A Summary Report of the Impacts of Disruptive Technologies in the Newfoundland and Labrador Mining Sector

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About this Project

This report is part of *Remote controlled: The impacts of disruptive technologies in the Canadian mining sector,* which was designed to understand the impacts of disruptive technology adoption, including the scope of technologies that could disrupt traditional production practices and the future of work. For more information, please visit our project website.

Acknowledgements

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Executive Summary

Mining is moving into an 'age of disruption' where new technologies are reshaping the future of work and presenting mining communities and regions with new development opportunities/challenges (Stuart et al. 2015); however, the extent of technology adoption in Canadian mining is not clear, nor is the nature of the opportunities and challenges being presented to mining communities and regions. Remote Controlled is a national research project exploring technology adoption in the Canadian mineral mining industry and the future of work and economic development. This study sought to address these knowledge gaps through research in four case study regions: Newfoundland and Labrador; Northern Ontario; British Columbia; and the Yukon.

Technology in the Newfoundland and Labrador Territory Mining Sector

This report details findings from the Newfoundland and Labrador (NL) case study region. To understand the impacts of technology in the NL mining sector, including the types of technologies being adopted, the extent of their adoption, and the technologies that are being developed, we conducted 19 in-depth interviews with 21 key informants between October 2022 and May 2024. Key informants represented NL industry specialists (10 interviewees), mining company representatives (3 interviewees), and mining technology companies (8 interviewees).

Top Technologies

- Over the past five years, the top technologies cited by industry experts and mining companies were autonomous equipment and remote operations, followed by sensors, processing equipment, and drones.

Drivers and Barriers for Technology Adoption

- Industry experts and mining companies identified improving productivity and efficiency, making mining sustainable, and worker safety as top drivers for technology adoption.
- A range of barriers for technology adoption were identified by industry experts and mining companies. The top responses were technology barriers and infrastructure, mining culture and attitudes, and managing risks and costs.

Enablers and Barriers for Technology Development and Adoption

- The products and services offered by participating technology companies fit within multiple supporting technology categories, including drilling-related software and hardware/tool handling, monitoring software, and value-added.
- Technology companies identified several enablers with regards to technology adoption and development. The top enablers were funding, organizational culture, and cross-sectoral exchange (with technologies from a different sector being adopted within the mining sector, for example).

- The top barriers identified by technology companies with regards to adoption and development were mining culture and attitudes, insufficient collaboration within the mining sector, and implementation challenges (specifically the challenge of implementing technologies in cold, northern climates).

Impacts on Regional Development

Employment Skills, Education, and Training Impacts

- Given that mining workforces are currently shrinking and aging, it was hoped that new technologies would help fill current labour shortages and improve the efficiency and viability of existing mining operations. Though there was some debate, several interviewees felt it was more likely that mining companies would retrain existing employees to use new technologies than see employees lose their jobs as a result of new technologies.
- The nature of mining work was expected to shift with technology adoption, with fewer manual labour jobs and more jobs requiring specialized skills training expected in the future.
- New educational programs were thought be needed to upskill existing mining workers and train new entrants to the mining industry on these new technologies. Short-term programs (like micro credentials) offered in partnership with educational institutions coupled with specific in-house training was thought to be a viable training model.
- The types of training programs required were not discussed in detail. Training around the installation and maintenance of renewable technologies (wind, solar, etc.) were one educational opportunity raised given the interest of mines in electrifying/producing green minerals in the future. Another was broader education opportunities covering topics like automation and instrumentation (including high-precision GPS), control systems (include programmable logic controllers), communications (network wireless radios and systems), and data analytics.

Business Development Impacts

- Some new businesses have emerged in NL using disruptive technologies to support mining exploration and operations.
- Mines in NL were interested in diversifying their revenue streams/enhancing the stability of their operations through value-added processes, like mining waste tailings for critical minerals or repurposing tailings. This was expected to have a positive impact on mining-related business development in the future.

Regional Development Impacts

- It was thought that mining communities could benefit from mining technology adoption, such as renewable energy or wireless connectivity infrastructure, through corporate-community benefit agreements, impact benefit agreements, or corporate-community partnerships.

- New technologies could see mines developed in the future with smaller environmental footprints; the trade-off would be fewer direct employment opportunities in rural/remote areas.
- Repurposing of mine waste could be an opportunity for supporting communities, with these landscapes reimagined as local economic assets.
- In mining-dependent regions, maintaining the viability of operating mines through new technologies was valued; however, mining-dependent communities were expected to continue to be impacted by boom-bust cycles.

Responses to Regional Development Impacts

Organizations in NL responded to the impacts of technology mainly through education and training programs, as well as outreach/connector activities.

- Mining companies, educational institutions, non-profit organizations, and technology companies offer some training and upskilling programs, often in collaborative arrangements with mining companies.
- Mining companies have collaborated with other mining companies and non-profit organizations to mobilize knowledge about their technologies and processes. The goals of this work are to attract new employees, build interest among youth, and to be more transparent about the role technology plays in optimizing/sustaining their operations.
- Non-profit organizations (e.g. industry associations, chambers of commerce, etc.) have been facilitating connections within the mining sector through connector/conference events, including youth outreach programs.

Specific responses include:

- Future Workforce Program – College of the North Atlantic & IOC
- Customized and continuous learning – College of the North Atlantic & Vale
- Indigenous training and skills development – Labrador Aboriginal Training Partnership
- Underground mining simulator – College of the North Atlantic
- Find Your Future in Tech (ending in March 2025) – TechNL
- High School Tech Immersion Program – TechNL
- Mining Tech Market (2022, 2023) – TechNL
- Mining youth career fair, "Young Minds in Mining" (2023) – Martime Resources Corp.
- Central MinEx (annual conference) – Gander & Area Chamber of Commerce, Town of Gander
- Labrador MineX (annual conference) – Labrador West Chamber of Commerce
- Mineral Resources Review (annual conference) – CIM Newfoundland and Labrador Branch
- Expo Labrador (annual conference) – Labrador North Chamber of Commerce

COVID-19 and Technology Adoption

The impacts of Covid-19 most often identified by key informants were disruptions in workforce and supply chain.

- Workforce impacts included challenges accessing fly-in/fly-out workers with specialized skillsets and increased adoption/acceptance of remote work and communication technologies (i.e. conferencing software).
- Supply chain impacts included delays in receiving parts and maintenance products as well as increased interest in producing value-added products locally/within Canada.

Future Considerations

In the next five years, industry experts and mining companies expected the top technologies to be autonomous equipment, remote/integrated operations, and technologies that enable the production of value-added products.

- While this research was not able to determine the specific skills and/or training courses needed to accommodate future mining technology needs in NL, a skills-gap assessment would be a logical next step to build a fuller understanding of training programs/opportunities that are needed in NL. The mining sector may also look to like-minded industries in the context of technology, like oil and gas, to compare skills/training needs and opportunities.
- Future technology adoption in NL might be hampered by infrastructure barriers. Communities also reported some impacts related to these infrastructure challenges. Considering possibilities for collaborative community infrastructure projects to address these energy needs may be fruitful, as with Innu-Inuit Envest in Voisey's Bay.
- As new mining technologies are adopted in NL it may be beneficial to look to other regions where they have already been implemented to assess opportunities and challenges. For instance, the wider adoption of electric vehicles in Northern Ontario mines has spurred discussions around safety that are not relevant to the NL context yet but may be in the future.
- Some interviewees suggested that increased knowledge-sharing about technologies between mining companies in NL could be beneficial for supporting mutual learning and collaborative problem solving within the sector.

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1 Introduction and Context

The mining sector in Canada has entered an "age of disruption" (Stuart et al. 2015), where advances in technology are fundamentally reshaping the future of work and economic development. Globally, increased automation and digitalization in the mining sector are becoming a growing reality. For example, in Australia Rio Tinto's Mine of the Future™ features autonomous (driverless) haul trucks that operate 24/7 from a control centre located over 1,500 kilometres away (Rio Tinto, 2022). Growing alongside these trends is a rich body of international research examining how emerging technologies are transforming mining operations and redefining the relationship between mines and the people and communities where they operate (McNab and Garcia-Vasquez 2011).

However, comparatively little is known about these technological shifts and the adoption of emerging technologies in the Canadian mining sector, particularly the community and regional level impacts and responses. Remote Controlled is a national research project exploring technology adoption in the Canadian mineral mining industry and the future of work and economic development in four case study regions: Newfoundland and Labrador; Northern Ontario; British Columbia; and the Yukon.

1.1 Overarching Research Objectives and Methods

The key objectives of the research are to:

(1) Determine the nature and extent of emerging technologies in the Canadian mining sector;
(2) Examine how these technologies are reshaping the sector;
(3) Identify what is driving the adoption of emerging technologies in the Canadian mining sector; and
(4) Explore the impacts on mining communities/regions and the related responses by companies, organizations, governments etc.

To better understand technology adoption, impacts, and responses, we conducted:

- A **systematic scoping review** of articles in the *Canadian Mining Journal* to assess the main drivers, barriers, and opportunities for technology adoption in the Canadian mining sector between 2016 and 2024 (see Crabbe et al. 2025);
- A **survey** of Canadian mining representatives exploring the drivers, enablers and barriers to technology adaption in the mineral mining sector (see Crabbe, 2023);
- **Interviews** in the case study regions with a range of Newfoundland and Labrador Mining Industry Experts, Newfoundland and Labrador Mining Company Representatives, Newfoundland and Labrador Mining-Related Technology Company Representatives, and local and regional support organizations;
- The **creation of a novel dataset** of Canadian mining technology organizations to explore the national MineTech landscape (see Huneke et al., forthcoming); and
- A series of **MineTech case studies** exploring specific technologies and their potential

