BRIMM Sustainable Mine Energy Systems White Paper

BRIMM
BRADSHAW RESEARCH INITIATIVE FOR MINERALS & MINING

May 2021

Executive Summary

The mining industry is facing immense pressure to align with the Paris Agreement to decarbonize the economy. Many companies have made public commitments to reach net-zero emissions targets within the next few decades. Some have committed to including their material supply chain carbon emissions reduction (Scope 3). These targets coincide with a period of increased demand to produce the minerals and metals for the global energy transition, declining ore grades, increasing complexity of ore bodies, and deeper mines. Even with improvements in energy efficiency and novel technologies, the total energy consumed by the industry will increase and complicate the pathway to net-zero carbon emissions.

The University of British Columbia has deep expertise in both mining engineering and clean energy technology. In launching the Sustainable Miner Energy Systems research theme, BRIMM aims to bring the many faculty conducting research and development in these areas together to address the challenges of moving the mining industry to net-zero carbon emissions by 2050. Our position is that net-zero will only be realized through a systems approach to energy and carbon. Every mine will have its system of technologies to achieve full decarbonization. This integrated system involves energy efficiency and waste reduction, renewable power supply, energy storage, renewable-powered transport, carbon capture and carbon accounting and reporting. Carbon capture will be critical to achieving the 'last mile' towards net-zero, and all mines will be reliant to some degree on removing carbon on-site or buying offsets.

BRIMM will commence the Sustainable Mine Energy Systems program with three focal areas of research. These are:

1. Decarbonizing mine operations: How to select and integrate different energy technology options in supply, use and storage to maximize the removal of carbon-emitting processes on mine sites.
2. Carbon removal and the circular economy: Waste from mining has the potential for capturing carbon dioxide. This can be done directly by cementing carbon in mine tailings or by remediating disused mines to turn them into biodiverse carbon sinks.
3. ESG, shared value and energy justice: As miners reduce their carbon footprint, they will need to be transparent with customers and stakeholders to build trust. Blockchain technology can enable the tracking of carbon footprints for different mined products. Miners can also benefit local communities by designing energy infrastructure to be shared with local communities and handed over to them at the end of the mine life.

BRIMM works in partnership with industry collaborators by responding to inquiries and meeting to understand the nature of the challenge. BRIMM will then bring its diverse network of UBC faculty to customize an R&D program to co-create a solution with the industry partner.

1 Introduction

Mining is necessary to power the low carbon future. The energy transition demands an increase in critical metals and minerals production, and the next "boom" phase of the mining cycle is fast approaching. The World Bank's Climate Smart Mining initiative has forecasted the demand increase over the next few decades. The initiative recognizes that some minerals, such as copper, aluminum, and nickel, will play a decisive role in all scenarios. In contrast, others, such as lithium, will depend on developing and adopting new and alternative storage technologies.

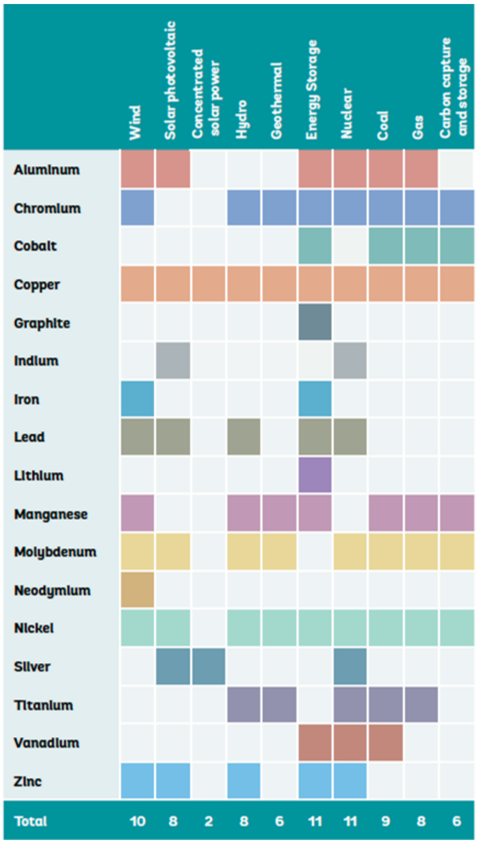

Figure 1: Minerals and metals for low carbon products (World Bank, 2020)

