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AN OVERVIEW OF **GENOMICS** IN **BRITISH COLUMBIA'S** MINING SECTOR

Genome BritishColumbia

Leading ▸ Investing ▸ Connecting

2018 Revision

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Executive summary

In 2016, British Columbia's mining sector generated $8.7 billion in gross mining revenue and paid $650 million to the provincial government in the form of taxes and levies. BC's mines produce steelmaking coal, copper, gold, silver, lead, zinc, industrial minerals, and molybdenum. The mining sector employs over 9000 people directly at 14 operating metal and coal mines and numerous smaller industrial and aggregate operations. It is estimated that for every job provided by the mining industry, another two are created in businesses that supply the industry.

However, due to the cyclical nature of global commodity prices, BC mine operators, and therefore the people they employ and the suppliers and communities who rely on them, are susceptible to the boom-and-bust of the global mining industry. Only the most efficient mines can afford to continue operating when prices are low. In addition, BC's mining sector faces challenges from carbon pricing schemes, ever-tightening environmental regulations and the constant challenge of gaining a social licence to operate from communities. For the sector to remain globally competitive in the long term, it is imperative to diversify and adopt innovative technologies.

Genomics has emerged as a promising technology for building sustainable, future-proof mines. Genome BC's investment in genomics aims to develop novel exploration tools for geochemical prospecting and bioremediation of sites contaminated by metal leaching and drainage; more efficient water and effluent treatment; processing, refining, and extracting metals; tailings management, and; environmental monitoring and risk assessment.

This document lays out a strategy for expanding on previous Genome BC investments in genomics-based research to improve the sustainability and productivity of the mining sector. The overarching goal of Genome BC's mining sector strategy is to distill knowledge of the challenges and opportunities facing the sector; the previous investments, results, and strengths; and the priorities of all stakeholders relevant to the sector into an actionable set of next steps.

1. Importance of BC's Mining Sector

British Columbia's abundant mineral resources and rich, diverse deposit types have allowed the province to build an innovative, robust mineral exploration and mining industry. As a key contributor to the provincial economy, BC mining generated $8.7 billion in gross mining revenue in 2016[i] and the industry paid $650 million to the provincial government in the form of taxes and levies[ii] to fund infrastructure and social programs, including health and education, around the province.

BC is Canada's largest producer of metallurgical coal and a leading copper producer. Coal is BC's second-largest export product - $4.2 billion in 2016 (11 per cent of total) – and copper ores and concentrates are the forth-largest - $2.7 billion (7 per cent of total)[iii]. The province also produces gold, silver, lead, zinc, and industrial minerals, and is the only molybdenum producer in the country[iv].

Mining is the process of extracting valuable, naturally-occurring resources from the earth, refining those resources into a pure form, and delivering them to downstream users where they are transformed into the goods society depends on. As our demand for resources rises, so does the size of mining operations and the impact on the environment and communities.

Mining activities, with their large-scale infrastructure and waste management requirements, pose significant risks to surrounding environments including endangered species, remote communities, and unique cultures. Mitigation of these risks is an important social, political, and increasingly economic factor to consider when examining the sector. The critical challenge facing BC's mining sector is how to grow it efficiently while ensuring safety, sustainability, and the ability to deliver benefits to British Columbians now and in the future.

In line with recently-developed provincial and national strategies and outlooks, including the Canada Mining Innovation Council's Zero Towards Waste Mining Plan Innovation Strategy (2015), the Federal Government's Global Markets Action Plan (2013), the 2016 Review of the Environmental Assessment Process, and the Pan-Canadian Framework on Clean Growth and Climate Change (2016), Genome BC believes the new tools that genomics can offer at an ever-improving price point will provide significant opportunities for making greater impacts on the sector with benefits for all stakeholders. The principal areas of opportunity for genomics in mining are: water and effluent treatment; processing, refining, and extracting metals; improved remediation and tailings management, and; environmental monitoring and risk assessment.

This strategy is intended to outline a path to support development and application of genomics to address sector challenges and opportunities. Genome BC promotes sector innovation by facilitating ongoing partnerships between researchers, industry, government, and Genome BC, with Genome BC playing a leadership role to bring stakeholders together and facilitate delivery of benefits.