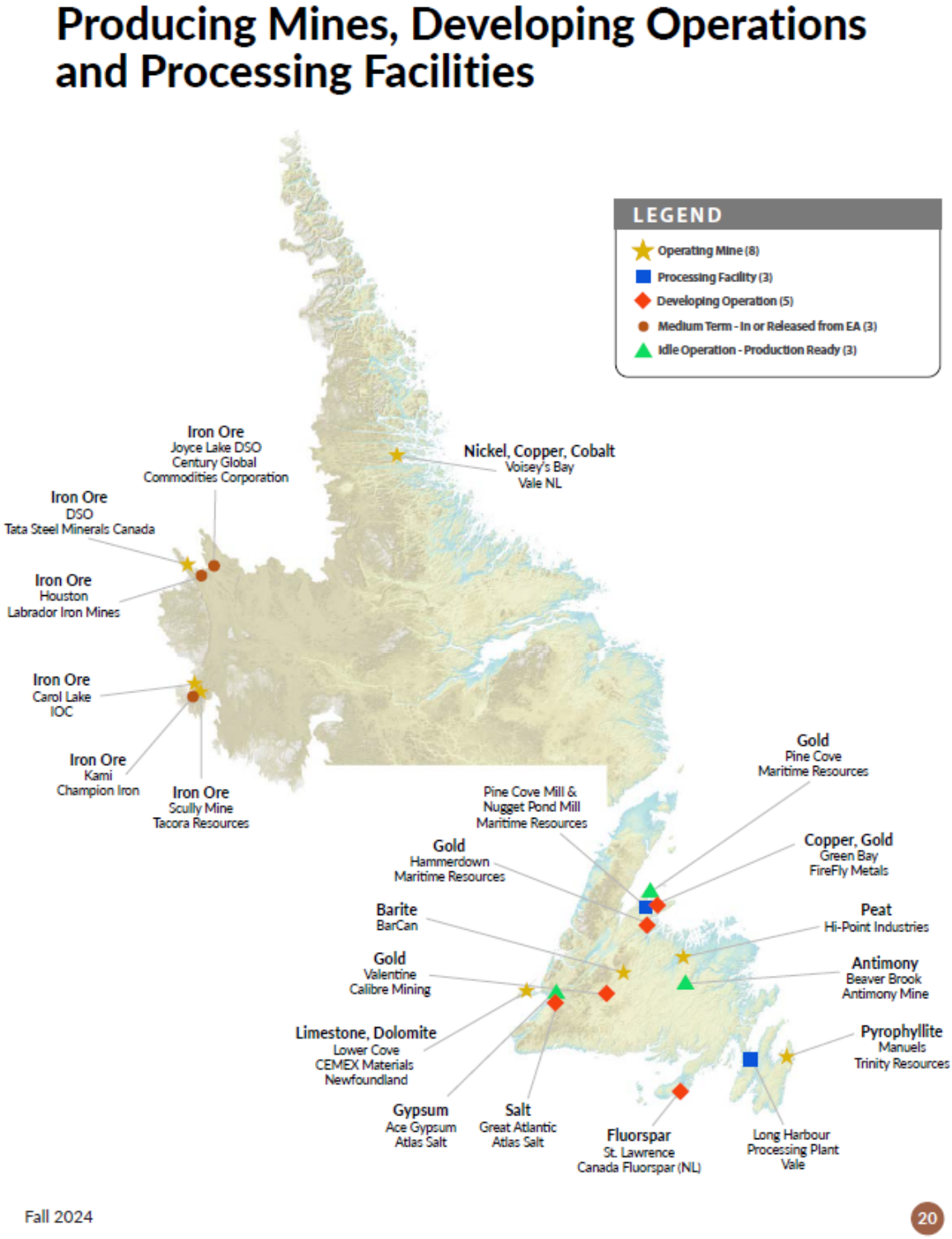
impacts on the future of work and economic development (see Zhou, Huneke, and Hall et al., 2026a; 2026b; 2026c; Huneke and Hall et al., 2026).

1.2 Mining and Technology in Newfoundland and Labrador

This report is focused on the Newfoundland and Labrador (NL) case study region of the Remote Controlled project. Mining is among the oldest industries in Newfoundland and Labrador (NL) and continues to be a large contributor to the provincial economy (Department of Industry, Energy and Technology n.d.). In 2024, the value of mineral shipments from NL was projected to hit $4.56 billion and supported an estimated 8,200 person years in employment (that is, the number of employees multiplied by their time spent in the industry) (Government of Newfoundland and Labrador 2024). In 2024, NL had eight active mines and three processing facilities, as well as five developing properties and three idle operations (Government of Newfoundland and Labrador 2024).

Mining activities take place in regions across the province. Several iron ore mines operate in the Labrador West Region and nickel, copper, and cobalt are mined in Voisey's Bay. The island portion of the province currently produces barite, peat, limestone, dolomite, and pyrophyllite. Three gold mines are also in development along with a fluorspar mine and a salt mine (see Figure 1).

Figure 1: Mining in Newfoundland and Labrador



Source: Government of Newfoundland and Labrador, 2024

The push for critical minerals to support energy transitions has ignited additional interest in provincial mineral reserves, with NL having deposits of over half of the minerals identified as critical by the Canadian government (Government of Newfoundland and Labrador 2022). The Provincial Governments' critical minerals strategy, *Our Critical Minerals Advantage*, was released in November 2023 (Government of Newfoundland and Labrador 1 Nov 2023). It outlines a plan for growing the provincial mining sector though: strategic investments in geoscience; additional training programs to support prospecting and exploration; attraction of investment (marketing, outreach); identifying value chain opportunities; investments in research and development capacity; supporting the development of a highly-skilled workforce; reviewing the Mining Act and Mineral Act, and; investments in strategic infrastructure to support mining, processing and manufacturing (i.e. roads, seaports, telecommunications, renewable energy). Energy projects being developed within the province, ranging from large-scale wind hydrogen to new hydroelectric transmission lines, may further support critical mineral capacity (Kennedy 17 Mar 2024, The Canadian Press 9 Apr 2024). *Our Critical Minerals Advantage* also highlights the need to invest in mining technologies. This includes building connections between NL's "thriving technology sector" (p. 22) and innovation research and development in the mining industry, as well as developing/supporting programs that assist workers in gaining specialized skills in operating/maintaining advanced technology and machinery.

As is the case with many mining jurisdictions in Canada, technology is poised to play a larger role in NL's mining sector (Statistics Canada A 2023). In Atlantic Canada, advanced technologies already adopted in the mining, quarrying, and oil and gas sector include software and services (23.1%) and inter-company computer networks including Extranet and Electronic Data Interchange (23.1%) (Statistic Canada 2023). Mining, quarrying, and oil and gas enterprises also planned to use executive dashboards for analytics or decision-making in the future (7.5%) (Statistic Canada B 2023). The nature and extent of technology adoption specifically within the NL mining sector to date, however, is not well-documented. This includes the drivers, barriers, and enablers of technology adoption and development in NL. It also includes the realized and potential impacts of technology adoption for employment, education and skills training, and regional development.

1.3 Regional Research Approach

For this case study in NL, a mixed-method qualitative approach was adopted, including the following methods:

1) **Media and document review:** Reviewing websites, media articles, government press releases, and policy/planning documents. This allowed the researchers to follow socio-economic and technology-related trends in the NL mining sector, as well as gather contextual data that linked to findings emerging from interviews with key informants.

2) **Observation**: Researchers made two field visits to Labrador West in June 2022 and November 2023. They also attended two mining conferences (Prospectors and Developments Association of Canada (PDAC) conference 2023 and Mineral Resources Review (MRR) 2022) over the course of the research. The goal of this observation was to connect with potential interviewees, conduct in-person interviews, and attend sessions/presentations that would supplement contextual knowledge collected through media and document review (in terms of identifying drivers, barriers, enablers, and technology trends).

3) **Semi-structured interviews:** A total of 19 interviews were conducted with 21 key informants (see Table 1). The interviews were anonymized, transcribed, and then analyzed using Nvivo software for thematic content analysis. Key informants were provided with a different set of questions depending on which of the three categories below they best fit:

    a. **Industry experts** (government representatives, industry associations, non-profit organizations, union leaders, researchers, and other specialists)
    b. **Mining companies** (mining companies with operations in NL)
    c. **Mining technology companies** (technology companies based in and/or with technologies adopted by mining companies in NL).

    In addition to the 19 completed interviews, an additional 34 organizations were invited to participate. The majority of invitations were sent by email (23), with some organizations also contacted by telephone (9) or visited in-person (2). Most of these invitations were not answered (21). A few invitations received an initial response, but the invitee did not respond to subsequent communications (7). A total of 6 invitees declined to participate, largely because they felt they could not speak to the research topic.

4) **Thematic content analysis:** Thematic content analysis was used to identify thematic trends in the interview transcripts. The goal of this analysis was to identify the technologies that were discussed most often (now and in the future) along with their drivers, barriers, and community/regional impacts as well as responses. As such, it is important to note that findings in this report detail themes and technologies that were top of mind for mining industry experts, mining companies, and mining technologies companies rather than strictly quantitative analysis (i.e. how many mines adopted specific technologies).

Knowledge mobilization efforts in NL took place throughout the research process. Preliminary findings were shared at academic conferences, including the Northern Policy Institute/Canadian Rural Revitalization Foundation (CRRF) conference in North Bay, Ontario (2022) and the CRRF conference in Whitehorse, Yukon Territory (2024). Between January and February 2025, a total of 10 report-back presentations were organized with 9 organizations and 14 individual interviewees to share preliminary project findings. Any feedback collected during these

presentations has been incorporated into this report, with adjustments made to increase the specificity of our data analysis methods, for example.

2 Technology Adoption in the Newfoundland and Labrador Mining Sector

To understand the impacts of technology adoption in the NL mining sector, including what technologies have been adopted and what challenges and opportunities they present for rural/remote community development, we conducted 19 in-depth interviews with 21 key informants between October 2022 and May 2024 virtually and in-person. This included ten industry experts, three mining company representatives, and eight technology company representatives (see Table 1). Interviews were divided into three categories: 1) mining industry experts, 2) mining companies, and 3) mining technology companies. It is important to note that some interviewees did not fit into a single category. For example, three interviewees classified as mining technology companies did report working for mining companies or mining service companies concurrently or in the past.

Table 1: Key Informants in Newfoundland and Labrador

Interviewee Category	# of Interviews	# of Interviewees
Mining Industry Experts	10	10
Mining-Related Technology Company Representatives	6	8
Mining Company Representatives	3	3
Total	**19**	**21**

Source: Created by authors

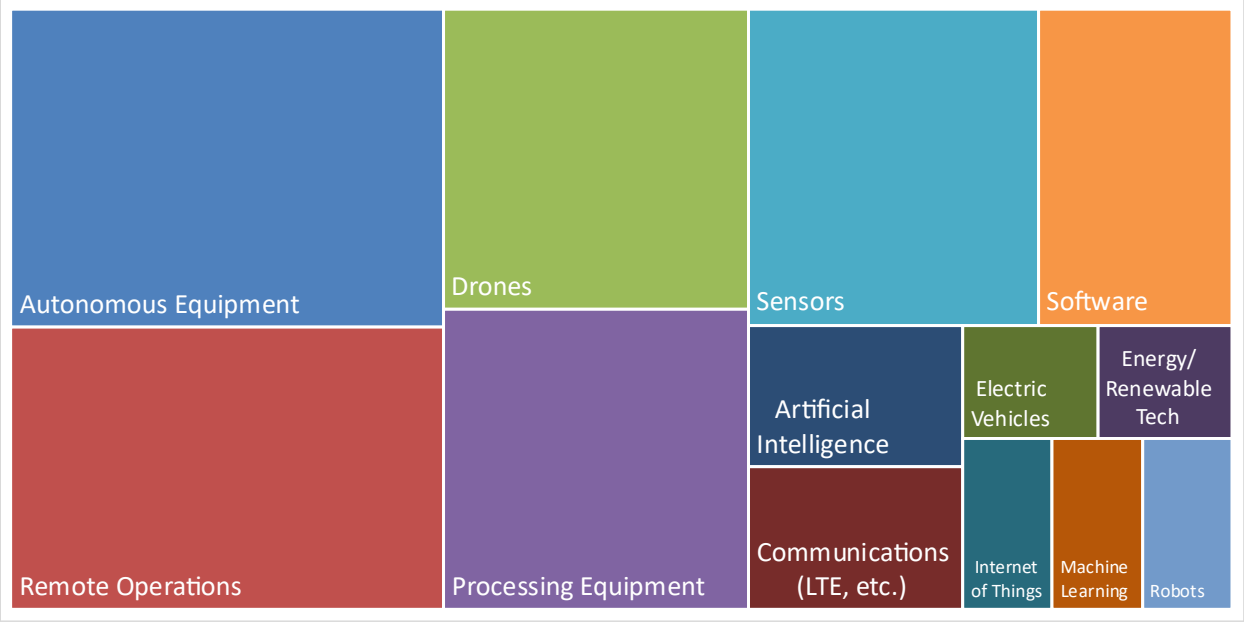
Key informants were provided with a different set of questions depending on which of the three categories they best fit (see Table 1). Mining industry experts (e.g. government representatives, industry associations, researchers, etc.) were asked what specific technologies had been adopted in the NL mining sector in the last five years and about what technologies might be adopted in the next five years. For each specific technology identified, follow-up questions were posed to identify drivers and barriers to adoption, impacts on employment, education and skills training, impacts on business development, and impacts on regional/community development. Mining companies were similarly asked what specific technologies they had adopted in the last five years and what technologies they might consider adopting in the next five years. As with mining industry experts, mining companies were asked to identify drivers and barriers for adopting each specific technology, enablers for their adoption, and impacts on employment, education and skills training, as well as business development and regional/community development. Mining technology companies (i.e. companies who created and/or sold technology products/services within the NL mining sector) were asked questions about their specific technology products and/or services. They were also

asked to identify any enablers/barriers for developing the technology or having it adopted as well as any impacts on employment, education and skills training, business development and regional/community development.

