Canada's

VENTURES TO VALUE CHAINS

MINING TECHNOLOGY

OCTOBER 2023

FORESIGHT
CANADA

Foresight is Canada's cleantech accelerator.

We bring together innovators, industry, investors, government, and academia to address today's most urgent climate issues and support a global transition to a green economy.

ABOUT

ACKNOWLEDGEMENTS

Foresight acknowledges that the lands on which we conducted this work are the traditional, ancestral, and unceded territories of the xwməθkwəy̓əm (Musqueam), Sḵwx̱wú7mesh (Squamish), and səlilwətaɬ (Tsleil-Waututh) Nations.

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BC NET ZERO
INNOVATION NETWORK

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INTRODUCTION

CANADA HAS A STRONG AND WELL-ESTABLISHED MINING SECTOR

MINING CONTRIBUTES APPROXIMATELY 5% OF THE COUNTRY'S GDP,

21% OF CANADA'S TOTAL DOMESTIC EXPORTS, AND CANADA IS KNOWN INTERNATIONALLY AS A LEADING PRODUCER OF MINERALS AND METALS. [1]

Canada is also recognized globally as a leader in **low-carbon mining**, [2] a key producer of **critical minerals** [3] to support the green economy, and a leader in **technological innovation**. [4] Canada's strength in these spaces has been supported by a wide network of collaborative organizations, research institutions, government initiatives, and industry collaborations.

As the industry faces increasing pressure to reduce its environmental footprint, innovative technologies that improve efficiency, reduce greenhouse gas (GHG) emissions, reduce and manage waste, and reduce the impact of extraction on ecosystems and biodiversity will play an important role.

Canada's operational ecosystem is generally well understood. [5] However, our knowledge of strengths, gaps, and areas of opportunity in the national mining technology innovation ecosystem across the value chain remains fragmented. Mining technology is critical to developing and operating mines and processing facilities. Understanding the landscape of mining innovation in Canada while painting a picture of mining technology across the value chain is an important step toward growing both its market share and impact.

By growing Canadian expertise at every point along the critical mineral value chain — from mining to manufacturing to recycling — we will create good jobs, build a strong, globally competitive Canadian economy, and take real action to fight climate change.

- Government of Canada, Canadian Critical Minerals Strategy [3]

RATIONALE

VENTURES TO VALUE CHAINS

is a Foresight initiative that leverages data from technology companies and other key stakeholders to map and categorize strategically important industry value chains for Canada in the clean economy.

This initiative will result in a searchable database, which can be used as a tool to inform stakeholders on Canada's competitive strengths, ecosystem gaps, and areas of opportunity and growth. These insights can identify where targeted programming, research and development, or funding will bolster Canada's leadership and economic development as we transition to a net zero economy.

MINING TECH: THE VALUE CHAIN

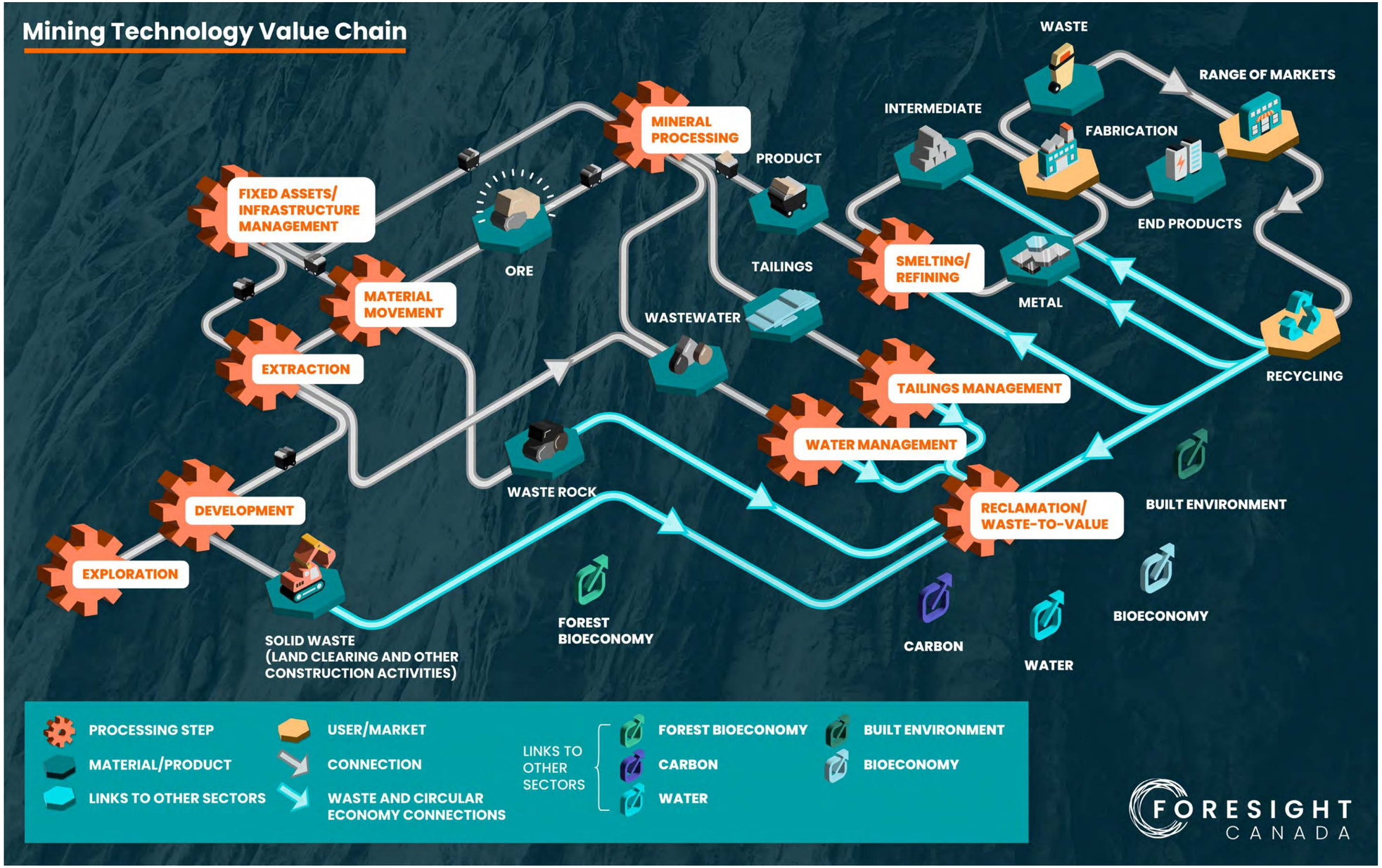


Figure 1
Value Chain

THE MINING TECH VALUE CHAIN (Figure 1)

describes key steps from exploration to smelting and refining by outlining a series of processing steps [1] and inputs and outputs along the value chain.

[1] While these are labelled as processing steps for the purposes of the value chain, they include processing activities (e.g., mineral processing, smelting/refining) and other types of actions within the value chain (e.g., extraction, material movement). For definitions of each of the processing steps, see Appendix A.

The operations section of the value chain is presented in the most granular detail as it represents the life of the operating mine and the steps that typically occur onsite. It includes:

- Key production and mineral processing activities (extraction, material movement, and mineral processing)
- Support systems and infrastructure management (covered in the fixed assets and infrastructure management category)
- Waste and water management (water management, tailings management, and reclamation / waste-to-value)

The mapping ends at smelting and refining, as that is the point where minerals will enter other markets. Fabrication, however, is included as a reference point.

This value chain is also intended to highlight how multiple waste streams can contribute to the circular economy. Companies that recover value from these varied waste streams are therefore all assigned to the reclamation / waste-to-value step to show overall waste-to-value trends.

Because the mining sector touches on many others, this value chain also identifies areas where there are overlaps with other sectoral value chains that Foresight is mapping. These are not intended to be an exhaustive list of sectors that intersect with mining.

METHODOLOGY

This research was conducted by mapping the mining technology ecosystem, categorizing companies based on the processing steps outlined in the value chain, and analyzing how the companies were distributed across the value chain.