This strategy provides an update of actions and areas of focus consistent with the priorities identified in the Genomics Strategy developed in 2013-2014 and developed in consultation with sector stakeholders since that time. It is by its nature designed to complement and align with co-existing industry, government, and sector strategies.

Managing BC's Mineral Resources

Mining is a cyclical business, driven primarily by global commodity prices set in response to global supply and demand. Commodity prices have been falling since 2011 but showed sustained signs of recovery throughout 2016 and into 2017. In 2016, the mining sector in BC directly employed 9,329 people, a 1 per cent increase from 2015[v]. By adding in exploration, mineral refining and smelting, and downstream mineral processing, the sector directly employed over 38,000 people in 2016[vi]. Mining is also the largest private sector employer of Aboriginal peoples in Canada; nationally, Aboriginal peoples make up 6 per cent of the mining sector[vii].

1.1 Prospecting, mineral exploration and mine evaluation

In 2016, 3,255 people[viii] were employed in mineral exploration activities, including geophysical and geochemical surveying, trenching, drilling, and sampling to locate and define mineral resources below the surface of the earth. In tandem with exploration efforts, early to advanced mineral exploration activities also include community engagement, collecting baseline environmental information, economic pre-feasibility work, and secondary target exploration. In 2016 exploration and development expenditure in BC was $102 million, just one-third of what was spent in the previous year, partly due to major projects such as the Brucejack gold mine moving from development to construction, but also due to still-low commodity prices. Vancouver is home to the world's leading exploration companies, and Canada is the global leader on exploration spending on non-ferrous metals.

BC's mining industry began in the mid-18th century developing coal deposits on Vancouver Island and placer gold in Cariboo but has largely exhausted the province's economically feasible high-grade deposits over the life of the industry. The drop in average grade of new mines is a global issue, one that is compounded by increased permitting, reclamation, and social engagement costs. Overcoming the technical challenges of operating cleaner, more-efficient mines while minimizing operating costs to remain competitive has spurred innovative partnerships across the industry.

The Association of Mining and Exploration British Columbia (AME) is comprised of thousands of members who are working to drive best practice in the mining industry in BC. AME's strategic five-year plan focuses on land access and use, permitting and environmental assessments, aboriginal engagement, taxation and investment, and public geoscience. To ensure a strong future for British Colombia and the mining industry, AME sees the need for continuous and sustainable investments in exploration, the development of new deposits to meet the demand for new materials, in our province and abroad.

1.2 Mining and production

The development of mineral deposits creates mines that are the life blood of communities throughout BC. Eight metal mines operated in the province during 2016, plus seven coal mines, 30 industrial mineral mines and 1,000 quarries were in operation for at least part of the year, directly employing 11,805 British Columbians[ix]. The province has the fourth-largest mining industry in the country. BC's second- and fourth-largest exports are coal and copper, respectively[x]. Growing the industry in BC requires viable deposits, and transparent open policy around mine site development, operation, carbon-taxation, impact assessment, and reclamation agreements.

The Mining Association of British Columbia (MABC) is one of the oldest industry associations in the province, representing the voice of the mining industry to government, lobbyists, and the public. MABC supports the industry through its continuous development of policy, education, and engagement of members to enable continuous dialogue between all stakeholders. The value mining brings to the province is immense, but only when everyone is informed and supported.

Supporting MABC's provincial policy efforts, the Prospectors and Developers Association of Canada (PDAC) supports Canadian mining companies to access capital, land and the skillsets needed to bring mines through discovery, exploration, development, and into operation. PDAC and its members focus on creating a supportive, competitive, and responsible industry known around the world as a global leader in mineral extraction.

Supporting the sustainable development of mining is critical to meeting the future production needs of a growing population and increasing consumer demand. Nearly all materials used by humanity to create the world we live in are mined. Demand for base metals such as copper, found in everything from cellphones to buildings, is estimated to rise 341 per cent by 2050, especially as renewable technologies like electric cars, wind-power plants, and solar panel production increases[xi].