2.1 Top Technologies

When asked about top technologies that had been adopted in the last five years in the NL mining sector, industry experts and mining company representatives cited autonomous equipment (9/13, 69.2%) most often. Remote operations (8/13, 61.5%), processing equipment (6/13, 46.1%), sensors (6/13, 46.1%) and drones (6/13, 46.1%) were also cited as top technologies adopted over the last five years (see Figure 2).

Figure 2: Top Technologies in the Last 5 Years (NL)



Source: Created by authors

Autonomous equipment includes autonomous drills, programmable logic controllers (i.e. for chutes, valves), and autonomous trains, among others, as described by Newfoundland and Labrador Mining Industry Expert 5:

> *You know basically, what it comes down to, is every device. Any type of process out there, there is always a means and a will to automate it. I mean, just like turning valves, opening and closing chutes. You know, moving – being able to move trains, you know, that's another one. You know, we have automated trains…Simply starting up the boilers used to require a person to manually open dampers, a person to manually open valves. You know, adjust things right there on the floor. Now it's strictly in a control room. We sit back and push a button, and it does everything for you.*

With regards to remote operations, mining experts specifically described operating mining equipment from a distance and from a remote operating centre, as described by Newfoundland and Labrador Mining Industry Expert 1:

> *The other thing that would work into that would be remote operations. Okay, so it's not exactly automation but it's operating remotely. You know, controlling all of the equipment from a central control room. Right, so it's not automated that you've taken people working out of the plant or the processing plant, and you're controlling it from a central room on monitoring what's happening. For example, trying to take, you know, getting people out of those dangerous situations. So, for confined spaces… if you've got to have a digger or something operating in a confined space you could have a remotely controlled digger that somebody is actually sitting in a room, controlling it. Right, as opposed to being at the face. So that sort of technology is hugely increased.*

Remote operating centres allow for several technologies within a mining operation to be operated remotely. In NL, these specific technologies include remotely operated dozers, excavators and mobile equipment in addition to autonomous drills and autonomous trains. A distinction was made between remote operating centres and centralized control rooms in NL, with centralized control rooms focused on monitoring operations (data, etc.) rather than remotely operating equipment.

Processing equipment referred to a range of technologies, including concentrators/separators, reduction circuits, electric boilers, and electric plasma furnaces. For example, Newfoundland and Labrador Mining Industry Expert 7 describes the use separators to concentrate manganese:

> *So, at the time our separation process back in the day we used to use an electromagnet system. We called it high tension. So, this is an electric magnet, an electromagnet separator. At that time, they didn't process manganese…back any time between like 1960 and 2012-2014, when it shut down, manganese was either just dumped into waste or they just literally just drilled around it and avoided it. But since then, they've installed these new manganese separators. So, essentially, our old separation system has been completely gone and when they started back up, they put in these new manganese separators. So, it's a process that separates the iron ore from the manganese and then, also, so that they recapture the manganese at a later process down the line.*

Sensors and drones were used by mining companies across the province and, while not entirely new to the sector, were being improved to enhance data collection capabilities. For example, autonomous equipment with sensors was allowing for real-time monitoring of mining processes, as described by Newfoundland and Labrador Mining Industry Expert 4:

I would think in terms of, you know, I think automation and the march to better real-time monitoring and feedback. So that if I'm sitting in a boardroom in Toronto and I'm an investor in a mine in Baie Verte and I have a dashboard in front of me that's providing me with real-time monitoring of my investments, banking. So, if I see downtime, you know, it might prompt me as a member of the senior management or the board to say, "Okay, what's happening here?"

Drones were also being enhanced to collect data, for example, through lidar scanning as described by Newfoundland and Labrador Industry Expert 9:

A lot of companies nowadays are adopting the drone technology. And not just drones to, you know, go up and take a nice picture or video of your site, but actually having that technology on there like Lidar scanning…enhancing that drone in order for it to gather more data for you, right?

2.2 Drivers for Technology Adoption

Mining companies and industry experts identified a range of drivers for technology adoption (see Table 2). The top three drivers, however, were increasing productivity and efficiency (12/13, 92.3%), making mining sustainable (84.6%), and worker safety (76.9%). Several interviews highlighted that the capacity and willingness of companies to adopt technology in NL varied greatly, due to the size of a mining company (with larger companies more likely to innovate) and their mining phase (with developing mines more likely to innovate than active mines). Site-specific characteristics also drove technology adoption, particularly the specific geology of a mine site (i.e. presence of impurities, challenging/dangerous geological structures). As most mines in NL had experienced shutdowns/closures over the last few decades, remaining economically viable was a critical concern highlighted by both mining companies and mining industry experts. This was thought to impact the willingness/ability of mining companies to adopt new technologies in NL, emphasizing the need for new technologies that could ensure a return on investment (i.e. improved efficiency/productivity).

Table 2: Top Drivers for Technology Adoption (NL)

Top Technologies (Last 5 Years)	Experts (10)	Mining Companies (3)	Total
Increasing productivity and efficiency	**9**	**3**	**12**
Making mining sustainable	**9**	**2**	**11**
Worker safety	**8**	**2**	**10**
Economic demand and industry development	7	2	9
Managing risks and costs	8	1	9
Discovery, development and assessment	4	1	5
Improving mining operations	5	0	5
Site-specific characteristics	3	2	5
Need for better data collection, management and utilization	3	1	4
Corporate structure	2	2	4
Tech advancements	3	0	3
Improve communications and collaboration	1	1	2
Labour recruitment and training	1	1	2
COVID-related drivers	0	0	0

Source: Created by authors

2.2.1 *Increasing Productivity and Efficiency*

With regards to increasing productivity and efficiency, mines reported their top priority being maintaining the viability and/or improving the efficiency and productivity of their operations. Specific drivers within this category included improving the purity of extracted minerals prior to sale. For example, Newfoundland and Labrador Mining Company Representative 1 described how the use of manganese reduction circuits allowed them to produce high-purity iron ore:

> *…we're producing right now because of this technology. It's not necessarily new technology to the industry, but it is new to this manganese, to us… where we are today, right now, because of that [technology] we're producing an iron ore product that's 65.5% iron, 2.5% silica, and 2.0% manganese. And that particular product is very, very attractive for steel mills, especially in Asia, Europe, and the Middle East. Because it reacts very well in the steel furnaces because of the low impurities… Without [the reduction circuits] we would not be operating today. Simple as that. Cause, we would have to produce the same type of ore that [a previous owner] was producing, which was not very attractive. But because of this, our ore now is in big demand. Around the globe, really.*

Another specific driver was productivity gains, or being able to accomplish more work with fewer resources and in less time as described by Newfoundland and Labrador Mining Company Representative 3:

> *And then the second one, then, is around the productivity. So, you know, in the old recipe manual drills, one driller, one drill. In the new recipe, in the autonomous drills, they are basically doing everything machine-controlled, and there is a person monitoring the drills. That person is sitting in the operation center has a bunch of screens in front of them with application and monitors and so forth. And it's just monitoring the activities of the drills. Which, you know, from a productivity perspective explains, of course, the gain where one person can monitor 2 drills, 3 drills, and more. So, there's clearly a - there's also no stopping anymore for meal breaks, you know, shift change, weather. Sometimes we have weather events, you know, where we have to evacuate people because there's lightning in the area. So, there's a productivity gain which is significant.*

A final efficiency/productivity driver was production cost savings or being able to reduce the base cost of extraction/production to improve profit margins as described by Newfoundland and Labrador Mining Industry Expert 10: *"You know, here we have, obviously always a drive to do things better and more efficiently so that they are more cost effective. You know, maintaining and improving your position on the industry cost curve."*

Mining companies and industry experts felt that these productivity and efficiency gains could also have spin-off sustainability and safety benefits. For instance, it was thought that traceable minerals produced by companies that could demonstrate environmental and social responsibility would increase product values in the marketplace, as described below by Newfoundland and Labrador Mining Industry Expert 4. This demand, in turn, created additional incentives for mines to produce minerals in accordance with ESG principles and using environmentally-sensitive technologies.

> *So, the social, economic and governance context in which we operate is also a base driver because we want, in Canada and Newfoundland, we want to do things safely and responsibly. That might not be the case of jurisdictions around the world. And… so if we have a philosophy or a culture that says ESG is important, and here's the elements we're focused on: material. And above that, here's the technology we're using to help enable some more efficiency: safety-focused communications, methods, throughput on flow sheets. Then, that there gives another level of value to your product in the marketplace, over and above your peers. And so, if markets and investment houses are valuing that sustainable part of the equation in the value chain, then, having additive technologies that support that is also an incentive to adopt, right?*

2.2.2 *Making Mining More Sustainable*

With regards to making mining sustainable, ESG considerations were described by some interviewees as having supported a cultural shift within the mining industry in NL that was having implications for technology adoption. In broad terms, Newfoundland and Labrador Mining Industry Expert 5 describes mining companies as being attentive to market demands. If ESG is an 'input' influencing the market, then companies will be more motivated to align their processes with that input:

> *You know what the investment really wants, it's what consumers of the end products want. Really, you know, if the investment market wants value, sustainable investment in, you know, let's say, ESG-sensitive companies, then companies are gonna respond to that input and try to align, right? So that's an input. So, what's the market driving? What's the end consumer that's buying the cell phone with the rare earth in it that came from the Congo that was scattered up by an artisan miner that was abused and really exploited, right? Versus a rare earth element that's coming from a mine that has traceability right back to source and in a jurisdiction that's more fair and equitable.*

From the investment side, investors might ask a mining company about its commitment to ESG or to see their sustainability plans before contributing financially to a project. Newfoundland and Labrador Mining Industry Expert 7 thought that increased demand for critical minerals would see more mining operations, generally, making these ESG commitments more important:

> *...we're seeing this in all industries, in regard to it's not just the bottom dollar people are worried, are thinking about when it comes to who they want to partner with as an organization…We are becoming more and more conscious of where our products and services come from. And the benefits that that organization then gives back to the communities that they operate in, right?*
>
> *So, as a generational shift that's happening, is that every company is becoming more and more conscious. Yes, we talked about dirty oil or dirty mining, and all that kind of – there are that portion of the population that will always think of it as a dirty industry. But in general, a lot of these products are still needed day-to-day. So, you know, these industries are not just gonna stop…Well, we need critical minerals and that means more mines in order to get those critical minerals. So, but in order to do that, we have to do it with a social license to operate. We have to be able to do it sustainably, environmentally-friendly, lowest carbon possible on what will get us there.*

They also noted how shareholders are now also asking: "*"Where is your ESG plan? Where's your sustainability plan? What are you doing in the governance side of things to make people more safe in your organization?"* This customer and investor interest in sustainability together with environmental policies/legislation, carbon taxes, and other external pressures was thought to

impact the types of technologies mining companies adopt. As Newfoundland and Labrador Mining Industry Expert 4 describes, economic, environmental thresholds, and ESG were being considered by mining companies in tandem when it came to whether or not to adopt a technology:

> *Right, so - For them to adopt a technology, it would have to make economic sense. So, the bottom line would be one, and I guess another reason to adopt technology is that they wouldn't be able to advance if they don't. So, if there's certain thresholds of whether it's water, quality, air, quality, carbon emissions, if there are certain thresholds they have to meet them, they need to find the technology to meet those thresholds... like the ESG might ultimately, you know - if the banks will only invest in green projects, that's an incentive as well.*

Newfoundland and Labrador Mining Industry Expert 4 further clarifies that sustainability considerations were particularly impactful for motivating the adoption of electric equipment/infrastructure by mining companies:

> *Decarbonization is a driver, right? It's larger companies like Rio [Tinto] that are reporting on their on their carbon footprint globally, right. All of these are definitely going to be driving technology to electrification, you know. You know, in case of iron ore, green steel. So, the inputs on steel - If you got a green steel input, iron ore input, you're going to get a higher premium in the marketplace for that. You're going to get a better value for that. At the end of the day, you're going to have the customers making that steel rebar, or that washing machine, is going to be benefiting from that input stream as well. So, incentives around decarbonization.*

Some interviewees felt that maintaining good relations with communities in proximity to mining operations (sometimes referred to as the social license to operate) was also increasingly important from a mining company perspective. This, in turn, was having implications for technology adoption, with technology adopted because mining companies felt pressure to "actually do things better" as described by Newfoundland and Labrador Mining Industry Expert 10:

> *You know, if we think though about the environmental social governance piece. There's also the impact on the cost curve there as well. But also, I think, it's the better understanding that you need to be able to demonstrate to, say, local communities that you are pursuing responsible development. So, you know, this is, this is driving the technological piece because companies need to actually do things better. It's not just saying that we are, it's actually doing it. Capturing it and being able to communicate that piece to communities so that - And again, I'm always hesitant to use the term social license. Because, you know, it I think I'm more comfortable with social acceptance. Because, you know, there's technically no license provided. But yet, there is a degree of acceptance that if*

you, you know, if an operation does not secure, I mean, it can essentially shut them down through, you know, one form or another.

2.2.3 *Worker Safety*

The third top driver was worker safety. As with sustainability, safety considerations were sometimes linked to increasing productivity and efficiency. For example, Newfoundland and Labrador Mining Industry Expert 5 mentioned that a high commitment to safety could reduce liability insurance costs for a mining company:

> *And liability, that's a two-fold one. I mean, I could use safety. Obviously, if there's not people interfacing with machinery or directly operating the machinery it's a safety point. But, it's certainly got to be more costly from a liability standpoint to, you know - safety is drove from want to be safe. But also, a need to lower insurance premiums and costs.*

However, the safety of mine workers was also highlighted as important in its own right as remote operating capabilities, for example, could see workers exposed to fewer hazards in their day-to-day activities as described by Newfoundland and Labrador Mining Industry Expert 8:

> *But a lot of the control [operations] room, they're actually watching the equipment and those kinds of things. They are not down inside the gate now. And that's a huge deal, not only for you know, not only for the for the operation, but there's a big difference between, you know, someone having to go through the gate. You know, there's still gate cards. People go through doors and buzz in and stuff. But there's a big difference between controlling who's in your mine that could get hurt. You know, there's trucks moving around. There's all kinds of things happening in those facilities that is way better off if there's less people around. So, you know, they've been moved off site.*

A focus on mine safety was also thought to be strategically important for the mining industry as it relates to labour recruitment and training. It was thought that prevailing perceptions of mining as dangerous were a deterrent to potential new and/or younger employees. Some interviewees felt that new technologies that allow for safer jobs could be a mechanism for shifting these negative perceptions of the industry as described by Newfoundland and Labrador Mining Industry Expert 1:

> *Mining companies, you know, my experience of mining companies, is they had a very bad reputation, you know, 20-30 years ago as being dangerous places to work. And mining companies, the best way - especially the bigger ones if you're talkin' the Rio Tinto and the Vales and even, and it's trickling down to the smaller ones - is they're safety companies that do mining on the side.*

As such, if adoption of a new technology allowed for fewer people interfacing with mining equipment or fewer people working underground, this might incentivize a mining company to adopt new technologies. Caveats to this perspective were also identified by a couple of interviewees, who identified possible hazards of relying on technology. For example, Newfoundland and Labrador Mining Industry Expert 7 mentioned that not having enough people in the mine to recognize and/or respond to small challenges could pose safety risks in the future, especially if those challenges compound over time:

> *So, for some of it is a benefit, because, like, you know, you can cut down on a workers' exposure to, you know, hazardous materials or hazardous areas. But at the same time, I guess it's also negative, because, you know, you're not always 100% there all the time to fully see or you don't have someone in the fields as often as you should because, you know, the automation is the ones looking after it. So then, if something does happen, now someone's gone into the field and there hasn't been somebody there for the last 3 weeks and all of a sudden something major has happened because something small has turned into something big.*

2.3 Barriers for Technology Adoption

In terms of barriers to technology adoption, technology and infrastructure barriers were described most often by interviewees (76.9%) followed by mining culture and attitudes (53.8%) and high costs and inadequate funding (46.2%) (see Table 3). Some site-specific barriers emerged as well. For example, one mining company had piloted autonomous drills and, finding them inappropriate for the depth at which they were drilling, did not ultimately adopt them. Another example was the need to adapt processing equipment to suit the unique geology of a mine site, or "fine tuning", which could contribute to uncertainty or risk when adopting new technologies (Newfoundland and Labrador Mining Industry Expert 10).

Table 3: Top Barriers for Technology Adoption (NL)

Top Technologies (Last 5 Years)	Experts (10)	Mining Companies (3)	Total
Technology barriers and infrastructure	**8**	**2**	**10**
Mining culture and attitudes	**5**	**2**	**7**
High costs and inadequate funding	**4**	**2**	**6**
Fear of job losses	3	2	5
Uncertainty and risk perception	4	0	4
Implementation challenges	2	1	3
Insufficient industry collaboration	2	1	3
Lack of skilled labour and workforce shortages	3	0	3
Site-specific characteristics	2	0	2
Pandemic challenges	1	0	1

Source: Created by authors

2.3.1 *Technology Barriers and Infrastructure*

With regards to technology and infrastructure barriers, these discussions ranged from access to a reliable supply of electricity, to improving wireless connectivity underground, to the challenge of funding infrastructure upgrades and infrastructure challenges limiting their ability to recruit workers (e.g., housing and access to healthcare).

Access to reliable electricity was a concern expressed by several interviewees, especially in the context of rural/remote regions of the province. As described by Newfoundland and Labrador Mining Industry Expert 10, mineral deposits are not always located in areas connected to the power grid, which can make mineral development challenging:

> *The availability of the electricity is probably the, the largest barrier. So, for mining there's kind of several aspects to it. So, you know, with a mineral deposit, we can't locate that in a convenient place. It is where it is. And many times, these deposits are in remote locations. They're off, they're, you know, they're not connected to the grid. The possibility to, I mean, nothing is impossible. Anything can get connected. However, the financial, the environmental barriers to accomplishing that can be significant…being an industrial operation, things are generally big. So, if you look to electrify, you know, we're not talking about adding a house to the grid.*

Much (though not all) of the discussions around electricity focused on the Labrador West region. Existing mines in Labrador West were reported to be limited in their ability to electrify/adopt new technologies due to insufficient electric infrastructure to support their use, as described by Newfoundland and Labrador Mining Industry Expert 6:

> *...well, there's a lot of discussions taking place, for example, Tacora is either awaiting or advocating, I think, for more power for their operations. A lot of companies like Rio Tinto are looking to green their operations. A lot of talk about green steel, what that might look like, too. So, I think it's primarily now a discussion with Hydro and trying to figure out how these companies can tie into the grid if they've got this huge requesting for Newfoundland Labrador Hydro.*

With new iron ore mines expected to open in the Labrador West region in the future, like the Kami project, concerns about electricity were particularly acute at the time of the interviews. In December 2024, a memorandum of understanding was signed between the governments of Quebec and Newfoundland and Labrador aiming to support the expansion of hydroelectric capacity in Labrador.

Wireless connectivity was another infrastructure barrier identified by interviewees across NL. Several mines reported wireless connectivity challenges where their existing wireless

capabilities were insufficient to support adoption of remote/autonomous technology. As described by Newfoundland and Labrador Mining Company Representative 2, it is often easier to install wireless infrastructure during the development phase of a mining operation. Once a mine is operational, it can be difficult to justify the capital costs as installation time could hamper productivity:

> *I think introducing the Wi-fi and everything else is just, I guess, just the infrastructure and the funding…the next level of funding is just to make sure that the capital funding of implementing and rolling it out so that you can link the entire mine to this new connectivity. It's, I guess, it's always a barrier. It's better for smaller operations…It's always difficult when it's a retrofit. But when you set it up from the beginning, it's easier.*

2.3.2 *High Costs and Inadequate Funding*

Another top barrier was the cost of adopting new technologies, both in terms of the upfront cost of purchasing and of installing technologies. These concerns were often (though not always) linked to managing costs and risks. For example, Newfoundland and Labrador Mining Industry Expert 1 noted that innovation can be seen as secondary to the primary goal of maintaining the productivity and viability of operations, especially among small and medium-sized mining operations:

> *It's the cost and having the people trained to do it. And in the end, how do you use it, right? So, if you've got a mining operation and they've been doing the same things 10 years they, you know, 20-30 years, they can see the benefit. But more often than not, they're too busy doing their day job to bring in new innovation, and that's what we experienced a lot of with, especially the medium sized companies. The bigger companies like the Vale's and the Rio's they, they can hire a whole [research and development] team and innovative team and things like that. But the smaller companies, you know, if you're running a mill, that you're, you know, full time job, you don't have time to sit there and think, "how am I going to bring in a new technology and oversee it" and things like that.*

The phase of a mining operation was raised in this context as well. As Newfoundland and Labrador Mining Industry Expert 9 pointed out, adopting technology can be especially risky when a mine is operational (in the process of extracting/refining ore) because of its potential impacts of productivity and economic efficiency:

> *But when you're in the operational phase of things, you are in that phase of making money now. So, you're into this… for lack of a better word, 9 to 5 everyday sequence of doing the same thing, of getting that resource out of the ground and selling it. Money into your pocket. So, adopting new technology provides this added risk. So, if we adopt this new technology, regardless if they*

tell us it's a ten-fold enhancement of our bottom line. But when will we see that come online? If we adopt it, how many times do we have to shut down and readjust on those parameters before we can get a return? So that means right now: "what do you mean I'm gonna be shut down for a day or a month?" Or "how long are we shut down?" So that risk of not making money is heightened.