Despite the potential growth, the mining sector continues operating within an increasingly complex world of risk factors. Gone are the days when the simple geological potential was enough to drive mining investment. In recent years, the industry has responded the market volatility and a downturn in commodity prices with a new normal where cost reduction and operational excellence are business imperatives. Additional industry-wide challenges include access to world-class resources, geopolitical issues, regulations, workforce, innovation and environmental, social, and governance (ESG) performance. Over the past 24 months, the pressure from stakeholders, government, and investors has sprung the decarbonization and green agenda with an unprecedented momentum and COVID-19 has not slowed down this movement.

Mining companies must capitalize on their strengths and build new competencies to stay relevant in the global decarbonization path. Encouragingly, there is a growing trend that the industry is aligning with the Paris Agreement objective of being well below 2° Celsius global temperature change, developing science-based targets, and setting net-zero Scope 1 and Scope 2 emission targets by 2050 (some as early as 2030). Many mining companies are operationalizing these targets with data-driven plans and transparent reporting processes. However, there remain significant challenges in designing and operating a low carbon mine, decarbonizing electricity and fuel supplies, and maximizing carbon sequestration and removal potential.

1.1 Sustainable Mine Energy Systems

Completely decarbonize mining operations is a daunting task and must be site-specific. Mining is an energy-intensive industrial activity. The nature of the resource dictates the mining method and mineral processing flowsheet, available energy infrastructure options, environmental conditions, waste treatment and management, and geopolitical issues. A typical grid-connected mine's decarbonization pathway may include the following opportunities:

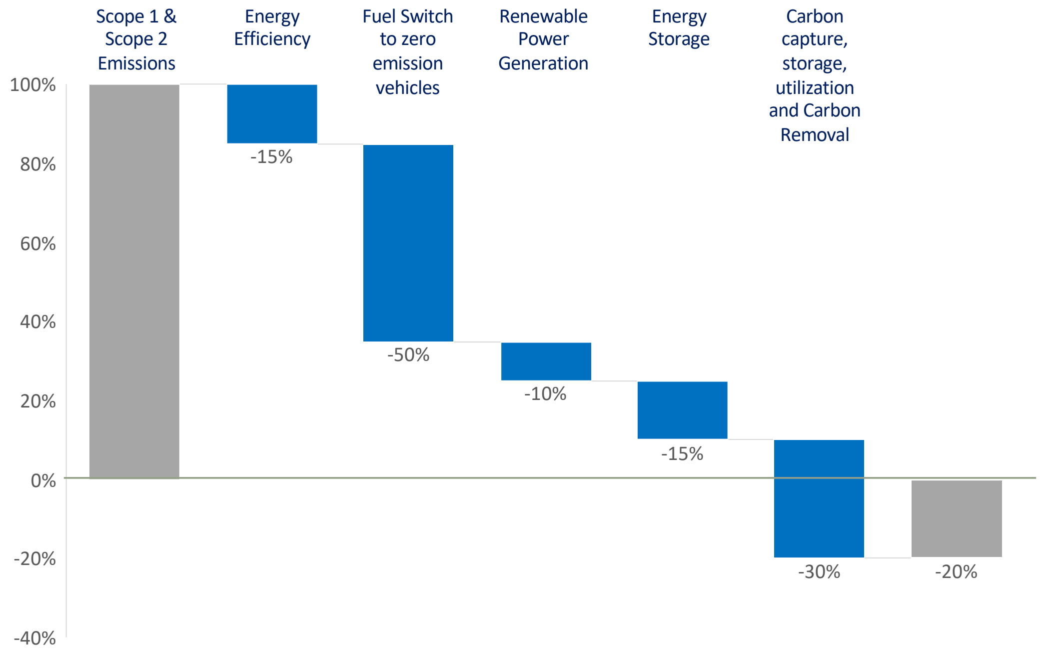

Figure 2: Mine site emissions abatement opportunities for a typical grid-connected mine (EELO Solutions, 2020)

- Energy efficiency is the most cost-effective abatement opportunity and can reduce emissions by 15% or higher depending on the site conditions.
- The single most significant decarbonization opportunity in many operations is to replace diesel with low carbon and zero-carbon fuel options in the mining fleet, including electrification in jurisdictions with low carbon intensity grid power. In some operations, this measure alone can eliminate 50% of the total emissions.
- Energy efficiency and zero-emissions fleet do not fully decarbonize a mine. Emissions from the power grid, mineral processing, heating and cooling, fugitive gases, and backup power generation remain significant. Renewable energy supply and storage can offset emissions by up to 25%, yet this value swings widely in both directions depending on site conditions.
- To achieve a net-zero target, carbon capture, sequestration, and utilization (CCSU) and carbon removal must be considered and is likely necessary.