1.3 Processing and transportation

BC has a long-established mineral-processing and refining industry, currently home to one smelter, one secondary smelter, a smelter/refinery, and a processing plant[xii], as well as ore processing facilities at individual mine sites. The Rio Tinto Kitimat aluminum smelter, for example, has been operating for over 60 years and is located close to low-cost marine transport and a reliable source of low-cost hydroelectricity. The mining industry is also the largest industrial customer group for Canada's trucking, rail, and marine transportation sector, who move a substantial tonnage of bulk commodities, such as iron ore, coal, potash, and sulphur, to domestic customers and onward to international markets.

The economic benefits of mining extend beyond the mine site, and it is estimated that for every direct mining job in BC, at least two indirect jobs are created to support the industry and facilitate downstream mineral processing and refining[xiii].

1.4 Reducing environmental impact throughout life of mine

Canada is a world-leader when it comes to building sustainable mines, and was the first to create an externally-verified performance system in 2004 to evaluate sustainable practice in the industry; the Mining Association of Canada's (MAC)'s Towards Sustainable Mining Initiative[xiv]. These tools and indicators, developed by Canadian companies and adopted internationally, help mining companies reduce the risks to people and the environment, build public trust, and support the development of social licenses to operate – the cornerstone of all modern mine development projects.

To reduce the ecological impact and physical footprint of mining operations, innovative technologies that reduce water and energy use are critical to meeting carbon-offset goals, as well as ore sorting, in-situ mining and bioleaching processes that have the potential to reduce mine waste and tailings volume. The Canadian Innovation Mining Centre (CMIC) has created a long-term strategy to develop these key technologies through the Towards Zero Waste Mining. They recognize the challenges faced by the

resource extraction industry and in partnership with 40 companies, have created a 10-20-year roadmap to progressively integrate innovative technologies to reduce mining waste.

Genomics research is relatively new to the mining sector, and regulators, industry, and other sector stakeholders are beginning to better understand its utility. There remains reluctance to embrace technologies that involve bacterial cultures for fear of lack of robustness, sensitivity to changes in process parameters, low process availability, and challenging environments. There is an opportunity to demonstrate the applicability of genomics as a tool for the sector through experience and stories, not only from within the industry but also from other sectors where it has already made an impact, such as health or forestry.

Application of bio-heap-leaching and bioreactors, while successfully employed abroad, has not been widely used in Canada due to many technical and economic challenges. With a careful review of these processes, there is an opportunity to optimize these for Canadian climate and operations.

2. Sector Challenges and Opportunities

To realise the many opportunities for growth and investment in the sector, it is necessary to examine the challenges facing BC's mining sector in the context of a fluid socio-economic and geo-political environment, and reframe them as opportunities for innovation in the sector. Innovative thinking and collaboration are required to maintain the productivity of BC's minerals sector, build sustainable mines, and for BC to remain globally competitive.

Market access and pricing

The global mining sector periodically faces significant economic uncertainty, as supply and demand fluctuates, along with commodity prices. This so-called 'boom-and-bust' is the nature of the global mining sector. Currency fluctuations and capital financing difficulties often result in risk aversion towards investment in non-core activities, such as research and development or investing in new cost-saving and revenue-generating technologies. However, these challenges provide a unique opportunity for building strong relationships within industry, pooling funds, and creating strategic working groups to de-risk research and development investment and spending limited resources efficiently.

Productivity and operational efficiency

To reduce the risks arising from boom-and-bust fluctuations, most mining companies focus on minimizing capital and operating costs while maximizing extraction efficiencies. Only the most efficient mines can afford to continue operating when prices are low. Companies must overcome the challenges of challenges identifying new resources and expanding current reserves, reducing energy consumption at mine sites, and efficiently managing resources, including water and human capital.

As a carbon-emitting sector, mainly through the consumption of fossil fuels, carbon pricing schemes have a significant impact on mining operations. In late 2016, Prime Minister Justin Trudeau announced that all provinces and territories must adopt a federally-imposed carbon "floor price" if no pricing scheme is in place by 2018. In response, MAC released a statement on behalf of its member companies describing how difficult it is for mining companies to remain cost-competitive against other jurisdictions without carbon tax schemes, when all are operating within the same global commodity cycle. Carbon-

pricing schemes introduced in response to the federal challenge may be the catalyzing force behind Canadian mining companies adopting innovative strategies that allow them to meet their carbon emission targets and leading the sector globally in emissions reduction.