Interviewees highlighted that mining companies are looking for a good return on their investment when it comes to adopting new technologies. If the risk is too high, mining companies may be less inclined to adopt them, especially small and medium-sized companies with shorter mine lives and/or less capital. This was thought to be a manifestation of 'risk aversion', which is another top barrier to technology adoption identified in this research, as it may motivate companies to seek out proven technologies, or technologies that have worked in other mining operations, as described by Newfoundland and Labrador Mining Company Representative 1:

I think it all comes down to cost and the decision to make the investment. I mean, yeah, you got to have proven technology. But there's lots of people there doing that. Any technology that we implement is usually proven technology. So, that's anytime you make a decision to put in new technology, it's something that we know that should work. So, I think… these [are] factors, I guess, in making decisions to invest in any new technology.

2.3.3 *Mining Culture and Attitudes*

This links to another top barrier: mining culture and attitudes. Risk aversion was thought to be a characteristic of the Canadian mining industry more broadly, sometimes described as "the race to be second" by Newfoundland and Labrador Mining Industry Expert 1:

I think part of the biggest kind of the biggest hurdle to mining is - it's that miners are very conservative by nature. We always talk about the race to be second. Mining company always look to see what everyone else is doing when they're successful at it then they'll take it on.

Newfoundland and Labrador Mining Industry Expert 2 clarifies that some mining companies in Canada will wait for a later generation of an emerging technology to come out before they adopt it. Other companies with more nimble organizational cultures might be early adopters or be involved in the development of new technologies:

…some companies are a little more risk averse, and so they will hardly ever adopt first or second-generation technology. They'll wait until all the bugs have been worked out and they'll take the third or fourth-generation. So, because a lot of these technologies are emerging, there'll be a combination of reluctance, I think, from more risk averse organizations to adopt them. But then a whole pile of

other companies that are more nimble and they'll probably be, you know, the early adopters, or even be involved with the development.

In NL, risk aversion was tied most closely to economic/financial risk. It is worth noting that in other Canadian mining jurisdictions risk aversion is related to multiple factors (Crabbe 2023). For example, structural barriers, such as risks to worker health and/or safety, and organizational characteristics, like lack of employee engagement in technology adoption, may contribute to risk adverse mining cultures (Crabbe 2023, Crabbe et al. 2025).

Another barrier related to mining culture and attitudes is the challenge of having employees buy-in to using new technologies. For example, Newfoundland and Labrador Mining Company 3 described internal resistance to change as a barrier for adopting technologies within their enterprise. They addressed this challenge by inviting workers to work with the company to "shape the future" of their workplace:

Let's talk about internal resistance to change. You know, I was talking about the drillers earlier and this is a unionized workforce. And they were very concerned. Like the truckers today are concerned that autonomous trucks will take over their jobs, right, and a million truckers in Canada will lose their jobs. It is a concern, and we worked closely with the Union to explain that our duty, as in running a business, is to improve the business. Make it more productive, make it safer, and so forth. So…in the beginning there was quite a bit of resistance to that from the Union, the Union members, and so forth. But we created a pilot and invited the unions to work with us and shape, let's say, the future… They used to be sitting on the drill, and we brought them into the operation center. [Now] they say, "I don't want to go back", you know. They walk around in their slippers and running shoes. They go fetch themselves a coffee, have interactions. But also, I think they got really interested and curious about the technology and adopted it. And they're happy with what they do today compared to where they were a couple of years ago.

2.3.4 *Lack of Skilled Labour and Workforce Shortages*

Though it did not emerge as a top barrier, lack of skilled labour and workforce shortages were an acute concern raised by several Industry Experts. This includes access to employees with skills in renewable energy and electric technologies. Sometimes, as in the Labrador West region, infrastructure barriers like a shortage of housing and unreliable healthcare access enhanced these concerns, as described by Newfoundland and Labrador Mining Industry Expert 8:

...you know, we have 3 real issues in Labrador West. A housing issue. And a power issue which will obviously come into the autonomous space, you know, the remote space. And the healthcare problem as well. And they're all intertwined.

Industry Experts in this region were concerned, for example, about the ability of the region to attract skilled workers and their families. It was thought that this might lead to a growth of the existing fly-in/fly-out (FIFO) workforce to fill labour gaps in skills trades and several interviewees felt this could be problematic for the community (see Butters et al. 2019 for additional information). Newfoundland and Labrador Mining Industry Expert 7, for instance, described community concerns regarding FIFO (despite critical skilled roles currently being filled by FIFO workers):

> *I mean you could still go around town now and there's still stickers and everything everywhere that says like, you know, no fly-in/fly-out or just FIFO with an 'x' through it. They put a huge push on. So, obviously there still is quite the resistance here for it. At the same time, though, the company here does for staff, for like critical staff roles, they have offered fly in/fly out as a way to fill those positions. So, like chief power engineers and stuff like that, in order to keep that running, they have them doing fly-in/fly-out. Major engineers like senior engineer positions are fly-in/fly-out, so yeah…so the ones that are staff fly-in/fly-out are just ones that they can't get - its such a demanding job that they don't have anybody local to fill in.*

2.4 Enablers and Barriers for Technology Adoption and Development

The products and services offered by participating technology companies fit within multiple supporting technology categories, including drilling-related software, hardware/tool handling, monitoring software, and value-added technologies (see Table 4). A total of six technology companies participated. All technology companies had clients in NL, with five (83.3%) also having offices in NL. One mining company in NL also reported having in-house R&D and so have been included in the data below. As part of the interview process, mining technology companies were asked about factors that enabled the development and/or adoption of their technologies or were barriers to the development or adoption of their technologies.

Table 4: Technologies Utilized by Participating Mining-Related Technology Companies in their Products/Services (NL)

Technology Utilized by Mining-Related Technology Companies	Total (6) + (1)
Software	3
Artificial Intelligence	2
Autonomous equipment	2
Drones	2
Sensors	2
Energy or renewable technologies	1
Tool handling	1
Value-added	1

Source: Created by authors

2.4.1 *Enablers for Technology Development and Adoption*

The top enablers for technology development, from the perspective of technology companies, were access to funding (3/7, 42.8%), organizational culture (3/7, 42.8%), and cross-sectoral exchange and collaboration (2/7, 28.5%). Often it was a combination of these factors that contributed to a technology company's ability to develop successful products/services, as described by Newfoundland and Labrador Mining-Related Technology Company Representative 1:

> *There are three things necessary for technology development. One is the idea, and one is science, and one is money, and they are all of equal importance… I think there's a lot of ideas held here in rural Newfoundland, you know, in mining. You just gotta find a way to tap into those guys and girls with these great ideas to get them linked up with the science and the science research and the and the money for research to make them reality. Because with any one that is without the other, it doesn't get anywhere.*

With regards to funding, technology companies reported that they had secured development funding from various sources. These included federal and/or provincial government funding, participating in start-up competitions, and/or making use of business/product incubators to develop their products. Newfoundland and Labrador Mining-Related Technology Company Representative 5, for example, mentioned accessing funding through several of these avenues:

> *So, we did certainly have access to funding, provincial, federal, and incubator…We've also won a number of awards in terms of environmental sustainability awards.*

With regards to organizational culture, interviewees described working within progressive technology companies or companies with 'visionary' corporate leaders (Newfoundland and Labrador Mining-Related Technology Company Representative 1) as contributing to their ability to develop innovative technologies. Interviewees also described having business models that allowed them to be flexible and/or responsive to the needs of their clients or community partners. Newfoundland and Labrador Mining-Related Technology Company Representative 6, for example, described having community support and encouragement in their development of post-mining waste into an economic asset:

> *…the enablers were really, you know National Research Council, RDC, College of the North Atlantic, the community itself. But there's strong community support and encouragement from the community, because the community - it's sort of like a community asset…They're very close to it. You know, they wanna make sure that, you know, you don't go up there and create a hazard.*

Cross-sectoral knowledge exchange and collaboration were other enablers for technology development. This included working with academic researchers and with other partners to support technology development. It also included technology companies drawing from knowledge or experiences in industrial sectors outside of mining that are aligned in terms of their technology needs. For example, Newfoundland and Labrador Mining-Related Technology Company Representative 5 described similarities in their experiences working in oil and gas, construction, and mining which supported the development of their technology:

> *Yeah, so I've worked in mining, oil and gas, construction... Did a little bit and then - those are kind of the main ones. And then a bunch of other kind of varied experience. So, I've worked in kind of the 3 main industries that we work in, along with utilities. So, while there's definitely people out there that have better experience in terms of there's people out there with 30 years mining experience. Which is fantastic. Whereas I've kind of done a little bit of a lot of things across heavy industry rather than really focused on one thing or the other…So, between oil and gas and mining, within the majors, people can fairly easily transition between them...on a global scale we see a lot of people bounce back and forth between mining and oil and gas. Very similar. Like obviously one like your drilling, I guess you're both drilling. But one your hauling ore and the other one you're running pipe. But at the end of the day, it's a mechanical system. The people that are actually designing like a mine engineer type role - that's probably a fairly mining-focused role. If you look at a project manager, you look at the safety manager, an engineer. Project controller, [Chief Financial Officer] type thing. All of those roles are very, very similar across mining, oil and gas.*

From the perspective of technology companies, increasing productivity and efficiency were a top driver for mining companies to adopt their technologies (5/7, 71.4%). For instance, when asked what has driven the adoption of their technology across Canada, Technology company 4 responded: *"I think it's efficiency. I think it's time-saving."* Another top driver for adoption was reported to be making mining sustainable (4/7, 57.1%). Economic efficiency played into sustainability-related adoption considerations as well, with mining companies looking to improve the efficiency and productivity of their operations using circular technologies, as described by Newfoundland and Labrador Mining-Related Technology Company Representative 2:

> *So, for example, our SRU, which is solid removal unit. So, it recycles the drilling water that's used on the diamond drills for exploration mining. As the water is returned to surface, it is run through our solid removal unit, and it removes all the solids and recycles the water. So, it helps reduce the water being used in communities… Whatever we can do to help minimize our footprint altogether is what the end goal is. But it also, it also improves efficiency and productivity at the end of the day. By recycling and removing…you don't have much as a reclamation site at the end of the operation. Everything, the cuttings from your drill hole, it can all be hauled away during operations and you're not left with a*

sum full of drill cuttings at post-operation. So, again, reclamation - site reclamation, whatnot is very minimal to nothing at all. You're just left with a drill hole…And then the water consumption throughout the operations is minimize drastically. So yeah, it's all positive environmental impacts.