The mining ecosystem database comprises technology companies, enablers, and knowledge generators. The value chain mapping and analysis focused on the companies, which were included based on the following criteria:

- Are involved in mining technology innovation, research, and development
- Are headquartered in Canada or have a strong Canadian presence in mining technology innovation, research, and development
- Have a valid website

Companies were categorized to up to three value chain steps based on their innovation focus then analyzed to identify both regional and national trends. Keywords, functional classifications, notes, and secondary research were also used to provide additional context to the trends.[2] Because the data can only indicate clustering and concentrations, and not why trends exist, observations are communicated as:

- **Areas of strength:** Areas where the data and supporting research suggests that the mining technology sector is doing well and should continue to support.
- **Opportunities:** Areas where the data and supporting research suggests that there is an opportunity to grow, either because of minimal or uneven concentrations or because it is an area that can help meet the growing need for sustainable solutions.

See Appendix B for a more detailed methodology.

[2]The key functional classification used to better distinguish within categories was based on the climate adaptation technology (CAT) framing and taxonomy, which is the intellectual property of Mazarine Ventures LLC, available to all under the Creative Commons (CC) license. It distinguishes between technologies that address (effect change), analyze (interpret, understand trends), and observe (measure and monitor).

CANADA'S MINING TECH COMPANIES

Overall, the Canadian mining technology ecosystem covers all value chain steps but is most concentrated in the categories that represent core operational activities (Figure 2). Companies included in the database represent a wide range of sizes and levels of maturity.

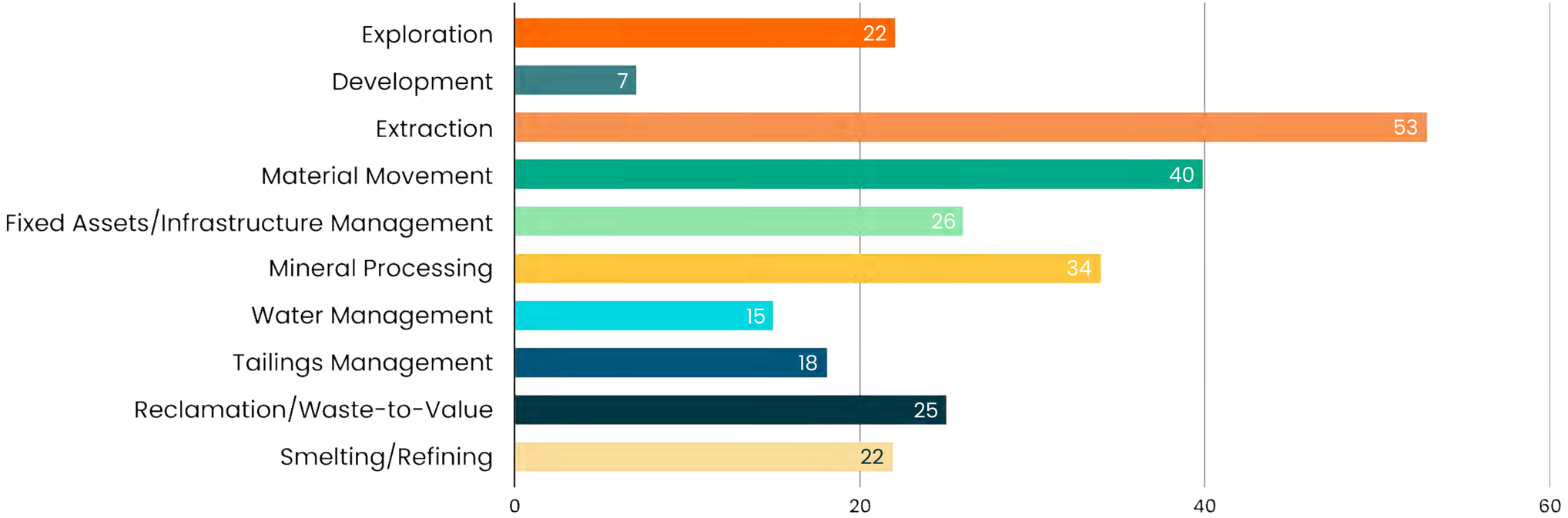


Figure 2 Distribution of Canadian Mining Technology Across the Value Chain

170 companies are assigned to this value chain.[3]

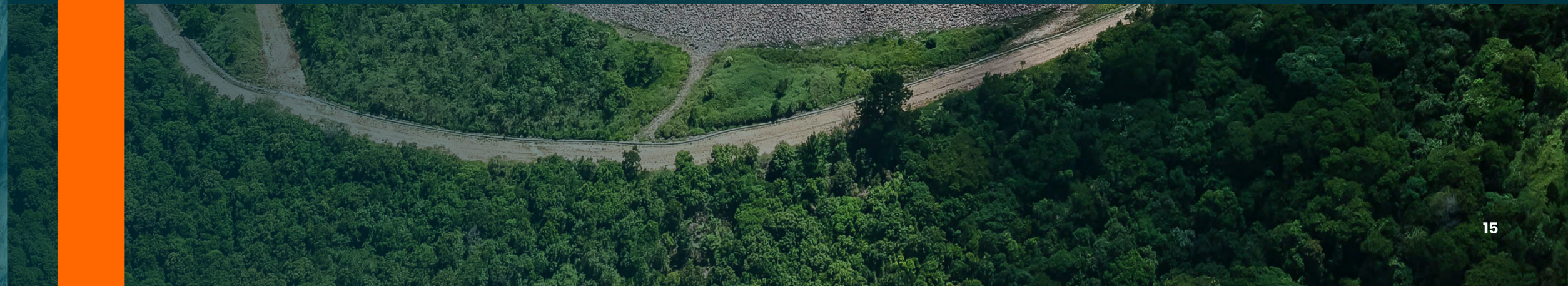
THE TOP THREE CATEGORIES ARE FOCUSED ON THE CORE OPERATIONS ONSITE:

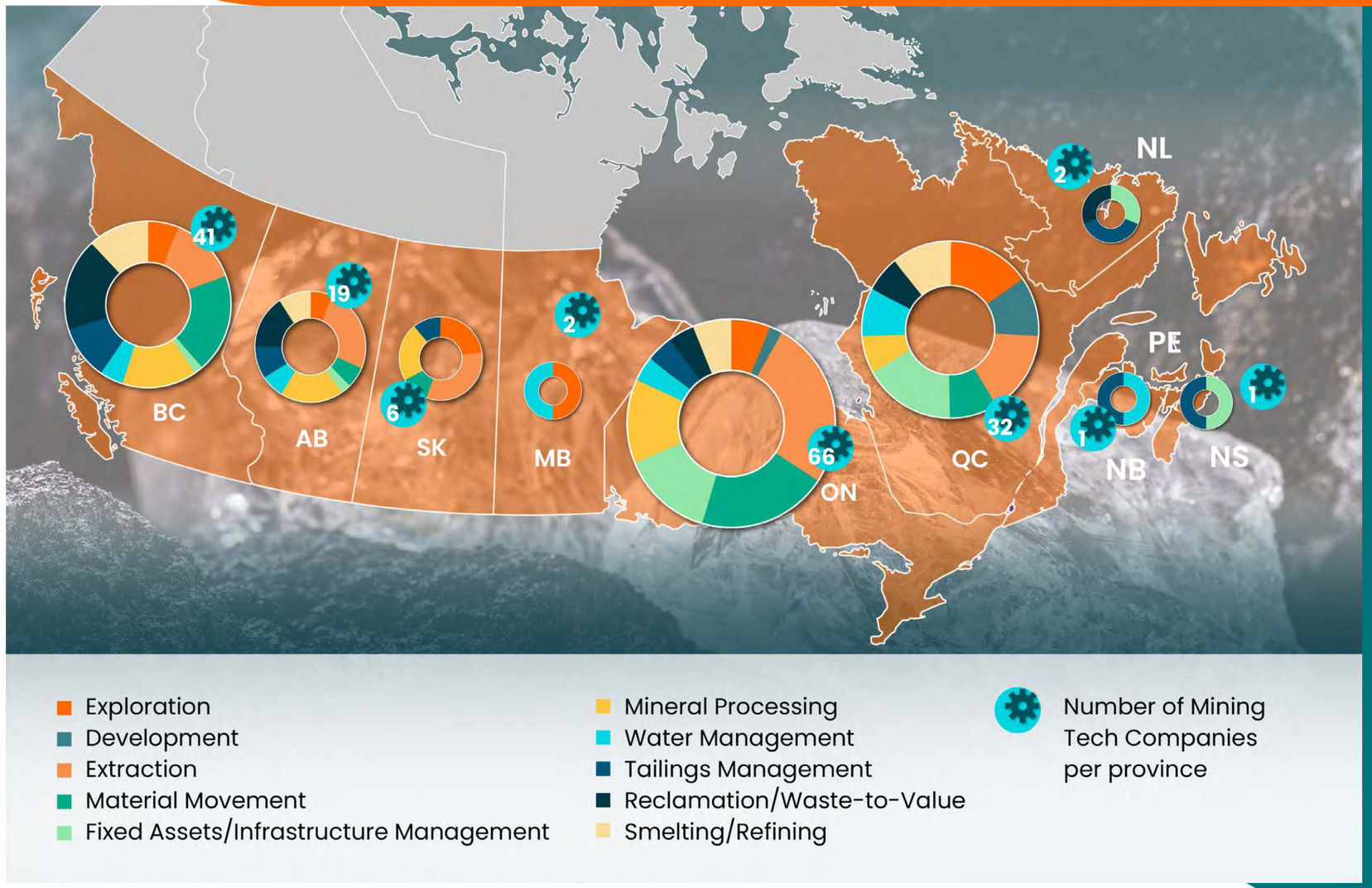
- Extraction: **53** companies
- Material movement: **40** companies
- Mineral processing: **34** companies

