



Natural Resources  
Canada

Ressources naturelles  
Canada

# CanmetMINING

## Research Plan

### 2016-2021

## *Green Mining Initiative*

ENERGY EFFICIENCY

ENHANCED PRODUCTIVITY

WASTE MANAGEMENT

WATER MANAGEMENT



Canada





Natural Resources  
Canada

Ressources naturelles  
Canada

**CanmetMINING**  
**Research Plan**  
**2016-2021**

***Green Mining Initiative***

Information contained in this publication or product may be reproduced, in part or in whole, and by any means, for personal or public non-commercial purposes, without charge or further permission, unless otherwise specified.

You are asked to:

- exercise due diligence in ensuring the accuracy of the materials reproduced;
- indicate the complete title of the materials reproduced, and the name of the author organization; and
- indicate that the reproduction is a copy of an official work that is published by Natural Resources Canada (NRCan) and that the reproduction has not been produced in affiliation with, or with the endorsement of, NRCan.

Commercial reproduction and distribution is prohibited except with written permission from NRCan. For more information, contact NRCan at [nrcan.copyrightdroitdauteur.nrcan@canada.ca](mailto:nrcan.copyrightdroitdauteur.nrcan@canada.ca).

Cat. No. M154-107/2016 (Print)  
ISBN 978-0-660-06806-0

Cat. No. M154-107/2016E-PDF (Online)  
ISBN 978-0-660-06804-6

*Aussi disponible en français sous le titre : CanmetMINES Plan de recherche 2016–2021 – L'Initiative Mines vertes*

© Her Majesty the Queen in Right of Canada, as represented by the Minister of Natural Resources, 2016

## Message from the Director General

I am pleased to present CanmetMINING's 2016–2021 research plan. The research plan outlines how CanmetMINING will reduce the environmental impacts of mining and improve Canada's competitiveness, through its research, development and innovation.

CanmetMINING will continue to collaborate closely with Canada's mining sector partners to deliver the results included in this plan. By connecting with innovators across the mining innovation chain, from pre-competitive research and development to commercialization, CanmetMINING aims to accelerate the development and uptake of new technologies and to reduce barriers to commercialization.

With over 100 years of innovation, CanmetMINING is experienced in delivering science and technology that is valued for its excellence.

The research plan streamlines CanmetMINING's priorities to the following four issues for Canada's mining sector:

- energy efficiency
- enhanced productivity
- waste management
- water management

Through this research plan, we will build on the successes of CanmetMINING's Green Mining Initiative and its mining innovation work. For simplicity, the term "Green Mining Initiative" will be used in this research plan to cover CanmetMINING's full suite of activities in pursuit of environmental performance and economic competitiveness. The research plan is accompanied by an integrated logic model and performance measurement framework for the Green Mining Initiative. Together, they explain the intended outcomes of this work and the outputs we will achieve over the next five years.



Magdi Habib, PhD  
Director General, CanmetMINING  
Natural Resources Canada





## Contents

---

<b>Introduction</b> .....	<b>1</b>
Scope of CanmetMINING's research and development .....	2
<b>Summary of priorities and fields of research</b> .....	<b>2</b>
Priority 1: Energy efficiency .....	3
Field of research 1: Tackling comminution, the largest energy consumer in mining	
Field of research 2: Benchmarking and automation for energy efficiency underground	
Field of research 3: Replacing diesel power in underground mines	
Priority 2: Enhanced productivity .....	5
Field of research 1: Increasing underground productivity through automation and innovative equipment	
Field of research 2: Safer access to deep underground mines	
Field of research 3: Developing novel techniques for processing rare earth elements and chromite	
Priority 3: Waste management .....	6
Field of research 1: Generating value from mine waste	
Field of research 2: Enhanced mine waste management for ecosystem restoration and mine closure	
Priority 4: Water management .....	8
Field of research 1: Improving water recovery and recycling in the milling process	
Field of research 2: Understanding the fate and effects of metal contamination and other pollutants in receiving environments	
<b>Logic models and performance measurement frameworks</b> .....	<b>10</b>
Green Mining Initiative logic model .....	10
Logic models for each priority and performance measurement framework .....	10
Research priority 1: Energy efficiency .....	13
Research priority 2: Enhanced productivity .....	15
Research priority 3: Waste management .....	17
Research priority 4: Water management .....	19
<b>Engagement strategy</b> .....	<b>20</b>
<b>Monitoring, evaluating and reporting strategy</b> .....	<b>22</b>
<b>Annex: Specialized expertise, research and development, and services</b> .....	<b>24</b>





## Introduction

---

The CanmetMINING branch of Natural Resources Canada (NRCan) developed this research plan to guide its research, development and innovation (R&D&I) over the next five years (2016–2021) and to explain the outcomes of this work. The outputs described here will be monitored and reported on for performance.

Under the banner of the Green Mining Initiative, CanmetMINING has two intertwined objectives: reduce the environmental impacts of mining and improve Canada's competitiveness. Strong environmental performance is closely linked to the long-term economic growth of Canada's mining industry and is essential for maintaining public trust in Canada's development of its mineral resources.

CanmetMINING identified four priorities for this research plan, based on engagement with its stakeholders on key industry issues and its own knowledge and expertise developed through its R&D&I projects:

- energy efficiency
- enhanced productivity
- waste management
- water management

The work done on these priorities will address the Government of Canada's agenda, including taking action on climate change, investing in clean technologies and enhancing watershed protection, while also increasing the competitiveness of mine operations.

The research plan builds upon and expands the work carried out by CanmetMINING under subprograms in the NRCan Strategic Outcomes and Program Alignment Architecture:

- Green Mining (2.2.2<sup>1</sup>)
- Mining Innovation (1.2.1)
- Radioactive Waste Management (2.3.4)

Through the Green Mining Initiative, CanmetMINING will continue to work with stakeholders to develop and deploy green technologies that will increase energy efficiency, reduce greenhouse gas (GHG) emissions, minimize wastes and increase productivity. The Green Mining Initiative also equips Canada to manage ecosystem risks and to craft and implement sound, science-based regulations. CanmetMINING receives about \$12 million in direct funding annually from the Government of Canada for this work.

---

<sup>1</sup> In the past, the Green Mining Initiative has largely referred to work under the Green Mining subprogram 2.2.2 in the NRCan Strategic Outcomes and Program Alignment Architecture. For simplicity, this research plan refers to CanmetMINING's full suite of activities in pursuit of economic competitiveness and environmental performance.

## Scope of CanmetMINING's research and development

CanmetMINING conducts research and development (R&D) across the mining life cycle – from extraction to closure – through its three business lines.



Recently, CanmetMINING commissioned a study to assess the economic, social and environmental benefits of 13 green mining technologies and services developed and delivered by CanmetMINING in collaboration with stakeholders.

The identified benefits include:

- decreased GHG emissions and air contaminants
- improved energy efficiency
- decreased business costs
- reduced workplace injuries
- decreased water use and contamination
- decreased land degradation impacts
- decreased impacts to wildlife and fisheries

## Summary of priorities and fields of research

Science and technology innovation in the mining sector enables Canada to expand its mineral resource potential. This happens through unlocking the benefits from the discovery and extraction of new deposits, extending the life of existing mines, and turning previously uneconomical sites into viable opportunities. Government plays a key role in enabling innovation and supporting industry needs. Government also challenges companies to seek new opportunities that help ensure that the sector's long-term productivity benefits all Canadians within the context of a world that increasingly values sustainable practices and low carbon processes.

The four priorities and related fields of research under this research plan will address key mining industry issues identified by CanmetMINING and its stakeholders and address the Government of Canada agenda. The four priorities are energy efficiency, enhanced productivity, waste management and water management.

## PRIORITY 1: Energy efficiency



This priority focuses on improving energy efficiency in mining and on mitigating climate change by reducing GHG emissions through reducing the consumption of fossil fuels. Under this priority, CanmetMINING will focus efforts in three areas:

- Reducing energy consumption in mining and milling.
- Increasing automation for energy efficiency.
- Replacing diesel in underground mines.

