditional grid-scale reactors do.

Microreactors are capable of autonomous operation and have minimal moving parts. They are designed to need refuelling only every few years, and some for as long as a decade. They are factory built and then assembled on site. Because of their small size, they can be easily decommissioned and the site fully remediated. There is no need to store spent fuel or waste on site (see Westinghouse 2023).

As all Gen IV reactors are still being developed, it is difficult to know with certainty what the cost will be for one of these units. However, Canada's SMR Roadmap Economics and Finance working group has estimated that first-of-a-kind (FOAK) units suitable for mining could cost in the order of CA$200-350 million for a 20 MWe SMR, but costs would be lower thereafter as the supply chain develops (NRCan 2021). That represents an estimated 20 to 60 percent advantage over diesel in the levelized cost of electricity (LCOE) based on a capital cost (median) of $13,565/KW (approximately $270M for a 20 MWe system) and a fuel cost (median) of $64M where the fuel is replaced every 10 years (NRCan 2021). Most remote communities have lower energy needs than that, and smaller energy units would be even cheaper.

A study from MIT (Macdonald and Parsons 2021) looked at the costs of microreactors in Alaskan remote communities and compared them with other forms of energy. They based their costing comparison on a number of scenarios, including natural gas fuel availability, whether a community had a district heating network, future reductions in the capital cost of renewables, the price of fossil fuels, and, last but not least, the need to reduce system-wide emissions. The microreactor variable cost was assumed to be $15/MWe. SMRs were not cheaper for communities with natural gas access or for communities with no need for waste heat. They were reasonably economic for remote communities with the ability to use heat waste, and for mines. And when any kind of emissions reductions goals were factored in, the reactors were very competitive.

Figure 3: Microreactor capital cost ceiling for select scenarios (in $US)

| Community | Natural gas available? | CHP accessible? | No emission reduction target | 25% emission reduction target |
|---|---|---|---|---|
| Railbelt community | Yes | No | $4,700/kWe | Not tested |
| | | Yes | $8,300 /kWe | >$30,000/kWe |
| Mine & Remote community | No | No | $12,500/kWe | Not tested |
| | | Yes | $12,500/kWe | >$30,000/kWe |

Note: The capital cost ceiling is the highest overnight capital cost a microreactor can have while still being included in the least-cost generation portfolio.

Source: Macdonald and Parsons (2021).

Finally, microreactors have the potential to produce hydrogen through electrolysis: a type of clean hydrogen referred to as "pink" (compared to blue hydrogen made from methane plus CCUS, and green hydrogen made from electrolysis plus renewables). Pink hydrogen would provide a local source of fuel that could be used for transportation needs, as opposed to importing diesel.

*SMRs and Mines*

In addition to meeting remote community needs, SMRs can provide clean heat and power to heavy industry in remote regions, such as oilsands producers and mines.

There is very limited energy infrastructure in northern Canada. In some places hydroelectricity is available and mines can have access to it via transmission lines. However, installing these lines can be very costly if a mineral deposit is not conveniently located close to the hydro source. As a result, mining in the Canadian North depends heavily on diesel. Rio Tinto's Diavik diamond mine in NWT, for example, uses 85 million litres of diesel a year. This fuel needs to be trucked in on ice roads, the timeframe of which is shortening due to climate change, and then a year's worth of fuel must be stored on site. While Diavik uses one of the world's largest hybrid wind-diesel power facilities at a remote mine site (since coming on line in 2012, the wind farm has offset Diavik's diesel use by over 43 million litres) (Rio Tinto Undated), it still requires a tremendous amount of energy that cannot be affordably sourced elsewhere.

The economic cost of diesel dependence for remote mining is a huge disincentive for investing in such locations; but so is the environmental cost. Major miners such as BHP, Anglo American, Rio Tinto, and others all have emissions reductions targets and seek to compare favourably in ESG ratings that investors and financers use to assess their attractiveness. It is difficult to see big miners investing in the North American Arctic where alternatives to diesel do not exist. SMRs are therefore a key option in developing critical minerals in a responsible, and investable, manner.

Finally, in Canada, the largest emitting sector is the oil and gas industry due to the high amounts of energy required to heat bitumen off of the oilsands in northern Alberta to a point where it can flow. There are credible plans to decarbonize the oilsands through the Pathways Alliance, a consortium of the six largest oilsands companies who represent about 95 percent of production there. Those plans largely depend on carbon capture and storage (CCS), but there is also strong interest in high temperature SMRs, which would displace industrial heat now produced with fossil fuels. The Alliance is waiting for the technology to mature and models to become commercially available, as well as the regulatory system to support licensing.

***Airships***

Energy access is an issue in the North, but at least diesel always offers an option. The same cannot be said of transportation. There are great deposits that are not realistic to mine because they cannot be transported to market. The reason that northern mining is currently dominated by gold, silver, and diamonds is because those can be flown out: there is high value in a small physical amount of product. Many other minerals are too heavy for air transport and require a road or a railroad to be moved.

Enter the airship: a lighter-than-air aircraft that operates under its own power. Airships will fill the gap between sea cargo and air freight – and come with unique advantages: they can stay aloft for long periods of time, they have long ranges, and they can carry heavier payloads than fixed wing aircraft. They also don't require the same landing infrastructure (i.e., runways). Significantly, they produce much less emissions than traditional air freight.