[3] One methodological factor that limits the scope of the database is the inclusion of only companies with a prominent mining focus in order to avoid overwhelming certain categories with highly generalized technology companies. The criteria used was that mining had to be one of less than five industries listed or a clear focus indicated by the prominence of mining in another way such as case studies, content, or customer lists. Many technologies used along the value chain aren't necessarily specific to mining. The development, water management, and reclamation piece of the reclamation/waste-to-value value chain steps are likely the most affected.

DEEP DIVE:
PROVINCIAL AND REGIONAL TRENDS

This section covers key provincial and regional trends to identify some ways in which different types of mining technology innovation are distributed across the country and consider the factors that might contribute to them.





SUMMARY:

- Ontario (**66**), British Columbia (**41**), and Quebec (**32**) are the most represented.
- Key provincial strengths include **reclamation / waste-to-value** in British Columbia, **underground mining** in Ontario, and a small cluster of **lithium extraction** in Alberta.
- **Over half** of the companies in the database are in Canada's three largest cities, with clustering in artificial intelligence (AI) innovation. There is also an important cluster in the **Sudbury/North Bay** region, with a focus on operational innovation.

Figure 3

Canada's mining technology companies by province

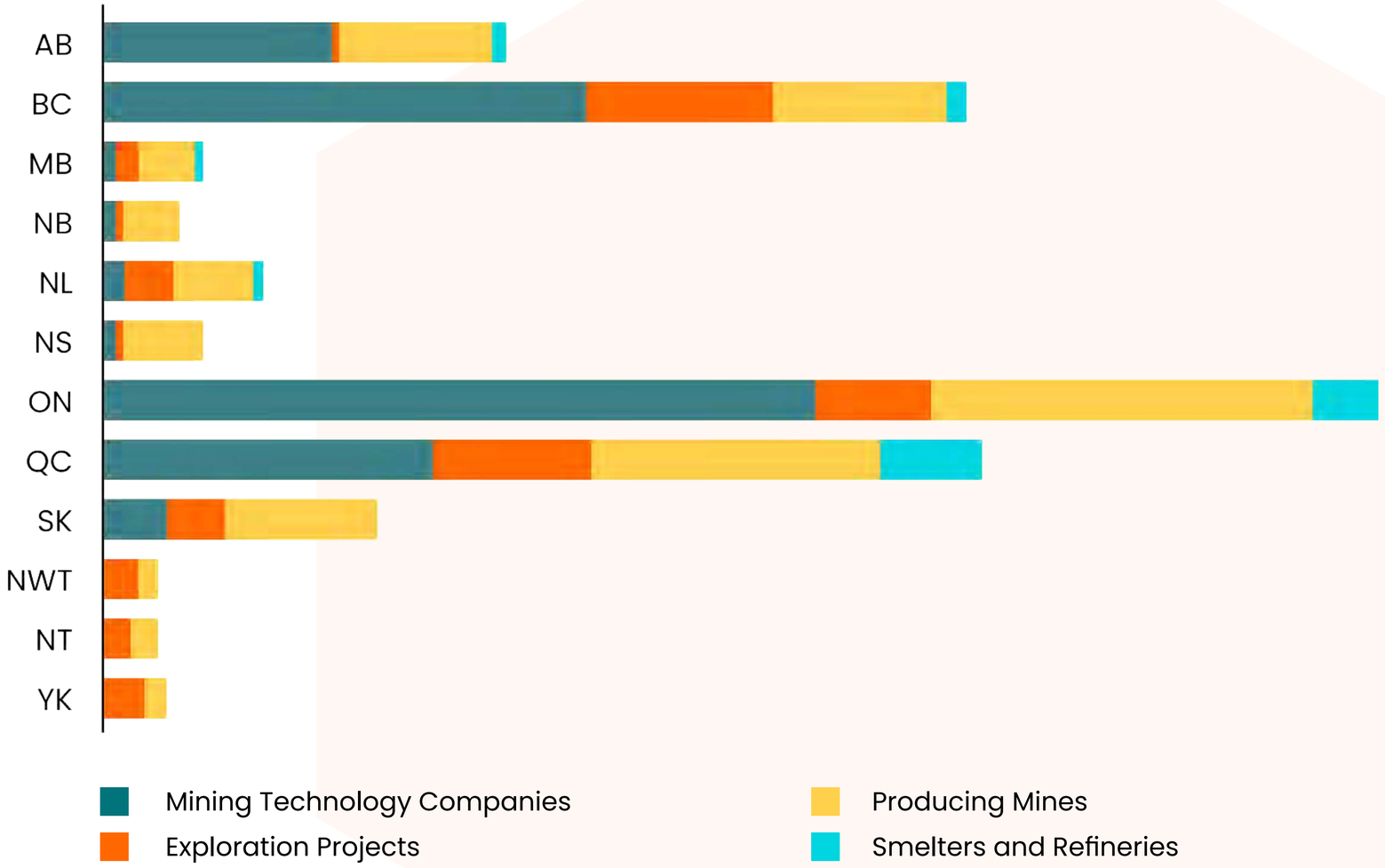


Figure 4 shows the number of mining technology companies alongside exploration projects, producing mines, and smelters and refineries in each province and territory. It highlights two key factors that inform the mining technology companies' distribution:

- **Proximity to important mining regions:** For example, the top three provinces in mining technology are also the top three in terms of total value of mineral production [6] and number of top exploration projects, producing mines, and smelters and refineries. [7,8]
- **Population:** The less populated provinces and territories have a smaller proportion of mining technology companies (if any) compared to their other mining activity.

Other factors also affect the distribution (e.g., the adjacent oil and gas industry in Alberta). Further, many of the companies, even if headquartered in one of the more densely populated regions, serve other provinces and territories.

Figure 4

Mining Technology Companies, Exploration Projects, Producing Mines, and Smelters and Refineries in Canada. Additional information is sourced Natural Resources Canada's Principal Mineral Areas, Producing Mines, and Oil and Gas Fields and Top 100 Exploration Projects datasets both licensed under the Open Government License – Canada.

KEY PROVINCIAL TRENDS

Overall, the provincial trend distribution is generally consistent with known focuses and activities within the province. The key trends suggest that the mining context and needs, emerging economic opportunities, and broader provincial strengths are likely key drivers of innovation.

OBSERVATIONS

MOST TECHNOLOGIES SPECIFIC TO UNDERGROUND MINING ARE IN ONTARIO, THE REST ARE IN QUÉBEC.