**Partners and collaborators:** Canada Mining Innovation Council, National Research Council, Centre for Excellence in Mining Innovation, Canadian Association of Mining Equipment and Services for Export, mining companies, equipment suppliers and universities

### Field of research 1: Tackling comminution, the largest energy consumer in mining

Studies<sup>2</sup> suggest that the following reductions in consumption can be achieved:

- **50 percent** – Investing in state-of-the-art equipment and further research could reduce energy consumption by more than 50 percent from current levels.
- **33 percent** – Implementing best practices could reduce energy consumption by more than 33 percent from current levels.
- **66 percent** – R&D that improves mining technologies could reduce energy consumption by an additional 66 percent from current levels.

Comminution is the process of crushing and grinding solid materials. It is by far the largest energy consumer in the world (3 percent of all electric power generated in the world). This consumption has major implications for both cost and climate change because of the production of GHGs.

This field of research focuses on pre-concentration R&D to reduce the amount of waste material hauled to the surface from underground mines. The result would be that less comminution would be required, and therefore energy use and costs would be reduced. Also, the research will focus on developing and deploying more efficient comminution technologies by applying ore sensors and mill liners and by recovering and eliminating waste energy.

A targeted technology scan will identify potential energy saving technologies in the milling circuit.

***At least two technologies, one to eliminate waste through pre-concentration and one to improve efficiency in the milling circuit, will be demonstrated at a mine site by 2021.***

---

<sup>2</sup> U.S. Department of Energy, 2007. *Mining Industry Energy Bandwidth Study*

## **Field of research 2: Benchmarking and automation for energy efficiency underground**

Another large energy consumer in the mining cycle is ventilation, which can account for 10 percent of the overall consumption or up to 40 percent of the energy used in an underground mine.

The concept of ventilation-on-demand has proven to be practical and to be effective in reducing overall energy expenditure. Ventilation-on-demand expends dilution air only where and when it is needed. This technology is slowly being adopted in new and existing mines but mine operators have yet to take full advantage of the technology.

This field of research will help foster the adoption and the impact of automated ventilation systems, both from a technical and a regulatory standpoint. Elements of the research include:

- real-time contaminant monitoring
- controlled air recirculation
- concept of control and management of air based on air quality

Furthermore, this research area will develop better benchmarking and energy analysis tools to enhance the adoption of energy-efficient technologies.

***At least one new automation technology to reduce energy consumption in mines will be field-tested by 2021. This will be an automated ventilation management system that is quality-based. It would further reduce requirements for ventilation by providing air on the basis of quality rather than a fixed quantity.***

## **Field of research 3: Replacing diesel power in underground mines**

Emissions from diesel engines are known human carcinogens and irritation factors that can lead to cardiovascular disease. Diesel exhaust constitutes a large burden on ventilation systems, and those systems are currently designed mainly to dilute diesel contaminants.

Encouraging the development and use of technologies that use different energy sources will reduce the burden on the current ventilation systems. Such changes will save energy and improve health and safety in the underground workplace.

The goal of this field of research is to help eliminate the use of diesel engines in underground mines.

***At least one vehicle technology that uses hydrogen-powered fuel cells as alternative energy will be demonstrated by 2021 to reduce the use of diesel in underground mines, contributing to reducing energy consumption from ventilation in mines and to a healthier workplace.***

## PRIORITY 2: Enhanced productivity



The Canadian mining industry must continue to improve its productivity to remain competitive against other industries and other mining nations..

Under this priority, CanmetMINING will examine how to:

- Increase the productivity of existing mines through the demonstration and development of automated technologies and innovative equipment.
- Accelerate the development of new mines in new commodities with the goal of reducing operating and capital costs while increasing efficiency and recoveries.

The work will be concentrated in three areas:

- automation and innovative equipment
- deep mining
- rare earth elements and chromite processing

**Partners and collaborators:** Canadian Rare Earth Element Network, Canada Mining Innovation Council, Canadian Rare Earth Elements and Chromite Research and Development ([reechromite.ca](http://reechromite.ca)), major and junior mining companies, equipment suppliers, universities, engineering firms and consultants, provinces and territories

### Field of research 1: Increasing underground productivity through automation and innovative equipment

Because mining is traditionally a labour-intensive industry, mining companies and industry suppliers anticipate that automation can address many needs, challenges and demands, especially in operations.

Efficiencies could be gained through continuous and consistent operations, improved communications, and reduced infrastructure. Mine site health and safety could be improved by moving personnel from dangerous environments to control rooms where they can operate equipment from a safe distance.

This field of research will demonstrate and develop technologies to:

- Allow mines to more effectively hoist materials from underground to the surface.
- Break rocks without explosives, saving considerable time and money for mining operations.

***At least one innovative hoisting technology will be demonstrated at a mine site by 2021, which will greatly improve productivity, particularly in deep and ultra-deep mines.***

### Field of research 2: Safer access to deep underground mines

Extending the life of existing mines by developing mineral resources at greater depths presents technological challenges, the most significant of which is the major health and safety issue of ground stability.

Under this field of research, CanmetMINING will:

- Demonstrate and develop technologies to create instrumented rock bolts (bolts that have sensors) for live, real-time monitoring of rock bolt integrity.
- Advance the development of a research testing facility that can cost-effectively test ground support “systems” under dynamic loading conditions. The test conditions will closely match those found underground during seismic events, such as in deep mines that are prone to rockburst.

***The design and costing of a research facility to mitigate underground instability and the risk of rockburst will be completed by 2021.***

### **Field of research 3: Developing novel techniques for processing rare earth elements and chromite**

In recent years, the steady, reliable and secure supply of critical metals has become increasingly important to major industrialized economies that seek to sustain their industrial base and develop advanced technologies, such as clean energy. In light of this, Canada has an opportunity to supply some of the global demand for critical metals because of its significant critical metal resources.

However, to transition promising mineral deposits to marketable products, investment in fundamental R&D and expertise is needed. These must address the complex technological challenges related to the production, separation and processing of critical metals and improve our knowledge of the global market for these key commodities.

For many small and medium-sized enterprises such as junior mining companies, investing in R&D is extremely challenging with their limited resources. Therefore, federal investment in R&D will catalyze the development and growth of new businesses and highly qualified personnel.

***At least two flowsheets will be developed for recovering a rare earth element from primary and secondary sources.***

***A processing pilot plant for rare earth elements will be designed and constructed by 2018.***

***At least one process will be developed to reduce energy demand and improve chromite recovery by 2021.***

### **PRIORITY 3: Waste management**



Managing mine waste is one of the most costly and risky aspects of mining. Under this priority, CanmetMINING will:

- Take a holistic approach to look at tailings as a source of secondary metals and other valuable industrial minerals.
- Seek to demonstrate and develop technologies that can cost-effectively recover metals from mine waste.
- Develop and demonstrate enhanced mine waste technologies for ecosystem restoration and facility closure.

For example, CanmetMINING will evaluate the climate change risks to tailings impoundment areas from extreme weather events.

**Partners and collaborators:** Mining Association of Canada, Canada Mining Innovation Council, mining companies, equipment suppliers, universities, engineering firms and consultants, other government departments, provinces and territories

### **Field of research 1: Generating value from mine waste**

It is estimated the liability for managing mine wastes in Canada and the United States exceeds \$50 billion. These wastes represent a huge liability for mining companies and the federal, provincial and territorial governments.

However, in some cases they also offer a source of metals at grades often higher than new mining projects. Couple this with the fact that many mine wastes are already “pre-processed” and do not demand extraction or comminution processes prior to further beneficiation or leaching. The case to reprocess mine waste offers a significant environmental and economic green mining opportunity.

The cost of waste reprocessing is often considered to be prohibitive and the process problematic. As a result, technologies for metal recovery from wastes are rarely adopted. However, with increasing environmental pressures and mining costs, the option for metal recovery from mine waste becomes more attractive, especially when coupled with the revenue from the recovered metals. With this in mind, there is a need for technologies that can cost-effectively recover metals from mine wastes. Some technologies exist to reprocess tailings particularly for metal recovery (e.g. gold and silver) but a holistic approach to look at tailings as a source of secondary metals and other valuable industrial minerals has not been undertaken.