Like SMRs, many airships models are being designed with remote applications, including mining, as a target market. The benefits are obvious.

The first benefit is timing flexibility. One criticism of airships is that they are slow. For cargo, waiting a few extra hours or days is not a big problem. And in the Arctic, slow airships still offer a big advantage over existing options. Arctic mines and communities today rely to a significant extent on seasonal ice roads or annual sea lift to be resupplied, or, in the case of Mary River, have only a few weeks a year during which to export their product. Not only is this logistically challenging, it's also expensive, as warehouse and storage capacity needs to be extensive. Having access to year-round cargo options would impart a variety of benefits.

The second benefit is location flexibility. Cargo airships are being designed to land almost anywhere as they use an air cushion landing or hovering system. Sometimes they do not have to land at all, acting like a giant flying crane that load and unloads from the air. This means they can conduct operations where there is limited infrastructure and with very little environmental disturbance.

The third benefit is autonomy. For remote cargo operations, many airship models are expected to be autonomous, requiring no pilot on board. Given the long distances and long flight durations needed to serve remote mines and communities, autonomous flight would not only address the problem of finding pilots to do long, northern journeys – finding pilots is a challenge for all airlines today, but finding pilots for northern routes is particularly problematic – but also the cost of complying with fatigue rules, which require that two to three pilots be on board for long-range flights. Finally, not needing a habitable space for humans on board frees up room for more cargo.

Fourth, and perhaps most importantly in northern Canada, is the low environmental impact of airships. Airships use helium or hydrogen for lift, and fuel cells and electricity for dirigibility and propulsion. They discharge a fraction of the emissions of fixed wing aircraft. And they avoid the large footprint and disruption to migratory species such as a caribou – essential for northern food security and culture – that roads often cause, not to mention the incredible costs of remediating the road once the life of the mine has ended.

For the mining industry, the more important benefit is that if you can use airships to haul product, you don't need to invest in building roads or railroads to deposits in remote locations. The cost savings are enormous. As an example, the proposed Mackenzie Valley Highway, an all-season gravel road, is estimated to cost CA$2.0 to $2.4 million per kilometer (Chernos 2019), or about $700 million for 321km. Others peg northern road construction at closer to CA$3 million/km (ISOPolar Undated). For a mining company to secure the investment to pay for this infrastructure up front, before a single ounce of ore is sold, is very challenging and has become even more so in 2023 now that interest rates have shot up.

Maintaining northern roads once they are built is also very expensive. The Tuk highway maintenance costs were estimated at CA$12,000 to $15,000/km per year in 2017 (Bird 2017), and are almost certainly higher now. But building roads and railroads on permafrost that is melting obviously adds other challenges. Consider the Hudson Bay railroad, running through northern Manitoba and linking Prairie farms with the town of Churchill since 1929. In its long history it has rarely been profitable. In 2017, service was suspended after spring flooding damaged the tracks. Since then, federal and provincial governments have committed CA$117 million in 2018, CA$40 million in 2019, and another CA$147 million in 2022 to get the railroad in working order (Canadian Press 2022), despite there being no prospects that the port at Churchill will become economic due to its shallow waters and short shipping season.

Added to road building and maintenance costs is the difficulty of getting social license and permits for linear projects. The 110-km Webequie supply road to the Ring of Fire mining jurisdiction in northern Ontario is a worst-case scenario. It has been delayed and bedevilled by controversy, and years into it, despite government funding commitments, remains at the consultation, negotiation, and environmental impact assessment stage. It will take years more to construct when it finally gets the approvals it needs to proceed.

Airships are cheaper, quicker, endure less regulatory and consultation burden, and are far more environmentally friendly than many road or railroad options. And so the remaining question is, are they economical enough, not just compared to roads and railroads but on their own, to spur northern mining investment? And are they sufficient for the job?

According to University of Manitoba Professor Barry Prentice's work, the value-to-weight ratio of metals becomes critical. For some heavier metals, such as iron, copper, and nickel, airships are probably not a viable solution. These materials will always require a road or railroad for transport. But for precious metals and minerals like gold, silver, and diamonds, platinum group metals, rare earth elements, lithium, and gems, airships would work (ISOPolar Undated).

The cost and return on investment of an airship varies depending on the circumstance. But in general, the more valuable the product, the shorter the mine's lifespan, the longer the distance from existing transportation infrastructure to the deposit, and the bigger the cargo payload, the more competitive airships become. There is indeed a range at which they are cheaper than building a road, and this makes them an important option for the development of critical minerals in the Arctic (see Prentice et al. 2013).

Airships are also a good option for remote community food and supply transport. Based on an assessment of remote communities, Prentice and Adaman (2017) find that airships can be 33 to 48 percent cheaper for community food transport in northern Manitoba, and 22 to 50 percent cheaper in northern Ontario, compared to the full costs of ice road trucking and fixed wing aircraft.

If airships are such a good idea, why are they not yet available commercially? The market and the regulatory system still have work to do to make airships a reality, but they are well on their way.