UNDERGROUND MINING IS ALSO A LIKELY CONTRIBUTOR TO SPECIFIC AREAS OF STRENGTH IN ONTARIO AND QUÉBEC:

- Significantly higher concentrations of fixed assets / infrastructure management than in other provinces
- Electrification keyword is concentrated in Ontario, and to a lesser extent, Quebec

SUPPORTING DATA

Underground keyword (**16** nationally)
ON: **13**
QC: **three**

Fixed assets / infrastructure management (**26** nationally)
ON: **14**
QC: **eight**

Electrification keyword (**15** nationally)
ON: **eight**
QC: **three**

DISCUSSION

Ontario and Québec are prominent underground mining regions. Ontario has the largest number of producing underground mines in Canada and Québec the second largest.[4]

While the underground classification in the dataset was only assigned to those that marketed themselves as exclusively serving underground mining, some other key innovation trends can also be tied to the underground context:

- **Fixed assets / infrastructure management:** Key technologies covered in this category include communications and connectivity, personnel and asset tracking, and ventilation and air quality control, which are key challenges in underground mining. [9,10]
- **Electrification:** Battery electric vehicles (BEVs) can make mining at greater depths more economically viable and reduce the presence of GHG emissions and dangerous diesel particulate matter in underground mines. The strong business case and several practical factors such as smaller vehicles contribute to a higher maturity of BEV technology and adoption in underground mining compared to surface mining. [11]

Innovative technologies such as BEVs are recognized as playing an essential role in enabling companies to create safer underground working environments and adapt to progressively tightening air quality regulations (e.g., the recent update to Ontario's diesel exposure limits). [12]

[4] Based on data sourced from Natural Resources Canada's Principal Mineral Areas, Producing Mines, and Oil and Gas Fields (900A) dataset under the Open Government License - Canada.

OBSERVATIONS

RECLAMATION / WASTE-TO-VALUE IS AN AREA OF STRENGTH IN BRITISH COLUMBIA, AND TO A LESSER EXTENT, ALBERTA.

THERE IS A SMALL CLUSTER OF LITHIUM EXTRACTION TECHNOLOGIES IN ALBERTA.

BRITISH COLUMBIA HAS THE HIGHEST CONCENTRATION OF TAILINGS MANAGEMENT COMPANIES BY POPULATION AND FREQUENCY.

QUÉBEC HAS THE HIGHEST CONCENTRATIONS BY FREQUENCY AND POPULATION IN EXPLORATION.

SUPPORTING DATA

- **25** nationally
- BC: **12**
- AB: **Five**

- **Five** of **eight** companies identified as lithium extraction

- **Seven** of **18** nationally

- **Seven** of **22** nationally.

DISCUSSION

The three key waste-to-value applications in British Columbia are resource recovery from tailings, e-waste recycling, and battery recycling. These are consistent with the overall national trends in the category.

In general, British Columbia showed circular economy leadership in recycling programs, extended producer responsibility, and resource recovery from wastewater. [13,14, 5]

While these examples are not specific to the mining industry, the general regional strength and support combined with it being a significant mining region likely contribute to this clustering. This highlights the potential for cross-sectoral shifts to drive cleantech innovation.

In Alberta, the waste-to-value applications are varied and include resource recovery from tailings, e-waste recycling, and recovering value from carbon feedstocks including coal and oil sands waste. The circular economy appears to be a growing interest for Alberta. For example, the Government of Alberta recently announced $58 million of funding for circular economy projects. [15]

Extracting lithium from oilfield brines is recognized as an emerging opportunity for Alberta and considered in key provincial strategies such as Alberta's Recovery Plan and minerals strategy and action plan. [16]

Technology innovation is needed to access the province's lithium brine potential, and companies in Alberta have therefore been developing and testing direct lithium extraction (DLE) technologies. [16]

This concentration is likely due to key interrelated factors:

- A robust regulatory framework for tailings storage facilities. [17]
- The aftermath of the 2014 Mount Polley Disaster, which increased public awareness and scrutiny and prompted further regulatory change. [18]
- BC has a larger fraction of open pit mines versus other regions in Canada, which tend to produce larger quantities of tailings

Despite regulatory changes, tailings still pose a significant risk to the environment and surrounding communities.

This clustering is consistent with Québec's position as a province with promising mineral deposits and a leader in spending on exploration. [6] Only five per cent of Québec's territory has been assigned exploration rights, and strategies such as the Plan Nord focus on growing sustainably. [19]

[5] Resource recovery was an area of strength for BC identified in the Water Ventures to Value Chains report.
Further information on the Water report is available here: https://foresightcac.com/2023/07/25/canadas-ventures-to-value-chains-water-technology

SPECIFIC REGIONAL CLUSTERS

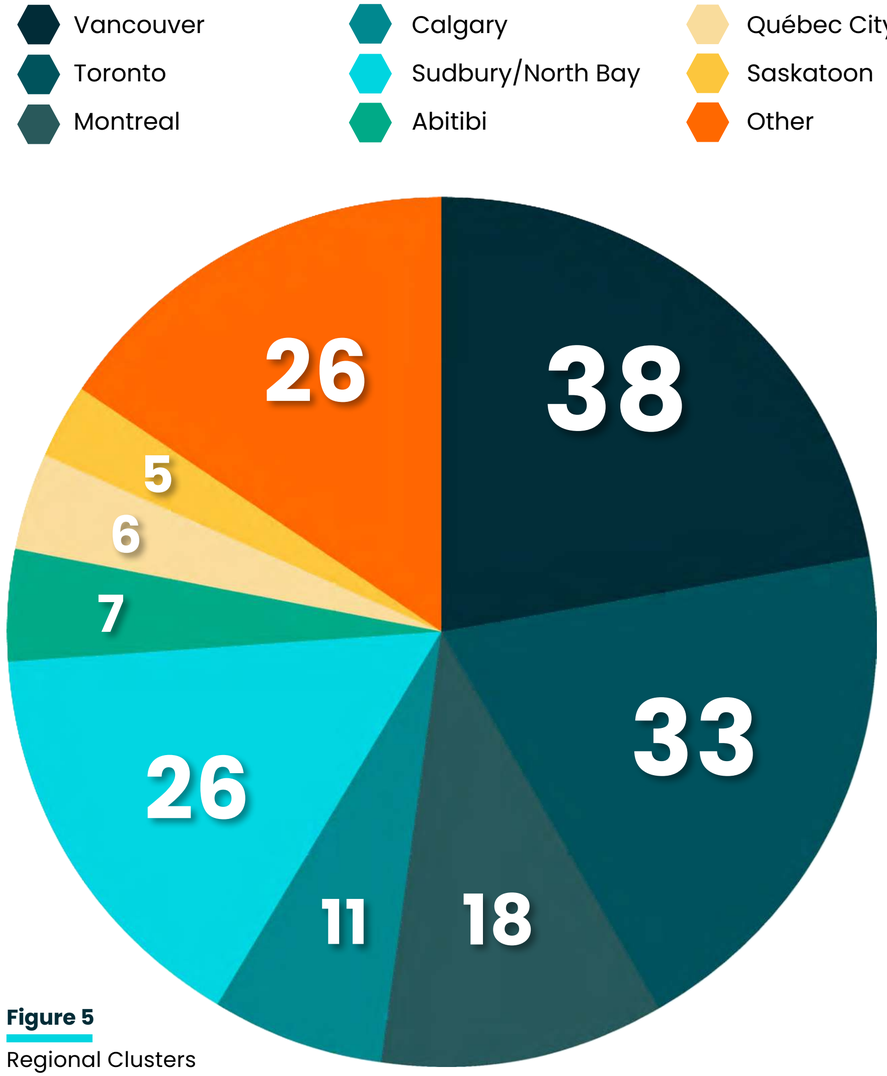


Figure 5
Regional Clusters

126 OF THE 170 companies in the database fall into one of five key clusters: the regions around Canada's four largest cities (Toronto, Montreal, Vancouver, and Calgary) and the Sudbury/North Bay area, a prominent mining region. The prominence of these key clusters highlights that innovation in mining does not happen in a vacuum and is driven by key factors such as:

- **Proximity to mining decision-makers (e.g., operating mines and mining company headquarters)**
- **Presence of academic institutions and research facilities**
- **Industry-led collaborative associations and initiatives**
- **Government support through incentives and funding**

While a lot of these structures and supports might naturally occur in large urban areas, there are good reasons to enable innovation hubs in regions outside of major cities, including fostering different types of innovation. [20] The regional clusters in this database represent different types of innovation, such as AI in Vancouver, Toronto, and Montreal, processing in Calgary, and operations in the Sudbury/North Bay region. Since mining is an industry that operates in rural and remote locations and where key operational challenges vary based on regional factors (e.g., geology, surrounding environment and community) and types of mines, there may be opportunities to support innovation in smaller cities and key mining regions to further grow and diversify the innovation landscape and meet varied industry needs.