Environmental sustainability and protection

Collecting and storing high-quality baseline data for Environmental Impact Assessments (EIA) and mine site reclamation is time consuming and expensive, especially since most mine sites are in remote areas that are difficult to access. Upon collection, it can take weeks, months, or even years to sort through the information and assess the state of the environment. This possess significant challenges to regulators and mining operations who are often operating on old information that may not fully reflect the state of the environment, nor the impact of the mine.

Both industry and regulators need rapid and accurate tools to provide data within hours, quickly generating the information they need to make rational judgements, but can be easily and cheaply re-analyzed as situations change. Field-deployable biotech solutions that provide real-time data about living systems and the environment are critical to sustainable practices in the mining industry and building trust between industry, regulators, and communities.

Innovation

Mining companies are struggling to extract maximum value from the huge volumes of data collected at each stage of the mining life-cycle, particularly as many aspects of mining become monitored and automated. Data harmonization from these sources can create forecasting models that predict equipment failures, allowing for planned maintenance scheduling, and reducing operational costs. Applying artificial intelligent systems to mining data collection systems may allow for the predictive tracking of tailings spills, water leakages, and other potential incidents.

Communities

Obtaining and maintaining a social licence to operate is a challenge all exploration and mining companies face. Traditional perceptions of mining as a careless land manager are becoming increasingly outdated. Improving public perceptions will take time and conversations with local communities are vital. Community priorities don't always align with company timelines and economic drivers, and patience is required. However,

Aboriginal entrepreneurs and businesses are becoming an integral part of mining supply chains across Canada. For mining companies, maximizing procurement from Aboriginal businesses not only contributes to their social licence to operate, but also establishes a reliable source for goods and services and a local workforce for the life of the mine and beyond.

The biggest challenges involve overcoming the industry's distrust of biological processes and building enough interest to trigger resource investment into exploring genomics solutions through demonstration projects.

3. Genomics in the Mining Sector

Genomics is the science that deciphers and understands the genome – the code or blueprint, of a living organism (humans, animals, plants, microbes) – to better understand biological systems at a molecular level. In the last decade, the field has advanced rapidly and is increasingly becoming cost-effective. The scientific knowledge and innovations emerging from genomics-driven research are unearthing solutions to a broad range of complex biological challenges, including applications in health, forestry, fisheries, aquaculture, agri-food, energy, mining, and environment. At the same time, these state-of-the-art approaches are also giving rise to the need for dialogue regarding societal, economic, and ethical implications of genomic information.

Genomics has the potential to improve on processes that occur throughout the mining life-cycle, such as finding undiscovered resources, reducing EIA timeframes, improving recovery of minerals, and supporting ecosystems as mine sites are closed and remediated. It is easy to see a role for genomics in the mitigation of environmental disturbances, especially the effects on biodiversity and wildlife, where genomics can provide deep insights into the health of ecosystems and our impact on them. But, what is sometimes more difficult to see, is the environment around rocks and minerals that also contains special organisms evolved to serve unique purposes. Most of these unique functions, often associated with minerals and extreme environments, are unexplored to date but offer unique opportunities for true innovation potential.

Advances in tools that allow scientists to read, manipulate and translate genomic data benefit all industries; health, agrifood, pharmaceutical, the natural resources and many others. While the utilization of bacteria to bioleach copper has been occurring at the industrial level since the 1950's, the application of genomics research to mining is a relatively new endeavour.