A number of start-ups have now developed airship prototypes and the sector is attracting investment. Enhanced technology and engineering, consumer demand, and concerns with emissions are getting them close to being revived (see Koziol 2022). The government of Quebec invested CA$55 million in July 2022 in one such company, Flying Whales, which specializes in cargo airships for remote locations (Dunn 2022). And Transport Canada funded a "Cargo Airship Strategy for Northern Canada" through the Canadian Arctic Innovation Association. The group concluded that airship service can be viable in the North, and it's made a number of recommendations (Kelly 2023).

Airships have long been an idea ahead of their time. But that looks set to change soon.

**Fibre Connectivity**

Access to the internet has become critical for participating in modern society: for work, play, education, health care, and business. Yet remote areas face significant challenges in access, speed, reliability, and affordability of the internet. These challenges were highlighted and exacerbated by the COVID-19 pandemic: while many services, workplaces, and businesses were able to cope with the pandemic restrictions by going digital, the lack of telecommunications infrastructure in the North reduced people's options to adapt.

This is doubly frustrating because remote communities stand to benefit most from the promise of the internet to shrink time and space. They are great candidates for services such as telehealth, distance education, e-commerce, and remote work, which could address current challenges in accessing services. However, the lack of reliable internet means the connectivity gap between remote and urban communities is growing, rather than closing. According to Nunavut Tunngavik Inc. (NTI), in 2019 a household in Nunavut using the same amount of broadband as the average Canadian household paid more than six times the price for the same amount of data, largely due to high overage fees; and the fastest possible speed Nunavut households could access (15 Mbps) was eight times slower than the Canadian household weighted average for 2018 (126 Mbps).

Many communities in northern Canada still rely on satellite broadband. Satellites provide a service in remote locations that is relatively easy to access, and it has been a revolutionary technology for the North. Starlink has added new consumer options on top of services from legacy providers. However, satellite faces some inherent disadvantages. These include interference from weather and atmospheric interruptions that can result in slow service or service outages, latency due to the lag in sending and receiving signals over long distances, and capacity and speed limits (NTI 2020).

The government of Canada released a connectivity strategy in 2019, with a minimum high-speed internet connectivity target for all Canadians: 50/10 Mbps, with the goal of connecting 98 percent of Canadians by 2026 and 100 percent of Canadians by 2030. As of 2021, 90.9 percent of Canadian households had access to those speeds, but only 42.9 percent of households on reserve and 59.5 percent of households in rural and remote areas had such access (Auditor General 2023).

The discrepancy has led to enhanced funding for remote internet access and a few fibre links have already been built. Yukon has the Dempster Highway fibre optic line from Dawson City to Inuvik, which is Indigenous owned, and NWT has the Mackenzie Valley Fibre Link, from Fort Simpson to Inuvik. The primary telecommunications provider for the territories, Northwestel, plans to provide unlimited high speed internet through either fibre-to-home or low-earth-orbit satellite to all NWT and Yukon communities by 2023.

The conditions are most challenging in Nunavut, which currently has no fibre connectivity. However, plans are in place to provide fibre to that territory. Quintillion and CanArctic Inuit Networks Inc., a majority Inuit-owned company, signed a memorandum of understanding in March 2023 to construct a subsea fibre line from Happy Valley-Goose Bay, NL, to Iqaluit, NU, with construction planned to begin in 2024.

*The Role of Fibre Connectivity in Mining*

While it is well accepted that fibre connectivity is essential for social and economic development and efforts to provide reliable high speed internet to all northern communities is advancing, the impacts to mining are less discussed.

Modern mining requires the internet for productivity, safety, and environmental monitoring. Applications that rely on the internet include autonomous drilling, driverless haul trucks, drones for surveying and safety, wearable technologies, and predictive maintenance (Mining Technology 2023).

In many ways, remote mines would benefit from the internet of things even more than their southern counterparts. Because labour is more expensive in remote locations and retention can be a challenge due to longer fly-in, fly-out shifts, autonomous work and monitoring would result in higher savings. As a whole, the mining industry in Canada is facing a severe shortage of workers (Mining Industry Human Resources Council 2019), a result of market conditions following the commodity downturn, as well as cultural factors that have made extractive sectors, blue collar work, and camp jobs less attractive to millennials and Generation Z, despite their high wages.

However, northern mines in Canada have poor access to high quality internet. The diamond mines in NWT, for example, use satellite and microwave towers, but their speed, reliability, and capacity are very poor. It would be very risky to automate work with only a satellite connection. But beyond labour savings, the operations that rely on satellites are subsequently less sophisticated (and thus achieve lower productivity), and the working conditions are more difficult. For those in camp for what are often two-week shifts, a lack of access to the internet for streaming or gaming in off hours and the inability to call or videoconference with family members over long periods affects morale and retention.

A key ingredient for attracting mining investment to the North and in ensuring those mines can attract an adequate labour force as well as meet high environmental and safety standards is to expand access to fibre networks.

Recognizing this, the government of Quebec paid for half of a $3.5 million project to connect Newmont Goldcorp's Eleonore mine facilities to the internet through a 124 kilometer fibre optic line; the project was delivered by an Indigenous owned corporation, Eeyou Communications Network (Cabinet du ministre de l'énergie et des ressources naturelles 2019). Future efforts to encourage more mining in northern Canada will need to include strategies for high speed internet connectivity.