***Two process flowsheets will be developed for metal recovery and removal for specific waste types and sources by 2021.***

***At least one demonstration field trial for tailings reprocessing will be completed by 2021.***

***A demonstration for an alternative binder technology will be completed by 2021. This novel mine backfill technology is made almost entirely from recycled mining waste and is estimated to reduce backfill binder costs by 50 percent and GHG emissions associated with traditional binder manufacturing and transportation by up to 90 percent.***

### **Field of research 2: Enhanced mine waste management for ecosystem restoration and mine closure**

The Canadian mining industry typically uses the widely accepted practice of disposing of mine waste under water in human-made impoundments or in natural water bodies such as isolated, low productivity head water lakes. The use of water cover strategies is a proven and effective technique to prevent acid rock drainage, which occurs naturally when sulphide minerals oxidize because they are exposed to air.

However, there are concerns about the long-term stability of human-made impoundments and the negative perception of using natural bodies of water for disposing of mine waste. New methods to safely and effectively manage and reclaim mine waste are essential.

Work under this research area will evaluate and assess the use of saturated barrier technologies as a safer and more effective method to stabilize tailings and limit metal mobilization.

In locations where water cover strategies are not an option, the functionality of the cover and vegetation as a store-and-release system for water needs to be investigated.

Numerous questions need to be answered in that regard:

- Thickness and degradability of the cover.
- Impact of vegetation on the stability and build-up of the cover.
- Role of the cover and vegetation in carbon sequestration to speed the recovery toward a viable and diversified ecosystem.

Work will also address challenges and opportunities associated with long-term tailings management and mine site reclamation strategies under a changing climate.

***Best practices will be developed by 2021 for rehabilitating tailings impoundment areas into healthy and productive ecosystems through the beneficial reuse of organic waste.***

## **PRIORITY 4: Water management**



Mining is a water-intensive activity and improving water efficiency through reducing water intensity is a key requirement in moving toward a more sustainable mining sector in Canada and other countries.

Under this priority, CanmetMINING will:

- Examine options to treat, recycle and reuse water.
- Improve our understanding of the biological, chemical and physical factors that influence the fate and toxicity of metals in order to develop a watershed-based approach for assessing cumulative effects.
- Assess the risks of climate change on mines.
- Study the effects of changes in water balance (surplus leads to difficulties in treatment and an increased risk of contaminant release; shortage leads to increased demand for processing).

**Partners and collaborators:** Mining Association of Canada, Canada Mining Innovation Council, mining companies, equipment suppliers, universities, engineering firms and consultants, Environment Canada, provinces and territories

### **Field of research 1: Improving water recovery and recycling in the milling process**

An integrated approach to water management is needed to ensure that mineral processing and mining activities are efficient and do not adversely affect water resources. Such an approach must take water use, treatment and recycling into consideration.

The integrated approach must consider the potential benefits of:

- Reducing pressure on the environment.
- Reducing costs by decreasing the amount of water needed to produce a tonne of rock.
- Recovering valuable metals and other chemical components.



Recycling and reusing water used during processing are essential steps toward reducing or eliminating the use of fresh water. They also minimize the risk of releasing potentially contaminated process waters to the receiving environment.

Research on and understanding of the control of water quality in mineral processing separation is relatively limited. When we consider recovering process water and using recycled water, it is important that we understand the impact of water chemistry on mineral process and separation efficiency. Using technologies such as membrane separation in combination with other processes could both help reduce water use and improve the process efficiency through continuous control of the water quality in the mineral processing and separation circuits.

***A proof-of-concept for a minimal liquid discharge (MLD) mill will be completed by 2021. If successful, this technology could reduce the amount of freshwater used in milling and reduce the potential release of contaminants.***

***At least one process flowsheet to provide design specifications for an MLD mill will be developed by 2021.***

## **Field of research 2: Understanding the fate and effects of metal contamination and other pollutants in receiving environments**

Watersheds in mineralized zones may contain more than one mine, each of which can contribute to acidity and the metal load of a stream. The resulting complex downstream environment is due to the confounding influences of multiple contaminant input sources.

Mitigating the effects on the environment caused by incremental, accumulating and potential future activities requires a watershed-based approach for cumulative effects assessment (CEA). However, there are still no widely accepted scientific methods for analyzing and evaluating cumulative environmental changes. Also, many biological, chemical and physical factors influence the fate and toxicity of metals on a watershed scale.

This field of research will focus efforts on improving our understanding of:

- The role of particulate matter as a source of contaminants into both freshwater and marine environments.
- The processes involved in the fate of dissolved metals, particularly in multi-component and complex systems and in the context of a changing climate.

Understanding the contribution of contaminants through these pathways will help address environmental concerns about the discharge of metals, be it in the dissolved, colloidal or particulate form. We will also improve our understanding of impacts at a watershed scale.

***At least one novel method to evaluate the rate of removing metals from the water column will be developed, implemented and accepted by regulators by 2021.***

## **Logic models and performance measurement frameworks**

---

### **Green Mining Initiative logic model**

The following logic model identifies the relationships within NRCan's Green Mining Initiative research program. It lists the:

- priorities
- fields of research and their associated outputs
- intended outcomes: immediate, intermediate and ultimate

The outputs for each field of research will be delivered within the next five years and will lead to immediate outcomes within the same time frame.

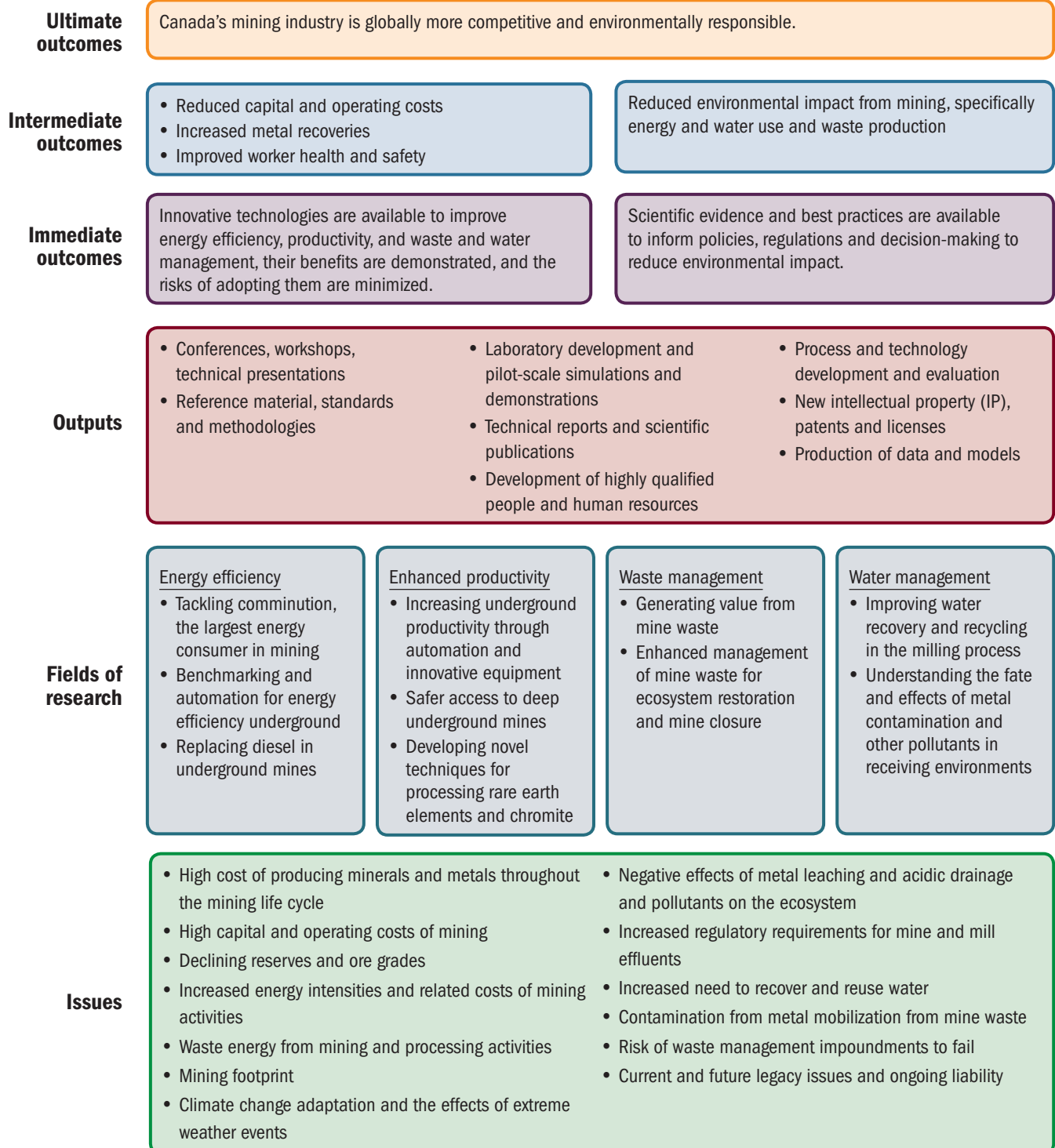
The fields of research and outputs are under the direct control of NRCan's CanmetMINING branch. However, it can only influence (not determine) the outcomes because external factors may also influence these outcomes.