For the mining sector to remain globally competitive in the long term, it is imperative to diversify and look to other industries for innovative technologies that have not been traditionally adopted. Genome sciences can contribute to the development of novel exploration tools for geochemical prospecting, providing an additional layer of information to support regulators and industry. For example, species of microorganisms known to be associated with specific ore bodies can support exploration decisions, while other microbes known to survive in harsh acidic environments may indicate a tailings leak. Biologically-mediated processes can be developed using genome-based technologies to assist mineral extraction, reducing chemical use, and improving recycling of waste products. Genome BC is investing in mining research projects in the areas of bioremediation of contaminated water to remove selenium, as well as nitrites from explosives. Current water mitigation technologies are expensive, however natural enzymes or passive systems could be used in a variety of mining processes to contribute to more cost-effective mitigation strategies once the basis for bacterial metabolism and enzymatic reactions are better understood.

Impact of BC investment in genomics

Genome BC is an innovation hub who has brought together top BC researchers and academic institutions with industrial partners from around the globe to form cross-disciplinary teams who are leading their industries. Since 2008, Genome BC has strategically invested $6.2 million in eight genomics

projects in the BC mining sector that are leading the world in mine wastewater management, mine reclamation, and understanding the long-term genomic effects of tailings containment failures.

Genome BC's investment in the mining sector is relatively new and has focused primarily on discovery and early-stage applied research to improve our understanding of environmental conditions, and the development of tools for monitoring environmental and operational conditions. As these projects reach completion, follow-on research is building on this knowledge and testing the tools in bench- or pilot-scale applications. For instance, current research into developing bioreactors to remove selenium from waste water have been built upon GBC funded research from 2008 to develop the tools needed to work with bacterial communities present in mine wastewater, and identify those that show potential for remediation.

Other projects are laying the foundation for further work to improve the sustainability of mining and mineral processing, including the degradation of explosives, the advancement of reclamation using biosolids and metagenomics assessment of the environmental impacts of mining operations and accidents.

In BC, the potential socio-economic impact of these investments on our mining sector is significant. Beyond cost savings due to improved efficiencies and reduced water and energy consumption, the wider acceptance of genomic-based tools could increase public confidence in the mining sector as the sector demonstrates the capacity to track their impact more accurately, using biome monitoring tools like environmental DNA (eDNA), as well as detect and clean up spills to mitigate serious disasters. These investments also create professional and specialist jobs, supporting new education needs and bring a skilled workforce to the sector and the province. Overall, the investment in applied technologies within the mining sector is critical for the sector to innovate and meet the demands of a changing commodity market while maintaining sustainable and efficient industry operations that can meet future challenges.

4. Opportunities for BC:

Creating Opportunities for Genomics in BC's Mining Sector

Genome BC has initiated several genomics projects with researchers and industry partners in BC to develop the mining sector and positively impact the social and economic well-being of the province. There are further opportunities in the expanding bio-economy for BC's mining sector, such as passive water treatment, in-situ mining, greenhouse gas reduction and advanced environmental monitoring techniques, and the sector is well-positioned to take advantage of these opportunities. By applying practical genomics tools at various points, from prospecting to production to rehabilitation, genomics can create opportunities for the mining sector in BC. Some short- and long-term projects are underway in the following areas:

Shortening permitting timelines

Current EIAs require significant human capital and resources to map an ecosystem, especially in remote or sensitive locations. Tools such as eDNA have the potential to detect rare species, increase EIA accuracy and allow industry to conduct more advanced environmental

assessments. Collectively these improvements allow for industry and regulators to reduce the time taken to collect and translate data and make decisions – ultimately decreasing permitting times and improving environmental reporting using fewer resources.

Increased productivity and operational efficiency

Genomics solutions can be applied at nearly all points around the mining life cycle. Bio-prospecting uses existing geological maps in combination with mapping of bacterial populations found near specific deposits. Combining the two provides an additional layer of information for exploration teams to identify potential ore bodies and a database that can be used for future mines and reclamation planning.

Recovering minerals using bacteria, known as bioleaching, is an inexpensive alternative for ores of low grade, but can be slow, requires low pH and energy to warm water to temperature for the bacteria to function efficiently. Using genomics, the metabolic pathways of these bacteria can be better understood, and changes can be made allowing them to work in cooler temperatures, neutral pH and at faster rates. Bioleaching is currently applied to ore heaps or in bioreactors to extract copper, uranium, zinc, lead, arsenic, nickel, molybdenum, and other metals.