**Arctic Security Environment**

The above sections have highlighted the ways SMRs, airships, and fibre connectivity are essential not only to overcoming the challenges of remoteness for northern communities, but for supporting critical mineral development as well.

There is a third stakeholder that would benefit from these technologies: the military.

While the Arctic has been free of hot conflict since WWII, there is obviously great power competition in the region, and the Russian invasion of Ukraine has heightened tensions. Finland has joined NATO, and Sweden is expected to follow soon. The Russian northern fleet and its nuclear deterrence capabilities are concentrated in the Kola Peninsula, which grants it access to the North Atlantic Ocean.

While the potential for conflict on the North American side of the Arctic is very low, concern about the detection of incoming missiles and the defence against them is very real, even given that in many cases such missiles would pass over the Arctic region. With the next generation of intercontinental missiles and platforms coming to fruition, including hypersonics, continental defense depends to a great deal on early warning systems in the Arctic. Canada and the United States are thus investing significantly in NORAD modernization in response to Russia's belligerence.

The need to defend North America and deter Russia – and China – from attacking in the first place depends on a strong presence and effective domain awareness (full operational knowledge) in the Arctic. This is where SMRs, airships, and fibre optic lines can serve a dual purpose (civilian and military), and perhaps could secure the military as an anchor customer.

The US military already uses small nuclear reactors on submarines. Russia is currently the only country to have nuclear icebreakers, with seven currently in service and three under construction. The coming promise of microreactors for military use will bolster operations in remote or undeveloped areas, support forward-basing (i.e. equipment, armed forces, and persistent military facilities abroad), reduce dependence on fuel shipments, and ensure the availability of energy needed for high-tech combat systems. In addition, SMRs can reduce the GHG emissions of defense activities (Harlow 2023). It is no surprise that the US Air force has chosen the Eielson Air Force base in Alaska as the location of its first microreactor, with plans to have it operational by 2027 (Associated Press 2021).

Similar to microreactors, airships could prove beneficial to military operations by increasing the military's options and capabilities for operating in remote or underdeveloped locations, or during emergencies and humanitarian crises. Because of their long range and large payload, airships are also ideal for surveillance. They could, for example, track submarines attempting to cross through the GIUK (Greenland-Iceland-United Kingdom) gap without risk of counterattack.

Airships with long-range and multi-day station-keeping times (ability to maintain position and heading) are well suited for many military tasks. They could even act as an airborne drone mothership with the ability to provide high-altitude command-and-control, as well as acting as a delivery vehicle for smaller craft (French 2023).

Finally, secure and reliable connectivity is obviously essential for any military; all have high data needs. Installing subsea fibre optic lines through the Arctic would not only enhance intercontinental data security. Such lines could also be optimized and engineered as SMART cables that would enhance marine monitoring and climate research, making a substantial contribution to the marine component of NORAD's modernization for the digital age (Exner-Pirot, Shadian, and Redfern 2022).

Using the Arctic region for subsea cables also makes them more resilient to tampering, as only a handful of states are capable of sabotaging them in the Arctic Ocean. The lower volume of vessel traffic also reduces the likelihood of damage to the cables from anchors (Khorrami 2022).

**Conclusions**

Remoteness imposes tremendous challenges on development in the North American Arctic. Over the past five decades the strategy for addressing those challenges has been to transfer public money to those regions with the goal of producing outcomes that are "good enough." But the strategy has left a lot to be desired.

The Arctic region frequently goes through periods of economic boom and bust, and through times of intense interest from the South followed by long periods of neglect, and it is fair to ask if the current interest in the area is another one of those cycles. But the combination of the desired energy transition and the need to secure critical minerals from friendly sources may finally be the impetus needed to shake the region out of its current development paradigm. Fortunately, technologies including SMRs, airships, and fibre optic networks are now emerging that have the potential to address the challenges that remoteness imposes on energy, transportation, and connectivity. The arrival of these technologies has the potential to not only improve the quality of life for the region's inhabitants, but allow more economically and environmentally responsible development of critical minerals. These technologies will have the added benefit of providing tools for the military to enhance their presence and operations in the Arctic.

Much work remains to turn these innovations into reality, and there are undoubtedly other tools and strategies that will play an important role as well. But the concurrent climate, energy, and security crises are presenting an opportunity to address the challenges of remoteness in the Arctic in new and better ways. It would be a shame to waste it.

*Acknowledgments*

The author would like to thank the Wilson Centre for its support of its paper, the research for which was conducted during her fellowship there from September-December 2022. Particular thanks are owed Mike Sfraga, Rebecca Pincus, Jack Durfee at the Polar Institute, and Chris Sands and Xavier Delgado at the Canada Institute. Madeleine Redfern has also been instrumental in providing inspiration on Arctic technologies.

**Bibliography**


Associated Press. 2021. "Eielson to Receive Air Force's First Nuclear Microreactor." *Air Force Times* (October 20). Available at https://www.airforcetimes.com/news/2021/10/20/eielson-to-receive-air-forces-first-nuclear-microreactor/

Auditor General of Canada. 2023. *Connectivity in Rural and Remote Areas*. Auditor General of Canada. Available at https://www.oag-bvg.gc.ca/internet/English/parl_oag_202303_02_e_44205.html

Austria, Federal Ministry of Finance. 2023. *World Mining Data 2023*. Volume 38. Government of Austria. Available at. https://www.world-mining-data.info/wmd/downloads/PDF/WMD2023.pdf.