OBSERVATIONS

OVER HALF OF THE DATABASE IS CLUSTERED AROUND CANADA'S THREE LARGEST URBAN AREAS (VANCOUVER, TORONTO, AND MONTREAL).[6] AI COMPANIES ARE CLUSTERED IN THESE URBAN REGIONS.

CALGARY IS AN EMERGING URBAN CLUSTER.

SUPPORTING DATA

- Vancouver: **38**
- Toronto: **33**
- Montreal: **18**

- **21** of **27** companies with the AI keyword are in Vancouver, Toronto, or Montreal

- **11** companies
- **Nine** address (rather than observe or analyze)

DISCUSSION

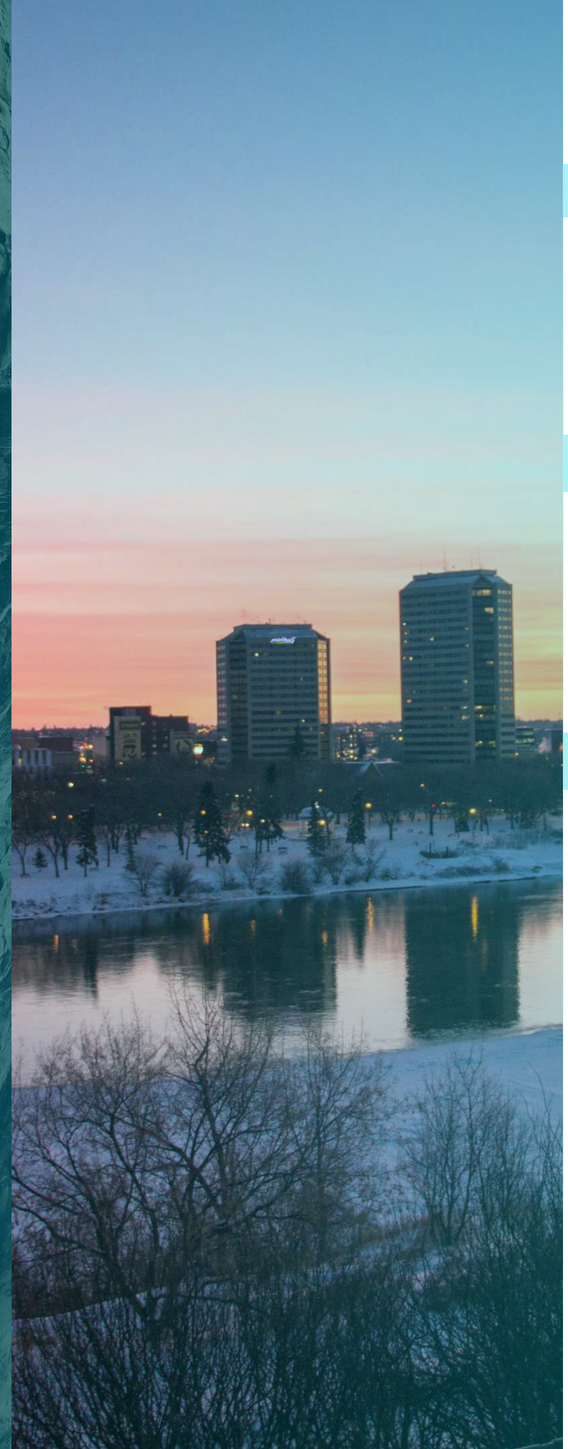
It is not surprising that technology hubs are located in urban areas. Beyond being densely populated regions, the following factors are key contributors:

- Headquarters and bases for mining companies and equipment and service providers.[1,6]
- Cross-sectoral technology innovation hubs and academic and research institutions. For example, the Digital Technology, ScaleAI, and Advanced Manufacturing Superclusters are based in Vancouver, Montreal, and the Greater Toronto Area respectively.[21]
- Thriving AI ecosystem. They are the top three cities in Canada in terms of number of pure-play AI firms.[22]

The growth of Calgary as a regional centre of expertise is generally attributed to the oil sands.[1]

The companies located in Calgary mostly focus on processing or waste treatment applications such as direct lithium extraction technologies, resource recovery from tailings, and water treatment.

[6] Surrounding suburbs and nearby cities were also considered in defining these urban regions.



OBSERVATIONS

THE SUDBURY/NORTH BAY REGION IS A STRONG CLUSTER, CONCENTRATED IN EXTRACTION, MATERIAL MOVEMENT, AND FIXED ASSETS / INFRASTRUCTURE MANAGEMENT.

THERE ARE SLIGHT CLUSTERINGS IN ABITIBI AND SASKATOON.

SUPPORTING DATA

- **26** companies
- **11** extraction
- **12** material movement
- **Seven** fixed assets / infrastructure management

- **Seven** companies in Abitibi
- **Five** companies in Saskatoon

DISCUSSION

This region is known as a key hub for mining services and innovation with a global reach, especially when it comes to underground innovation. [23] Key factors that contribute to innovation in this region include:

- Mining is central to the region's economy and history. [24]
- A thriving community of organizations such as NORCAT, CEMI, MineConnect, MICA, and Workplace Safety North and educational institutions support various aspects of technology innovation such as underground communications and connectivity, safety, and BEVs.

This region sets a great example for how an innovation culture can develop and thrive outside of major cities.

While the clustering in these two regions is not necessarily significant, they both have strong mining presence and have made recent efforts to develop mining innovation hubs:

- An innovation zone is being developed in Rouyn-Noranda to support a greener industry in the Abitibi region. However the city has been waiting on the provincial government for support since 2021. [25]
- There are efforts to develop a rare earth element (REE) supply chain in Saskatchewan. The Government of Saskatchewan and the Saskatchewan Research Council are developing a Rare Earth Processing Facility in Saskatoon. Plans for an additional Saskatoon REE processing facility spearheaded by Vital Metals are currently on pause due to concerns around economic viability. [26]

These situations highlight that while smaller cities and mining regions like these may be well positioned for innovation activity, it does not happen quickly or easily, and they require intentional support from different levels of government.

CLEANTECH INNOVATION IN THE CANADIAN MINING SECTOR

THIS SECTION OUTLINES IDENTIFIED AREAS OF STRENGTH + POTENTIAL OPPORTUNITIES FOR GROWTH

ACROSS THE VALUE CHAIN THROUGH THE LENS OF CLEAN TECHNOLOGY (CLEANTECH) AND SUSTAINABILITY.

CLEANTECH WILL PLAY AN ESSENTIAL ROLE IN ENABLING SUSTAINABLE MINING IN THE FACE OF INCREASING PRODUCTION DEMANDS AND PRESSURES TO ADOPT SUSTAINABLE PRACTICES.

For example:

- Reducing GHG emissions by adopting BEVs
- Contributing to the cleantech supply chain by targeting innovation related to battery metals and other critical minerals
- Reducing impact on the environment by applying advanced digital technologies that reduce inefficiencies or enable more precise methods
- Reducing energy, water, and chemical use by adopting efficient processing methods
- Reducing impact from toxic waste and developing alternative sources for critical minerals by adopting a circular approach

Cleantech innovation in mining is currently being prioritized at the federal level. For example, the *Canadian Critical Minerals Strategy* identifies clean technology as one of the three key areas where Canada has the greatest potential for national integration and competitive growth. [3]

There is a wide range of technical maturity reflected in the database. While this variation is present across the value chain, steps such as exploration, material movement, and fixed assets/infrastructure management tend to be more populated by established technologies. Earlier-stage technologies tend to cluster around the waste-to-value applications and advanced extraction and mineral processing technologies that are highly focused on specific critical minerals (e.g., lithium and rare earth elements).