2.4.2 *Barriers for Technology Adoption and Development*

The barrier for technology development and adoption discussed most often by technology companies were mining culture and attitudes (5/7, 71.4%). This included orienting mine workers to the new technology, ensuring the technologies are used properly, as well as addressing worker concerns and/or distrust of the technology (i.e. concerns around tracking their productivity, location, etc.). For instance, Newfoundland and Labrador Mining-Related Technology Company Representative 5 observed that workers were concerned about downloading work-related apps to their personal mobile devices. These concerns were mainly related to their employers being able to track their activities during work hours as well as after hours:

So, that was kind of some of our observations that, people are fairly sensitive on putting a work app on their phone. And probably rightly so because you can track location. You can track a lot of different things that probably don't want your employer to see after hours.

Technology companies often developed strategies to support workers once their products were adopted by mining companies. These strategies ranged from on-site workshops and technology demonstrations to shadowing exercises, all with the goal of building trust/employee buy-in and ensuring companies would see the full benefit of the product and/or service, as described by Newfoundland and Labrador Mining-Related Technology Company Representative 3:

Well, the biggest challenge for us, I know…was getting the driller to scan it. It was easy as that. …we have a really good relationship with a lot of our customers so they kind of – we always have guys near their drills for support and stuff, so they have a lot of trust in us…. We kind of explain that to them because we're – we're tracking this information for them. It's not for us.

Mining culture and attitudes also include the risk averse culture of the mining industry as a barrier. For instance, Newfoundland and Labrador Mining-Related Technology Company Representative 6 described the burden of proving their technology in a sector that is cautious about adopting innovative technologies:

One of the things is the mining industry is a slow technology adopter. They are resistant to change. They do they spend - they take a lot of risk on exploration and finding the resource. But when they go to process it, they're very resistant to change…So you have to go through this technology adoption process, trial and

> *error, demonstrate it... I mean, they are adopting AI, you know, with drones and all that kind of stuff on the exploration side, but on the mineral processing side it's…very traditional.*

Again, the impact of mining phase was raised in this context. It was suggested by Newfoundland and Labrador Mining Industry Expert 9, for example, that there is added risk when an operational mine wants to adopt a new technology because it could impact their profit margins. A mine that is in its exploration or development phases, on the other hand, might have more funding to put towards technology adoption/development. The issue of scale was thought to be relevant here too, with larger, multi-national companies having more human and economic capital to build on, allowing them to "de-risk" technologies:

> *In a bigger multinational company, they might have multiple sites around the world. And they can - they can see that technology, and you know, be sold on how it benefits, that value added that technology has…So, a large multinational can de-risk it a little bit because they have a larger portfolio… But a smaller player who might only have one or 2 mines. And all those mines are only going to be operational for 5 to 10 years. That's a big risk to tell them about this emerging technology that can disrupt.*

Interviewees did identify a trade-off in this issue of scale, however. Larger mining companies may have more capital and capacity to adopt new technologies, but bottom-up shifts could be challenging due to complex corporate structures as described by Newfoundland and Labrador Mining Company Representative 3:

> *I think, one of the big advantages that we have within [our multinational company], we can always look to the left and right in other business units and product groups. Most of them have done similar stuff before…There's a governance structure and typically corporate functions that help us in implementing these things.*
>
> *At the same time, when you're a large organization like this, it is difficult to change larger organizations compared to small organizations…The best is your mom-and-pop shop. You know, where the CEO is also the janitor, and you can just make changes very quickly. Whereas in a large organization, just the communication to bring people along on the journey and then also think about all the various scenarios and impacts, it makes it difficult.*

Another barrier for technology adoption and development was insufficient industry collaboration, particularly competition (4/7, 5%). Often this was discussed by small and medium-sized businesses who were competing with larger, more established (and often older) businesses. For example, Newfoundland and Labrador Mining-Related Technology Company Representative 4 described the challenge of competing with larger companies offering similar products/services:

> *Like, I think, another barrier… is we'll almost be like the first person to like introduce this space to a potential client. And then we'll be like, "Hey, these are things that you can do. These are the different ways you can do them", and they'll be like – it's almost like they have like an aha moment. So, then they are like, "Oh, I can actually go into Google and I can Google this." So, when they start googling this… all of a sudden, you're like looking at [our software] compared to this this big guy, you know, that can maybe do some of the things, you know. So, that's something that we have a little challenge with because they're like, "Okay, be right back. Let me go sniff around the market and find all of your competitors."*

A final barrier for technology development/adoption were implementation challenges (3/7, 42.8%). In NL, this challenge specifically referred to the adoption of technologies developed in warmer locations and/or adapting technologies to ensure they function in cold, northern weather conditions. Newfoundland and Labrador Mining-Related Technology Company Representative 2, for instance, described this challenge:

> *Stuff everything like most people would - most companies would face, such as competition, supply chain, the accessibility to certain goods, particularly during the pandemic. I mean other issues may have been related to like climates around the world. For example, lots of this stuff is being developed in Australia, where head office is located, and as you'd be aware that the climate is a little different down there than it is here in Canada, so implementing these technologies in the field in a true Canadian winter can definitely be a barrier compared to what they're tested in in a freezer in Australia.*

Newfoundland and Labrador Mining-Related Technology Company Representative 2 had developed a strategy to address this challenge, however, with their technologies developed abroad being tested at a facility in Northern Ontario.

2.5 Impacts on Regional Development

An important goal of this research was to identify impacts of technology adoption in the NL mining sector, especially for employment, skills and training (including on the number of jobs, the type of work available, locations of work, and any skills/training required for emerging employment options), business development (including mining business development and opportunities around procurement or servicing), and regional development (including infrastructure needs/opportunities, local spending, and policy/regulations).

2.5.1 *Employment, Skills, and Training*

Employment, skills and training were the theme discussed most often by interviewees with regards to regional development impacts. While all interviewees agreed that technology

adoption would have impacts in this area, not all interviewees agreed about the extents of those impacts. For instance, some interviewees expressed concerns about a net loss of jobs due to the adoption of automated equipment (26.3%), while others felt it was more likely that there would be no loss of jobs that are currently filled by people (26.3%). The latter group argued that the mining workforce is already aging and shrinking, meaning that many mining jobs currently go unfilled. New technology, in these circumstances, could help fill these gaps as described by Newfoundland and Labrador Mining Industry Expert 8:

> *You know, the workforce is a struggle for us here. And so, there's always gonna be a workforce issue. And you know, we've done a lot of thinking about as a community about, you know, how autonomous equipment affects us, and you know, certainly we hope that autonomous equipment makes a more profitable, bigger mine, as opposed to, you know, taking jobs away from the local economy. And I think so far, that's been held out - born out, you know. Certainly, there's more jobs here than there was before…there's jobs that can be done onsite, and there's jobs that can be done offsite, and you know…and I guess we will struggle, having enough people. So, the automation may be an advantage in a way, you know, to fill some of those jobs to keep us. Not saying that it will be, but it's easy to think about well, we're just gonna lose jobs. But at the end of the day we need, we still need to mine the ore and sell it and manufacture and do those things. So, if we don't, if we don't have the housing, then we don't have to grow the mine, you know. There's advantages to being able to fill some of those job, sometimes.*

Several interviewees also felt that new types of jobs will become available due to the adoption of technologies (52.6%). For instance, over time there would be fewer people working manual labour jobs underground and more skilled professional opportunities in remote operating centres. Linking back to discussions about changes in the number of jobs, several interviewees noted that, given the small and shrinking nature of mining industry, it was more likely that individuals occupying unskilled/manual jobs would be retrained in-house rather than lose their jobs. It was thought by some interviewees that these new skilled jobs might also be more fulfilling for employees, in the sense that they would find themselves doing less repetitive or monotonous work and would be working in safer environments. A few interviewees hoped that this shift in employment would also attract new employees to the sector, particularly younger generations who may have no interest in going underground but might be interested in controlling mining operations from a control room (likened to 'video games' by some). These thoughts are summarized by Newfoundland and Labrador Mining Industry expert 1:

> *You know, when I've seen automation happen and things like that, there hasn't been a huge reduction of employment. People are retrained to move on because it is a shrinking workforce in the mining sector, it's an aging workforce [and] is shrinking. The other thing we always look at too, is if you're doing a job that can be automated it's not a job you want to be doing. Right, isn't it, you know, if a machine can do what you can do. You're better off doing something else that involves the skill sets that make humans unique, right.*

All interviewees agreed that education and skills training opportunities would be needed both to tool new employees entering the mining workforce and to upskill existing employees to work with new technologies. As Newfoundland and Labrador Mining Industry Expert 2 discusses, training programs could be developed through partnerships between mining companies and educational institutions in NL. Short-term programs, like micro credentials, were expected to be preferred over more typical 2- and 4-year academic programs*:*

> *And I think a lot of industries because of where they're located, there are agreements with either municipal, provincial, or Indigenous governments, you know, for socioeconomic benefits, and for hiring people from within those communities within those provinces and those regions and using contractors and things like that. So, I think some of that need will be filled either by partnering with education institutions like Memorial [University]. You know, to have university-based training in those areas, or CNA [College of the North Atlantic] to have, you know, shorter technology training trades, evolving. Or it might even be, because of timelines, and so on, in-house training, and perhaps the growth of the organizations, maybe even partnerships with MUN or CNA to do in-house training rather than sort of, you know the longer term 2 to 4-year degree, or technology program. So. But I think, as these industries are getting more technological and the types of technology is changing, there will need to be more education and training to meet those needs.*

Mines in Labrador had already built partnerships with educational institutions, like the College of the North Atlantic and the Engineering Department of Memorial University, to offer education and skills training programs. These programs were coupled with in-house training opportunities provided by mines and/or technology providers at the mine site, allowing for operators to be trained to use specific technologies as described by Newfoundland and Labrador Mining Company Representative 3:

> *So, we're working together with a couple of institutions…and they are helping us to upskill our maintenance workers, mostly electricians, by providing courses just in instrumentation, automation, and so forth. Just basic, let's say, engineering technology skills sets that go beyond the red seal electrical education…And this is stuff that, let's say, the regular electrician doesn't come across and doesn't necessarily know from day one. They eventually would also be pulled along and educated, but it's good to have, like, a formal school type of education. …*
>
> *…with the drills, there are very few off-the-shelf trainings that we can say, "Okay, you follow that training, and then we can put you in the seat". As I said before, similar to the college training that they offer for the MOE 2s, they can provide sort of the, the underlying layer of understanding of the technology and so forth. But then, when it comes to the specifics… we need to have an additional training both theoretical training as well as on-the-job training aspect that we have to*

supply and provide. Because especially these technology solutions that I've been talking about here today, they are so custom. There's no one off the shelf.