In-situ mining - the injection of fluids and bacteria into ore deposits deep underground - would completely change the mining model. Rather than bringing the ore to the surface, water, bacteria, and catalysts would be injected into the ore body to leach the desired minerals, and then be pumped to the surface. Such a design would drastically reduce the mine footprint, waste rock volumes and tailings facilities to almost zero.

Meeting and exceeding environmental regulations

BC-based companies have a competitive advantage in international jurisdictions because of their experience meeting higher environmental standards and permitting requirements. To meet future environmental compliance requirements, companies need tools that provide real-time accurate information about the environment, water quality, and health of the biosphere they operate in. eDNA, is easy to collect and can be used to accurately identify what species are present for minimal cost. This genomic data can be used to provide insight into individual organism's lifecycles, metabolism, and the environmental disturbances it has faced. Collectively this data can be used to map ecosystems that allow industrial operations to understand and mitigate or eliminate their impact on the natural world.

Using genomics in this way, leveraged with current environmental monitoring techniques and deep learning algorithms, decreases data collection time and analysis, and increases accuracy to de-risk decision making.

Water beyond the mine

Water is a necessary ingredient for all stages of mining, but over the decades, as requirements have tightened, water withdraws from the environment have been reduced and discharge conditions have become stricter. In many places in the world, mining companies are in direct competition for water with local business, farms, and communities, which can lead to conflict, reducing their capacity to operate in the region.

With these challenges in mind, organizations are striving to eliminate mining water consumption, such as CMIC's Towards Zero Waste Mining Strategy and Goldcorp's H2Zero, as well as many others. No single technology will accomplish this, rather it will take innovators from a variety of disciplines to create a slew of solutions for all aspects of the mining cycle to achieve zero-waste and zero-water mines.

Genomics technologies will play an integral role in this as the technologies mature, creating passive fens to treat water, understanding bacterial consortia in bioreactors and creating building materials that are self-healing. Cross-disciplinary collaboration and investment are key to bring water-saving genomics technologies to the industrial market.

Reclamation and restoration

Genomics has significant potential to revolutionize how mine sites are built, reclaimed, and integrated into the environment after closure. Current research into the storage and use of overburden at BC's Highland Valley, Mt. Polley, Bralorne and New Afton mines seeks to understand the microbial communities that exist in healthy soils and what tools and conditions are needed to restore those communities. By mapping the genomic footprint of natural and disturbed sites, researchers and industry are working together to revolutionize how reclamation is applied to disturbed sites.

Life-of-mine innovation

Genomics-based tools are being employed to harmonize data and increase collaboration throughout the life of a mine. Undiscovered 'Omics potential from cross-industry collaboration will contribute significantly to the industry's move towards zero-waste through the novel application of technology and science.

Biosensor technologies, such as FREDsense, that utilize bacteria in a cartridge, provide field-deployable real-time measurements for arsenic, and potentially other elements in the future. Bacteria capable of sequestering carbon dioxide into minerals allow mines with the right geology to store greenhouse gases from the air and create solid tailings.

The potential impacts of genomics across the life of a mine are endless. Strategic funding of projects aimed to create industry-scale applications are needed to entice the sector as a whole toward adopting genomics, and building strong relationships with innovative partners.

Securing a social licence to operate

Developing and adopting biofingerprinting tools, sensors, bioreactors, and novel reclamation strategies provide the mining industry with the innovative solutions they need to meet their goal of zero-impact. Utilizing these tools provides a greater understanding of pollutants through toxico-genomics and the real impact of industrial operations. In doing so, each mine will build trust with the communities they operate within, further developing their social license to operate, securing their current project, and future exploration efforts.

Genome BC is committed to the development of knowledge, tools, and applications that can contribute to sustainable mining solutions for BC and Canada. This commitment includes strategic investment in earlier discovery-stage research to prove the utility of genomics in the sector, while working with key stakeholders to de-risk investment in research and development and to deliver tangible impacts in the short and long term.

4.1 Pilot projects

Within the current strategy, the following types of pilot projects may be considered to provide a range of impacts that could benefit stakeholders across BC's mining sector.