In terms of maturity, Natural Resources Canada's 2022 Canadian Cleantech Industry Survey found that **19 per cent** of mining, processing, materials, manufacturing, and industry firms are in research and development and **62 per cent** are in demonstration and testing — 35 per cent higher than the next highest sector. [27]

There are several contributing industry factors that affect the pace of technology innovation in mining and can make it challenging for innovators to get past the demonstration and testing phase, and most of these factors are not unique to Canada:

- Mining — as a capital intensive, highly regulated, and cyclical industry — has a **risk-averse** industry culture. Mining companies have an easier time justifying proven technologies, and innovation tends to happen gradually and incrementally. [28,29] This can make it challenging for early-stage innovators to raise sufficient capital to prove their solution.
- Mining is a very **global industry**, and a lot of technology development is done by large multinational players. Canadian companies are therefore competing on a global stage.
- The industry tends to **adopt a closed approach**. [30] For example, in-house innovation and R&D at mining companies are usually considered competitive advantages and kept under the radar. This can make it difficult for innovators to connect and collaborate with their customers and obtain data they require to derisk and prove their technology, and this causes innovation to happen unevenly.
- More broadly, a **public perception** of the industry as technologically conservative and environmentally destructive does not attract as many innovators to the ecosystem. [31]

Technology innovation also only provides part of the picture of innovation in mining, which also includes operational and business process innovations. [29] Technology and process solutions often support each other, and there could be opportunities for technology companies and consulting engineering companies to collaborate and align their efforts to further advance the pace of innovation.

The rapid pace of technology innovation, depleting resources, and growing climate pressures are all pushing the industry to become more innovative and to adopt more collaborative models. [29] The areas of strengths and opportunities suggested in this dataset show some promising pathways where Canada can lead the way.

The mining industry will require technologies that support cleaner transportation, power generation, and material processing and manufacturing that either do not currently exist, are economically unviable, or are in an early stage of development at this time.

- Mining Association of Canada [1]

BATTERY METALS AND MINE ELECTRIFICATION

Both the demand for and use of electric vehicles is growing globally in order to reduce greenhouse gas emissions.

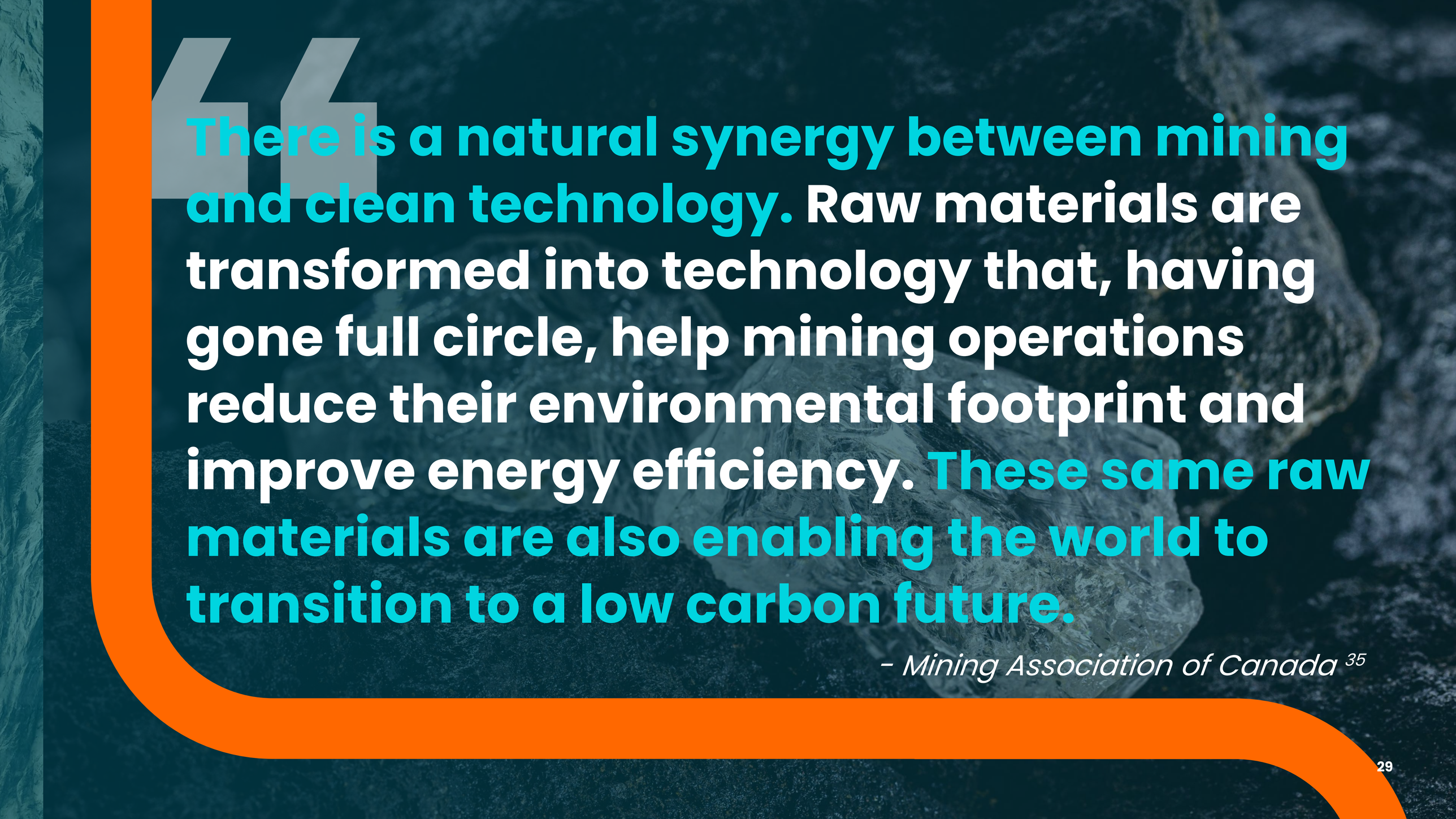
Innovations in both battery metal production and BEV adoption in mining are reflected in the database. Overall, this space has been a priority cleantech area for government initiatives, for example the 2019 Mines to Mobility initiative, which funded innovation and attracted global players. [3]

Canada has a **robust battery metals supply chain:**

- Canada's Lithium-Ion battery supply chain is ranked second in the world according to the BloombergNEF global lithium-ion battery supply chain ranking, which considers raw materials, battery manufacturing, environmental and social governance, industry, innovation and infrastructure, and downstream demand. [32]
- Canada is a leading producer of minerals used in battery production such as cobalt, graphite, and nickel. [5]

Canada is also an **early adopter** of BEVs in mining:

- In 2012, Kirkland Lake Gold implemented one of the first BEV load haul dump (LHD) machines in Kirkland Lake, Ontario. [33]
- In 2016, Newmont's Borden Mine near Chaperleau, Ontario became one of the world's first all-electric mines. [34]



There is a natural synergy between mining and clean technology. Raw materials are transformed into technology that, having gone full circle, help mining operations reduce their environmental footprint and improve energy efficiency. These same raw materials are also enabling the world to transition to a low carbon future.

- Mining Association of Canada [35]

OBSERVATIONS

ELECTRIFICATION IS AN AREA OF STRENGTH, ESPECIALLY WITHIN THE MATERIAL MOVEMENT CATEGORY.

INNOVATION IN BATTERY METALS AND OTHER CRITICAL MINERALS TO ENABLE ZERO EMISSIONS VEHICLES IS A GROWING AREA OF OPPORTUNITY.

SUPPORTING DATA

- **15** companies with the electrification keyword
- **13** of the **40** material movement companies have this keyword

- **10** companies focus on lithium (innovation in extraction, processing, and/or recycling)
- **Five** reclamation / waste-to-value companies focus specifically on battery recycling
- **Two** reclamation / waste-to-value companies focus specifically on rare earth elements

DISCUSSION

Canada is recognized as a leader in BEV expertise and technology development. [36]

The types of technologies included in the database are most concentrated in material movement (including auxiliary vehicles, haulage, LHD, and rail), but there are also charging system and battery manufacturers represented. Auxiliary vehicles are currently the most prominent application, which is unsurprising since they are often a good starting point for companies who are not yet ready to adopt a full electric fleet.