To unpack the opportunities in developing sustainable mine energy systems, we need to understand critical challenges throughout the mine life cycle:

1. **Mining and mineral processing is energy-intensive** – there are many steps involved, from identifying where the mineral is to upgrading and producing a sellable product. In addition to meeting the energy demand, balancing the supply and managing the cost are also challenging:
   - Electricity supply can be limited to grid capacity or self-generation capacity
   - Fuel supply can be limited to pipeline capacity and transportation network
   - Energy costs are high, particularly in remote operations
2. **Lack of the capability to design and evaluate integrated sustainable energy systems** – with novel and alternative energy supply options and emerging technologies in mining and mineral processing,

designing a low energy and carbon footprint mine is becoming more complex. There is a gap in expertise amongst typical mining suppliers for advanced energy management. For example:

- Dynamic modelling of emissions and cost impacts of implementing renewables, hydrogen and carbon capture systems on the supply side to balance against the demand of heat, electricity and motive power based on mine design and site conditions
- Evaluating possibilities for hybridization and optimization of various energy solutions to achieve the most cost-effective and environmental scenarios

3. **The mining sector is reactive to carbon pricing signals. I**nstead of focusing on gaining export competitiveness through carbon pricing rebates, the industry needs to invest in carbon reduction and carbon removal activities to achieve long-term competitiveness.
4. **Fragmented innovation ecosystem that limits collaboration and knowledge sharing** – opportunities to solve mining challenges require collaboration between a broad range of ecosystem actors: miners, technology providers, academia, and others. Stakeholders have often described the mining innovation ecosystem as fragmented within Canada, and these organizations compete for funding and resources, making it difficult to accelerate and scale-up solutions. Universities have many small research centers that don't work with each other, and numerous technology incubators around Canada are subscale.
5. **Mine waste is considered a liability and risk instead of opportunities. T**here are opportunities to capture and store carbon at scale on mine sites, and circular economy principles can also create carbon capture options for legacy mine sites.
6. **The industry needs to gain the social license to operate through transparency and shared value creation –** the current mining business model is not satisfying the stakeholders nor improving ESG performance to the level required. Technologies that are part of a trusted reporting system (such as blockchain) to track and report ESG metrics will allow stakeholders and investors to influence the industry positively.

2 BRIMM – Challenge Based Cross-Disciplinary Research Partner

The Bradshaw Research Initiative for Minerals and Mining (BRIMM) was founded in 2017 to connect scientists and engineers across the University of British Columbia (UBC) to promote cross-disciplinary research spanning the entire lifecycle of mining, from early exploration to mine closure and rehabilitation.

Created by a generous philanthropic gift from Dr. Peter Bradshaw, a long-time supporter of mining and minerals research at UBC, BRIMM operates primarily within the Faculties of Science and Applied Science at UBC, connecting several centres of excellence, including the Norman B. Keevil Institute for Mining Engineering (NBK), the Mineral Deposit Research Unit (MDRU), the Clean Energy Research Center, the UBC Data Sciences Institute, and the Hydromet Group. Within the wider UBC community BRIMM collaborates with Blockchain@UBC, the Sauder Business School and the Faculty of Forestry.

BRIMM drives transformation of the mining sector by connecting the unique insights of researchers and industry to generate solutions for the benefit of the economy, society and the environment.