Pilot Project	Impact	
	Short Term	Long Term
Using bioreactors and bacterial consortia to extract minerals and heavy metals.	Develop the genomic tools and understanding optimum environmental conditions needed to maximize mineral recovery.	To develop large scale, turn-key bioreactors for recovering multiple from processing streams and to remove heavy metals from waste-water streams.
eDNA tools used to support and improve upon current EIA practices and for bio-fingering minerals in exploration.	Build a library of important microbial species to the mining industry and the capacity to deploy eDNA tools in the field.	The adoption and recognition of eDNA tools by the mining industry and regulators, as well as their use to monitor ecosystems on a large scale in conjunction with current practices.
Development of passive water treatment systems capable of precipitating and containing harmful chemicals for the long term.	The development of tools and techniques needed to create proof of concept wet-lands that are self-sustaining and capable removing harmful chemicals from the water.	Creating reliable passive waterways that are fully integrated into the environment and are capable of treating water runoff from mine and industrial sites.
Developing reclamation techniques that promote the succession of natural ecosystems post-closure and support mining company's requirement to return the land to its original form.	Develop genomic tools to understand the impact of mining operations on surrounding ecosystem, and develop tools and best practises to support closure programs	The development of commercial, full-scale genomic solutions to be applied over the life-cycle of a mining operation to ensure the full reclamation of sites and minimize the impact of the mining operation during all stages, exploration to closure.
To create field-deployable sensors to provide real-time information to replace current practices that can take days or weeks to return data.	Proof of concept bio-sensors that demonstrate their potential to reduce measurement timeframes and capital costs, while building industry trust in their performance	Full spectrum of industry ready biosensor products, high-quality professional training and regulatory adoption of the technology.

4.3 Community engagement

While cutting-edge technology opportunities and genomic applications are well known among BC researchers engaged in mining and related environment genomics, gaps exist between thinking and doing. To increase the adoption of genomics-based tools by managers and executives in both the public and private sectors whose responsibilities relate to broader issues of public policy, resource management or competitiveness and achieve high impacts in industry sooner, it is important to bridge these gaps and connect these groups. Whether the gaps arose from premature promotion of genomics potential, or use of language that is too technical or otherwise inaccessible, it is important that the

mining community finds a common language to understand and address the opportunities. The solutions presented by applications of genomics need to be embraced but the fundamental dialogue gap between providers and users of genomics technologies must be closed to see real progress in applications. Genome BC will help address this opportunity by pursuing a coordinated approach to stakeholder engagement, dialogue and collaboration on prominent issues related to mining sector innovation.

5. Advancing the Implementation of Genomics

The prime genomic opportunities for practical applications of genomics in BC mining sector include: development of novel exploration tools for geochemical prospecting, and bioremediation of sites contaminated by metal leaching and drainage, water, and effluent treatment; processing, refining, and extracting metals; tailings management, and; environmental monitoring and risk assessment.

To achieve these targets, Genome BC has been consulting with stakeholders not only in BC's mining sector but across the rest of Canada, as well as with international experts, to understand how genomics might continue to be applied to maximize economic and social benefits arising from various sector activities. The overarching goal of developing this genomics strategy for BC's mining sector is to distill knowledge of the challenges and opportunities facing the sector; the previous investments, results, and strengths; and the priorities of all stakeholders relevant to the sector into an actionable set of next steps.

Genome BC has developed this Roadmap to encourage the uptake of genomics across sectors, and makes the following commitments to support the Roadmap;

- Education
    - All stakeholders: Inspiring students through education programs and empowering teachers with new education tools
    - Genome BC: Geneskool, public talks BGH
- Stakeholder engagement
    - All stakeholders: Bringing together and supporting the life sciences community to a reach a common vision and achieve a common goal
    - Genome BC: sector work/task forces
- Partnership Development
    - All stakeholders: Engage with partners and catalyze user-academic interactions to bridge the academic-industry gap
    - Genome BC: sector work/task forces
- Development of pilot projects
    - All stakeholders: Pilot projects demonstrate the practical and cost-saving value of genomics.
    - Genome BC: Funding for partnered, applied research
    - Genome BC: Through the development of Sector Innovation Centres, Genome BC's goal is to help build ecosystems beyond projects – as a partner with key players in the sector.
- Communicating successes

- Genome BC: Position Genome BC and the corporate brand as an “honest broker” contributing to government policies, strategies, and regulations
- Genome BC: Share success stories in targeted publications, including Genome BC news releases and sector-relevant trade journals.