Bird, Hilary. 2017. "As Inuvik-Tuktoyaktuk Highway Opens, Will the $300M Price Tag Be Worth It?" CBC News (November 13). Available at https://www.cbc.ca/news/canada/north/inuvik-tuktoyaktuk-nwt-road-worth-it-1.4395052.

Bjørst, Lill Rastad. 2022. "To Live Up to Our Name 'Greenland': Politics of Comparison in Greenland's Green Transition." In Lassi Heininen, Heather Exner-Pirot, and Justin Barnes (eds). *Arctic Yearbook 2022*. Arctic Portal. Available at https://arcticyearbook.com/images/yearbook/2022/Scholarly-Papers/18A_AY2022_Bjrst.pdf

Cabinet du ministre de l'énergie et des ressources naturelles. 2019. "$1.75 Million to Connect the Eleonore Mine to the Fibre Optic Network." News Release. Government of Quebec and Cision (May 22). Available at https://www.newswire.ca/news-releases/-1-75-million-to-connect-the-eleonore-mine-to-the-fibre-optic-network-888376691.html.

Canadian Press. 2022. "Rail Line to Churchill, Man. Receives More Support Through Federal, Provincial Funding." *Global News* (August 3). Available at https://globalnews.ca/news/9034674/rail-line-churchill-man-federal-provincial-funding/.

Chernos, Saul. 2019. "The Road North: Building Through the Most Inhospitable Terrain and Harshest Conditions Canada Has to Offer." *On Site* (February 21). Available at https://www.on-sitemag.com/features/the-road-north-building-through-the-most-inhospitable-terrain-and-harshest-conditions-canada-has-to-offer.

Dunn, Brian. 2022. "Quebec Invests $55M in Flying Whales' Cargo Airship Project." *SKiES* (July 6). Available at https://skiesmag.com/news/quebec-invests-55-million-flying-whales-cargo-airship-project/.

Exner-Pirot, Heather, Jessica Shadian, and Madeleine Redfern. 2022. "Transformative Arctic Innovation Is Possible – With Smart Investments." *Inside Policy* (November 2). Macdonald-Laurier Institute. Available at https://macdonaldlaurier.ca/transformative-arctic-innovation-is-possible-with-smart-investments-exner-pirot-redfern-and-shadian-for-inside-policy/.

Exner-Pirot, Heather. 2019. "Canada's Northern Economic Development Paradigm and Its Failures." In John Higginbotham and Jennifer Spence (eds.), *Canada's Arctic Agenda: Into the Vortex* (Centre for International Governance Innovation).

Exner-Pirot, Heather. 2022. "The Baffinland Saga Highlights the Precarious Balance Between the Environment and Development in Nunavut." *Globe and Mail* (August 26). Available at https://www.theglobeandmail.com/opinion/article-the-baffinland-saga-demonstrates-the-precarious-balance-between-the/.

French, Jonathan. 2023. "Bring Back the Dirigibles, Maintain the Undersea Advantage." *US Naval Institute* (April 2023). Available at https://www.usni.org/magazines/naval-history-magazine/2023/april/bring-back-dirigibles-maintain-undersea-advantage.

Glomsrød, Solveig, Gérard Duhaime, and Iulie Aslaksen (eds.). 2021. *Economy of the North: ECONOR 2020.* Arctic Council Secretariat. Available at https://oaarchive.arctic-council.org/handle/11374/2611.

Hamelin, Louis-Edmond, and William Barr. 1979. *Canadian Nordicity: It's Your North Too*. Harvest House.

Harlow, Jared. 2023. "Why the US Military Should Build Modular Nuclear Reactors." *Commentary* (March 16). Defense News. Available at https://www.defensenews.com/opinion/commentary/2023/03/16/why-the-us-military-should-build-modular-nuclear-reactors/.

Humpert, Malte. 2023. "Russia to Export 100m Tons of LNG by 2030." *High North News* (March 13). Available at https://www.highnorthnews.com/en/russia-export-100m-tons-lng-2030.

International Atomic Energy Agency [IAEA]. 2021. What are Small Modular Reactors (SMRs)? https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs

International Energy Agency [IEA]. 2021. *The Role of Critical Minerals in Clean Energy Transitions.* World Energy Outlook Special Report. International Energy Agency. Available at https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.

International Energy Agency [IEA]. 2022. "Energy Fact Sheet: Why Does Russian Oil and Gas Matter?" International Energy Association. Available at https://www.iea.org/articles/energy-fact-sheet-why-does-russian-oil-and-gas-matter.

ISOPolar. Undated. "Airships for the Mining Industry." ISOPolar (July 30). Available at https://isopolar.com/airships-for-the-mining-industry/.

Kelly, Lindsay. 2023. "Could Airships Offer a Cheaper, Greener Supply Line for the Far North?" *NOW Newswatch* (June 7). Available at https://www.nwonewswatch.com/local-news/could-airships-offer-a-cheaper-greener-supply-line-for-the-far-north-7108942.