BRIMM provides seed funding to UBC research projects that drive data integration across the traditional silos of exploration, mining, and environmental impact. BRIMM's goals are to:

- Expand capacity and visibility of UBC mining-related research on-campus and across the globe
- Foster collaboration and engage new UBC research expertise
- Engage with the minerals industry to identify new & relevant areas of multi-disciplinary research
- Motivate and provide seed funding to new integrated and multi-disciplinary research across the entire mine cycle in projects that attract direct industry financial support
- Provide advanced training across mineral systems and the mining life cycle
- Increase mining-related research capacity at UBC

2.1 Research Themes within the Sustainable Mine Energy Systems Program

Through internal engagement sessions with cross-campus researchers, BRIMM identified key research and collaboration strengths and explored existing collaborations with or relevant to the industry. The engagement aspect was complimented by reaching out to our ecosystem network and building on our understanding of mining challenges. From this process, we have distilled and defined three research themes for the Sustainable Mine Energy Systems research program:

Theme 1: Decarbonizing mining operations	Theme 2: Carbon Removal and Circular Economy	Theme 3: ESG, Shared Value and energy justice

These themes are broad categories to rethink and massively reduce asset level emissions, create carbon sinks unique to mining in a circular economy, and ensure transparency and shared value to our stakeholders in the long term. Recognizing that this is a new research program, we will be agile and ready to adjust.

2.1.1 Theme #1: Decarbonizing Mining Operations

Each mining operation has unique attributes based on the "nature of the resource," which dictates the environmental conditions, access and infrastructure requirements, mining and mineral processing methods, and waste management. To design or operate an ultra-efficient and low emissions operation, systems-level thinking must minimize net energy required in all activities balanced by reliable, flexible, and integrated low carbon energy supply solutions. Emerging technologies will be essential to reach net-zero; however existing technologies play an equally important role. The International Energy Agency (IEA) estimated that technologies on the market could diminish 50% of current global emissions.

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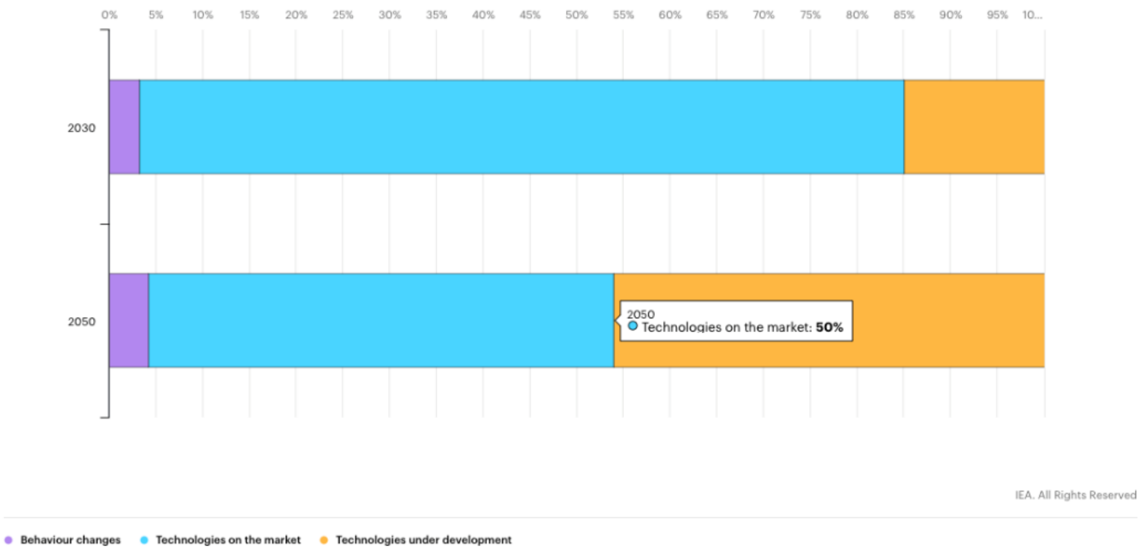


Figure 3: Annual CO_2 emissions savings in the net-zero pathway, 2030 & 2050, relative to 2020 (IEA, 2021)

For mining, the integration of low-carbon supply and usage is a complex system. For example, the overall energy landscape at a mining operation must be assessed by the activity – all require energy input, but some also generate energy as a waste product. Renewable electricity supply is essential; however, renewable or low carbon heating sources are also critical. A summary of renewable energy supply and storage is demonstrated below:

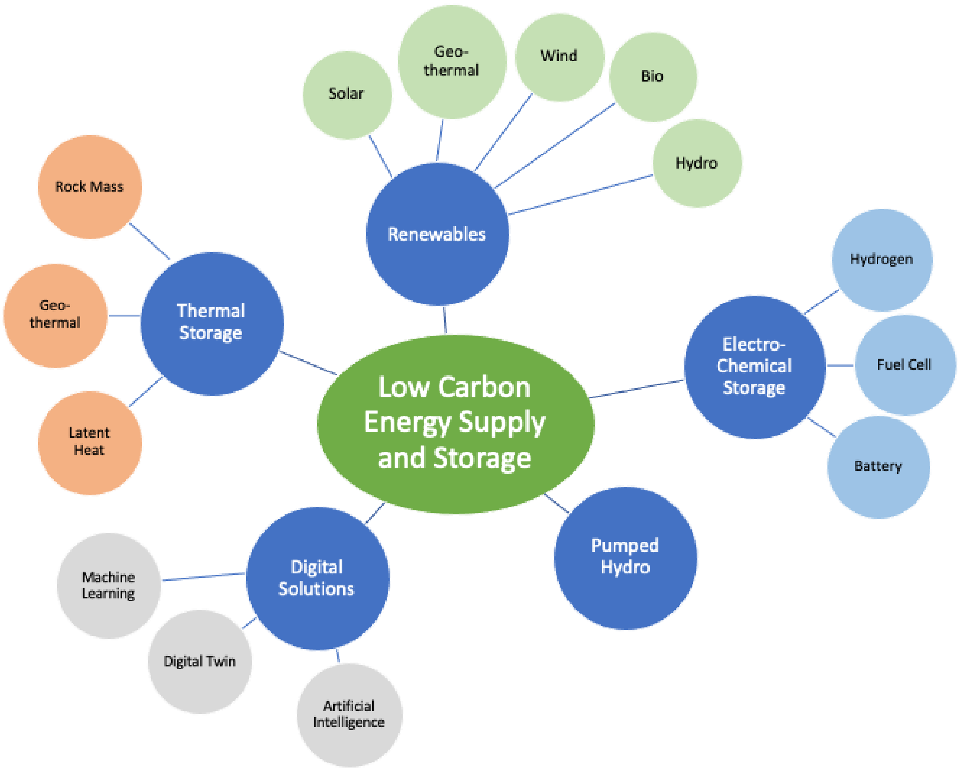


Figure 4: Low carbon energy supply and storage options for mining (Ali Madiseh, 2021)

Example research areas that may be interesting under this theme:

Example Research Area	**Topics**
Decarbonization systems and technologies	• Sustainable energy technologies research, development, planning, and integration. Examples include: ○ Developing next-generation energy technologies and systems architecture with a focus on hydrogen ○ Modelling of entire mine site energy systems ○ Water for energy storage (i.e. green hydrogen, pumped hydro) • Extreme (cold or hot) weather energy systems research • Novel bio-based fuels production processes • Green hydrogen production and utilization in decarbonized mines - heat, power, processing plant input, and mobility
Research on renewable energy supply and storage	• Ammonia, methanol • Electrochemical pathways: hydrogen, fuel cells, batteries • Catalytic material breakthrough research (i.e. Platinum)
Digital technologies	• Digital twin, machine learning, AI

2.1.2 Theme #2: Carbon Removal and the Circular Economy

Circular economy, referring to the recycling and reusing of products at the end of their useful life, is gaining momentum globally in all aspects of life. The forecast demand increase in critical minerals and metals to power the low carbon future will result in new mine development, production, and significant waste generation. In addition, recycling and reusing critical minerals and metals back into the economy will also become prominent, potentially disrupting the mining sector.