Intermediate outcomes are expected within 5 to 10 years, while the final outcomes are expected within 10 to 20 years.

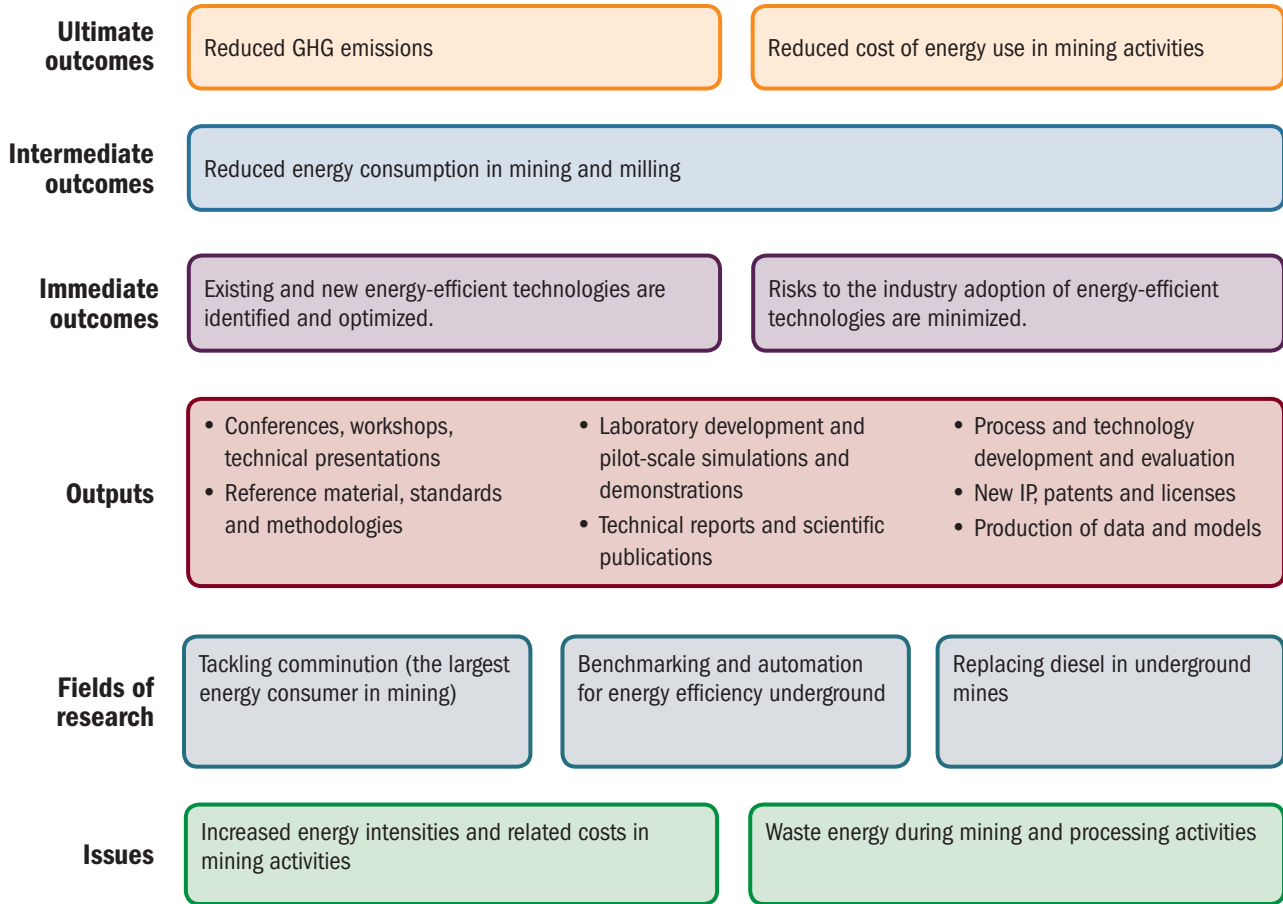
### **Logic models for each priority and performance measurement framework**

Individual logic models for each of the four priorities are located immediately after the logic model for the Green Mining Initiative on the next page. Each individual logic model is paired with a table that shows the outputs associated with that priority and related performance indicators that show how the outputs will be measured.

## Green Mining Initiative logic model



### Logic model for energy efficiency (Research priority 1)



## RESEARCH PRIORITY 1: Energy efficiency

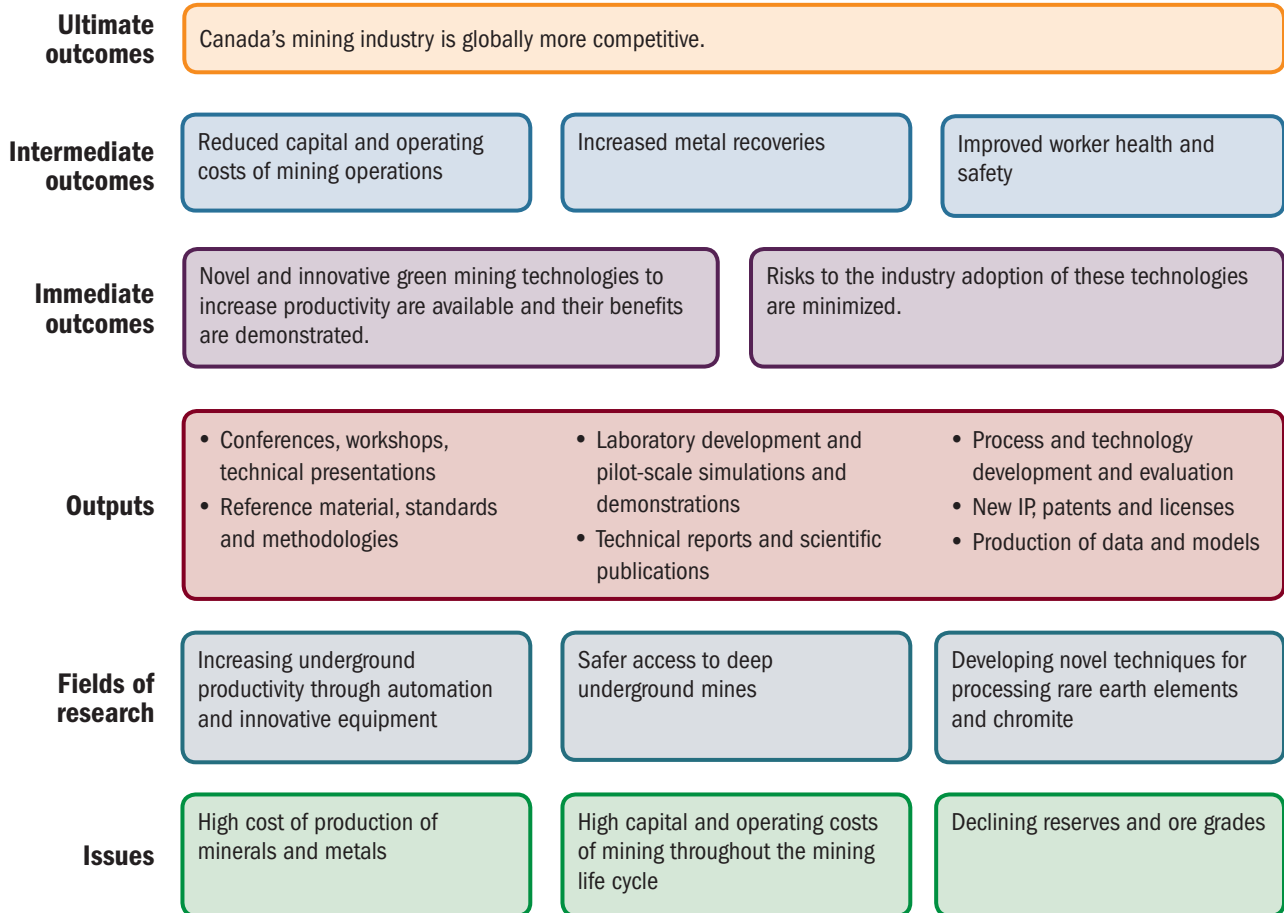
*The objective is to develop tools and identify best practices to reduce energy consumption and GHG emissions from the mining industry.*

### Performance measurement framework: Fields of research, outputs and performance indicators

The following outputs and performance indicators are for the next five years (2016–2021).