Khorrami, Nima. 2022. “A Looming Cable Race in the Arctic: What Role for NATO?” Wilson Center (September 21). Available at https://www.wilsoncenter.org/article/looming-cable-race-arctic-what-role-nato.

Koziol, Michael. 2022. “The Tech Is Finally Good Enough for an Airship Revival.” IEEE Spectrum. (December 10). Available at https://spectrum.ieee.org/airship.

Krymalowski, Sarah. 2023. “Fibre Optic Internet Comes to Whatì, N.W.T.” CBC News (April 6). Available at https://www.cbc.ca/news/canada/north/whati-fibre-optic-1.6803900.

Macdonald, Ruaridh, and John E. Parsons. 2021. *The Value of Nuclear Microreactors in Providing Heat and Electricity to Alaskan Communities*. MIT Center for Energy and Environmental Policy Research. Available at https://ceepr.mit.edu/wp-content/uploads/2021/11/2021-018.pdf.

Manalo, Paul. 2023. “Discovery to Production Averages 15.7 Years for 127 Mines.” S&P Global (June 6). Available at https://www.spglobal.com/marketintelligence/en/news-insights/research/discovery-to-production-averages-15-7-years-for-127-mines.

McGwin, Kevin. 2022. “Greenland’s Uranium Ban Hasn’t Killed Off Its Most Talked-About Project… Yet.” *Polar Journal* (January 10). Available at https://polarjournal.ch/en/2022/01/10/greenlands-uranium-ban-hasnt-killed-off-its-most-talked-about-mining-project-yet/.

Mejía, Julio, and Elmira Aliakbari. 2023. *Annual Survey of Mining Companies, 2022*. *Fraser Institute.* Available at https://www.fraserinstitute.org/sites/default/files/annual-survey-of-mining-companies-2022.pdf.

Menezes, Dwayne Ryan (2023). “The Case for a Five Eyes Critical Minerals Alliance Focusing on Greenland.” In Christian Leuprecht and Douglas Casey (eds), *Polar Cousins: Comparing Antarctic and Arctic Geostrategic Futures* (University of Calgary Press): 109-141. Available at https://ucp.manifoldapp.org/system/actioncallout/e/f/b/efb6d9a6-f9c5-4603-9078-6c6856a094c1/attachment/ab3cf70380604f718ec9644261bb122e.pdf.

Mining Industry Human Resources Council. 2019. *Canadian Mining Labour Market: 10 Year Outlook 2020.* Mining Industry Human Resources Council. Available at https://mihr.ca/wp-content/uploads/2020/03/MIHR_National_Report_web2.pdf.

Mining Technology. 2023. “Leading Mining Companies in the Internet of Things Theme.” Mining Technology (March 14). Available at https://www.mining-technology.com/data-insights/leading-mining-companies-in-the-internet-of-things-theme/.

Murphy, Kevin. 2022. “Planned Mining Capital Spending to Fall $11B in 2023.” S&P Global (December 2). Available at https://www.spglobal.com/marketintelligence/en/news-insights/research/planned-mining-capital-spending-to-fall-11b-in-2023.

Murphy, Peter. 2019. *The Statistics Canada Population Centre and Rural Area Definition and the Proposed European and Global Version of the Degree of Urbanization: A Short Comparative Overview*. PowerPoint presentation. Presented at the UN Expert Group meeting on Statistical Methodologies for Delineation Cities and Rural Areas. Statistics Canada. Available at https://unstats.un.org/unsd/demographic-social/meetings/2019/newyork-egm-statmeth/docs/s09-01-CAN.pptx.

National Snow and Ice Data Center [NSIDC]. 2023. "A Slow Start to the Arctic Spring." *Arctic Sea Ice News and Analysis* (May 3). Available at http://nsidc.org/arcticseaicenews/2023/05/a-slow-start-to-the-arctic-spring/.

Natural Resources Canada [NRCan]. 2021. *Small Modular Reactors (SMRs) for Mining.* Government of Canada. Available at https://natural-resources.canada.ca/our-natural-resources/energy-sources-distribution/nuclear-energy-uranium/canadas-small-nuclear-reactor-action-plan/small-modular-reactors-smrs-for-mining/22698#q3.

Nunavut Tunngavik Inc. [NTI]. 2020. *Nunavut's Infrastructure Gap*. Nunavut Tunngavik Inc. Available at https://www.tunngavik.com/files/2020/10/2020.10.20-Nunavuts_Infrastructure_Gap_Report_vf.pdf.

Pebble Watch. Undated. "Pebble Project." Pebble Watch. Available at https://pebblewatch.com/pebble-project/.

Prentice, Barry, and Matt Adaman. 2017. "Economics of Cargo Airships for Food Transport to Remote Northern Communities." *Research in Transportation Business & Management* 25 (December): 87-98.

Prentice, Barry, Nirbir Grewal, Bryce Doell, and Matt Adman. 2013. "Cargo Airships Versus All Weather Roads – A Cost Comparison." Canadian Transportation Research Forum. Proceedings Issue: 48th Annual Meeting: 89-104.