Figure 5: Reusing and recycling is the future of the mining industry (eitrawametrials.eu)

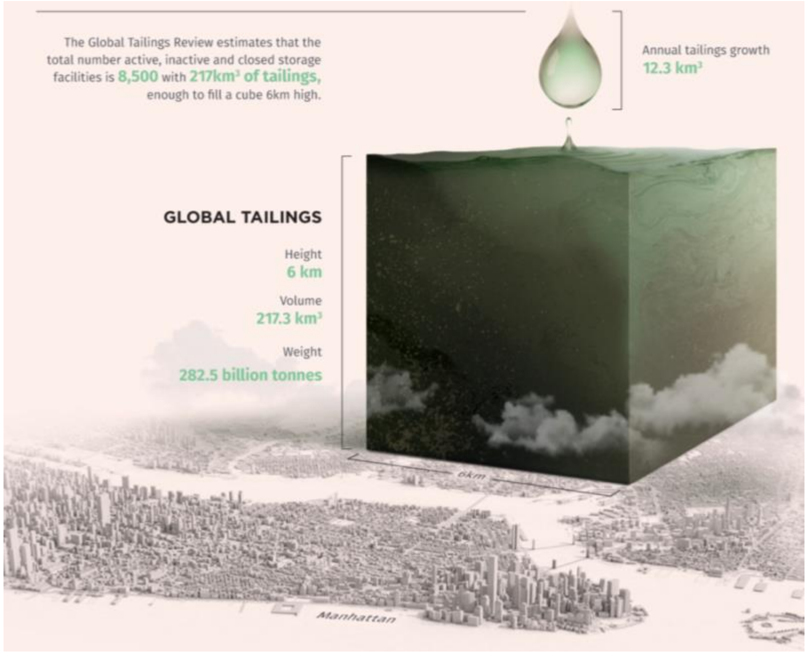


Figure 6: The World's Mine Tailings (Visual Capitalist, 2021)

Mine waste in tailings has been a significant risk to the industry and will continue to accumulate in the current way of mining. With the creation of an international standard on tailings management, the recent Global Tailings Review estimated the total volume, weight, and growth in tailings, highlighting the inevitable waste problem that we need to address.

There are many areas where circularity can be applied in mine waste streams, including repurposing select mine tailings as carbon sinks and re-mining the waste ($10B in total metal value in Canadian gold mining waste alone, according to Natural Resources Canada). Carbon capture, sequestration and utilization (CCSU) and carbon removal are necessary "last mile" opportunities to decarbonize an operation fully and is a new investment focus area to meet global net-zero targets.

Example research areas that may be interesting under this theme:

Research Area	Topics
CCSU/Carbon Removal	• Novel and efficient CO_2 fixation pathways in mine tailings based on mineralogical, geochemical, and isotopic properties of mine tailings • Optimizing CO_2 sequestration in ultramafic tailings • Quantification of the full potential of carbon mineralization by mapping ultramafic rock deposits in BC and globally • Quantification of carbon offsets in mine tailings • Stability and safety of stored carbon
Circular economy	• Waste utilization and valorization in mine reclamation, incorporating biodiversity, forestry, bioenergy, and decontamination opportunities

2.1.3 Theme #3: ESG, shared value creation and energy justice

Environmental, social, and governance (ESG) performance creates opportunities and poses risks to the mining sector. In the past 24 months, ESG has been a dominant theme echoed by CEOs from the biggest mining companies to emerging critical minerals suppliers to downstream customers. At the same time, governments, stakeholders, Indigenous Peoples, and investors are demanding transparency and progress for mining companies to maintain or obtain a social license to operate. In the Sustainable Mine Energy Systems theme, we focus on the green agenda aspect and their impacts on shared value creation and energy justice.

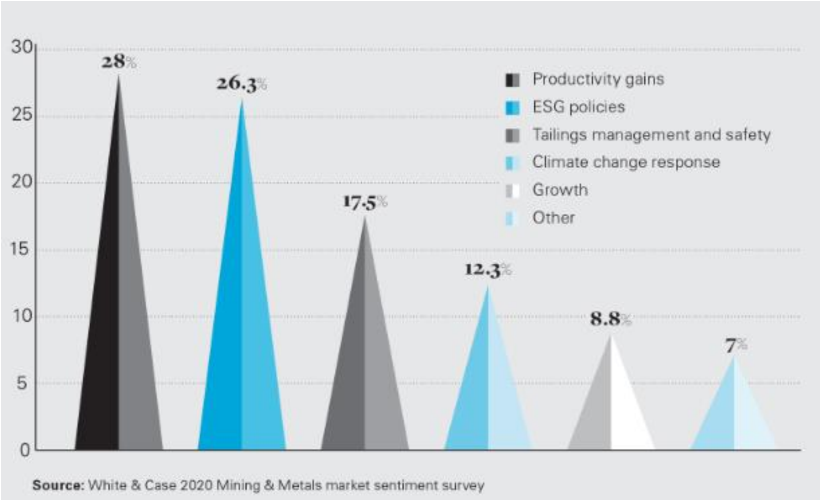


Figure 7: Main priority for the mining sector (White & Case, 2020)