It is expected that more training programs will be needed in the future to accommodate new technologies as they are adopted, though few specific examples were provided. One example mentioned by Newfoundland and Labrador Mining Industry Expert 5 was that with increased interest in the production of green minerals, like green steel and green copper, education institutions might consider training programs in the installation and maintenance of solar, wind, or other renewable technologies:

> *The biggest challenges right now, I guess, for technology, you know, being adopted and implemented for us – well one of the stark ones is skilled trades. You know, I don't know regionally, provincially, or even nationally, are we ready for it? You know, and mining in particular is – mining has a big player in the green future and any types of future. [Laughs] solar panels, windmills, batteries…you know, that's jobs in my industry. That's a net growth. So, do we have the skilled trades to do it?*

Another suggestion, made by Newfoundland and Labrador Mining Company Representative 3, was to consider broader education opportunities covering topics like automation and instrumentation (including high-precision GPS), control systems (include programmable logic controllers), communications (network wireless radios and systems), and data analytics. These knowledge areas might be useful for training operators to use autonomous equipment, for example.

2.5.2 *Business Development*

Over the course of this research several new, small businesses emerged in NL making use of disruptive technologies, such as AI. Several (though not all) of these technology companies supported mining companies during their exploration phase as opposed to their operations phase. Industry Expert 9 explained that mining companies can be more willing to spend money on technology supports during their exploration phase, especially if that technology allows them to become operational sooner. Newfoundland and Labrador Mining Industry Expert 9 thought this might explain the prevalence of newer technology companies supporting exploration efforts in NL:

> *In an exploration, [it is all] about spending money. And so, you want to find your resource as quick as possible. So, the adoption of technology, cause you're spending money anyways, so adopt up that technology that helps you. Be it surveying equipment, Lidar, whatever it is that helps you find that nugget quicker and easier. You know, to reduce it from a 3-year exploration program to a one-year exploration program. They're more willing to spend money on new technology that they can then turn around and start making money quicker. Because, you know, standard economics.*

A few existing service companies were also found to be incorporating technologies into their service offerings, like drones as described by Newfoundland and Labrador Mining-Related Technology Company 4:

> *And then there's this consulting company called [name redacted]. They're one of our partners. They do all sorts of stuff. So, they seem to really work alongside mining. So, they have a lot of big mining clients. They do everything from like geo-mapping to like marketing. They really touch a bunch of the space but they're not just mining specific.*

Most of the clients of technology companies were mines in their operations phase (5/6, 94.9%). Two of these technology companies were developed and based in NL, 2 were developed in NL with offices within and outside of the province, 1 was a global firm with a local office in NL, and the other was a global firm with an office based out of province. Several of the technology companies interviewed offered services related to drilling (i.e., water recovery, tool handling, drill bits, precision drilling, etc.).

In addition to disruptive technologies, new business opportunities were being sought out in the value-added and/or circular economy space, such as mining minerals from waste tailings/waste streams. As discussed earlier, business development that pursued environmental and social responsibility was thought to be an economic opportunity for mines in the future, as consumers continue to demand transparency through the value chain. This includes producing green steel and green copper.

Interviewees regarded the opportunities afforded by new technologies as important for mining business development and for local economies. For example, Newfoundland and Labrador Mining Company Representative 1 described how diversifying a mine's revenue streams could result in more jobs and a more stable economy for local communities:

> *…the manganese tailing that we're removing from the ore, because of these machines, now becomes very attractive because…manganese has been identified as one of the critical minerals in Canada and the province…that would mean millions and millions of dollars to the local economy. More, it would be more employment.*

Maintenance of new technologies were mentioned by a couple of interviewees as a possible avenue for further business development; however, it was not discussed as often as the themes presented above. Several technology companies reported offering servicing and/or training alongside their technology products which may account, in part, for this gap.

2.5.3 *Regional Development*

It was thought that the impacts of new technologies for mining communities and regions could be quite positive if corporate community benefit agreements, impact benefit agreements, or company-community partnerships were in place to ensure those benefits. For example, Newfoundland and Labrador Mining Industry Expert 3 pointed to Innu-Inuit Envest as an example of a corporate-community partnership that would benefit both the Voisey's Bay mine site and nearby Indigenous communities through the production of wind energy:

> *Yeah, I mean, the Voisey's Bay development is being done in partnership with the Innu and Inuit. So, they're actually an Innu- Inuit owned company that is building and operating the wind turbines, selling the power to Voisey's. So, there's an opportunity, I guess, post-mining that that power might, if the windmills are still functional, that power might be available to nearby communities. Similarly, if you know, infrastructure was built to supply hydropower to the site, it's an opportunity to also supply hydro power to the communities on the way.*

Given the demand for critical minerals, some interviewees felt NL might see smaller mines develop with shorter mine lives in the future. New drilling technologies could lessen the environmental footprint of these mines, which was thought to be a benefit; a possible trade-off, however, would be relying on FIFO employment over local employment as described by Newfoundland and Labrador Mining Industry Expert 2:

> *You know…these technologies and these new emerging sort of targets for mining, sort of critical minerals and things like that - there's potential to have more and perhaps even smaller scale deposits being developed that wouldn't have been developed before, you know. Not everything is a Voisey's Bay or an IOC with, you know, a forty-year mine life. So, a lot of these smaller deposits you go in, you know, with a mobile workforce. Do the extraction for 5 or 6 years [and] you leave a small environmental footprint. But there is potentially - a lot of potential for the benefits, I think, in Northern communities, and areas.*

Interviewees weighed the challenges and opportunities presented by remote operations for communities as well. On the one hand, you might see less intensive, smaller-scale mining operations with minimal impact on local environments (when compared to traditional mining). On the other hand, concerns were expressed about the negative impact on local communities if remote operating centres were based out-of-region or even out-of-province in the future as described by Newfoundland and Labrador Mining Industry Expert 3:

> *…when they initially started talking about it, you know, government had the concern that you know a control center to control operations in Lab West should be in Lab West and not in Sept Iles or Quebec or Montreal, or wherever. So that's always a concern when you get into remote control, but you, know the province wants its resources to benefit its people. So, exporting jobs and good jobs to*

another jurisdiction wouldn't be here would be something [the provincial government] would object to.

It was suggested by a few interviewees that repurposing mine tailings could benefit mining communities. This was because an industrial landscape in the community that might have been seen as a hazard could, with the use of new technologies, be reimagined as an economic asset. As described by Newfoundland and Labrador Mining-Related Technology Company Representative 6, thinking about these value-added and circular economy opportunities and building businesses to support them could also help communities. This includes by growing employment opportunities, generating alternate revenue and/or employment streams (i.e., circular economy), and providing a bit of stability for local economies impacted by boom/bust cycles.

...but it's important that social license part of. It is extremely important that the community is at the table, you know…. communities have been so negatively impacted by boom, bust cycles or environmental waste that's left behind and in resource extraction industry. So, this is one of the - let's call it community reconciliation. Where the community can benefit from this.

Several interviewees mentioned that, in rural and remote regions, new technologies that allowed mines to remain viable would support regional development in that jobs would be available that might not be otherwise. In other words, community sustainability was tied to the ability of mines to operate as described by Newfoundland and Labrador Mining Industry Expert 4:

If it provides a longer term, more stable mining operation in a region or community. If that's of interest because of the technology, then that's to the benefit of everybody, because that economic impact and benefits is going to continue without…so if [a technology] can de-risk a mining operation that means it's going to increase the value of that wealth generation in the community. Cause it's gonna be operating, right?

This dependence is a trade-off for communities, however, given the challenges presented by boom-bust cycles in natural resource sectors. But, maintaining the viability of mines in NL was a key theme emerging from these interviews, perhaps because so few mines in NL have remained consistently operational in the past several decades.

2.6 Responses to Regional Development Impacts

Organizations in NL have responded to the impacts of technology mainly through education and training programs, as well as outreach/connector activities. Response organizations in NL include mining companies (private sector), educational institutions, the mining industry association, non-profit organizations, and some technology companies.

For example, mining companies in Labrador reported collaborating with educational institutions and non-profit organizations to offer some training and upskilling programs. Mining companies were also upskilling their employees in-house, together with educational institutions and/or with technology companies whose products they adopted, as described by Newfoundland and Labrador Mining Industry Expert 5:

> *…we know the electricians are one of the key components into the future. So, that was one of the ones that was easy for us - an easy one to target and get ahead of the game. Instead of what happened with the drills, with us being behind the 8-ball on it and, you know, the technology advancing and we not having the skillset. We're taking a bit more of a proactive approach with [training] the electricians. So, the – the company and the College of the North Atlantic have gotten to a partnership and what they've done is they've developed a program... And basically, these are the skillsets that we're going to need, some of them now but a lot of them these are future ones, you know, dealing with PLCs and, you know, other different types of logic programming and, you know, these types of interfaces.*

Mining companies were also actively mobilizing knowledge about their technologies in order to attract new employees, build interest among youth, and be transparent about the role technology plays in optimizing/sustaining their operations. Non-profit organizations as well as regional Chambers of Commerce had facilitated connections through mining connector/conference events and youth outreach programs, as described by Newfoundland and Labrador Mining Company Representative 2. Some had also brokered connections between mining and other industries that require similar technology-related education/training and/or workforce needs/gaps (i.e. oil and gas, healthcare).

> *We believe that we need to encourage…the younger generation to come into mining. And to also try and paint the picture that, you know, when you ask up anyone "what is mining?" the first thing they think of is the hard hat, helmet and the hammer, and the shovel, and hard physical work. And you're trying to say, "I think the industry is gonna change". It is changing into a much smarter environment where young people can actually thrive.*
>
> *For your information we actually, at MineX in Gander next week, we will focus a lot on the youth which is taking place there. And I think we're also gonna…be exhibiting, talking to young people as well. And there's another one in… May, June, early June in Baie Verte. Which again, the focus is just to try and encourage the younger generations to…come up and take up mining roles in the future.*

An overview of the educational programs and outreach activities identified in NL can be found in Table 5.

Table 5: Responses to Technology Adoption in NL

Program	Lead Organization	Scale	Description
Future Workforce Program	College of the North Atlantic, Iron Ore Company of Canada	Regional (Labrador)	A training program to upskill maintenance electricians in mining technology advancements.
Customized and continuous learning	College of the North Atlantic, Vale	Regional (Labrador)	A training program for entry-level applicants to Vale's nickel mine in Labrador.
Indigenous training and skills development	Labrador Aboriginal Training Partnership	Regional (Labrador)	A training program with Vale (specifically for Indigenous applicants) to train employees for Vale's mine expansion project.
Underground mining simulator	College of the North Atlantic	Regional (Labrador)	An underground mining training simulator is housed at CNA in Happy Valley-Goose Bay to support hands-on training.
Find Your Future in Tech	TechNL	Provincial	A federally-funded program intended to support technology-related upskilling in several sectors, including mining, The program ended in March 2025.
High School Tech Immersion Program	TechNL	Provincial	A program allowing high school students to explore technology careers in various sectors, including mining.
Mining Tech Market **(2023, 2024)**	TechNL	Provincial	An event where mining technology companies could pitch their service/solution to mining sector representatives.
Mining youth career fair**, "Young Minds in Mining" (2023)**	Maritime Resources Corp.	Regional (Central Newfoundland)	An event hosted in Central Newfoundland, intended to mobilize knowledge about careers in mining among high school students.
Central MinEx	Gander & Area Chamber of Commerce, Town of Gander	Regional (Central Newfoundland)	An annual mining conference hosted in Central Newfoundland.
Labrador MineX	Labrador West Chamber of Commerce	Regional (Labrador)	An annual mining conference hosted in Labrador West.