Prospectors and Developers Association of Canada [PDAC]. 2015. *Levelling the Playing Field: Supporting Mineral Exploration and Mining in Remote and Northern Canada*. PDAC (April). Available at https://www.pdac.ca/docs/default-source/priorities/securities/levelling-the-playing-field---final.pdf?sfvrsn=8b46a798_2.

Prospectors and Developers Association of Canada [PDAC]. 2023. *Mineral Finance 2023: Shifting Tides Within the Mineral Industry*. Access to Capital. PDAC. Available at https://www.pdac.ca/programs-and-advocacy/access-to-capital/mineral-finance-2023.

RioTinto. Undated. "Diavik." RioTinto. Available at https://www.riotinto.com/en/can/canada-operations/diavik.

S&P Capital IQ. 2023. "Energy Transition Minerals Provides an Update on the Developments with the Kvanefjeld Rare Earth Project in Greenland." MarketScreener (March 22). Available at https://www.marketscreener.com/quote/stock/ENERGY-TRANSITION-MINERAL-

10202831/news/Energy-Transition-Minerals-Provides-an-Update-on-the-Developments-with-the-Kvanefjeld-Rare-Earth-Pro-43318682/.

Saul, Jonathan. 2020. "Arctic Headache for Ship Insurers as Routes Open Up." Reuters (October 27). Available at https://www.reuters.com/article/climate-change-arctic-shipping-insurance-idUSKBN27C1VZ.

Sgaravatti, Giovanni, Simone Tagliapietra, Cecilia Trasi, and Georg Zachmann. 2023. "National Policies to Shield Consumers from Rising Energy Prices." *Bruegel* (June 26). Available at https://www.bruegel.org/dataset/national-policies-shield-consumers-rising-energy-prices.

Staalesen, Atle. 2023. "As Russian Gas Company Novatek Readies New Arctic Production Platform, LNG Export to Europe Beats Record." *Barents Observer* (May 2). Available at https://thebarentsobserver.com/en/industry-and-energy/2023/05/russian-gas-company-novotek-readies-new-arctic-production-platform-lng.

Statistics Canada. 2018. Canadian Merchandise Trade Database. Statistics Canada.

Statistics Canada. 2022. *Census in Brief: Population Growth in Canada's Rural Areas, 2016 to 2021*. *Census of Population, 2021.* Statistics Canada. Available at https://www12.statcan.gc.ca/census-recensement/2021/as-sa/98-200-x/2021002/98-200-x2021002-eng.cfm.

Statistics Canada. 2023a. "Index of Remoteness." Statistics Canada. Available at https://www150.statcan.gc.ca/n1/pub/17-26-0001/172600012020001-eng.htm.

Statistics Canada. 2023b. "Table 16-10-0022-01: Production, Shipments and Value of Shipments of Metallic and Non-Metallic Minerals, Annual." Statistics Canada. Available at https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1610002201.

United States, Energy Information Administration [EIA]. 2021. "Oil Production in Alaska Reaches Lowest Level in More Than 40 Years." *Today in Energy* (April 26). EIA. Available at https://www.eia.gov/todayinenergy/detail.php?id=47696.

Westinghouse. 2023. "eVinci Microreactor." Westinghouse. Available at https://www.westinghousenuclear.com/energy-systems/evinci-microreactor