Field of research	Outputs	Performance indicators
Tackling comminution, the largest energy consumer in mining	<ul style="list-style-type: none"> <li>• Technical reports identifying energy-efficient technology scan results.</li> <li>• Pre-concentration sampling protocols.</li> <li>• Sensors identified for reduced feed to the milling circuit.</li> <li>• Energy savings for process control.</li> <li>• Merits of alternative rock breakage technologies quantified.</li> </ul>	<ul style="list-style-type: none"> <li>• At least 2 energy-efficient technologies identified, assessed and demonstrated at mine sites.</li> </ul>
Benchmarking and automation for energy efficiency underground	<ul style="list-style-type: none"> <li>• Technical reports evaluating live, real-time ventilation monitoring technologies.</li> <li>• Technical reports characterizing the current energy use in the underground mining system.</li> </ul>	<ul style="list-style-type: none"> <li>• At least 1 automation technology for energy efficiency identified and field tested.</li> <li>• 1 energy-saving toolbox software program developed.</li> </ul>
Replacing diesel in underground mines	<ul style="list-style-type: none"> <li>• Potential alternative energy vehicles are identified (through sessions at the annual Mining Diesel Emissions Council conference).</li> <li>• Technical reports identifying best practices for alternative energy sources.</li> <li>• Input to standards and regulations for the <i>Canadian Hydrogen Installation Code</i>.</li> </ul>	<ul style="list-style-type: none"> <li>• At least 1 alternative energy vehicle technology identified, tested and demonstrated.</li> <li>• Input to the development of mining standards provided.</li> </ul>

## Logic model for enhanced productivity (Research priority 2)



## RESEARCH PRIORITY 2: Enhanced productivity

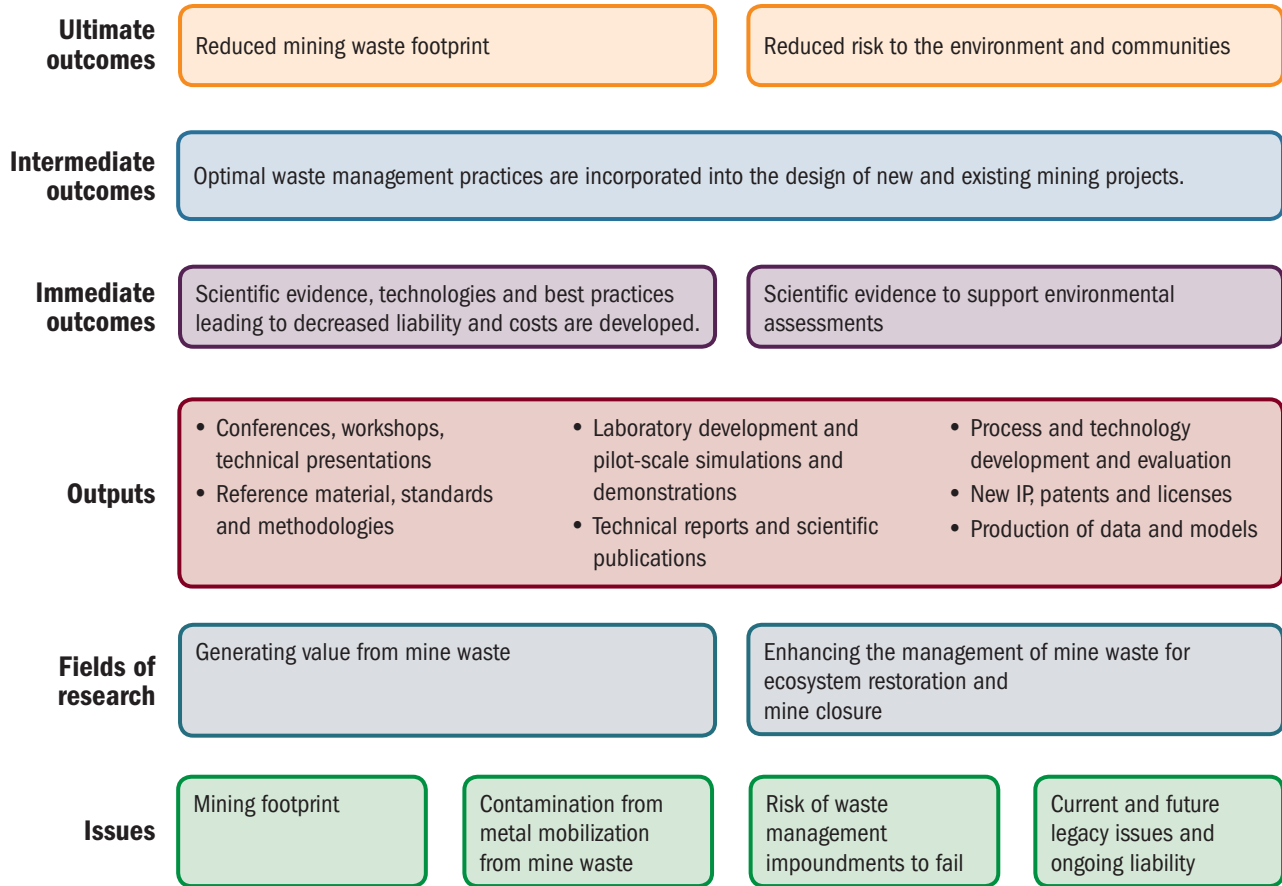
*The objective is to enhance productivity by 10 percent by 2021 through technological innovation.*

### Performance measurement framework: Fields of research, outputs and performance indicators

The following outputs and performance indicators are for the next five years (2016–2021).

Field of research	Outputs	Performance indicators
Increasing underground productivity through automation and innovative equipment	<ul style="list-style-type: none"> <li>• Technical reports evaluating the feasibility of implementing synthetic ropes for hoisting at depth.</li> <li>• Innovative equipment technologies for enhanced productivity identified.</li> </ul>	<ul style="list-style-type: none"> <li>• At least 1 new hoisting technology demonstrated at a mine site.</li> <li>• At least 1 technology that uses innovative equipment evaluated.</li> </ul>
Safer access to deep underground mines	<ul style="list-style-type: none"> <li>• Technical reports evaluating:               <ul style="list-style-type: none"> <li>- Live, real-time instrumented rock bolt sensors.</li> <li>- The design of a rig that can assess integrated ground support systems to mitigate underground instability and rockburst risk.</li> <li>- Techniques and procedures that assess workers' exposure to airborne contaminants underground.</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• At least 1 rock bolt technology identified, assessed and demonstrated at a mine site.</li> <li>• The design and costing of a research testing facility to mitigate underground instability and rockburst risk completed by 2021.</li> </ul>
Developing novel techniques for processing rare earth elements and chromite	<ul style="list-style-type: none"> <li>• Improved process efficiencies.</li> <li>• Economic and market analyses.</li> <li>• Laboratory and pilot-scale testing facilities.</li> <li>• Technical reports and publications.</li> <li>• Engaged and informed rare earth elements and chromite stakeholder communities.</li> <li>• High quality personnel trained.</li> <li>• Processes developed and evaluated.</li> </ul>	<ul style="list-style-type: none"> <li>• 3 processes and technologies developed to reduce energy demands and apply green processing technologies or improve rare earth elements and chromite recovery.</li> <li>• 2 pilot testing labs and facilities established.</li> <li>• At least 10 technical workshops held.</li> <li>• 10 new scientists and 50 students trained.</li> <li>• 5 techno-economic analyses of promising technologies.</li> </ul>