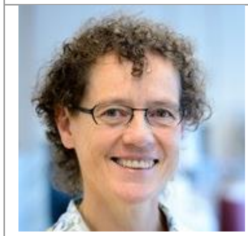
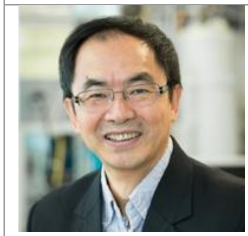
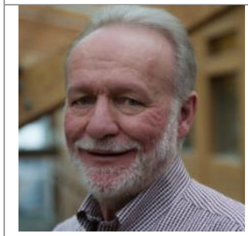
When a new remote mining operation is undergoing the design phase, there are opportunities to share energy, water, and road infrastructure with other industrial users and with nearby communities and Indigenous communities. To create long term shared value, the infrastructure will be used during the operations phase and be designed to continue providing value after closure. Government and corporate policies should enable considerations on alternative design scenarios in ESG metrics.

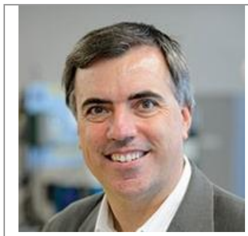
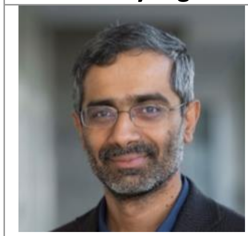
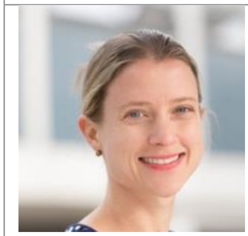
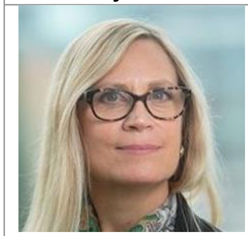
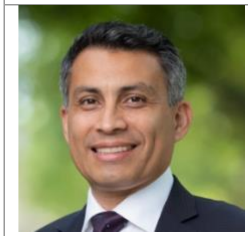
Example research areas that may be interesting under this theme:

Research Area	Topics
Distributed ledgers and blockchain	• Verification of low carbon, carbon-neutral, and carbon-negative operations • Validation of emissions compared to targets • Carbon trading schemes
Regional level planning to create shared value	• New design principles to consider long term energy and water legacy • Policies and programs to enable new business ventures led by Indigenous organizations • Policy to increase local and distributed clean energy production and access to clean water supply • Education and training for highly skilled employees for mining • The potential market for small modular reactors in mining and remote communities in Canada
Indigenous partnerships	• Collaboration models with Indigenous communities and organizations

2.2 BRIMM's Internationally Recognized Research Experts

The "living list" of researchers below demonstrates what we envision as the *starting point* to connect the mining industry to UBC's internationally recognized researchers. The number of researchers and their expertise will grow with an expanding portfolio of research collaborations.

Researcher	Expertise
 **Ali Madiseh**	• **NBK Institute of Mining Engineering, Canada Research Chair in Advanced Mine Energy Systems, BRIMM Sustainable Mine Energy Systems Theme Lead** • Mine energy decarbonization, integrated energy systems; hybridized renewable energy generation and storage • Cold-climate focused research • Mine fleet electrification • Mine energy system design with all energy sources
 **Susan A. Baldwin**	• **Department of Chemical and Biological Engineering; and BRIMM Microbiome Theme Leader** • Oxidative leaching of minerals under high temperatures and pressures • Removal of heavy and toxic metals from aqueous streams through anaerobic bacteria and biochar • Novel bioreactor designs are being investigated to enhance the kinetics of precipitation and separation of the metals from each other
 **Toni Bi**	• **Director of UBC Clean Energy Research Centre (CERC) and Department of Chemical and Biological Engineering** • Model and evaluate bioenergy and biocarbon capture systems • Novel thermo-catalytic technologies to convert biomass residues to biofuels, biochar, torrefied pellets and renewable natural gas
 **Gary Bull**	• **Department of Forest Resources Management** • Protocols and standards on forest carbon offsets • Economics and policies on sustainable business development with First Nations communities
 **Greg Dipple**	• **Department of Earth, Ocean and Atmospheric Sciences** • Research and commercialization of carbon mineralization, using mine waste that takes CO_2 from emissions and the atmosphere and converts it into rock • New efficient reaction pathways for carbon sequestration • Science-based verification protocol for crystallographic trapping of carbon • Stability and safety of stored carbon • Novel CO_2 fixation pathways that offset anthropogenic GHG production