BEV adoption and innovation in mining is supported by government programs such as the Clean Growth Fund and Zero Emission Vehicles Tax credit. [37,38]

As discussed previously, innovation is currently clustered in Ontario and generally has an underground focus. However, BEV adoption is expanding:

- Mines in Saskatchewan, Quebec, and British Columbia are in various stages of BEV implementation. [39]
- Electric options for open pit mines such as electric rail systems, while less mature than the underground equipment, are present in the database.

As adoption grows, technologies that support BEV automation, battery advancements, and the optimization of energy distribution are also opportunities.

Battery metals and other critical minerals essential to BEV manufacturing are present in the value chain.[7]

This is a growing opportunity for Canada identified in the *Canadian Critical Minerals Strategy*. [3]

The Battery Metals Association of Canada roadmap identifies building out the “midstream” of the supply chain such as innovative chemical processing as the most critical near-term priority. [40]

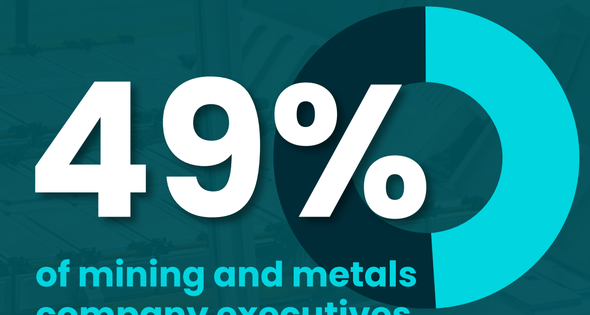
[7] The dataset does not specify commodities, so it is difficult to quantify this innovation space. More definitive numbers of lithium focused companies or battery recyclers were able to be identified to provide a general picture of this presence, but technologies focusing on other battery metals (e.g., copper) are also present.

DIGITAL TRANSFORMATION AND OPTIMIZATION

Digital transformation and optimization are strategic opportunities for the global mining industry to improve productivity, safety, and sustainability.

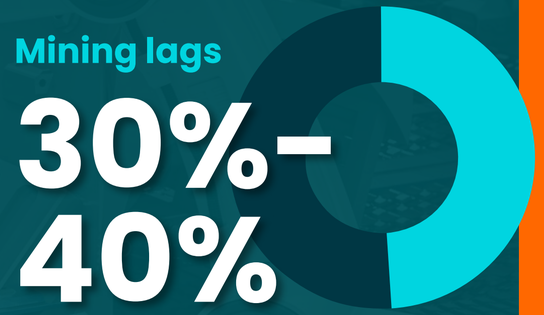
From a sustainability lens, they can help industry players reduce inefficiencies that contribute to energy and emissions intensity and reduce their impact on the environment through more precise and optimized methods. Since mining employs long-term assets and mines have a finite lifespan, replacing equipment and key infrastructure might not always be economically feasible, and when it is, it can take a long time. Optimizing existing assets and processes can therefore give companies options to make shorter-term changes or better prepare the mine for longer-term changes.

Current support for growth in this innovation space tends to be through directing government funding to industry led-initiatives such as the digital technologies supercluster, which has ongoing mining projects. [41]



49%

of mining and metals company executives that participated in PwC's 2022 CEO Survey "include automation and digitization goals in their long-term corporate strategy." [42]



Mining lags

30%-40%

behind comparable industries in digital maturity according to the Boston Consulting Group's Digital Acceleration Index. [43]

OBSERVATIONS

TECHNOLOGIES THAT ANALYZE AND/OR OBSERVE ARE AN AREA OF STRENGTH, ESPECIALLY IN EXPLORATION, EXTRACTION, MATERIAL MOVEMENT, AND FIXED ASSETS / INFRASTRUCTURE MANAGEMENT.

AI IS AN AREA OF STRENGTH.

TECHNOLOGIES THAT INTEGRATE OR OPTIMIZE ACROSS MULTIPLE VALUE CHAIN STEPS ARE AN OPPORTUNITY.

SUPPORTING DATA

- **71** of the total **170** companies observe and/or analyze.
- Value chain steps with over 50 per cent concentration of technologies that observe and/or analyze:
  - Exploration: **16** of **22**
  - Extraction: **27** of **53**
  - Material movement: **22** of **40**
  - Fixed assets/infrastructure management: **21** of **26**
- **27** have the AI keyword
- **12** are noted as "cross value chain" (noted when a company applied to many steps and was just assigned to the most prominent or relevant ones).

DISCUSSION

The companies that analyze primarily include those that contribute to the industry's digital transformation such as data-driven analytics, diagnostics, modelling, automation, and optimization. Those that observe primarily include key enablers such as connectivity, sensing, and imaging technologies. Key applications by value chain step include:

- **Exploration:** image analytics, core logging, geological modelling, drill accuracy.
- **Extraction:** production planning and optimization, orebody knowledge, drill and blast accuracy and precision.
- **Material movement:** autonomous and remote systems, collision avoidance, fleet management and optimization.
- **Fixed assets / infrastructure management:** connectivity, asset and personnel tracking, worksite safety, infrastructure monitoring and optimization.

There may be opportunities to further support digitalization in other steps of the value chain such as mineral processing, smelting and refining, and tailings management. These will be discussed in the next two sections.

There are varied AI applications represented in the database, for example machine vision, advanced data analytics, fatigue management wearables, and process optimization.

Canada is strong in AI across sectors and is currently ranked fifth on the global AI index. [44] This can likely be attributed in part to robust government strategy, most notably the Pan-Canadian AI Strategy. [45] More specifically, the Natural Resources Canada Digital Accelerator and the ScaleAI supercluster both have mining-specific AI projects. [46,47]

The companies represented include mostly mine-to-mill optimization and traceability technologies. Technologies that optimize and integrate across the value chain provide opportunities to pinpoint vulnerabilities to climate change, identify critical inefficiencies, and identify where changes will make the greatest impact.

Optimizing what they already have can be a valuable initial step for mining companies in addressing environmental concerns and meeting tightening regulatory requirements. [48]

EFFICIENT PROCESSING

Overall, most of the companies assigned to mineral processing and smelting and refining have an efficiency focus.

Processing is energy-intensive, so innovating to improve efficiency has benefits both in terms of profitability and environmental performance.

For example, comminution accounts for **25 per cent** of mining emissions, so even incremental improvements have the potential to make a big difference. [49]

OBSERVATIONS

TECHNOLOGIES THAT ADDRESS MINERAL PROCESSING AND SMELTING AND REFINING ARE AN AREA OF STRENGTH.

TECHNOLOGIES THAT OBSERVE AND/OR ANALYZE MINERAL PROCESSING AND SMELTING AND REFINING ARE AN OPPORTUNITY.

SUPPORTING DATA

- **24** of **34** companies assigned to mineral processing are classified as address
- All **22** companies assigned to smelting / refining are classified as address
- **10** of **34** companies assigned to mineral processing observe and/or analyze.
- **No companies** assigned to smelting / refining are classified as observe and/or analyze. [8]

DISCUSSION

Most of these technologies provide some kind of process improvement to improve efficiency. For example

- Innovative processes that reduce the use of harmful chemicals, reduce water consumption, or improve energy efficiency
- More energy efficient equipment
- Waste to value innovations

Technologies like these are a key focus area for funding initiatives in the *Canadian Critical Minerals Strategy.* [3]

Technologies that analyze and/or observe in the mineral processing category primarily include data-driven process optimization and material analysis. These types of technologies are applied to enable decision support, improve overall efficiency, and reduce waste.

Potential for digital innovation in this space has been recognized by both government initiatives such as the CanmetENERGY Industrial Systems Optimization Program and industry organizations such as COREM. [50,51]

[8] There could be some contributing factors based on the scope of the database that affect these numbers. Some of the “cross value chain” companies that do optimization might apply to smelting/refining, but their other applications were more prominent. There might also be many solutions that apply to process industries generally (e.g., oil refining, pulp and paper, chemical).

WASTE MANAGEMENT AND CIRCULAR ECONOMY

Innovations in processing waste and enabling a circular economy are a growing industry priority as both mineral production and environmental pressures increase. There are a total of 35 companies in tailings management, water management, and reclamation / waste-to-value represented in the database.