### Logic model for waste management (Research priority 3)





## RESEARCH PRIORITY 3: Waste management

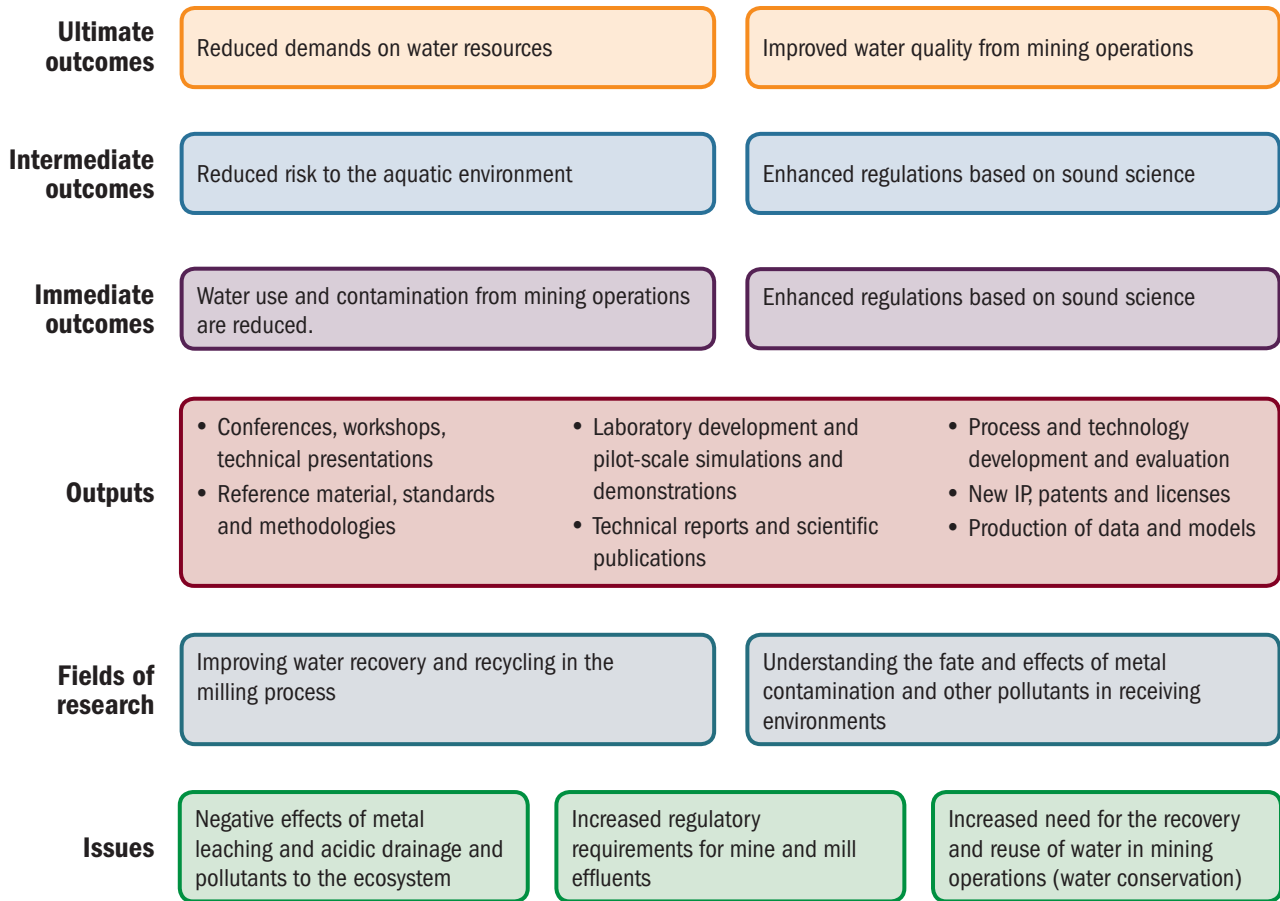
*The objective is to develop best practices in options for managing mine waste and options for reprocessing mine waste.*

### Performance measurement framework: Fields of research, outputs and performance indicators

The following outputs and performance indicators are for the next five years (2016–2021).

Field of research	Outputs	Performance indicators
Generating value from mine waste	<ul style="list-style-type: none"> <li>• Comprehensive waste analysis including reprocessing options.</li> <li>• Assessment of regulatory barriers.</li> <li>• Process for waste reprocessing.</li> <li>• Pilot-scale alternative binder technology.</li> <li>• Assessment of alternative industrial applications for mine waste components.</li> </ul>	<ul style="list-style-type: none"> <li>• R&amp;D gaps analysis completed.</li> <li>• Review of policies and regulations governing tailings reprocessing completed.</li> <li>• 2 process flowsheets developed for metal recovery and removal options for specific waste types and sources.</li> <li>• 2 techno-economic analyses on process flowsheets.</li> <li>• At least 1 demonstration field trial for reprocessing tailings.</li> <li>• Alternative binder demonstration tests completed.</li> <li>• 1 to 2 waste components characterized for potential industrial applications.</li> </ul>
Enhancing mine waste management for ecosystem restoration and mine closure	<ul style="list-style-type: none"> <li>• Evaluation of options for managing mine tailings to establish long-term risk management approaches to mitigate the production of acidic drainage and metal mobility.</li> <li>• Assessment of organic covers, such as biomass, to ensure long-term stability of mine waste and for developing alternative land-use applications.</li> <li>• Determination of the carbon sequestering potential of restored ecosystems as part of a mine waste management approach.</li> </ul>	<ul style="list-style-type: none"> <li>• Comparative performance evaluation of waste management technologies completed.</li> <li>• Role of diffusion barrier layer at the waste-water interface on oxygen diffusion and contaminants mobility characteristics established.</li> <li>• Biomass production, carbon sequestration and tailings stability for different reclamation strategies characterized.</li> </ul>

### Logic model for water management (Research priority 4)



## RESEARCH PRIORITY 4: Water management

*The objectives are to reduce water use in mineral processing, to reduce the overall consumption of freshwater by 50 percent by 2021, and to improve the understanding of the fate and effects of metal contamination in aquatic media.*

### Performance measurement framework: Fields of research, outputs and performance indicators

The following outputs and performance indicators are for the next five years (2016–2021).

Field of research	Outputs	Performance indicators
Improving water recovery and recycling in the milling process	<ul style="list-style-type: none"> <li>Water recovery process options for water recycling.</li> <li>Project proposal for on-site demonstration.</li> <li>Evaluation of water separation technologies.</li> <li>Minimal liquid discharge process flowsheet.</li> <li>Technical gaps and economic and process evaluation study and report.</li> </ul>	<ul style="list-style-type: none"> <li>Laboratory evaluation of water chemistry to determine the extraction efficiency for at least 2 mineral extraction processes.</li> <li>Technology Matrix for water recovery and recycling.</li> <li>Proof-of-concept for an MLD mill.</li> <li>Guidance document for an MLD mill and MLD technology.</li> <li>Process efficiency gains and potential to reduce costs and use of chemicals determined</li> <li>At least one MLD process flowsheet developed.</li> <li>At least 1 IP and 1 patent</li> </ul>
Understanding the fate and effects of metal contamination and other pollutants in receiving environments	<ul style="list-style-type: none"> <li>Studies to determine the fate, effects and transport of metals in the aquatic environment.</li> <li>Informed the regulatory community through workshops and technical reports.</li> </ul>	<ul style="list-style-type: none"> <li>Reactivities of concentrates in marine and freshwater environments are rated, and regulators are briefed.</li> <li>At least 1 novel method to evaluate the rate of removal of metals from the water column is developed and is implemented and accepted by regulators.</li> <li>Information dissemination through at least:               <ul style="list-style-type: none"> <li>1 workshop</li> <li>3 internal reports</li> <li>3 journal articles</li> <li>6 presentations</li> <li>2 briefings to NRCAN and/or other government departments and international organizations.</li> </ul> </li> </ul>

## Engagement strategy

---

At CanmetMINING, solving problems for the Canadian mining industry and institutions is a top priority. Its primary goal is to develop and deploy innovative green mining processes and technologies. CanmetMINING is one of the main research and technology development arms of the minerals and metals sector.