Mineral Resources Review	CIM Newfoundland and Labrador Branch	Provincial	An annual mining conference hosted in St. John's, NL.
Expo Labrador	Labrador North Chamber of Commerce	Regional (Labrador)	An annual economic development conference hosted in Central/Northern Labrador.
Prospectors and Developers Association of Canada (PDAC) Conference	Prospectors and Developers Association of Canada	National	An annual mining conference hosted in Toronto, ON.

Source: Created by authors

2.7 COVID-19 & Mining Technology Adoption

When asked about the impacts of Covid-19 on technology adoption, opinions were mixed. While some key informants felt there was minimal impact on the mining industry, (21.1%, 4/19), most identified impacts on workforce (57.9%, 11/19) and some identified supply chain impacts (21.1%, 4/19). Workforce impacts included challenges accessing fly-in/fly-out contractors and/or workers with specialized skillsets. For instance, Newfoundland and Labrador Mining Industry Expert 4 stated: "*…in Lab City, for instance, a lot of the contract…maintenance on the, you know, on the processing plants. That's fly in and fly out work specialists coming in. IOC did defer one year's worth of that type of work just to reduce the risk to the community*."

It also included increased adoption/acceptance of remote work and communication technologies (i.e. conferencing software). For example, according to Newfoundland and Labrador Mining-Related Technology Company 5:

> *I don't know if it's specific to mining. I think we've seen remote work - there's been like such a push towards remote work. Mining definitely was not a big adopter of remote work pre-COVID. Whereas post-COVID when I remember… I was up at IOC when COVID hit. We were one of the last people out because we were shutting down a big project. And up until then, everyone worked on site. There was no other options. And then after that, then we started to do all our project planning remotely. We all went home. Did all of our project planning remotely and then people started to say, "yeah, like, in a lot of ways this is more efficient".*

Supply chain impacts included delays in receiving mechanical parts, fuel, lubricants, and other products, as well as increased interest in producing value-added products locally/within Canada

rather than shipping raw materials for processing elsewhere. For instance, Newfoundland and Labrador Mining Industry Expert 2 noted:

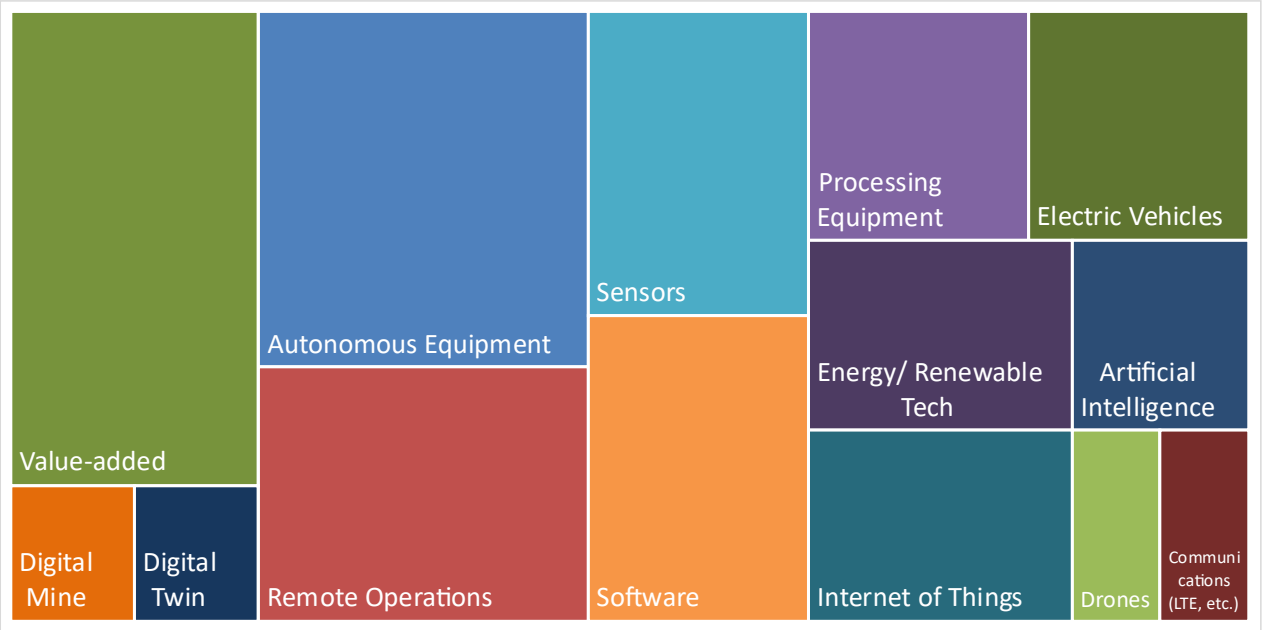
> *But the bigger impact was on supply chains. And we're so we're still seeing that now I mean transportation ground to a halt. Manufacturing in some places reduced. So, at the end of the day the reliance on rapidly getting products and fuel in, or, you know, spare parts. Things like that, that impacted negatively on mining. We're emerging from that now, but I think at the end of the day the fact that you can no longer rely on parts coming out of China or out of other countries where they had to be shipped, you know, great distances. I think that that's made organizations and countries look again at, you know, maybe the world as a large - one, big warehouse is not probably the best solution… which would actually improve value-added industries in places like in Canada, where - not only where the raw materials come from, but the energy is available and things like that.*

Among technology companies, just one reported being delayed in their product/service development due to Covid-19. The longer-term impacts of the pandemic on technology adoption in the mining sector are unclear. Two key informants suggested that the challenge of accessing fly-in/fly-out may have highlighted the value of upskilling local workforces rather than relying on individuals from elsewhere/abroad (Newfoundland and Labrador Mining Industry Expert 3, Newfoundland and Labrador Mining Industry Expert 5). Two key informants suggested the pandemic may have also highlighted the value of mines having remote operating capabilities (Newfoundland and Labrador Mining Industry Expert 7, Newfoundland and Labrador Mining-Related Technology Company Representative 5).

3 Future Considerations

In the next five years, industry experts and mining company representatives felt that autonomous equipment (10/19, 52.6%) would continue to be the top technology being adopted in the NL mining sector (see Figure 3). Discussions included wider adoption of autonomous drills, autonomous and remotely operated valves/chutes, as well as the adoption of larger equipment like autonomous haul trucks (currently not in use in NL). For instance, Newfoundland and Labrador Mining Industry Expert 07 notes: *"So automated haul trucks and just automated vehicles are definitely a huge thing that we're watching."*

Figure 3: Top Technologies in the Next 5 Years (NL)



Source: Created by authors

Remote operations were also cited as a top future technology (7/19, 36.8%) closely linked to the adoption of autonomous technologies, as described by Newfoundland and Labrador Mining Company Representative 2:

> *…remote monitoring and remote mining capabilities. …how do we use the… the ease of connectivity to do what we call remote mining. The way we create remote mining hubs. Well, what I mean by that is that conventionally we always used to have miners, which were unfortunately predominantly were men. And they'll go underground and physically drive the equipment and everything else. Where the world is moving and the way everybody else is moving is to say you don't need to be underground to operate a truck. You don't need to be underground to operate the scoop which works underground with drill, whatever it is. That can actually be done remotely through hubs and stuff like that. We're starting to look at and say, how do we incorporate that into our future mine? Because that is a whole lot of other things downstream from the skills perspective. We can attract more people. And people don't have to come to the mine to work.*

Newfoundland and Labrador Mining Company Representative 03 described that, eventually, they would like to see remote operations evolve into integrated operations where the system is able to generate recommendations/strategic decision options for operators:

> *Today, most of those decisions are being made by people. In the future, we want a system that can support the people by suggesting these things…This can save a lot of time and doesn't require that our people have 30 years of experience in the seat, you know. You, you continue to take this tribal knowledge and put it in the system…We want a system that has an intelligence based on data and on predefined strategies. So that's one example [where this technology can be used], planned care. Another example is…I'll call it our Odyssey 2000. Where you have - we have an operation that is not only monitored but controlled by artificial intelligence. It makes decisions for us. Those decisions might be, "Okay, autonomous drill 123, we take you out for maintenance because we don't need you in the, in this week". Today, these decisions are made by humans. Tomorrow, I want a system to understand what happens to our, to our fixed plans, to our railway, to our shipping condition, and to our customer, eventually. What happens if I take that, that drill out? Because today we don't fully understand the impact of such decisions that are made on a smaller scale.*

Finally, industry experts and mining companies identified value-added technologies and/or processes that would allow them to diversify a mine's product base and move towards "zero-waste mining" as a top technology trend in the next five years (5/19, 26.3%). Value-added processes could, for instance, allow a mine to diversify its revenue base by separating critical minerals from waste tailings or could allow a mine to process raw ore before it was sold as described by Newfoundland and Labrador Mining Industry Expert 2:

> *I think, with the growth of extractive industries it's gonna be growth of downstream value-added industries as well. So rather than just take the lithium, take the rare earth elements, you know, to make batteries or to make magnets, or to ship out the raw metals. I think there's an emphasis on exporting value-added product, so instead of exporting lithium ore or lithium concentrate, export, actual lithium batteries or rare earth element magnet assemblies, and you know the things go with that.*

It is expected that mining companies in NL will continue to adopt new technologies to improve their efficiency/productivity and extraction and/processing, to pursue sustainable mineral production opportunities, and to improve worker safety. A significant question that remains, however, is what skills and/or training programs should be offered in the province to accommodate those needs. Training programs around the installation and maintenance of renewable energy technologies were one suggestion (Industry Expert 5). Newfoundland and Labrador Mining Company Representative 3 also identified higher-level areas where skills-building may be needed: automation and autonomy, instrumentation (including high-precision GPS), control systems (include programmable logic controllers), communications (network wireless radios and systems), and data analytics.

Newfoundland and Labrador Mining Industry Expert 10 suggested that a skills-gap assessment would be a logical next step to build a fuller understanding of training programs/opportunities that are needed in NL. Part of that skills-gap assessment might be identifying organizations best to lead or build on identified opportunities for workforce and skills development, whether they be educational institutions, non-profit organizations, or others. It may also include looking to education/skills training utilized in like-minded industries when it comes to technology adoption, such as oil and gas.

It was also suggested that future technology adoption in NL might be hampered by the infrastructure barriers noted earlier in this report. Without reliable access to electricity, the adoption of electric equipment will be less feasible, for example. Without wireless connectivity, remote and autonomous operations will be similarly constrained. Communities also reported some impacts related to these infrastructure challenges. For example, data mining and storage was an emerging interest in some Labrador communities due to the cool climate; however, access to electricity has impacted its feasibility. Considering possibilities for collaborative community infrastructure projects to address these energy needs may be fruitful, as with Innu-Inuit Envest in Voisey's Bay.

As new mining technologies are adopted in NL it may be beneficial to look to other regions where they have already been implemented to assess opportunities and challenges. For instance, the wider adoption of electric vehicles in Northern Ontario mines has spurred discussions around safety that are not relevant to the NL context yet but may be in the future (e.g. managing electric battery fires). It was noted by some interview participants that knowledge-sharing around technologies is not common between mining companies, but that opportunities to support this could be beneficial as it may support mutual learning and collaborative problem solving within the sector.

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