Appendix 1. Members of the Genome BC Mining Sector Advisory Council, as at March 1, 2018

- Gavin Dirom, President, President and CEO, Geoscience BC
- Graham van Aggelen, Head, Environmental Toxicology, Environment Canada
- Rick Lawrence, President, Lawrence Consulting/ Mining Department, UBC
- Robert Stevens, Director of Partnerships and Learning, CIRDI
- Scott Weston, Sector Leader, Mining, Hemmera
- Sue Baldwin, Professor, Chemical and Biological Engineering, UBC

Appendix 2. List of Key Projects

UPP026: Field-applicable monitoring and process-control of industrial mine water treatment bioreactors

Total Budget: $399,975

Program: User Partnership Program

Project Leaders: Sue Baldwin, UBC

Dr. Susan Baldwin and Teck Resources, the second largest exporter of steelmaking coal in the world, are collaborating to minimize the environmental impact of naturally occurring constituents such as selenium and nitrate from waste rock to accumulate in the watershed and affect aquatic life. Together they are learning to optimize the bacterial consortia of bioreactors to treat waste water. This project represents a five year long collaboration between Teck, Tetra Tech, and UBC to identify the key components required to minimize the environmental risks of the naturally occurring constituents from waste rocks in steelmaking coal industry and to reduce the company's operating expense at many mine locations in BC.

SIP002: Genomics Solutions for Ecosystem Reclamation Following Mine ClosureTotal Budget: $249,900

Program: Sector Innovation Program

Project Leaders: Lauchlan Fraser, Jonathan Van Hamme, TRU

The Canadian mining sector is a major driver of the economy, contributing over $56 billion to gross domestic product (2015) through the creation and operation of mine sites all over the country. Since 1969 the province of British Columbia mandates that all new mine sites are returned to their natural state, prior to the mines existence. An environmental assessment is required prior to the start of mining operations, however it is time-consuming and costly process that seeks to identify environmental and social risk factors that, individually or collectively, may outweigh the benefits of the mine.

The team is collaborating with mining companies, regulators, and First Nations to improve efficiency and effectiveness of post mine reclamation by developing whole-ecosystem targets and drive restoration practices. Together, they will use molecular-based tools to provide predictive benchmarks for ecosystem recovery and remediation success, and will consider reclamation in terms of the entire ecosystem, as well as active participation from four mine sites representative of an array of regional ecosystems. The project aims to deliver an Environmental Assessment - Standard Operating Procedure intended for mine operators, environmental consultancy firms, regulators, and First Nations to assess soil health focusing on soil microbes.

UPP004: Development of innovative tools for the environmental assessment of metal contaminated sites

Total Budget: $249,900

Program: User Partnership Program

Project Leaders: Chris Kennedy, SFU, May Quach, Palmer Environmental Consulting Group

The discovery of a wetland capable of removing naturally occurring copper from the water column near Casino Mining Corp's open pit copper-gold-molybdenum-silver deposit, led the mine to partner with professors Chris Kennedy and May Quach from Simon Fraser University to investigate the causative agent. Natural wetlands have the potential to passively treat contaminated water for decades and have the potential to address the legacy issues of mine waste facilities that create contaminated water for centuries. Recreating complex living systems such as a wetlands is hinged on understanding each living organisms place and how they contribute to the overall ecosystem. Genomics will play a central role in understanding and applying living systems in industrial settings.

This industry and academic partnership will provide significant insight and characterization of the organisms responsible for processing these metals and the genes involved in tolerating acidic and metals-rich environments. This study paves the way for bioremediation as a mitigation strategy used to reduce metals concentrations in watercourses.

Appendix 3. Resources and references

[i] http://www.pwc.com/ca/mining
[ii] http://www.pwc.com/ca/mining
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