With about 100 scientists, engineers and technicians on staff and research facilities and offices in Ontario, Quebec and British Columbia, CanmetMINING is one of the largest mining technology development centres in the country. CanmetMINING helps the Canadian mining sector through exploratory research, task and cost-shared R&D, cost-recovery specialized services, and technology transfer.

CanmetMINING will continue to collaborate, engage and consult with its wide range of stakeholders to ensure the relevance and complementarity of its R&D programs. CanmetMINING serves a wide range of clients, including:

- private mining companies and their research laboratories
- universities
- mining associations
- consulting firms
- international organizations
- provincial research organizations
- other federal and provincial government departments and agencies

CanmetMINING will work closely in partnership with its stakeholders to:

- enhance their competitiveness and productivity
- improve and develop energy-efficient and alternative energy technologies
- optimize waste and water management practices
- support government policy initiatives

CanmetMINING recently implemented a new business model to accelerate the adoption of green mining technologies. Through this model, CanmetMINING brings together key partners from across the mining innovation value chain to target industry priorities and contributes scientific resources to address them.

CanmetMINING will support mining innovation in Canada by:

- Conducting basic and applied R&D, demonstration and testing for its clients.
- Disseminating up-to-date information on key issues about applying green mining innovation via various communication channels (websites, conferences, workshops, papers, patents, etc.)
- Ensuring that new technologies can be obtained by those who might benefit from it through licensing strategies.

CanmetMINING will regularly engage its stakeholders through advisory and steering committees and other consultation processes. The result will be to produce world-class science with tangible outcomes focused on the Canadian mining sector's most pressing issues. It will continue to obtain advice and strategic direction from its key committees:

- Green Mining Initiative Advisory Committee (GMIAC)
- Green Mining Initiative Intergovernmental Working Group (GMI-IGWG)
- Rare Earth Element and Chromite Steering and Technical Committees

The GMIAC meets three to four times each year and holds at least one workshop to address new issues and emerging opportunities and priorities.

The GMI-IGWG meets once every month or two, as required.

The Rare Earth Element and Chromite Steering Committees each meet four times per year in addition to each holding one workshop per year and attending meetings of the six technical committees.

CanmetMINING will also continue to ensure the relevance and complementarity of its R&D through its leadership and participation in multi-stakeholder initiatives. CanmetMINING has solid expertise in building and coordinating multi-stakeholder initiatives to address environmental issues of national concern and to obtain information for formulating sound policy.

One such initiative is the Mine Environment Neutral Drainage (MEND) program, which develops science-based technologies to reduce the effect of acidic drainage. Another is the National Orphaned and Abandoned Mines Initiative (NOAMI), which assesses key issues for orphaned and abandoned mines and recommends collaborative approaches and partnerships for remedial programs across Canada.

MEND and NOAMI have been described as models for industry, governments, non-governmental organizations and Indigenous Canadians for cooperating in policy and technology development for advancing environmental management in the mining industry. The successes of these programs are the results of the collaborative efforts of the partners, the sharing of experiences, and the thorough evaluation of technologies and practices.

CanmetMINING will also continue to ensure the relevance and complementarity of its R&D through regular dialogue with key stakeholders. They include:

- Canada Mining Innovation Council
- Mining Association of Canada
- National Research Council
- centres of excellence such as the Centre for Excellence in Mining Innovation
- provincial government research organizations
- other research organizations such as:
  - Mining Innovation Rehabilitation and Applied Research Corporation (MIRARCO)
  - COREM
  - Société de recherche et développement minier (SOREDEM)

## Monitoring, evaluating and reporting strategy

To help understand the role of CanmetMINING, information about where investments are made and what they are achieving is needed. This information can also be used to help understand how we can improve the delivery of R&D projects and programs. Monitoring, evaluating and reporting strategy is a simple concept that helps us understand what is being achieved and helps identify possible improvements for projects and programs in the long term.

CanmetMINING will gather essential data for this research plan over the next five years to deliver a complete, consistent, reliable and timely source of information, which is required to achieve the expected outcomes.

CanmetMINING will use the current GCDOCS infrastructure, the SAP project management software system and our unique Live Dashboard to track key business parameters and to monitor all R&D projects. These systems enable CanmetMINING to integrate, analyze, and disseminate relevant and timely information for decision-making.

### Monitoring

To facilitate the monitoring, CanmetMINING will also develop new interactive reports for internal use on key performance indicators for each research priority. CanmetMINING will periodically assess the progress of the major projects to mitigate any risks and to develop contingency plans accordingly.

### Evaluating

The performance strategy will set the stage for the upcoming, more in-depth performance measurements, which will focus on the impacts of scientific activities we consider. Also, to assess the impact of the research plan, CanmetMINING will develop an evaluation form for measuring the success and impact of IP adopted by industry. The performance strategy will be refined annually to meet the Green Mining Initiative objectives and to ensure its continued relevance.

In terms of governance, most of the research activities will be delivered in collaboration with industry and academic partners. They will be consulted and involved when appropriate during the evaluation of the research plan.

### Reporting

An annual report on the Green Mining Initiative research plan delivery and achievements will be distributed internally and used for the annual NRCan *Departmental Performance Report*. Key information about this research plan will be disseminated through publications, workshops and conferences.

Table 1 lists the outputs, frequency of measurement, performance indicators and performance targets each research priority.

**Table 1**

Priority	Outputs	Frequency of measurement	Performance indicators	Performance targets
Energy efficiency	<ul style="list-style-type: none"> <li>- Reduce the footprint.</li> <li>- Reduce energy consumption in mining and milling.</li> <li>- Foster the adoption of automated ventilation systems.</li> <li>- Eliminate internal combustion engines from underground mines.</li> </ul>	Twice a year	<ul style="list-style-type: none"> <li>• # of technologies completed and qualified through tests and field demonstrations.</li> <li>• # of software systems created.</li> <li>• # of new mining standards adopted.</li> <li>• # of technical reports produced.</li> </ul>	<ul style="list-style-type: none"> <li>• At least 4</li> <li>• At least 1</li> <li>• At least 1</li> <li>• At least 15</li> </ul>
Enhanced productivity	<ul style="list-style-type: none"> <li>- Develop live, real-time instrumented sensors.</li> <li>- Ability to access deep and ultra-deep ore deposits.</li> <li>- Ability to simulate environment ground support systems under dynamic loading conditions in a laboratory.</li> <li>- Address the complex technological challenges around the production, separation and processing of critical metals.</li> </ul>	Twice a year	<ul style="list-style-type: none"> <li>• # of technologies completed and qualified through tests and demonstrations.</li> <li>• # of models, processes or prototypes validated in a laboratory environment.</li> <li>• # of workshops delivered.</li> <li>• # of techno-economic analyses done.</li> <li>• # of new scientists and students trained.</li> <li>• # of technical reports produced.</li> </ul>	<ul style="list-style-type: none"> <li>• At least 3</li> <li>• At least 3</li> <li>• At least 10</li> <li>• At least 5</li> <li>• 10 scientists, 50 students</li> <li>• At least 60</li> </ul>
Waste management	<ul style="list-style-type: none"> <li>- Develop cost-effective technologies for recovering metal from mine waste.</li> <li>- Effective methods to stabilize tailings and limit metal mobilization.</li> </ul>	Twice a year	<ul style="list-style-type: none"> <li>• # of technologies completed and qualified through tests and field demonstrations.</li> <li>• # of models, processes or prototypes validated in a laboratory environment.</li> <li>• # of techno-economic analyses done.</li> <li>• # of searches for policies and regulations that govern tailings reprocessing.</li> <li>• # of technical reports produced.</li> </ul>	<ul style="list-style-type: none"> <li>• At least 2</li> <li>• At least 3</li> <li>• At least 2</li> <li>• At least 2</li> <li>• At least 10</li> </ul>
Water management	<ul style="list-style-type: none"> <li>- Knowledge of and the ability to control the water quality in minerals processing and mineral separation.</li> <li>- Better knowledge of the role of particulate matter as a source of contaminants into both freshwater and marine environments.</li> </ul>	Twice a year	<ul style="list-style-type: none"> <li>• # of technologies completed and qualified through tests and field demonstrations.</li> <li>• # of models, processes or prototypes validated in a laboratory environment.</li> <li>• # of workshops delivered.</li> <li>• # of technical reports produced.</li> </ul>	<ul style="list-style-type: none"> <li>• At least 2</li> <li>• At least 4</li> <li>• At least 1</li> <li>• At least 10</li> </ul>

## **Annex: Specialized expertise, research and development, and services**

The robust knowledge, expertise and capacity that CanmetMINING has built through its R&D allow it to deliver on this research plan. They also put CanmetMINING in the position to provide unique and specialized services and expertise to support NRCan and Government of Canada priorities, such as addressing climate change. Because CanmetMINING provides its unique expertise to address government priorities, no other government organization needs to duplicate the effort. The following are key areas where CanmetMINING offers specialized expertise, R&D and services.