Overall, waste management is highly regulated and an area where Canada has shown global leadership in terms of standardization and innovation. For example, the Mining Association of Canada's (MAC) Towards Sustainable Mining program, of which tailings management and water management are key pieces, is globally recognized and implemented. [52]

One answer to the waste management question is to enable the circular economy. Mining and metals waste streams are becoming increasingly recognized as an opportunity both in terms of economic competitiveness and in improving sustainability across the value chain. These opportunities are currently being prioritized in government policy, research, and strategy. For example, the circular economy is a key focus in the 2019 *Canadian Minerals and Metals Plan* (2019) and *Canadian Critical Minerals Strategy* (2022). [3,53]

Regulatory barriers (real and perceived) are a key challenge to innovation in this space. Circular Economy Leadership Canada suggests that adopting a circular approach to mining requires a joint effort between public and private sector involvement to reduce barriers and incentivize innovation and an industry-driven approach based on systems thinking and collaboration. [54]

[9] Methodological note: There is overlap between these three categories. While theoretically, many water treatment and tailings management companies are participating in reclamation, criteria for assigning tailings management or water management to reclamation / waste-to-value as well was if there was a specific focus on water release, remediation, or recovering value from waste.

“Governments have a big role in enabling this shift [towards a more circular approach]. With mining and minerals waste often being (correctly) associated with hazardous waste, there are existing regulatory restrictions on the recycling, repurposing, and reusing of these materials, as well as on trade and sourcing of secondary materials along supply chains, which need to be re-thought if waste is going to become a resource.”

- Alan Young and Geoff McCarney, Circular Economy Leadership Canada [55]

OBSERVATIONS

OVERALL, WASTE-TO-VALUE BOTH FROM MINE AND END-USER WASTE STREAMS IS WELL REPRESENTED, BUT THERE ARE OPPORTUNITIES FOR GROWTH.

RESOURCES RECOVERED FROM TAILINGS ARE PROMINENT WHEN IT COMES TO MINE WASTE -TO-VALUE.

BATTERY AND E-WASTE RECYCLING ARE THE MOST PROMINENT IN END-USER WASTE-TO-VALUE.

SUPPORTING DATA

- **25** overall in the reclamation / waste-to-value step. They all have some form of waste-to-value application.
- **13** mine waste
- **12** end-user waste
- **Eight** mine waste-to-value companies recover resources from tailings.
- **Five** battery recycling
- **Five** e-waste recycling

DISCUSSION

This value chain step is the fifth most represented in the database, behind core operational steps like extraction and material movement. This suggests that the government's prioritization of innovation in this space as discussed above may be having a practical effect. However, this is still an emerging area with room to grow.

As discussed previously, the provincial distribution is uneven. This uneven distribution combined with the national emphasis on growth in this space suggests there could be opportunities for provincial governments and industry bodies to assess barriers and provide incentives to further support and foster more coordinated innovation.

This clustering is unsurprising considering tailings are the largest waste stream and have the highest potential for metal recovery. [56] A circular approach to tailings management can be a valuable part of a company's strategy for more sustainable tailings management and has been a key component of Natural Resources Canada's Mining Value from Waste Initiative. [57]

Both of these waste streams have a high economic potential and are growing globally.

We are producing an increasing amount of e-waste globally and it is becoming recognized as a valuable source of metals such as gold, silver, palladium and copper. [1]

As global demand for BEVs grows, recycling batteries and the waste produced in manufacturing them is both an opportunity to extract critical battery minerals in a more cost effective and environmentally friendly way and to manage this growing waste stream. [40]

CIRCULAR ECONOMY AND THE IMPORTANCE OF CLOSING THE LOOP

While this dataset demonstrates some promising concentrations of companies that extract and process value from waste streams, a circular approach also requires the integration of downstream fabrication and markets (not covered in this dataset) to close the loop. One promising initiative is the Metal Tech Alley cluster in the Kootenay region in BC, a multi-industry, multi-stakeholder cluster that focuses on adopting circular economy practices and innovations. [61]

OBSERVATIONS

TECHNOLOGIES THAT OBSERVE AND/OR ANALYZE TAILINGS FACILITIES ARE AN OPPORTUNITY.

SUPPORTING DATA

- **Five** of **18** tailings management companies observe and/or analyze.

DISCUSSION

Overall, Canada does well in tailings management from a regulatory perspective.[58] Tailings facilities nevertheless present a high level of risk to the environment and to communities surrounding the mine. Recent incidents and failures have driven awareness around the need for better tailings management practices and accountability. [59]

The tailings management technologies represented in the database primarily include those that address: treat, remediate, and extract value from tailings. Monitoring and analysis technologies, classified as observe and/or analyze, are less represented. These types of technologies are also an important part of preventing failures and optimizing tailings management processes, and could be an opportunity to grow. [60]

RECOMMENDATIONS

VENTURES, INVESTORS, GOVERNMENT, AND INDUSTRY CAN ALL BENEFIT FROM THIS DATA AND THE INSIGHTS IT PROVIDES ABOUT THE SECTOR AS WE TRANSITION TO A NET ZERO ECONOMY.

VENTURES ARE RECOMMENDED TO USE THIS DATABASE TO GLEAN VALUABLE INSIGHTS ON GAPS AND OPPORTUNITIES WITHIN THE ECOSYSTEM TO:

- Identify innovation opportunities, potential partnerships, and competitors segmented both by geography and position in the value chain.
- Apply a broader understanding of where technologies fit on the value chain, and take stock of what other companies fit around them to better promote their existing strengths and make informed business decisions.

INVESTORS AND INDUSTRY WILL ALSO FIND THIS DATA TO BE AN INVALUABLE TOOL TO USE WHEN EVALUATING INVESTMENT AND/OR ACQUISITION OPPORTUNITIES IN ORDER TO:

- Understand the value-add prospective ventures provide by identifying their role in the value chain.
- Determine what competitors might exist for any given company.
- Identify strengths, opportunities, and trends in the Canadian market to inform business decisions.

KEY INDUSTRY STAKEHOLDERS CAN ALSO USE THIS DATA TO ADVANCE ADOPTION:

- Operators can identify strengths and opportunities to better understand their options and make informed technology adoption decisions.
- Engineering consultants and other service providers, who also often play a key role in connecting ventures to operators, can apply a broader understanding of the technology landscape and identify potential partnerships and collaboration opportunities that will support their clients' goals.

ADDITIONALLY, GOVERNMENTS CAN CONSIDER THE KEY INSIGHTS DERIVED FROM THIS DATA TO IDENTIFY TARGETED AREAS FOR SUPPORT IN A MORE COORDINATED AND INTENTIONAL WAY. KEY RECOMMENDATIONS FOR GOVERNMENT INCLUDE:

- Leverage and build on provincial strengths and regional clusters to support a thriving innovation landscape. Provincial strengths and clusters include underground innovation in Ontario, waste-to-value in British Columbia, and lithium extraction in Alberta. More specific regional strengths and clusters include AI in the major Canadian cities, mineral and waste processing in Calgary, and operational innovation in Sudbury/North Bay.
- Consider opportunities to foster strategic innovation clusters in key mining regions.
- Continue to build on Canada's strengths in BEV technology as mine electrification matures and support the advancement of innovation along the battery metals value chain.
- Continue to support industry-led collaboration and innovation in digital transformation technologies that can be used to improve efficiencies across the value chain.
- Consider opportunities to grow in terms of analytics and monitoring to enable efficient processing and support tailings management.
- Continue to build on funding and policy for waste-to-value opportunities and support more even technology development across the country.

CONCLUSION

THE CANADIAN MINING TECHNOLOGY ECOSYSTEM ACROSS THE VALUE CHAIN DEMONSTRATES THE SECTOR'S STRONG TRACK RECORD OF INNOVATION AND EXPERTISE WHILE ALSO HIGHLIGHTING SOME OF THE COMPLEXITIES OF THE MINING INNOVATION LANDSCAPE THAT AFFECT INNOVATION.

For a mature, capital-intensive, and global industry like mining, the technology landscape is only one piece of a much larger innovation context. When looking behind the scenes of our innovation strengths, there is typically a combination of government policy, funding, and support and industry-led collaboration between operators, service providers, global and local innovators, research and academic institutions, and associations and enablers. **Continuing to foster an integrated innovation landscape can help the industry seize these opportunities to innovate strategically in the face of increasing climate pressures.**

Interested in learning more about Canada's mining technology value chain?

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