 **Elöd Gyenge**	• **Department of Chemical and Biological Engineering** • Electrochemical science and engineering are for alternative energy sources (fuel cells, batteries, supercapacitors) • Catalyst layer engineering for direct fuel cells utilizing alcohols • Digital technologies for product design: using AI and machine learning to develop new platinum catalyst products for fuel cell
 **Harish Krishnan**	• **UBC Sauder School of Business and Blockchain@UBC** • Incentive distortions in supply chains – increasing transparency utilizing distributed ledger technology comparing different sources of natural gas • Contracts and supply chain coordination • Supply chain management
 **Nadja Kunz**	• **UBC School of Public Policy and Global Affairs, NBK Institute of Mining Engineering, and Canada Research Chair in Mine Water Management and Stewardship** • New business models to create long term shared values for mining & communities • Organizational constraints to implementing optimal system-level solutions • The evolving role of the mining sector in water stewardship and governance • Small modular nuclear reactors economics in mining and remote communities
 **Vicki Lemieux**	• **Founder and co-lead of Blockchain@UBC and Department of Archival Science at the School of Information (UBC iSchool)** • Risks to the availability of trustworthy records, in particular in blockchain record-keeping systems, and how these risks impact transparency, financial stability, public accountability and human rights • Information visualization and visual analytics
 **Walter Mérida**	• **Associate Dean of Research and Industrial Partnerships in the Faculty of Applied Science, Department of Mechanical Engineering, and Mérida Labs** • System architectures designed to deliver sustainable services —not to promote the adoption of a technology or energy source • An integrated approach focusing on policies, technologies, and partnerships
 **John Steen**	• **Director of BRIMM, EY Distinguished Scholar in Global Mining Futures** • Innovation and economic strategy and policy • Mining ecosystem and collaboration business research • Emerging digital business models and technology innovations for sustainable development in mining

3 Call to Action

BRIMM is launching the Sustainable Mine Energy Systems research theme co-developed between BRIMM and UBC partners, focusing on three areas: decarbonizing mine energy systems, carbon removal and the circular economy, and ESG, shared value creation, and energy justice. We believe that world-class researchers at UBC can collaborate with the mining industry to help solve these challenges and BRIMM is bridging expertise across faculties, departments, and institutes within UBC. We are looking for long-term collaborative relationships with the mining industry on short, medium, and long-term research projects.

3.1 The BRIMM Process

BRIMM drives the transformation of the mining sector by connecting the unique insights of researchers and industry to generate solutions for the benefit of the economy, society and the environment. The steps to begin a research project is straightforward:

1. Interested parties can reach BRIMM through all communications and social media channel
    - Email: info@brimm.ubc.ca
    - BRIMM website: https://brimm.ubc.ca/
    - LinkedIn: https://www.linkedin.com/company/brimm-university-of-british-columbia/
    - Twitter: @BRIMMinnovation

2. A discussion to understand the problem statement and identify collaboration opportunities that match BRIMM's expertise

3. Developing a research funding approach – we can multiply industry contribution by up to three times with Canadian government grants
    - Timeline for funding approval: 1 – 6 months
    - Project duration: 1 – 5 years

4. Execution of the project in partnership with industry, ensuring that there is feedback to support and guide the project

3.2 Research Facilities at UBC

UBC has several unique research facilities and laboratories to support the research:

- Clean Energy Research Centre
- Mineral Processing Laboratory (CMPL)
- UBC breaks ground for Renewable Energy Hub in May 2021
- Adaptive Microsystems Laboratory (AdaMist)
- UBC Okanagan Campus Engineering Laboratories