### **Specialized expertise – Research and development**

#### **Radioactive waste stabilization**

CanmetMINING provides expertise in and facilities for radioactive waste stabilization to develop methods and innovative techniques to characterize, recover key elements from, and treat and stabilize both solid and liquid forms of radioactive waste. This research minimizes the environmental impact of the waste generated by the mining industry and other industries.

#### **Development of tight oil and gas reserves**

Oil and gas companies working in Canada's Western Canadian Sedimentary Basin have identified over 500 million barrels of proven and probable light tight oil reserves, commonly referred to as shale oil. These estimates are expected to grow significantly as exploration efforts expand.

With current technology and production techniques, only a small portion of the oil and gas can be technically recovered. Technology is the key driver for economically bringing into production oil and gas from shale and other low permeability formations. This oil and gas was previously considered uneconomical to produce. But the key advancements of multi-stage hydraulic fracturing and horizontal drilling have helped make these tight reservoirs accessible.

### **Specialized services**

#### **Certified reference materials**

The Canadian Certified Reference Materials Program (CCRMP) improves the reliability of measurements performed in the laboratory by serving as a control to verify the accuracy and precision of instrumentation or analytical methods.

Laboratory measurements help determine whether:

- Exploration should continue.
- Mining is economical.
- A concentrate is undervalued.
- Emission control specifications are being met.

Laboratory analyses that are improved because CRMs are used can therefore affect decisions about the economics of exploration and mining, the commodity value, and actions to safeguard the environment.



### **Proficiency testing program for mineral analysis laboratories**

CanmetMINING operates a proficiency testing program for mineral analysis laboratories (PTP-MAL) in association with the Standards Council of Canada. A mineral analysis laboratory can use PTP-MAL to assess the performance of its analytical methods independently of internal quality control. A laboratory must participate in the program to receive accreditation for mineral analysis activities from the Standards Council of Canada for ISO/IEC 17025.

About 70 international laboratories currently participate in PTP-MAL. A certificate is provided to participants whose results meet stringent statistical and reliability criteria.

### **Transformation/Dissolution Protocol for metals and sparingly soluble inorganic metal compounds**

CanmetMINING played a leading role in developing and validating the Transformation/Dissolution (T/D) Protocol, a standardized test procedure to generate data for the aquatic hazard classification of metal-bearing substances. To gain access to international markets and to meet international regulatory requirements, Canadian metal exporters require an aquatic hazard classification for their products. The TD Protocol has been adopted by the United Nations Globally Harmonized System of Classification and Labelling of Chemicals and has been widely accepted as the approach to determine the T/D characteristics of metals and sparingly soluble inorganic metal compounds.

CanmetMINING continues to research the variables that affect the T/D characteristics of metals and has recently adapted the TD Protocol to marine systems in response to international maritime regulations. With specialised expertise and research capability, CanmetMINING has an established global reputation in the field of aquatic hazard classification of metal-bearing substances.

### **Geo-mechanics and rock mass characterization for mining**

Rock mass characterization is a key component of any mining operation. It helps optimize the mine design and ensure safety in the mine.

One of the principal threats to mine performance is the uncertainty of rock quality. This R&D is conducted to ensure a thorough understanding of the behaviour of the rock mass and to anticipate how the rock mass will respond to excavation activity. Long-term laboratory geo-mechanical characterization provides information about the underground rock mass.

CanmetMINING expertise includes engineers and technologists using a state-of-the-art laboratory to determine rock properties.

### **Geo-dynamics for static and dynamic support of underground excavations**

Underground excavations require ground support, such as rock bolts, shotcrete and mesh, to maintain stability and ensure the safety of personnel and equipment. Ground support design needs to match the support characteristics with the anticipated response of the rock mass.

Both static and dynamic conditions must be taken into consideration:

- **Static conditions** are the ability of the excavated area to support the weight of the surrounding rock.
- **Dynamic conditions** are the ability of the excavated area to survive additional forces that may be imposed instantaneously and without warning, as in the case of a rockburst.

CanmetMINING expertise includes engineers and technologists using a state-of-the-art laboratory to determine both static and dynamic rock properties of ground support elements.

### **Micro-seismic monitoring and analysis**

The hydrocarbon industry's interest in micro-seismic monitoring has increased significantly in the last decade. This heightened interest is due to the recent surge in using unconventional resources, such as shale gas and heavy oil.

Both hydraulic fracturing and steam injection change local pore pressures and in situ stresses. They cause brittle failure in intact rock and additional slip shearing in naturally fractured rock. These failures and slips produce acoustic emissions (elastic waves), known as micro-seismic events. Micro-seismic monitoring can provide information on the integrity of oil well casings or on the potential for shale gas to migrate, thereby harming the environment.

CanmetMINING expertise includes a team of researchers and professionals who are leaders in the field of seismicity.

CanmetMINING is adapting and transferring its expertise in the following areas to this new research niche:

- Expertise developed since the 1980s in geo-mechanics and rock testing for the characterization of underground nuclear waste repositories.
- Expertise developed since the mid-1990s in the field of seismic research and monitoring applied to underground oil sand extraction processes.

This CanmetMINING project is in collaboration with NRCan's earth sciences sector and CanmetENERGY and the oil and gas industry.

### **Mine hoist inspections**

Mine hoists safely transport people and material underground, so they must be completely reliable. They are sophisticated machines equipped with the latest technology, including:

- process control systems
- variable-speed drives
- electric motors
- controlled braking systems
- electrical networks
- temperature controls
- rope and shaft equipment protection

All of these things are programmed and finely tuned to work together reliably, efficiently and in a way that ensures these multiple levels of protection will prevent serious incidents.

Mine hoist systems need to operate at maximum efficiency with optimum capital and maintenance costs. CanmetMINING expertise includes mine hoist inspectors who ensure compliance with regulations related to:

- emergency deceleration rate during an emergency stop
- compensation for mechanical or tread wear
- drift in the duty cycle that is due to tread wear
- abnormal noises
- abnormal changes to the motor, running temperatures or bearings

#### **Diesel particulate matter control, sampling and analysis**

In 2012, the World Health Organization categorized diesel particulate matter as a Group 1 or known human carcinogen. CanmetMINING is a pioneer in this field and is recognized worldwide for its efforts in protecting workers from exposure to diesel particulate matter going back to the 1980s. Its expertise is that of researchers and engineers with a combined experience of nearly 100 years in the area of diesel particulate matter mitigation in the special context of underground mining. The facilities include a state-of-the-art laboratory to analyze diesel particulate matter (modified version of the NIOSH 5040 method).

#### **Diesel engine certification for use in underground mines**

CanmetMINING operates the only dynamometer facility in Canada that is equipped, staffed and accredited (ISO 17025) to perform specialized testing services and certification of diesel engines destined for use in underground mines (CSA and Mine Safety and Health Administration standards). Consequently, Canadian mining provinces and territories can allow these engines underground with the knowledge that emissions have been characterized and safe ventilation rates have been calculated. Also, mine operators can realize energy savings by acquiring the best, cleanest and most fuel-efficient engines.