# Appendix 1: List of mines in North American Arctic jurisdictions

| Mine Name | Mine Location (Country/Territory) | Mine Owner | Mine Extracts | Mine Method | Operation Start Year |
|---|---|---|---|---|---|
| Minto Mine | Yukon Territory, Canada | Minto Mining Co. | Gold, Copper, Silver | Open-Pit + Underground | 2007 |
| Eagle Gold Mine | Yukon Territory, Canada | Victoria Gold Co. | Gold | Open-Pit | 2019 |
| Keno Hill | Yukon Territory, Canada | Hecla Mining Co. | Silver | Underground | 1946 |
| Diavik Mine | NW Territories, Canada | Rio Tinto Group | Diamonds | Underground | 2010 |
| Ekati Mine | NW Territories, Canada | Arctic Canadian Diamonds Co. | Diamonds | Underground | 1998 |
| Gahcho Kué Mine | NW Territories, Canada | Canada Inc./Mountain Province Dia | Diamonds | Open-Pit | 2016 |
| Nechalacho Mine | NW Territories, Canada | Avalon Advanced Materials | Rare Earth Metals | Open-Pit | 2021 |
| Meadowbank Mine | Nunavut, Canada | Agnico-Eagle Mines Limited | Gold | Concentrator | 2010 |
| Mary River Mine | Nunavut, Canada | Baffinland Iron Mine Co. | Iron | Open-Pit | 2014 |
| Hope Bay Mine | Nunavut, Canada | TMAQ Resources Inc. | Gold | Underground | 2017 |
| Amaruq Mine | Nunavut, Canada | Agnico-Eagle Mines Limited | Gold | Open-Pit | 2019 |
| Meliadine Mine | Nunavut, Canada | Agnico-Eagle Mines Limited | Gold | Open-Pit + Underground | 2019 |
| Qilalugaq Mine | Nunavut, Canada | North Arrow Minerals | Diamonds | Open-Pit | ? |
| Goose Mine (Backriver) | Nunavut, Canada | B2Gold | Gold | Open-Pit + Underground | Planned |
| Pikoo Mine | Nunavut, Canada | North Arrow Minerals | Diamonds | N/A | Prospecting/Planned |
| Raglan Mine | Northern Quebec, Canada | Glencore Canada Co. | Nickel, Platinum, Copper, Cobalt, Gold, Silver | Underground | 1997 |
| Nunavik Mine | Northern Quebec, Canada | Canadian Royalties Inc. | Nickel, Platinum, Copper, Cobalt | Open-Pit + Underground | 1997 |
| Éléonore Mine | Northern Quebec, Canada | Newmont Co. | Gold | Underground | 2015 |
| Renard Mine | Northern Quebec, Canada | Stornaway Diamond Co. | Diamonds | Open-Pit + Underground | 2014 |
| Niobec Mine | Northern Quebec, Canada | Magris Resources Inc. | Niobium | Underground | 1976 |
| Bloom Lake Mine | Northern Quebec, Canada | Champion Iron Ltd. | Iron | Open-Pit | 2022 |
| Mont-Wright Mine | Northern Quebec, Canada | ArcelorMittal | Iron | Open-Pit | 1974 |
| Fire Lake Mine | Northern Quebec, Canada | ArcelorMittal | Iron | Open-Pit | 1976 |
| Scully Mine | Newfoundland/Labrador, Canada | Tacora Resources Inc. | Iron | Open-Pit | 2017 |
| Carol Lake Mine | Newfoundland/Labrador, Canada | Iron Ore Company of Canda Inc. | Iron | Open-Pit | 1950s~ |
| Voisey's Bay Mine | Newfoundland/Labrador, Canada | Vale Inco. | Nickel | Open-Pit | 2005 |
| Nugget Pond Mine | Newfoundland/Labrador, Canada | Rambler Metals and Mining PLC | Copper | Concentrator | 1997 |
| Ming's Bight Mine | Newfoundland/Labrador, Canada | Rambler Metals and Mining PLC | Copper | Underground | 2005 |
| Point Rousse Project | Newfoundland/Labrador, Canada | Anaconda Mining | Gold | Open-Pit | 2010 |
| Beaver Brook | Newfoundland/Labrador, Canada | na Minmetals Rare Earth Group Co | Antimony | nderground + Concentrat | 1998 |
| Buchans Mine | Newfoundland/Labrador, Canada | Barite Mud Services Inc. (BarCan) | Barite | Open-Pit | 1905 |
| AGS Fluorspar Mine | Newfoundland/Labrador, Canada | Canada Fluorspar Inc. | Fluorspar | Open-Pit + Concentrator | 2018 |
| Conception Bay S. Mine | Newfoundland/Labrador, Canada | strong World Industries Canada Lim | Pyrophyllite | Open-Pit | 1904 |
| Lower Cove Quarry | Newfoundland/Labrador, Canada | Atlantic Minerals | Dolomite, Limestone | Quarry | 1988 |
| IOC Labrador West Mines | Newfoundland/Labrador, Canada | Iron Ore Company of Canda Inc. | Dolomite, Iron | Open-Pit | 1962 |
| Coal Brook Gypsum Deposit | Newfoundland/Labrador, Canada | Galen Gypsum Mines | Gypsum | Quarry | 2009 |
| Maamorilik | Greenland | Angel Mining PLC. | Zinc, Iron, Lead, Silver | Underground | 2013 |
| Motzfeldt | Greenland | Stallion Resources Unlimited | Niobium, Tantalum | ? | ? |
| Qaqqaarsuk | Greenland | N/A | Niobium | N/A | Proposed |
| Isua Iron | Greenland | N/A | Iron | N/A | Proposed |
| Red Dog Mine | Alaska, United States | Teck Resources | Zinc, Silver, Lead | Open-Pit | 1989 |
| Fort Knox Mine | Alaska, United States | Kinross Gold | Gold | Open-Pit | 1996 |
| Northern Star Pogo Mine | Alaska, United States | Northern Star (Pogo) LLC. | Gold | Underground | 2006 |
| Usibelli Mine | Alaska, United States | Usibelli Coal Mine, Inc. | Coal | Open-Pit | 1943 |
| Kensington Mine | Alaska, United States | Coeur Alaska Inc. | Gold | Underground | 1928 |
| Greens Creek Mine | Alaska, United States | Hecla Mining Co. | Zinc, Silver, Gold, Lead | Underground | 1996 |
| Donlin Gold | Alaska, United States | Donlin Gold, LLC. | Gold | Open-Pit | Proposed (Permiting) |
| Pebble Mine | Alaska, United States | Northern Dynasty Minerals | Copper, Silver, Gold, Molybdenum | ? | Proposed (Permiting) |
| Graphite Creek | Alaska, United States | N/A | Graphite | N/A | Exploration |
| Upper Kobuk | Alaska, United States | N/A | Copper, Zinc, Silver, Gold | N/A | Exploration |
| Livengood | Alaska, United States | N/A | Gold | N/A | Exploration |
| Palmer | Alaska, United States | N/A | Copper, Zinc, Silver, Gold, Barite | N/A | Exploration |